Innovations in Landscape Research

Manfred Frühauf · Georg Guggenberger ·
Tobias Meinel · Insa Theesfeld ·
Sebastian Lentz *Editors*

KULUNDA: Climate Smart Agriculture

South Siberian Agro-steppe as Pioneering Region for Sustainable Land Use

Springer

Innovations in Landscape Research

Series Editor

Lothar Müller, Leibniz Centre for Agricultural Landscape Research (ZALF), Müncheberg, Brandenburg, Germany

Aims & Scope

The Springer series "Innovations in Landscape Research" presents novel methodologies and technologies to understand, monitor and manage landscapes of the Anthropocene. The aim is to achieve landscape sustainability at high productivity. This includes halting degradation of landscapes and their compartments, developing cultural landscapes, and preserving semi-natural landscapes. Clean water and air, fertile and healthy soils for food and other ecosystem services, and a green and bio-diverse environment are attributes of landscapes for the survival and well-being of humans who inhabit them.

How do landscapes function? How do future landscapes look like? How can we sustainably develop intensively used and stressed kinds of landscapes? Scientific innovations and decision tools are key to answer and solve those challenging questions. The series will inform about advanced methods and results of disciplinary, interdisciplinary and transdisciplinary work in landscape research. It presents a broad array of methods to measure, assess, forecast, utilize and control landscapes and their compartments. These include field and laboratory measurement methods, methods of resource evaluation, functional mapping and risk assessment, and sensing methods for landscape monitoring, advanced methods for data analysis and ecosystem modeling, methods and technologies for optimizing the use of multi-functional landscapes, for the bioremediation of soil and water, and basics and procedures of landscape planning. The series provides a new view on landscapes with some focus on scientific and technological innovations, on soils and problems of optimizing agricultural landscapes under conditions of progressive urbanization. Landscape research in a globalized world of the Anthropocene is based on gathering big data and scenario modeling. International long-term experiments and agri-environmental monitoring systems will deliver data for ecosystem models and decision support systems.

Edited volumes of this series will address the following topics at high priority: Status and Trends of Landscape Research; Understanding Key Landscape Processes; Landscape Services, Functions and Biodiversity; Assessing Soil Resources and Quality; Water Resource and Quality Monitoring; Landscape Monitoring Concepts and Studies; Landscape Sensor and Monitoring Technologies; Landscape Modeling and Decision Support; Agricultural Soil and Plant Management; Basics and Tools for Landscape Planning; Tools for Water and Wetland Management; Forest Management and Agroforestry; Rehabilitation of Degraded Landscapes.

The books of this series are a source of information for researchers, teachers, students, and stakeholders interested in the topics of landscape science and related disciplines. They present status analyses, methodical chapters and case studies showing the practical relevance and feasibility of novel decision tools and technologies. Thus, the books of this series will be a particular valuable information basis for managers and decision makers at various levels, from local up to international decision bodies.

An author/editor questionnaire, instructions for authors and a book proposal form can be obtained by contacting the Publisher.

More information about this series at http://www.springer.com/series/16118

Manfred Frühauf · Georg Guggenberger ·
Tobias Meinel · Insa Theesfeld ·
Sebastian Lentz
Editors

KULUNDA: Climate Smart Agriculture

South Siberian Agro-steppe as Pioneering Region for Sustainable Land Use

Springer

Editors
Manfred Frühauf
Institute of Geoscience and Geography
Martin-Luther-Universität Halle-Wittenberg
Halle (Saale), Germany

Georg Guggenberger
Institut für Bodenkunde
Leibniz Universität Hannover
Hannover, Germany

Tobias Meinel
AMAZONEN-Werke H. Dreyer
GmbH & Co. KG
Astana, Kazakhstan

Insa Theesfeld
Agricultural, Environmental
and Food Policy
Martin-Luther-Universität Halle-Wittenberg
Halle (Saale), Germany

Sebastian Lentz
Leibniz-Institut für Länderkunde (IfL)
Universität Leipzig
Leipzig, Germany

ISSN 2524-5155 ISSN 2524-5163 (electronic)
Innovations in Landscape Research
ISBN 978-3-030-15926-9 ISBN 978-3-030-15927-6 (eBook)
https://doi.org/10.1007/978-3-030-15927-6

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

At the Barayev Research Institute of Grain Farming, July 22, 2011. From right to left: Manfred Frühauf, Vladimir Belyaev, Guy Lafond, Tobias Meinel

The working group Geoecology from Martin-Luther-Universität Halle-Wittenberg has been examining damaging changes to soils caused by intensive crop farming in the Eurasian Steppe since 1998. For many years, we have been scientifically analyzing this topic from a geoecological perspective. However, in order for us to be able to make practical recommendations instead of just constantly noting what is harmful for the soil, we were forced to examine the situation from the farmers' and agronomists' perspective. Sustainably farming practices in the prairies of North America, a landscape which is very similar to our project area, were pioneered by research of Guy Lafond from the Indian Head Research Farm in Saskatchewan/Canada. The publications were exceptionally interesting, promising and dealing with the exact same topics that we were working on or about to work on. A former colleague from Halle, Prof. Ulrike Hardenbicker, then put us in direct contact with Guy Lafond. Of course, Prof. Frühauf and I promptly accepted his invitation to visit his research station and test sites in Canada in 2002.

What we saw was beyond our imagination and therefore a complete surprise. On the one hand, we were very impressed with the scientific level at which the research on direct seeding was conducted. It had long gone past the question which was driving us, "Direct seeding—yes or no?" It was exclusively examining the topic of "Direct seeding—how?" On the other hand, we were very impressed with Guy

Lafond himself. His absolute openness and knowledge of all agronomic aspects of dry farming was simply stunning. With his unique way of presenting complex correlations in an understandable and compact manner, he noticeably expanded our "direct seeding horizon" within just a day and a half.

This first contact evolved into an extensive exchange with several reunions in Canada and regular correspondence. In 2007, we were able to invite Guy to Siberia for the first time and introduce him to our partners, among them Prof. Vladimir Belyaev, and our test sites. As Guy Lafond and his colleagues had already been researching direct seeding in Saskatchewan for decades, he kept us from making mistakes and guided us around possible pitfalls. On top of everything, he always remained completely humble and loyal. During this time, we also developed a personal friendship.

When the Kulunda project started in 2011, it represented an excellent opportunity to confirm the Canadian results in Siberia and demonstrate the correct direct seeding system. Once again, Guy Lafond was at our side as a scientific and practical consultant. He provided significant impetus, especially concerning test design and crop rotation.

Without Guy, the Kulunda project would have never been possible, particularly regarding its practical relevance.

I am sure it is very painful to all contributors of this book that Guy was not able to discuss the results with us anymore. Guy Lafond passed away much too soon on April 26, 2013. It is all the more difficult as the good results led to a follow-up project which was launched in Kazakhstan in 2017, which Guy Lafond would have found to be just as interesting and visionary.

Dear Guy, we will continue to work on the large-scale establishment of sustainable direct seeding in the dry zones of the Eurasian Steppe in your spirit. Thank you for the foundation which you laid for us. We miss you, your advice and your zest for life.

Astana, Kazakhstan   Tobias Meinel
November 2019

Preface

Motivation

Not only science but also economy, society and politics face various enormous challenges due to global change. One global issue is the world population's steady growth. The challenge to achieve and maintain universal food security and an increase in the demand for natural resources call for research on land use management methods which conserve and protect natural resources. Signs and effects of climate change, socio-economic factors and effects of land use must be taken into consideration for a sustainable development of different regions. Scientific-based decision-making that takes ecological and socio-economic factors of land use and their dynamics into account is an essential prerequisite for a successful implementation as well as the participation and integration of different regional stakeholders.

This book presents findings of an interdisciplinary research project which offers solutions to these problems using an agrarian region in south-western Siberia as an example. The research project (Kulunda—How to prevent the next global dust bowl?—short title: KULUNDA) was funded by Germany's Federal Ministry of Education and Research (BMBF).

Project Integration

The BMBF set up the funding measure "Sustainable Land Management" between 2011 and 2016 within its research framework programme "Research for Sustainable Development" (FONA) to meet above-described global challenges. Its main goal was the science-based development of decision-making tools and strategies for the land use adaptation to global change. Based on transdisciplinary approaches of fundamental science and implementation-oriented research, focus was on sustainable, climate-optimized land use as well as strategies for the preservation of ecosystem functions and services in selected regions of the world.

Module A of the funding measure supported a total of 12 regional projects in different biomes and sociopolitical environments of the world (www.fona.de/de/nachhaltiges-landmanagement-19763.html). They represent typical global land use patterns and show characteristics as hotspots of land use and climatic change.

The Temperate Grasslands of the World Under Conversion Pressure

Temperate grasslands (Ricciuti 1996; Sala 2001) are targets and hotspots of ecosystem conversions. With its high conversion rate and speed, the "most noticeable trend of the biosphere's global change" (WBGU 1999, pp. 19–20) can be observed in these biomes. In the twentieth century alone, approximately 400 million hectares of steppe or prairie biomes were converted—mostly into arable land (Foley 2005). This agricultural expansion and the type and intensity of agrarian land use resulted in different forms of ecosystem change and degradation in these biomes (Ramankutty et al. 2006). Agrarian land use was impaired and socio-economic conditions deteriorated in the respective regions. Due to the importance of these biomes as major breadbaskets of the world, hotspots of biodiversity and greenhouse gas sinks, the consequences of ecosystem change and degradation go beyond the regions and reach the global dimension of human environment interaction problems.

Yet in this context a lot is still unknown. So, according to WBGU (1998, p. 36), "managed grasslands [are] under-represented regarding available data in contrast to their importance for the carbon cycle". One striking result of this lack of information and knowledge is that grassland conversions are not considered as human activities leading to greenhouse gas increase or decrease in Article 3, paragraph 3 of the Kyoto Protocol. Therefore, the German Advisory Council on Global Change (Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen—WBGU) supported the decision of the "Subsidiary Body for Scientific and Technological Advice (SBSTA)" to commission a report about land use, land use change, and forestry from the "Intergovernmental Panel on Climate Change (IPCC)" to decrease knowledge deficits.

Furthermore, the WBGU (WBGU 1996) drafted a transdisciplinary description of the mega-process of global change-based functional patterns. Inspired by medicine, 16 global change syndromes were identified. These syndromes influence the worldwide environment and development with all their negative aspects and impacts significantly. The so-called Dust Bowl Syndrome is of great importance for many of humanity's future challenges. The level of information about this syndrome improved during the last years due to newly gained knowledge from the eponymous dust bowl region in the Great Plains (Hornbeck 2012; McLeman et al.

2014). The findings did not only reveal manifestations of ecosystem change, type and intensity of resulting ecological and socio-economic problems, but also provided conclusions and innovative forms of land use, and are summarized in the term "Dust Bowl Syndrome" as one kind of global manifestations of human–environment interaction problems.

In contrast to North America, only few recommendations exist for a sustainable, resource-conserving land use of the Eurasian steppe regions and practical experience based on interdisciplinary analyses, and cooperation with landowners is limited (Frühauf and Meinel 2014).

Russia's (Agrarian) Steppes: Importance and Scientific Challenge

The lack of knowledge is especially pronounced in connection with the agrarian steppes of Russia, Ukraine and Kazakhstan. The causes for this are multiple and can be explained only partially by unfavourable conditions for interdisciplinary research during the Soviet era. Even after the breakdown of the Soviet Union and despite emerging new opportunities for research, these questions were not considered as important. With regard to Russia, this is especially deplorable considering the various challenges the country faces:

1. Although Russia is the world's largest country, only 13% of its huge area is designated for agricultural use. Only 53% of the agricultural land (6.7% of Russia's total land area) is used for growing grain crops (FSS Rossij 2014). The steppe is Russia's most important biome to grow and provide food. More than 50% of the agricultural output is produced here. Due to Ukraine's and Kazakhstan's separation from Russia, Russia lost fertile and productive agrarian regions (e.g. the very fertile Central Black Earth Region which went to Ukraine). Furthermore, large areas of farmland were left lying idle in Russia's European part (mostly in non-Chernozem regions). Thus, the steppes became of even greater importance for Russia's agricultural production (Frühauf and Meinel 2014).
2. In addition to altering political and economic conditions, climate change is likely to redefine these regions resulting in a large-scale transformation of land use and land cover. Temperature rise and moisture deficit are expected as negative impacts of climate change and global warming for this biome. They will significantly affect the agricultural sector: modern climate change simulations predict decreasing yields for Russia's currently most productive southern steppes due to more frequent droughts (Golubev and Dronin 2004; Tchebakova et al. 2011).
3. Apart from functioning as hotspots of climate change, steppes also represent hotspots of ecosystem change. The politically motivated Virgin Lands Campaign (1954–1963) was the world's largest ecosystem conversion of

temperate grasslands in the twentieth century. Yet only sectoral and almost no interdisciplinary scientific findings exist regarding the ecological and socio-economic consequences of this ecosystem change.

The Kulunda Steppe in South-Western Siberia as a Research Region: Hotspot of Ecosystem and Climate Change

With an area of 650,000 km^2, agricultural land accounts only for 5% of Siberia's area (13 million km^2) (Halicki and Kulizhsky 2015). Most of this agricultural land is located in the steppes and has historically constituted an important region in Russia—especially in the twentieth century. In the second half of the twentieth century, 75% of Siberia's wheat was produced in the south-western Siberian agricultural triangle between Omsk, Novosibirsk and the Altai. The south-western Siberian agricultural triangle encloses Siberia's biggest agrarian region with an area of 360,000 km^2. 55% of the land is used for tillage, 25% for pasturage and 20% is grassland (Chibilov 2005). Furthermore, these agrarian regions gained in importance due to the proximity and potential economic ties to central Asian and Southeast Asian countries.

The area of the Altai Krai (compare Fig. 2 in Chap. 1.2.2.), especially the Kulunda Steppe, is of great importance within the south-western Siberian agricultural triangle. Currently, the Altai Krai is one of the biggest agrarian areas in Russia (FSS Rossiij [Pub.] 2014). Agriculture accounts for 17% of the region's GDP, i.e. a number three times higher than the average of Russian regions. In recent years, the region managed to increase agricultural and other food production through an active modernization of the machine-tractor supply and technological equipment of farms and factories.

The Altai Krai is situated in the Russian foreland of the Altai Mountains with an area of 169,000 km^2 and a population of 2.4 million. Its capital is Barnaul. The Kulunda Steppe embodies characteristics of the Eurasian Steppe Belt and the virgin land region as well (Frühauf and Meinel 2014). Its history is not only exemplary regarding the interrelation of land use and settlement development but also represents the development's differences and specifics in comparison to the agrarian regions of Russia's European part. The agrarian sector and land use changed in this region after the breakdown of the Soviet Union and in connection with the new governmental/societal conditions. This illustrates on the one hand the importance of this region as a hotspot of ecosystem and land-cover/use change. These did not only have repercussions on ecosystem quality, but also on land use and its economic efficiency. These hotspot effects were mainly caused by political factors or decisions and took place in the twentieth century.

On the other hand, it shows this region's specifics regarding the signs of climate change in comparison with other parts of Russia or rather western Siberia

(Kharlamova and Silantyeva 2011). The results of regional climate research point out very clear trends of temperature and drought increase as well as changed snow and rain regimes. If and how changed climatic conditions, especially the increase of extreme weather events like droughts followed by torrential rain, affect the agriculture in this steppe region was the topic of this research project.

Involvement and Support of Regional Government

Like the central government in Moscow, the regional government attempts to include measures for a sustainable development of agriculture and agrarian regions in its policy. The regional development programme "Altai Krai 25" (www.altai22.ru) gives importance to a sustainable, climate-adapted and resource-conserving land use. For this purpose, scientific-based decision tools are viewed as one of the most important requirements. The focus is on the agrarian sector with its ecologic and economic determinants as the motor of regional development (Vinokurov and Suchodolov 1996). Another topic of interest within these strategic concepts is the importance attributed to the agrarian regions of the south-western Siberian steppe in the light of the implementation of the Kyoto Protocol (as well as its follow-up agreements). The same applies to the target to develop this region as a model region of sustainable land management. In this context, the programme for "Sustainable development of rural territories in the Altai Krai" plays a key role. The Ministry of Agriculture of the Russian Federation chose the Altai Krai to be the first region that would implement a sustainable development project.

With this, attention needs to be turned to nationwide and global networks of economy and science. The focus is thereby on the question if and to what extent the Altai Krai can be the next world's granary and how this goal is attainable in cooperation with science. Some of the paramount research goals of our project KULUNDA were exact within this context. Therefore, the project met strong support by the region's political and administrative decision-makers.

Structure of the Research Project KULUNDA and the Book

The motivation and goals of the interdisciplinary research project KULUNDA "How to Prevent the Next Global Dust Bowl? Ecological and Economic Strategies for Sustainable Land Management in the Russian Steppes: A Potential Solution to Climate Change." were determined by the targets of the funding programme FONA and the specifics and challenges of the south-western Siberian Kulunda Steppe in the Altai Krai.

Even before the start of the research project in 2011, there had been a long history of cooperation and ties between the German Research Foundation (Deutsche Forschungsgemeinschaft—DFG), the German Academic Exchange Service (Deutscher Akademischer Austauschdienst—DAAD) and this region including the exchange of scientists. Contacts to universities, academic institutions and stakeholders of the region were an excellent starting point to begin and conduct research in this region. KULUNDA's eleven subprojects pooled the competency of several German research institutions, two small and medium-sized enterprises and—based on 15 years of collaborative experience—the research expertise of multiple Russian universities, academic institutions, as well as different stakeholder groups of the region.

The subprojects' subject-specific goals were grouped in the following four work programmes (WP):

- WP1: Analysis of effects of land use and climate change regarding soil and vegetation degradation as well as yield development
- WP2: Analysis of causes and factors of land use in the context of changing socio-economic (political) and climatic conditions
- WP3: Testing and development of methods (including machinery) of site-adapted land management (emphasis on arable farming: tillage/crop rotation) and ecosystem restoration
- WP4: Development and implementation of a stakeholder platform to support site-/climate-adapted methods of land use and ecosystem restoration.

The structure of KULUNDA's work programmes is reflected in the organization of this book with its four main chapters.

As described earlier, research focussed on the agrarian regions of the Kulunda Steppe in the Altai Krai used for agricultural production. Core study areas were three test farms and their surroundings. Located in dry steppe, typical or ordinary steppe, and forest steppe, the test sites represent the typical landscapes of agrarian areas in the Altai Krai including typical soil, vegetation, climate and land use patterns of the Kulunda Steppe (Fig. 1).

Most of the natural scientific, social scientific and agriculture–economic research as well as field trials were conducted in the core study areas. Different tillage and crop rotation methods were developed and tested under the leadership of a German company for agricultural machinery and in cooperation with Russian farmers. The development was based on Canadian methods, and the tests were conducted in comparison with traditional Russian methods. Ecological and economic effects of the new methods were analysed and evaluated and, if necessary, immediately modified in cooperation with the land user. In this process, the carbon sink function of these agrarian ecosystems under consideration of the regional development programme "Altai Krai 25" was of special interest. The results were alternative methods for site-adapted, climate-optimized land use and ecosystem restoration. Results and experiences of involved subprojects and partners were a speciality of

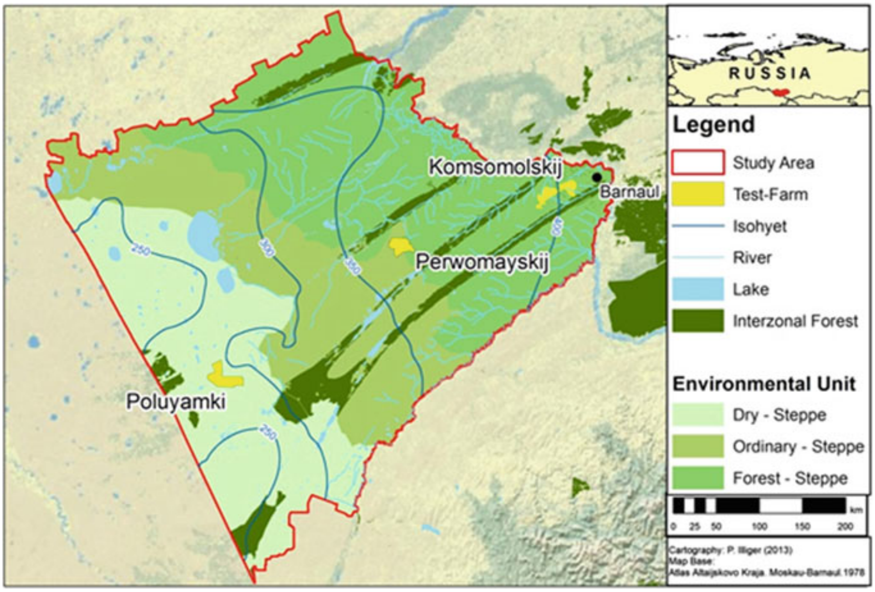


Fig. 1 Landscape structures and location of the test sites in the steppe regions of the Altai Krai. *Source* Illiger et al. 2014—modified

KULUNDA and were published and discussed with farmers and other regional stakeholder groups on field days during and at the end of the research project.

The societal structures and conditions of the region's agrarian sector were analysed to promote the sustainable implementation of developed methods and technology transfer. Especially institutional requirements and business effects were considered.

The project's target was not only the development and testing of methods for a climate-optimized land use and grassland ecosystem restoration but also the lasting support of the region's development. KULUNDA's target is therefore the support of the strategic goals of the regional programme for socio-economic development of the Altai Krai until 2025 and the further development of cooperative relationships with the region.

Purpose of the Book

This book is targeted especially at scientists and students in the fields of geo-, bio- and agriculture science, ecology as well as sustainable and climate research. The book offers also a multitude of practical and methodical experiences to professionals of agricultural and regional planning, economic and social sciences, agricultural engineering, and land users. The connections established during the KULUNDA project between German, Russian, but also Canadian and US farmers show opportunities and perspectives to utilize the approaches, targets and experiences for further international liaisons and cooperation. For this purpose, the book offers suggestions, as well.

Halle (Saale), Germany — Manfred Frühauf
Hannover, Germany — Georg Guggenberger
Astana, Kazakhstan — Tobias Meinel
Halle (Saale), Germany — Insa Theesfeld
Leipzig, Germany — Sebastian Lentz

References

Chibilov A (ed) (2005) Stepi Evrazii: Sohranenie prirodnogo raznoobrfaziya i monitorino sostoyaniya ekosistem [Steppe of Eurasia: Preservation of Biodiversity and Monitoring of the Ecosystems]. The Steppe Institute Press, Orenburg, pp 168 (in Russian)

Foley JA et al (2005) Global consequences of land use. Science 309: 570–574

Frühauf M, Meinel T (2014) Ökosystemkonversion in den temperierten Grasländern Südwestsibiriens: Steuerfaktoren, Etappen und Geoökologische Konsequenzen. *Geoöko* XXXV: 5–38

FSS Rossij (ed) (2014) EMISS—Jedinnaja Meshvedomstvennaja informatsionno-statistitsheskaja sistema. http://fedstat.ru/about.do. Retrieved 15 Jan 2014. (Moscow)

Golubev G, Dronin D (2004) Geography of droughts and food problems in Russia (1900–2000), Report No. A 0401. Center for Environmental Systems Research, University of Kassel, Kassel, Germany. http://www.usf.uni-kassel.de

Halicki W, Kulizhsky SP (2015) Changes in arable land use in Siberia in the 20th century and their effect on soil degradation. Int J Environ Stud 72 (39): 456–473. https://doi.org/10.1080/00207233.2914.990807

Hornbeck R (2012) The enduring impact of the American dust bowl: short- and long-run adjustments to environmental Catastrophe. Am Econ Rev 102 (4): 1477–1507. https://doi.org/10.1257/aer.102.4.1477. Retrieved 31 March 2016—via Harvard University, Department of Economics

Illiger P, Frühauf M, Schmidt G, Meinel T, Belyaew V, Silantyeva M, Kasarjyan M (2014) Ökosystemkonversion und ihre Folgen bezüglich der Kohlenstoffsenken-Funktion in der westsibirischen Kulundasteppe. In: Karsten Grunewald, Olaf Bastian, Alexander Drozdow und Vasil Grabovsky (eds), *Erfassung und Bewertung von Ökosystemdienstleistungen (ÖSD)—Erfahrungen, insbesondere aus Deutschland und Russland.* BfN-Skripten 373, Bonn, pp 300–319

Kharlamova NF, Silanteva MM (2011) Current status and trends of climate change in Kulunda. News of Altai State University 3/2 (71): 50–55

McLeman RA, Dupre J, Berrang FL, Ford J, Gajewski K, Marchildon G (June 2014) What we learned from the Dust Bowl: lessons in science, policy, and adaptation. Popul Environ 35 (4): 417–440. https://doi.org/10.1007/s11111-013-0190-z

Ramankutty N, Graumlich L, Achard F, Alves D, Chhabra A, DeFries RS, Foley JA, Geist HJ, Houghton RA, Klein Goldewijk K, Lambin E, Millington A, Rasmussen K, Reid RS, Turner II B (2006) Global land-cover change: recent progress, remaining challenges. In: Lambin EF and

Geist H (eds) Land-use and land-cover change: local processes and global impacts. Springer, Berlin, pp 9–39
Ricciuti ER (1996) Grassland. Benchmark Books, Tarrytown, pp 1–2
Sala OE (2001) Temperate Grasslands. In: Chapin FS, Sala OE, Huber-Sannwald Elisabeth (eds) Global biodiversity in a changing environment: scenarios for the 21st century. Springer, New York, pp 121–137
Tchebakova NM, Parfenova EI, Lysanova GI, Shvetsov EG, Soja AJ (2011) An agroclimatic potential in southern Siberia in a changing climate during the XXI century. Paper presented at the Annual EGU Assembly (Vienna, April). www.neespi.org/web-content/meetings/EGU_2011/Tchebakova.pdf. Retrieved 21 May 2016
Vinokurov MA, Suchodolov AP (1996) Sibir´v pervoj četverti XX veka [Siberia in the first quarter of the 20th century]. Irtutsk
WBGU (Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen) (1996). Hauptgutachten. http://www.wbgu.de/hauptgutachten/hg-1996-forschung. Retrieved 12 Mar 2016
WBGU (Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen) (1998) *Die Anrechnung biologischer Quellen und Senken im Kyoto-Protokoll: Fortschritt oder Rückschritt für den globalen Umweltschutz*. Sondergutachten. Bremerhaven. p 36
WBGU (Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen) (1999) Welt im Wandel: Erhaltung und nachhaltige Nutzung der Biosphäre—Jahresgutachten. Springer, pp 19–20

Acknowledgements

The editors of this book would like to thank especially the German and Russian authors, but also the many, not mentioned here contributors of the five-year research project KULUNDA. Included in this gratitude are also the beneficial impulses for this project and its successful success through various stakeholder groups in the research region. This applies in particular to the operators and agronomists of agricultural companies. Not only did they provide their space for the various field experiments and data surveys, but they also contributed significantly to the success of the research project through their information and advice, but also through their function as regional multipliers of KULUNDA.

In particular, the editors would like to thank, on behalf of all those involved in the project, the sponsor of this project, the Federal Ministry of Education and Research, and the project supervisors in Bonn (Dr. A. Wüstemeyer, Mr. M. Baudisch). Not only the provision of the project funds, but also the critical and constructive hints during the promotion resulted in diverse suggestions, which positively influenced the project implementation as well as the achieved results in many respects.

In this context, special thanks also go to the two external reviewers (Mr. Prof. Dr. Fabio Santucci/Italy, Dr. Hans Aeppli/Switzerland), who always supported our project positively with their suggestions. Thanks are also due to the members of the Advisory Board and above all to Prof. Dr. Peter Tillack and the rector of the state Altai University, Prof. Dr. S. V. Zemljukov. The advice and recommendation of Mr. Tillack based on great experience contributed in a special way to the success of the overall project. Likewise, the project gained a lot from the active support of the rector and the entire university management of our partner university.

For the organizational completion and linguistic revision of the book, we thank Dr. P. Liebelt, Dr. K. Wegerich, Dr. K. Sielaff and Mrs. J. Mogritz.

Contents

About the Editors

Prof. Dr. h. c. mult. Manfred Frühauf started his scientific career with the study of geography. In 1993, he was offered the Professorship (chair) of Geoecology at the Martin-Luther-Universität Halle-Wittenberg. In the following years, his research focussed on environmental geography; urban ecology, geomorphology and climate change. But his main research interest focussed on investigating the impacts of land use change as well climate change on soil degradation especially the Steppe regions of Russia and Kazakhstan. Till his retirement in autumn 2017, he served multiple times as Director of the Institute of Geosciences and Geography and as dean of the faculty. In recognition of his achievements in the development of cooperation in research and teaching, he was awarded honorary doctorates from three Russian universities.

Prof. Dr. Georg Guggenberger is Acting Director of the Institute of Soil Science of Leibniz Universität Hannover, Germany. His focus is on biogeochemical processes of carbon and nutrient cycling within the soil and its response and feedback to external drivers such as climate change and land use change. He is particularly interested to use his knowledge on basic soil processes to find solutions for concrete land use problems and to optimize soil and land use in forest- and agro-ecosystems in different parts of the world, including Russia. Georg Guggenberger published almost 200 papers in peer-reviewed journals, and he is listed as “highly cited researcher” (WoS/Clarivate Analytics).

Prof. Dr. Tobias Meinel studied geography and geoecology at the University of Halle-Wittenberg. He researched his thesis on radioactive contamination of the soils in the Altai Mountains at the Faculty of Geography at Barnaul. He obtained his doctorate from the University of Halle writing on soil degradation in Siberian semi-arid steppe regions. Meinel then worked as the Chair of Geoecology in Halle, focussing on the connection between crop farming and soil degradation. In 2007, Meinel took a position at Amazonen-Werke in Kazakhstan, developing sustainable crop farming in the steppe regions. In 2012, the Altai State Agricultural University in Barnaul awarded him an honorary professorship for his work.

Prof. Dr. Insa Theesfeld (Ph.D.) is Professor in Agricultural, Environmental and Food Policy and Governance at the Martin-Luther-Universität Halle-Wittenberg, Germany. She is an agricultural and institutional economist, who developed an interest for governance questions of various shared natural resources. She is particularly concerned about the compatibility between formal institutions and society's norms and values that influences effective policy implementation. Her geographical focus is on post-socialist countries. Insa Theesfeld is particularly known as a "Commons" scholar and has been elected in 2019 as the next president of the International Association for the Study of the Commons (IASC).

Prof. Dr. Sebastian Lentz is Director of the Leibniz Institute for Regional Geography in Leipzig and holds the Chair for Regional Geography at the University of Leipzig. His research interests focus on cultural and social geography, regional geography of Europe, mainly Eastern Europe, and the successor states of the Soviet Union. Another field of expertise is cartography, particularly thematic mapping.

He is speaker of the Leibniz Science Campus "Eastern Europe—Global Area", member of the Academic Advisory Board of the Centre for East European and International Studies, Berlin, and vice president of the Leibniz Association.

Part I
Background to the Natural Landscape and Consequences of the Ecosystem Conversation

Chapter 1
Background to the Natural Landscape and Consequences of the Ecosystem Conservation

G. Guggenberger

Abstract Human impact on vegetation and soils in the south-western Siberian steppes can be traced back several centuries. However, particularly large impact occurred with the Virgin Lands Campaign between 1954 and 1963 and all agricultural activities thereafter. Concurrently, climate change became relevant in this area, with potentially large impacts on productivity and organic carbon storage of the steppe soils. The goal of the first chapter is to identify the landscape evolution of the Kulunda steppe under human impact, considering both land use and climate change and to summarize the consequences of ecosystem conversion. Part I of this book consists of 14 chapters. Chapters 2–5 describe the general natural setting of the Kulunda steppe, while Chapters 6–9 explain the history of human impact on the Kulunda steppe, and Chapters 10–14 address the consequences of ecosystem conversion for vegetation and soils. With this, Part I of this book lays the ground for Parts II–IV, which address the socioeconomic factors of land use, the development of sustainable agronomic techniques, and the development and implementation of a stakeholder platform to support site and climate-adapted methods of land use and soil management.

Keywords Climate change · Land degradation · Land use · Land use change · Kulunda steppe · Remote sensing · Socioeconomic history · Soil cultivation · Soil degradation · Soil organic matter · Steppe soils · Steppe vegetation · Virgin Lands Campaign

Although the Virgin Lands Campaign between 1954 and 1963 is known to have had a particularly large impact on vegetation and soils, significant human impact in the southwestern steppes can be traced back for several centuries. Almost concurrently with the onset of large-scale agricultural use of the steppe soils climate change became relevant in this area, causing interactions of land use and climate change with respect to its effects on vegetation and soils. The goal of this chapter in Part I of this book is to discuss the response of the vegetation and soils of the Kulunda steppe to

G. Guggenberger (✉)
Institute of Soil Science, Leibniz Universität Hannover, Herrenhäuser Str. 2, 30419 Hannover, Germany
e-mail: guggenberger@ifbk.uni-hannover.de

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_1

the cultivation of the steppe soils in the era of climate change. With that, this chapter sets the natural science background for Parts II–IV, which address the socioeconomic factors of land use, the development of sustainable agronomic techniques, and the development and implementation of a stakeholder platform to support site and climate adapted methods of land use and soil management. Part I consists of 14 chapters. Chapters 2–5 describe the general natural setting of the Kulunda steppe, while Chaps. 6–9 explain the history of human impact on the Kulunda steppe, and Chaps. 10–14 address the consequences of ecosystem conversion for vegetation and soils. In the following, the different chapters will be briefly introduced.

The second chapter by Wesche et al., puts the Kulunda study region in the context of the Eurasian steppe belt with respect to climate, flora, and vegetation. The authors introduce the northeast to southwest gradient of the study region, which separates forest steppes, typical steppes, and dry steppes. As the Kulunda steppe in general receives high winter precipitation, resulting in moist soils during spring, the grasslands in the Kulunda region show rather similarities to western Eurasia than to the Mongolian plateau further east. In the following chapter, Kharlamova addresses the climate change within the last 50 years in the Russian steppes. Her analysis revealed that particularly the Kulunda steppe shows a prominent increase in the mean annual temperature, while mean annual precipitation varies much, but tends to decrease. Together, the increasing temperature and decreasing precipitation translates into a noticeable increase in the degree of aridity of the forest steppe and steppe landscapes of the Altai territory. As shown in the next chapter of Lashchinsky et al., the vegetation patterns of the Kulunda steppe depend on these climatic conditions, in addition to the geological substrate and the relief. Two vegetation patterns occur on loess—one on elevated plains and the other one in depressions, and both consist of dry grassland with scattered birch forests. The third vegetation pattern is situated on sandy parent material and is represented by pine forests in combination with psammophytic steppe plants. For all three vegetation patterns, the composition of plant communities changes significantly along the climatic gradient of the Kulunda steppe. The soils of the Kulunda steppe are introduced in the chapter by Mizigirev et al. Based on detailed soil information going back to the 1950s, the soils represent quite a mosaic and are dominated by Chernozems (49% of the total area) and Kastanozems (20%) with an increasing proportion of the latter towards the southwest. These soils are mostly accompanied by Acrisols, Phaeozems and Solonetz. Mizigirev et al. further present a detailed description of soils in the test areas, where the distribution of different soil types can deviate quite strongly from the average proportion, and further discuss the problem of translation of the soil types between different soil classification systems.

The sixth chapter by Prishchepov et al., deals with 800 years of agricultural use of the entire Asian part of Russia. By linking agricultural use to major socioeconomic and political developments in Russia, the authors show that until the mid nineteenth century the utilization of Asian Russia's agricultural potentials was very low. The abolishment of the serfdom of Russian peasants in 1861 and a rapid increase in the population of Russia led to a migration to Asian Russia and a moderate cropland expansion. Finally, the Virgin Lands Campaign contributed most strongly to the conversion to arable land. Prishchepov et al. discuss the response of agricultural land use to major socio-political disruption, but also ample opportunities to raise agricultural output. In another chapter, Frühauf and Borisenko focus on early settlements and stages of agricultural land use in southwestern Siberia until the early 1950s. Migrating peasants from European Russia began to populate the steppe in the nineteenth century, which was fostered by governmental provisions such as tax breaks and exemption from military service. In the early twentieth century, agricultural land use expanded strongly due to the Stolypin agrarian reforms and a developing infrastructure. The time between the two world wars was characterized by collectivization, whereas the settlement network continued to develop until the 1920s, where it did not change much between the 1930s and the 1950s. In the subsequent chapter, Frühauf et al. focused on the Virgin Lands Campaign between 1954 and 1963. The goal of this campaign was to increase the agricultural production to alleviate food shortage in the Soviet Union after the 2nd world war. The transformation of 420,000 km^2 steppe into arable land, mainly in northern Kazakhstan and southwestern Siberia, had a large impact not only on the annually ploughed soils but also on the population development. However, soon the new arable land showed signs of increasing soil degradation, so that new soil management methods, relying on less intensive soil management, were enforced. This shows that a detailed knowledge of the spatiotemporal land use and landcover change is crucial for the assessment of potential solutions for site/climate adopted agriculture. Hese et al. present multi-temporal and multi-sensor satellite data and historical topographic maps to detect these changes. With that, the authors could not only detect land use changes, but for the first time could quantify the land cover change over 60 years in the Kulunda steppe.

Chapter 10 addresses first the impact of the transformation of steppes to agricultural land on the vegetation cover and then on the soils. Silanteva et al. discuss the effects of total ploughing and long-term pasture operation on changes in the vegetation cover and biodiversity of the Kulunda steppe. Based on a number of examples, the authors show how anthropogenic land use causes to the destruction and fragmentation of plant communities, and the reduction of species numbers and cenotic diversity, leading to the loss of phytocenoses' self-regulation and self-regeneration ability. Instead agrophytocenoses emerge, which are low in species diversity of segetal plants in comparison with European agrophytocenoses and are characterized by immigration of invasive plant species. Schmidt et al. report then about some major soil physical properties and their changes after the conversion to arable land. Native steppe soils in fact are characterized by high humus contents and stable soil structure, leading to resistance against erosion. The conversion into arable land leads to severe deterioration of many soil physical properties, i.e. a decrease in aggregate stability, compaction and a decrease in water holding capacity. All this results in higher susceptibility to soil erosion and negatively affects soil productivity. The situation can be improved by adapting soil management techniques, which is introduced in Chap. 23 of Part III. The next chapter by Bondarovich et al. deals with soil moisture and evaporation. Using automatic weather stations, soil hydrological monitoring stations and in particular a sophisticated weighable gravitation lysimeter station, the authors show that soil under no-till agriculture has almost the same soil moisture balance as native steppe soils. Actual evapotranspiration measurements show the beforehand not considered large impact of dew on the water balance in native steppe soils, but also in no-till soils, where surface roughness helps to collect water. Anthropogenic land use and land use change also always impact the soil organic carbon stocks and the carbon sink or source function of soils. In their chapter, therefore, Guggenberger et al. evaluate land use and climatic effects on soil organic carbon stocks in the western Siberian grasslands and present scenarios of their future development. Cultivation of the Kulunda steppe led to a loss of about 20–35% of the soil organic carbon, independently of the climatic conditions. Minimum or no till provides an option to increase the soil organic carbon stocks, though the potential effect may be limited, and simulations with the Lund-Potsdam-Jena-managed Land model reveal a continuing climate-change-driven carbon loss from soil. In the last chapter, Frühauf et al. discuss cause and effect relationships between physical and chemical soil properties under different land use management regarding climate change adaption and sustainable regional development. One focus is put on the spatially differentiated identification of selected forms of soil degradation in the Kulunda steppe. The type and intensity of land management is directly related to the soil's erosion susceptibility and its overall vulnerability. The chapter finally describes a process structure of the different phenomena in order to identify solutions for regionalization of the syndromes of soil degradation.

Chapter 2
The Kulunda Steppe as Part of the Eurasian Steppe Belt

K. Wesche, A. Korolyuk, N. Lashchinsky, M. M. Silantyeva, C. Rosche and I. Hensen

Abstract The Eurasian steppes represent the continent's share of the world's temperate grasslands and once have formed one of the largest continuous terrestrial biomes at an extent of ca. 10 Mio km^2. The present chapter describes key aspects of steppes and puts the study region Kulunda in context giving overview data and maps on climate, flora and vegetation. Relatively dry conditions render tree growth limited throughout the biome, while grasses typically have high abundance. Major vegetation classes include meadow steppes often intersected with forest outposts (and then called forest steppe landscapes), typical steppes and dry steppes, all of which are present in the study region. Kulunda thus is a typical example of western Eurasian steppes, which receive a relatively large share of precipitation in winter. Spring conditions are not as dry as in neighbouring regions of Mongolia and China, resulting in a rich and partly specialised flora. Grasslands in the Kulunda region belong to the phytosociological class *Festuco-Brometea*, also highlighting similarities to western Eurasia rather than to the Mongolian plateau eastwards. The western Eurasian steppes have been subject to large-scale conversion to arable lands, and Kulunda is no exception. Less than 17% (ca. 28,000 km^2) of the potential grassland cover still is extant. These sites contain a high number of

K. Wesche (✉)
Senckenberg Museum of Natural History, Görlitz, PO Box 300 154, 02806 Görlitz, Germany
e-mail: karsten.wesche@senckenberg.de

A. Korolyuk · N. Lashchinsky
Central Siberian Botanical Garden SD RAS, Zolotodolinskaya 101, Novosibirsk 630090, Russian Federation

M. M. Silantyeva
Faculty of Biology, Altai State University, pr. Lenina 61, Barnaul 656049, Russian Federation

C. Rosche · I. Hensen
Geobotany, Martin-Luther-Universität Halle-Wittenberg, Am Kirchtor 1, 06108 Halle, Germany

K. Wesche · I. Hensen
German Centre for Integrative Biodiversity Research (iDiv), Halle, Jena, Leipzig, Germany

K. Wesche
International Institute Zittau, Technische Universität Dresden, Markt 23, 02763 Zittau, Germany

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_2

locally threatened plant species and still reflect most of the former diversity of vegetation types found in this key Middle Asian steppe region.

Keywords Climate · Biogeography · Flora · Middle Asia · Temperate grassland · Vegetation

2.1 The Eurasian Steppes—Extent and Importance

Steppes represent the Eurasian part of the world's temperate grasslands, which cover vast areas in the midlatitudes across the globe. Unlike many types of grassland in, e.g. western Europe or the eastern United States, temperate grasslands of the Eurasian steppe belt are typically devoid of trees, mainly as a consequence of at least seasonally dry climates.

The Eurasian steppes have once formed one of the world's largest continuous terrestrial biomes. They extend from small patches of steppe vegetation in central Europe, across eastern Europe and southern Siberia up to the Far East. Giving exact limits is difficult because the steppe biome crosses various political and scientific realms, each working with own languages and—more fundamentally important—with own concepts and definitions of steppes and their ecology (Zemmrich 2005). Russian authors were the first to provide comprehensive overviews of the steppes (summarised, e.g. in Walter 1974; Lavrenko et al. 1991; Lavrenko and Karamysheva 1993). Much has been published since, with rapidly accumulating studies from the Chinese part of the steppe belt perhaps being the most significant current development. According to recent reviews (Werger and van Staalduinen 2012; Wesche et al. 2016), the Eurasian steppe biome covers approximately 10 Mio km^2, which equals 7% of the global terrestrial surface (Fig. 2.1). Of these, about 9 Mio km^2 could actually be steppes; these numbers align with previous estimates (Dengler et al. 2014; Dixon et al. 2014). Russian steppes have been recently mapped in much greater detail and with high accuracy. For example, Smelansky et al. (2012) estimated a total cover of 2.3 Mio km^2 of potential steppe regions in Russia. They also provided a detailed list of grazing areas that may currently occupy ca. 0.6 Mio km^2, which equals 12% of the steppe biome of Russia. An updated map by the same team is available at http://savesteppe.org, and comparison with the natural extent (Fig. 2.1) highlights the fragmented character of Russian steppes.

Human land use strongly affects the distribution and the structure of Eurasian grasslands. This impact is limited in some regions, but has changed entire landscapes as shown, e.g., by our key study region. The Kulunda region still is among the top ten largest steppe areas in Russia. Situated in the centre of the steppe belt, it covers 170,000 km^2, 28,000 km^2 of which may be referred to as grasslands in the broader

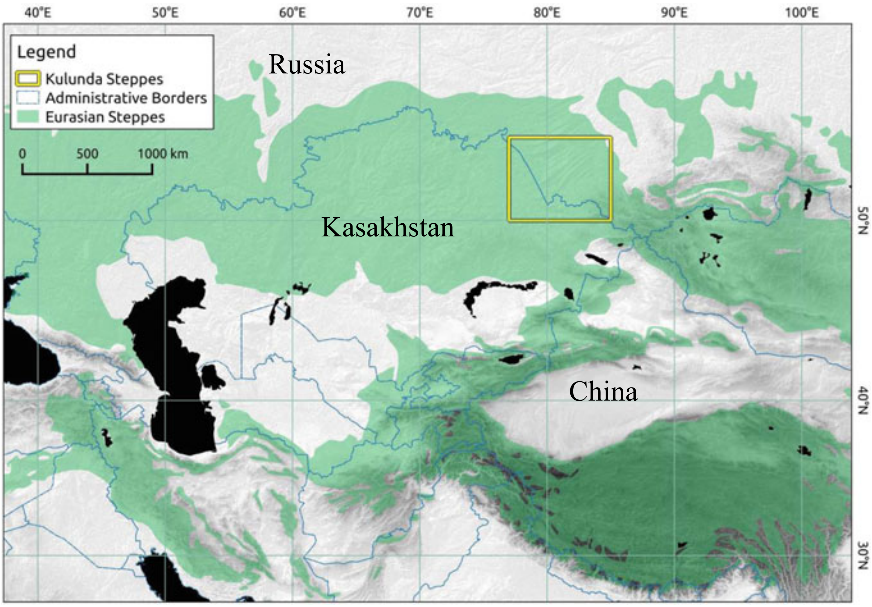


Fig. 2.1 Location of the Kulunda region within the Eurasian steppe belt. The green polygon indicates the potential distribution of the Palaearctic steppe biome; relief is shaded in black and white for orientation. See Fig. 2.6 for a map of the actual grasslands in the Kulunda region. *Source* J. Treiber adapted from Wesche et al. (2016)

sense (data after Smelansky and Tishkov 2012, including fallows and thus depending on agricultural impact; see Chaps. 10–14).

2.2 The (Macro-)Climatic Niche

Steppes are characterised by modest to low mean temperatures, overall dry conditions and a pronounced seasonality in both temperature and precipitation. In Russian steppes, mean annual temperatures typically range between 1 and 6 °C, with warm summers and often very cold winters. Annual precipitation is between 200 and 400 mm. In terms of spatial gradients, temperatures follow a latitudinal pattern (Fig. 2.2a, b) with warmer conditions southwards. Given that precipitation is generally limited, temporal and spatial variability in precipitation is, however, much more crucial in terms of ecosystem functioning (Wesche and Treiber 2012). Seasonal patterns in precipitation differ between major steppe regions with winter precipitation showing a longitudinal gradient (Fig. 2.2c, d). More precisely, the Tien Shan–Altay

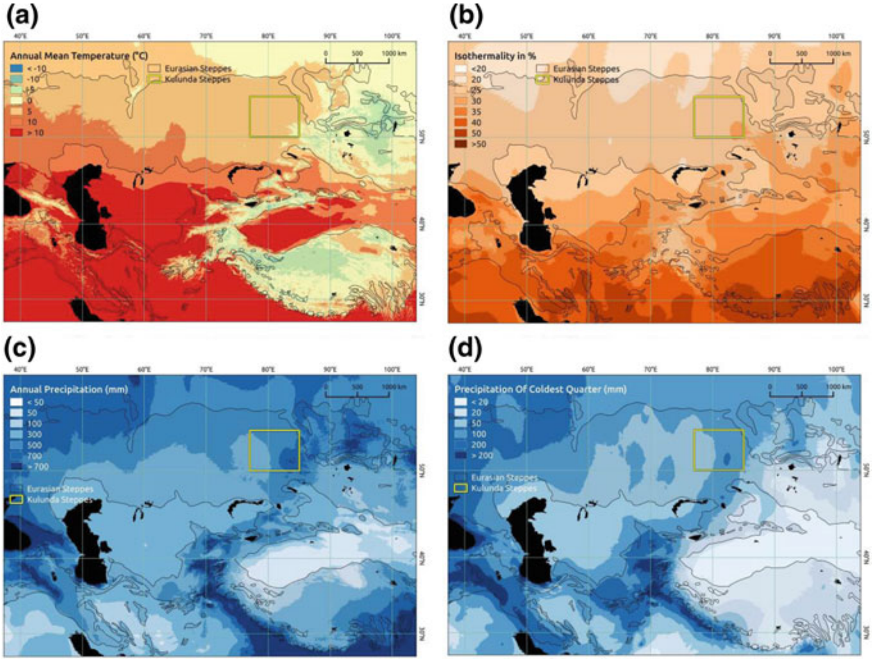


Fig. 2.2 Macroclimate of the Eurasian steppes biome. **a** Mean annual temperature; **b** continentality index as the difference between maximum temperature of the warmest month and minimum temperature of the coldest month; **c** mean annual precipitation totals; and **d** precipitation totals of the coldest quarter (December–February). The yellow polygons indicate the approximate position of the Kulunda region (see Chap. 3 for detailed climate maps of the Kulunda region). *Source* J. Treiber, adapted from Wesche et al. (2016) climate data from Hijmans et al. (2005)

mountain system (approximately at 80–90°E) forms a major divide in this context: Whereas precipitation east of this boundary (i.e. in steppes of northern China and Mongolia) is largely restricted to summers, the more western steppe regions receive a high share of winter precipitation. Biogeographers have traditionally acknowledged these differences referring to Central Asia (Tsentral'naia Aziia)—for the eastern parts of the biome—and to Middle Asia (Sredniaia Aziia) for the regions east of the Tien Shan–Altay (see, e.g. Jäger and Hilbig 2010).

The Kulunda steppe is located west of the aforementioned major climatic divide and is thus part of Middle Asia. The region represents the eastern periphery of Koeppen climate Dfb (snow/humid/warm summers, Kottek et al. 2006) and is rather humid as compared to the endorheic basins further south in Kazakhstan (Koeppen Bsk). The standard Walter-Lieth diagrams summarise the main latitudinal patterns from north to south (Fig. 2.3). Temperatures are broadly similar across the region (except for elevational patterns) with respect to both mean values and the pronounced seasonal change: Summer mean temperatures are above 20 °C; the vegetation period is limited by onset of frosts in September, and winters are cold with monthly mean temperatures

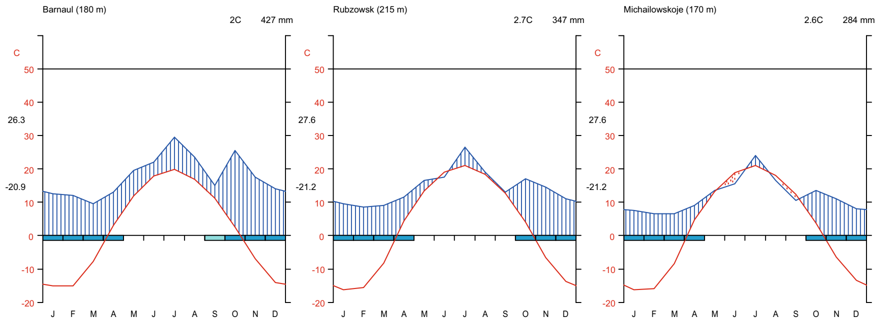


Fig. 2.3 Standard Walter-Lieth climate diagrams for selected governmental weather stations in the Kulunda region. **a** Barnaul (53° 21′N, 83° 50′E); **b** Rubzowsk (51° 31′N, 81° 12′E); and **c** Michailowskoje (51° 49′N, 79° 59′E). *Source* Data retrieved from climate data.org, Jan 2017

below 0 °C from October to April. Precipitation is more evenly distributed across the year; although there is a summer maximum, substantial rain or snow occurs from October across the entire winter season. In consequence, water availability in spring is relatively high, which is characteristic for Middle Asian regions and contrasts with the very dry springs towards the east in Central Asia. In terms of spatial patterns, annual precipitation increases from the Kazakh border in the south-west to the forelands of the Altay in the east (Fig. 2.3), which, in turn, triggers the main habitat zonation described below (see also Chap. 3).

2.3 Flora and Biogeography

The knowledge on the biogeography of Eurasia is more profound than for any other continent. Various authors have provided schemes for a biogeographical zonation, with those most important being based on the flora. Definitions and concepts differ, but following the pioneering work by Grisebach (1894), most authors consider Middle Asia a subunit of the Asiatic Flora Region (Takhtajan 1986) or of the broadly similar Irano-Turanian flora region (IT, Zohary 1962). In the system of Takhtajan (1986), Middle Asia (and thus Kulunda) corresponds to the Western Asiatic subregion, or to western parts of the Irano-Turanian region, respectively. The latter can be roughly subdivided along gradients of both climatic conditions and flora composition becoming more 'Mediterranean' further eastwards (Djamali et al. 2012).

With respect to north-south zonation, Kulunda is situated in the transition zone between Middle Asia's dry heartlands and the forest belt of northern Asia. The northern parts of our study region belong to the Euro-Siberian region or the boreal subkingdom (Takhtajan 1986), which is dominated by dark Taiga. The central and southern parts of Kulunda would fall in the northern-regional subcenter 3 of the Irano-Turanian flora region (IT, see discussion of concepts in Manafzadeh et al.

2016). Inhabiting about 27,000 species, the western part of the IT (i.e. Middle Asia) is much more species rich than its eastern part (i.e. Central Asian) that hosts ca. 5000 species. About 25–40% of the species of the western IT are considered to be endemic (mostly herbaceous taxa and shrubs, see, e.g. Zohary 1973; Takhtajan 1986).

The flora of the Kulunda region is represented by 785 species in the territory of the Altai Krai (Silantyeva 2013). The indigenous group includes 701 species and subspecies of higher vascular plants from 296 genera and 78 families. The adventitious group comprises 84 species of higher vascular plants relating to 64 genera and 28 families (Silantyeva 2013). The families of *Asteraceae*, *Poaceae* and *Chenopodiaceae* dominate in the indigenous flora according to the number of species, while the leading genera are *Artemisia*, *Carex*, *Potentilla*, *Astragalus* and *Atriplex*. The largest families among the adventitious species are *Asteraceae*, *Brassicaceae*, *Chenopodiaceae* and *Poaceae*; the largest genera are *Chenopodium* and *Atriplex*. The

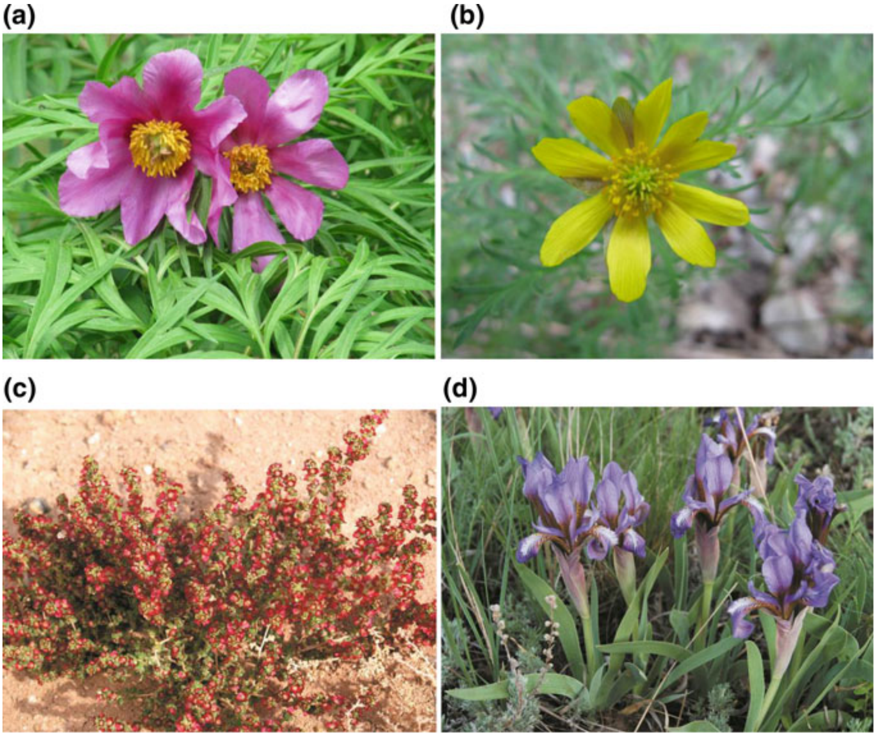


Fig. 2.4 Characteristic flora elements of the Kulunda region. **a** *Paeonia hybrida* Pall., an endemic of West Siberia, the Bashkir Trans-Uralian Region and Kazakhstan (Red'kina et al. 2008); **b** *Adonis villosa* Ledeb., an endemic of South-West Siberia (Hoffmann 1998); **c** *Anabasis salsa*, a characteristic species of dry deserts in Middle Asia extending to western Mongolia and western China; **d** *Iris glaucescens* grows on rocky slopes and mesic steppes in southern Siberia and adjacent regions of Middle Asia. *Source* Photos a, b by I. Hensen, c by S. V. Smirnov, d by P. A. Kosachev

respective species mostly occur in disturbed areas, settlements, agricultural fields and garden lots.

The flora comprises species from different biogeographical groups (Fig. 2.4). Most taxa have a Palaearctic, European–Ancient Mediterranean–Siberian global distribution range. The Holarctic geoelement and species with range patterns of the Ponto–Kazakhstan–Southern Siberian geoelement type (*Petrosimonia triandra*, *Salsola mutica*, *Crinitaria tatarica*) are slightly less numerous. The north-eastern distribution limit of the Western Asian–Northern Turanian–Kazakhstan–South-western Siberian geoelements (*Anabasis salsa*, *Artemisia pauciflora*, *Climacoptera crassa*, *Kalidium foliatum*, *Limonium suffruticosum*, *Nitraria schoberi* and others) runs through Kulunda. The endemic and subendemic geoelement (about 2%) is mostly represented by South-western Siberian and Altai–Dzungarian species. Strict endemics (neoendemics) of Kulunda are *Lotus krylovii* and *Puccinellia kulundensis* (Silantyeva 2013).

There are 69 rare and endangered species in the Kulunda steppe, out of which 33 species are listed in the ‘Red Book of the Altai Krai’ (2006), five species (*Fritillaria meleagroides*, *Stipa pennata*, *S. zalesskii*, *Caulinia flexilis*, *Marsilea strigosa*) are listed in the ‘Red Book of the Russian Federation’ (2008), and 37 species are listed in the ‘Red Book of the Novosibirskaia Oblast’ (2008).

2.4 Vegetation

Various schemes have been proposed to classify steppe vegetation on a macro-scale (see, e.g. Lavrenko and Karamysheva 1993; Zemmrich 2005). Such schemes may, on a crude physiognomic level, distinguish landscapes with alpine steppes, from those with desert steppes, from typical steppes and from mosaics of forests with meadows steppes (also known as forest steppe landscapes). While alpine steppes mainly occur in the mountain chains surrounding Central Asia, desert steppes are confined to the basins of Middle and Central Asia (Wesche et al. 2016). These occur in, e.g. Kazakhstan, whereas the less arid Russian Kulunda region already hosts some typical steppes and large areas of forest steppes. The latter represents the moistest type among the main formations, allowing for forest growth on sites with favourable water availability, such as north-facing slopes, small depressions or special soil conditions (Fig. 2.5). The mosaic character of forest steppe landscapes is also evident in the Kulunda region, where forest represents the zonal vegetation in the north-east and extends as bands well into the steppes westwards (see Chap. 3). Steppes and steppe-like old fallows form relatively small patches in the landscape and are often associated with the forest bands (Fig. 2.6). By and large, they cover only a small fraction of the Kulunda region.

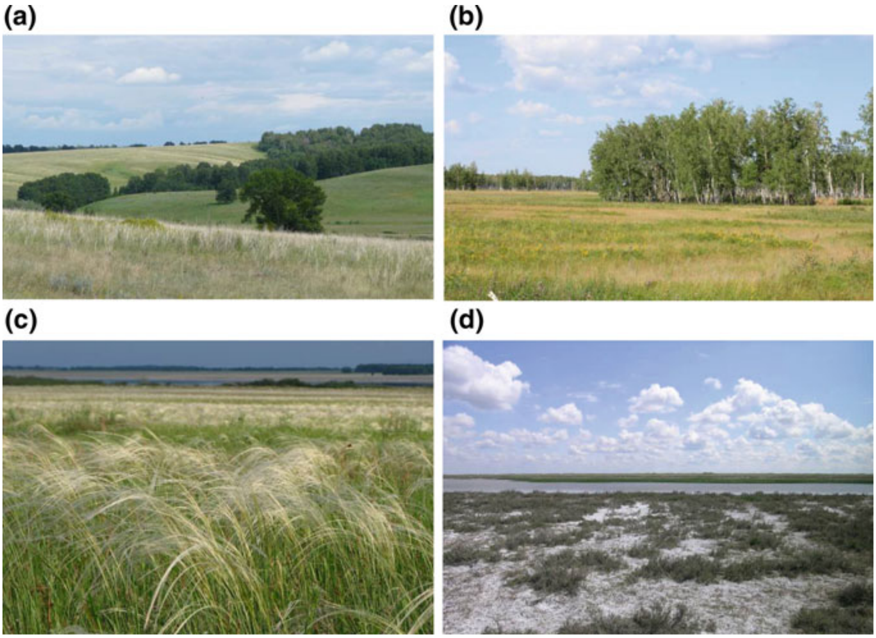


Fig. 2.5 Main vegetation types of the Kulunda region (see Chap. 3 for more detailed description. **a** Birch forest on slopes along erosion gullies; **b** 'Kolok' (plural 'Kolki') birch forests; **c** typical bunch grass steppe with *Stipa* spp; **d** wet depression with halophytic vegetation (*Halocnemum strobilaceum*). *Source* N. Lashchinsky

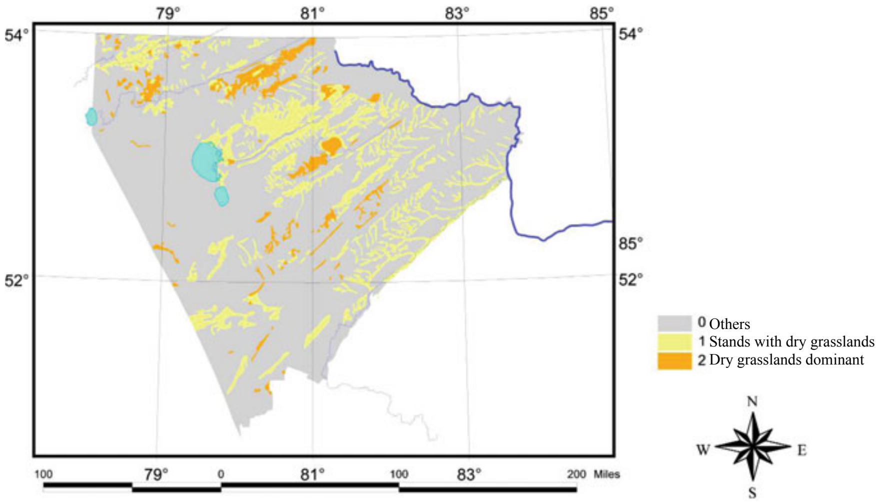


Fig. 2.6 Detailed map of the Kulunda region with larger steppe patches (lower threshold 500 hectares) based on field surveys (survey led by A. Korolyuk, unpublished data but see Smelansky et al. (2016) for further data availability)

Russian scholars have devised far more sophisticated schemes for classification of Russian steppes (for a recent overview, see Smelansky and Tishkov 2012). There are three main spatial gradients in Eurasian steppe vegetation: longitudinal, latitudinal and elevational. A main distinction is the longitudinal section along the Tien Shan–Altai (Yenisei) divide, thus following both climate and flora zonation described above. The east Siberian–inner Asian (Daurian-Mongolian) steppe subregion of central Asia is distinguished from the Pontic-Kazakh steppe subregion westwards (Lavrenko et al. 1991), which also includes the Kulunda region. This is also mirrored in formal phytosociological classification schemes. The class *Festuco-Brometea* Br.-Bl. et Tx. ex

Table 2.1 Importance value of species along the moisture gradient from the drylands along the Kazakh border to the meadows of the Altay

Mean indicator values of moisture, (Russian analogue of Ellenberg IV)	40–44	44–48	48–52	52–54	54–60
Number of relevés	38	181	299	236	131
Zonal type of steppes	Dry steppe	Typical steppe		Meadow steppe	
Psathyrostachys juncea	14	3	3	.	.
Artemisia gracilescens	19	+	.	.	.
Kochia prostrata	13	3	2	+	.
Festuca valesiaca	33	36	32	11	+
Stipa capillata	12	29	28	5	+
Artemisia frigida	17	19	10	+	.
Artemisia austriaca	13	14	13	3	+
Koeleria cristata	7	15	15	5	1
Carex supina	2	14	15	4	+
Stipa zalesskii	1	4	22	6	1
Medicago falcata	+	5	11	7	4
Thymus marschallianus	.	4	13	7	+
Artemisia glauca	+	4	13	6	1
Helictotrichon desertorum	+	2	15	3	.
Stipa borysthenica	.	7	13	+	.
Poa angustifolia	.	2	12	23	25
Calamagrostis epigejos	.	2	11	20	24
Fragaria viridis	.	+	11	22	22
Galatella biflora	+	1	12	16	15
Filipendula vulgaris	.	.	9	18	15
Festuca pseudovina	.	1	14	13	11
Peucedanum morisonii	.	1	10	11	6
Elytrigia repens	.	3	8	12	15
Carex praecox	.	1	10	13	12
Artemisia pontica	.	+	9	16	10
Phleum phleoides	.	1	9	10	11
Stipa pennata	.	+	9	13	6
Achillea asiatica	.	+	4	7	12

Adapted from Korolyuk (2014), for a detailed discussion, see Chap. 15

Soo 1947 unites temperate Euro-Siberian dry and semi-dry grasslands (Willner et al. 2017). In the Asian part of Russia, this class represents steppes of the West-Siberian plain (Korolyuk 2014) and of the northern periphery of the Altai-Sayan mountains (Korolyuk and Makunina 2001; Korolyuk 2007). The class *Cleistogenetea squarrosae* Mirkin et al. ex Korotkov et al. (1991) comprises the steppes of Inner Asia (Central Asia) east of the Ob River. Their continuous range encompasses Southern Siberia in Russia, most of Mongolia and the province Inner Mongolia in China (Mirkin et al. 1986; Hilbig 1995; Korolyuk 2002; Korolyuk and Makunina 2009; Ermakov 2012). Steppe communities also form extrazonal outposts as far to the North as North-Eastern Asia (Mirkin et al. 1985; Sinelnikova 2009; Reinecke et al. 2017).

Finer classifications are based on elevational belts and latitudinal gradients. The Kulunda region thus hosts three main types of steppe communities (Smelansky and Tishkov 2012): meadow steppes (forming mosaics with forests on a landscape scale), typical steppes and dry steppes. In the northern parts of the Kulunda region, relatively moist conditions (Fig. 2.3a) allow for productive and species-rich grasslands (for details, see Chap. 3). These meadow steppe communities typically grow on well-developed Chernozem soils (see Chap. 4). Characteristic species include bunch grasses: *Stipa pennata* and *Festuca pseudovina*, as well as rhizomatous grasses: *Poa angustifolia*, *Calamagrostis epigejos*, *Elytrigia repens* and *Phleum phleoides* (Table 2.1, Heinicke et al. 2016). A characteristic feature of the meadow steppes is a high abundance of perennial forbs that also occur far westwards, even into central Europe: *Fragaria viridis*, *Galatella biflora*, *Filipendula vulgaris*, *Peucedanum morisonii*, etc. (Table 2.1). With conditions getting drier towards the south and southwest (Fig. 2.3c), typical steppes are found with more drought-tolerant bunch grasses such as *Stipa capillata*, *S. zalesskii*, *Festuca valesiaca, Koeleria cristata* and *Helictotrichon desertorum*. Forbs and dwarf semishrubs such as *Artemisia frigida*, *A. austriaca*, *A. glauca* and *Thymus marschallianus* are also common. Typical steppes may still grow on Chernozems, though their vegetation cover is lower than in the northern part of the study region (Korolyuk 2014). Stands become increasingly open towards the Kazakh border, where the prevailing dry steppes (i.e. dry forb-bunchgrass steppes on Kastanozems) are characterised by a rather open vegetation cover, and by the fact that most of the biomass is stored below ground (Korolyuk 2014).

Acknowledgements Our sincere thanks go to Steffen Heinicke, the Botany team at ASU and all members of the Kulunda project for help during fieldwork and data processing. Georg Guggenberger and Gerd Schmidt kindly gave helpful comments on an earlier version of the text. Our work was mainly financed by a grant from BMBF to IH and KW as part of the Kulunda project.

References

Dengler J, Janisova M, Török P, Wellstein C (2014) Biodiversity of Palaearctic grasslands: a synthesis. Agr Ecosyst Environ 182:1–14

Dixon AP, Faber-Langendoen D, Josse C, Morrison J, Loucks CJ (2014) Distribution mapping of world grassland types. J Biogeogr 41:2003–2019

Djamali M, Brewer S, Breckle SW, Jackson ST (2012) Climatic determinism in phytogeographic regionalization: a test from the Irano-Turanian region, SW and Central Asia. Flora—Morphol Distrib Funct Ecol Plants 207:237–249

Ermakov NB (2012) The higher syntaxa of typical and dry steppes of southern Siberia and Mongolia. Vestnik NGU: Sibirja: Biologija, Klinicheskaja meditsina 10:5–15 [in Russian]

Grisebach A (1894) *Die Vegetation der Erde nach ihrer klimatischen Anordnung* [The vegetation of the earth according to its climatic arrangement]. W. Engelmann, Leipzig [in German]

Heinicke S, Hensen I, Rosche C, Hanselmann D, Gudkova PD, Silanteva MM, Wesche K (2016) Fragmentation and environmental constraints influence genetic diversity and germination of *Stipa pennata* in natural steppes. Flora—Morphol Distrib Funct Ecol Plants 224:42–49

Hijmans RJ, Cameron SE, Parra JL, Jones PG, Jarvis A (2005) Very high resolution interpolated climate surfaces for global land areas. Int J Climatol 25:1965–1978

Hilbig W (1995) The vegetation of Mongolia. SPB Academic Publishing, Amsterdam, NL

Hoffmann MH (1998) Ecogeographical differentiation patterns in *Adonis* sect. *Consiligo* (Ranunculaceae). Plant Syst Evol 211:43–56

Jäger EJ, Hilbig W (2010) Kommentare zu V. I. Grubovs pflanzeographischer Gliederung Zentralasiens und zur englischen Übersetzung der “Rasteniya Central’noj Azii” [Comments on V. I. Grubov’s plantographical classification of Central Asia and the English translation of the “Rasteniia Tsentral’noi Azii”]. Feddes Repertorium 121:14–17 [in German]

Korolyuk AJ (2002) Rastitel’nost’ [Vegetation]. *Stepi Central’noi Azii [Steppes of Inner Asia]*. Novosibirsk: Izdatel’stvo SO RAN, pp 45–94. (in Russian)

Korolyuk AJ (2007) Stepnaia rastitel’nost’ (Festuco-Brometea) predgorii Zapadnogo Altaia [Steppe vegetation (Festuco-Brometea) of Western Altai piedmonts]. Rastitel’nost’ Rossii [Veg Russia] 10:38–60 [in Russian]

Korolyuk AJ (2014) Soobshhestva klassa Festuco-Brometea na territorii Zapadno-Sibirskoi ravniny [Plant communities of the class Festuco-Brometea in the West Siberian plane]. Rastitel’nost’ Rossii [Veg Russia] 25:45–70 [in Russian]

Korolyuk AJ, Makunina NI (2001) Lugovye stepi i ostepnennye luga Altae-Saianskoi gornoi oblasti. Poriadok Stipetalia sibiricae, soiuz Aconito barbati-Poion transbaicalicae [Meadow steppes and xeric meadows of Altai-Sayan mountains. The order Stipetalia sibiricae, the alliance Aconito barbati-Poion transbaicalicae]. Krylovia 3:35–49 [in Russian]

Korolyuk AJ, Makunina NI (2009) Nastojashchie stepi Altae-Saianskoi gornoi oblasti (poriadok Stipetalia krylovii Kononov, Gogoleva et Mironova 1985) [Typical steppes of Altai-Sayan mountains (the order Stipetalia krylovii Kononov, Gogoleva et Mironova 1985)]. Rastitel’nyi mir Aziatskoi Rossii [Flora Veg Asian Russia] 2:43–53 [in Russian]

Kottek M, Grieser J, Beck C, Rudolf B, Rubel F (2006) World map of the Köppen-Geiger climate classification updated. Meteorol Z 15:259–263

Krasnaia kniga Altaiskogo kraia (Red Book of the Altai Krai) (2006) *Rasteniia (Plants)*. Publishing House of the Alt. University Press, Barnaul [in Russian]

Krasnaia kniga Novosibirskoi oblasti (Red Book of the Novosibirsk Region) (2008) Zhivotnye, rasteniia i griby (Animals, plants and fungi). Novosibirsk. (in Russian)

Krasnaia Kniga Rossiiskoi Federatsii (Red Book of the Russian Federation) (2008) Plants and Fungi. Association of scientific editions KMK, Moscow [in Russian]

Lavrenko EM, Karamysheva ZV (1993) Steppes of the former Soviet Union and Mongolia. In: Coupland RT (ed) Ecosystems of the world 8b—natural grasslands. Elsevier, Amsterdam, London, New York, Tokyo, pp 3–59

Lavrenko EM, Karamysheva ZV, Nikulina RI (1991) Stepi Evrazii (Eurasian steppes). In: Biologicheskie Resursy i prirodnye Usloviia Mongolskoi Narodnoi Respublike, vol 35, pp 1–144. (in Russian)

Manafzadeh S, Staedler YM, Conti E (2016) Visions of the past and dreams of the future in the Orient: the Irano-Turanian region from classical botany to evolutionary studies. Biol Rev 92:1365–1388

Mirkin BM, Alimbekova LM, Manibazar N, Onishhenko LI (1986) Vtoroe priblizhenie floristicheskoi klassifikatsii rastitel'nosti rechnykh poim Mongol'skoi narodnoi respubliki [Second approach of floristic classification of vegetation of floodplains of the Mongolian national republic]. Biologicheskie nauki [Biol Sci] 9:83–91 [in Russian]

Mirkin BM, Gogoleva PA, Kononov KE (1985) The vegetation of Central Yakutian alases. Folia Gebotanica et Phytotaxonomica 20:345–395

Red'kina NN, Mullagulov RY, Yanbaev YA, Muldashev AA, Akilov RZ (2008) Hybrid peony (*Paeonia hybrida* Pall.), a rare endangered plant of Bashkir Trans-Uralian Region: Autocorrelation analysis of the spatial genotype distribution under different environmental conditions. Contemp Probl Ecol 1:707–711

Reinecke J, Troeva E, Wesche K (2017) Extrazonal steppes of northern Siberia—Phytosociological classification and ecological characterization. Phytocoenologia 47:167–196

Silantyeva MM (2013) Konspekt flory Altaiskogo kraia [Abstract of the flora of the Altai region]. ASU, Barnaul (in Russian)

Sinelnikova NV (2009) Ehkologo-floristicheskaia klassifikatsiia rastitel'nykh soobshhestv verkhovii Kolymy [Classification of plant communities of the Upper Kolyma region (North-Rast Russia)]. Magadan. (in Russian)

Smelansky I, Tishkov A (2012) The steppe biome in Russia: ecosystem services, conservation status, and actual challenges. In: Werger MJA, van Staalduinen M (eds) Eurasian steppes. Ecological problems and livelihoods in a changing world. Springer, Heidelberg, pp. 45–102

Smelansky IE et al (2016). Map of the living steppe tracts of Russia. Transparent World & Sibecocenter LLC. http://savesteppe.org/ru/maps

Takhtajan AL (1986) Floristic regions of the world. University of California Press, Berkeley

Walter H (1974) Die Vegetation Osteuropas, Nord- und Zentralasiens [The vegetation of Eastern Europe, North and Central Asia]. G. Fischer, Stuttgart [in German]

Werger MJA, van Staalduinen M (2012) Eurasian steppes. Ecological problems and livelihoods in a changing world. Springer, Heidelberg, p 565

Wesche K, Ambarlı D, Kamp J, Török P, Treiber J, Dengler J (2016) The Palaearctic steppe biome: a new synthesis. Biodivers Conserv 25:2197–2231

Wesche K, Treiber J (2012) Abiotic and biotic determinants of steppe productivity and performance—a view from Central Asia. In: Werger MJA, van Staalduinen M (eds) Eurasian steppes. Ecological problems and livelihoods in a changing world. Springer, Heidelberg, pp 3–43

Willner W, Kuzemko AA, Dengler J, Chytrý M, Bauer N, Becker T, Biţă-Nicolae C, Botta-Dukát Z, Čarni A, Csiky J, Igić R, Kącki Z, Korotchenko I, Kropf M, Krstivojević-Ćuk M, Krstonošić D, Rédei T, Ruprecht E, Schratt-Ehrendorfer L, Semenishchenkov Y, Stančić Z, Vashenyak Y, Vynokurov D, Janišová M (2017) A higher-level classification of the Pannonian and western Pontic steppe grasslands (Central and Eastern Europe). Appl Veg Sci 20:143–158

Zemmrich A (2005) Die Steppengliederung der Mongolei aus Sicht der russischen und mongolischen Geobotanik [The steppe structure of Mongolia from the point of view of Russian and Mongolian geobotany]. Archiv für Naturschutz und Landschaftsforschung 44:17–35 [in German]

Zohary M (1962) Plant life of Palestine, Israel and Jordan. Ronald Pr, New York

Zohary M (1973) Geobotanical foundations of the Middle East, 2 vols. Gustav Fischer/Swets & Zeitlinger, Stuttgart/Amsterdam

Chapter 3
Climatic Variability of the Kulunda Steppe

N. F. Kharlamova

Abstract Natural conditions are important, constantly acting factors in the territorial organization of agriculture, which affect the efficiency of production. Among those, climate is the primary and most important factor. This paper deals with the spatio-temporal variability of the thermal regime and moistening conditions of the Kulunda steppe as an element of the South Siberian agro-steppe within the Eurasian steppe belt of the forest steppe and steppe natural zones. Interannual variability of climate has a great impact on agriculture. Better understanding and taking into account the factors of climate variability allows solving problems related to climate change. Reducing the vulnerability of various sectors, such as biodiversity, forestry and agriculture, to climate variability by raising awareness of policy, work methods and technology choices will in many cases reduce the long-term vulnerability of these systems to climate change.

Keywords Climatic variability · Hydrothermal coefficient · Moistening coefficient · Precipitation regime · Temperature increase · Thermal regime

3.1 Introduction

The Eurasian steppe belt of the forest steppe and steppe plays a leading role in the global production of agricultural products. The geopolitical and resource importance of these territories is increasing due to the world population growth, shortage of fertile land, climate change and the threat of food crises. In order to solve the fundamental problem of optimizing the interaction between nature and society of Eurasia under the conditions of global change of the natural environment, it is necessary to assess the current and projected climate change (Shumova 2005, 2007; Kharlamova et al. 2014).

N. F. Kharlamova (✉)
Faculty of Geography, Altai State University, Prospect Lenina 61, 656049 Barnaul, Russian Federation
e-mail: harlamovageo@rambler.ru

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_3

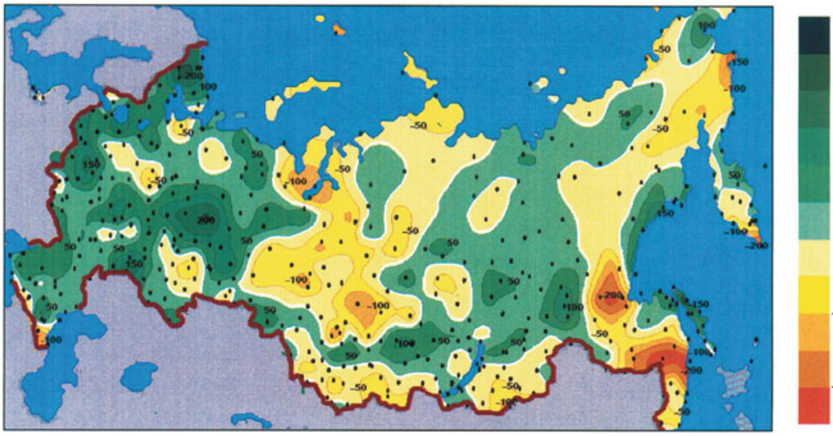


Fig. 3.1 Changes in annual precipitation (mm/75 years) in Russia for the period 1936–2010. *Source* Second Assessment Report (2014)

The Kulunda steppe belongs to the Russian steppe belt, which is a part of the Eurasian steppe system. The climate change taking place here is a bright reflection of global climate change and needs in-depth study, including an understanding of regional features of the inland area of the South Siberian agro-steppe. Here, in the Altai Krai, large areas of arable lands with fertile soils are concentrated. Their use strongly depends on the state of the arid moderate continental climate (Kharlamova and Silantyeva 2011a, b).

According to Roshydromet, during the past decades warming happened faster and to a larger extent in the Russian Federation than in most other areas of the world (Rosgidromet 2014). During the last 40 years, the average increase in global temperature was about 0.17 °C per decade. In the territory of Russia, this rise in temperature has been much faster with 0.43 °C per decade. The trend in annual precipitation for the period 1936–2010 was positive for most parts of Russia, while in the south-eastern part of Western Siberia, where the Altai Krai is located, a negative trend can be observed (Fig. 3.1).

It is necessary to study a longer period of observations throughout the steppe and adjacent forest steppe natural areas of Russia for an in-depth understanding of the temporal state and climate variability of the South Siberian agro-steppe.

3.2 Materials and Methods

Forest steppe and steppe zones of Russia extend in a continuous belt through the Eastern European Plain, the Southern Urals and the West Siberian Plain to the Ob River (steppe) and the Salair Range in the Altai Krai (forest steppe). To the east of

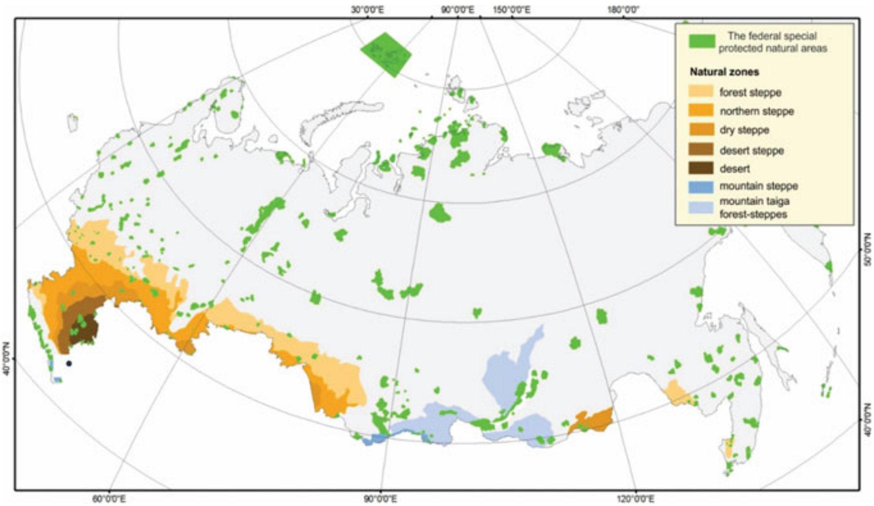


Fig. 3.2 Distribution of steppes and forest steppes in Russia. *Source* http://savesteppe.org/ru/steppe-oopt

the river Chumysh, the forest steppe and steppe are found only in the form of isolated islands near Krasnoyarsk, Kansk and Irkutsk and in the intermountain river valleys of the Altai and Sayan Mountains and Transbaikalian without the formation of a zone band (Kharlamova and Kozlova 2015). The total area of the steppe natural zone (northern and dry steppe) in the Altai Krai, the main territory of which lies within the Kulunda Plain, is relatively small, but it is here that the main massifs of arable land with the most productive chernozems and chestnut soils are concentrated (Fig. 3.2).

For the statistical analysis of the variability of the thermal regime and the annual atmospheric precipitation regime of the territory of the forest steppe and steppe zones of Russia during 1966–2012, the array of monthly open access data was used by RIHMI-WDC (http: www.meteo.ru) for 33 weather stations located from the west to the east of the Eurasian steppe belt. In order to assess the heat supply variety of agricultural crops, the commonly used indicator in Russia is applied—the sum of the active temperatures above +10 °C ($\Sigma T > 10$ °C). To estimate the conditions for moistening agricultural areas, the two most commonly used indicators in Russia are used: the hydrothermal coefficient by G.T. Selyaninov (HTC) and the moistening coefficient by N.N. Ivanov (CH) (Rosgidromet 2012). The HTC value is included in the list of indicators of aridity of the climate (Stadler 1987).

The HTC is defined by Selyaninov (1955) as the ratio of the sum of the growing season precipitation to the sum of average daily temperatures of this period:

$$\mathrm{HTC} = \Sigma P/(\Sigma T_{>10\,^{\circ}\mathrm{C}}) : 10,$$

where ΣP—sum of precipitation for the period with $t > 10$ °C in mm during the period with average daily air temperatures above 10 °C to the amount of heat (ΣT) during the same period, decreased by 10 times (Selyaninov 1955).

According to the HTC values, the following gradation of humidity of areas was identified:

- Moderately wet (1.3–1.5),
- Insufficient wet (1.0–1.3),
- Dry (0.7–1.0),
- Very dry (0.5–0.7),
- Extremely dry (HTC < 0.5).

When calculating the moistening coefficient (CH) by N.N. Ivanov, a one year's evaporation is calculated by the formula:

$$E_o = c \sum \theta,$$

where E_o—evaporation in mm/year, $\sum \theta$—sums of temperatures above 10° ($\Sigma T >$ 10 °C), c—coefficient of 0.18.

Accordingly, CH for the year is expressed by the formula:

$$CH = \frac{P}{0{,}18\ \Sigma\theta},$$

where P—precipitation for a year in mm (Keltchevskaya 1971).

The study of the changes in the distribution of the territories of the Altai Krai, the Republic of Altai and the Novosibirsk Region with the sums of active temperatures above +10 °C ($\Sigma T > 10$ °C) characterizes variations of heat supply for growing different crops, obtained by construction of empirical relationship $\Sigma T_{>10\,°C}$ as a function of altitude (z), latitude (φ) and longitude (λ) of the locality:

$$T_{>10\,°C} = f(z, \varphi, \lambda).$$

Estimation of the annual, monthly and mid-seasonal (winter—January, summer—July) changes in air temperature, annual precipitation and moistening coefficients CH and HTC was conducted on the basis of linear trend coefficients b, °C/10 years and mm/10 years.

3.3 Results and Discussion

The analysis of the thermal regime of forest steppe and steppe zones in Russia for 1966–2012 shows that the mean annual air temperature decreases from west to east from 11.9 (Krasnodar) to 0.8 °C (Barabinsk), the winter temperature from −0.1 (Krasnodar) to −8.5°C (Barabinsk) and the summer temperature from 24.0 (Krasnodar) to 19.2 °C (Barabinsk).

Table 3.1 Estimates of the linear trend of annual air temperature in forest steppe and steppe natural zones of Russia, 1966–2012

Weather station	*b*—coefficient of linear trend, °C/10 years	Weather station	*b*—coefficient of linear trend, °C/10 years
Krasnodar	0.4	Armavir	0.2
Stavropol	0.2	Rostov-on-Don	0.2
Tsimlyansk	0.4	Volgograd	0.4
Chertkovo	0.3	Valuiki	0.4
Voronezh	0.5	Kalach	0.4
Tambov	0.4	Uryupinsk	0.4
Frolovo	0.4	Penza	0.4
Saratov	0.4	Ershov	0.4
Bezenchuk	0.4	Sorochinsk	0.5
Dombarovsky	0.4	Bredy	0.4
Troitsk	0.4	Makushino	0.4
Ishim	0.5	Russkaya Polyana	0.4
Tatarsk	0.4	Barabinsk	0.5
Slavgorod	**0.7**	Rubtsovsk	0.4
Zmeinogorsk	0.4	Kamen-on-Ob	0.4
Rebrikha	0.3	Barnaul	0.3
Biysk, Zonalnaya	0.4	**Average**	**0.4**

The average annual rate of change of temperature in Russia with forest steppe and steppe landscapes in 1966–2012 was 0.4 °C/10 years (Table 3.1). The obtained results almost completely coincide with the estimates given in the Second Roshydromet Assessment Report, according to which the rate of warming over the period 1976–2012 was 0.52 °C/10 for the European territory of Russia and 0.29 °C/10 for Western Siberia (Rosgidromet 2014).

The rate of warming increases from the western to the eastern border areas of the forest steppe and steppe landscapes of Russia with increasing continental climate. Thus, the areas of the least increase in the annual air temperature are the south-western regions of Russia (Rostov-on-Don, Stavropol and Armavir). More intensive increase in annual temperature is observed in the West Siberian forest steppe (Barabinsk and Ishim), reaching the maximum values of 0.7 °C/10 years (Slavgorod) within the Kulunda steppe of the Altai Krai (Fig. 3.3).

Due to the large extent of the territory of Russia and the variety of its natural conditions, climatic change occurs unevenly and warming occurs at different rates in different seasons. A higher rate of temperature rise is typical for winter, which is 0.6 °C/10 years, whereas in summer, the rate of the rising average temperature in the forest steppe and steppe zones of Russia is two times less with 0.3 °C/10 years (Table 3.2). Thus, the results of studies indicate significant changes in the thermal

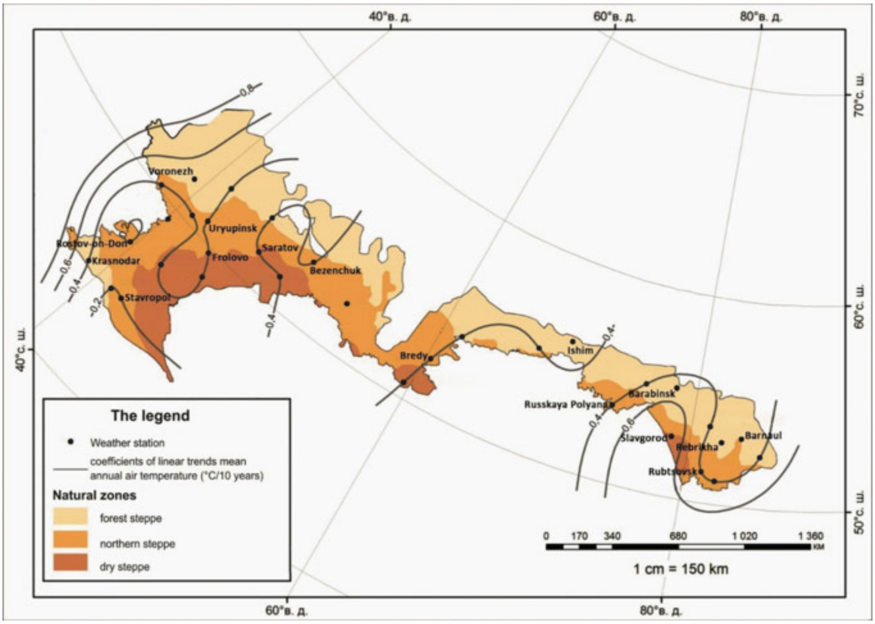


Fig. 3.3 Spatial distributions of the coefficients of linear trends mean annual air temperature (°C/10 years) in the forest steppe and steppe natural zones of Russia, 1966–2012

regime throughout the forest steppe and steppe natural zones of Russia, characterized by warming at an average rate of 0.4 °C/10 years. The highest rates of air temperature increase are observed in the winter season, reaching the maximum values in the European territory of Russia.

The study of the changes in the distribution of the territories of the Altai Krai, the Republic of Altai and the Novosibirsk Region with the sums of active temperatures above +10 °C ($\Sigma t > 10$ °C), which characterize variations in the heat availability of growing a variety of crops, shows that with the continuing rate of warming towards the end 2025, the sum of the active temperatures can increase by 300 °C or more. Therefore, the boundaries of the territories with heat availability $\Sigma T > 10$ °C equal to 2200–2400 and 2400–3000 °C (conditions of dry and extremely dry steppe) can significantly advance northwards (Fig. 3.4, Mikhailova and Kharlamova 2006; Mikhailova et al. 2008).

The variability of the annual precipitation is also characterized by non-homogeneity (Kharlamova 2013a, b). The most noticeable reduction in annual precipitation during the period 1966–2012 was observed in the western regions of Russia, especially in the steppe regions of the Western Caspian (−100 mm/10 years, Fig. 3.5). Negative trends in precipitation of lower values (−20 mm/10 years) were observed in Azov forest steppe and south of the forest steppe zone of Altai. The opposite tendencies of an increasing annual precipitation rate of 20 mm/10 years are noted along the northern borders of the forest steppe zone of Russia and, in particu-

Table 3.2 Estimates of the linear trend of averaged seasonal surface air temperature in forest steppe and steppe natural zones of Russia, 1966–2012

Weather station	*b*—coefficient of linear trend, °C/10 years		Weather station	*b*—coefficient of linear trend, °C/10 years	
	January	July		January	July
Krasnodar	0.6	**0.6**	Armavir	0.5	0.3
Stavropol	0.4	0.4	Rostov-on-Don	0.5	0.4
Tsimlyansk	0.7	0.5	Volgograd	0.8	0.5
Chertkovo	0.8	0.5	Valuiki	0.9	**0.6**
Voronezh	1.0	**0.6**	Kalach	0.9	0.4
Tambov	0.9	**0.6**	Uryupinsk	1.0	0.5
Frolovo	0.9	0.5	Penza	1.0	**0.6**
Saratov	**1.3**	0.2	Ershov	1.0	0.5
Bezenchuk	1.0	0.4	Sorochinsk	0.9	0.4
Dombarovsky	0.8	0.2	Bredy	0.8	0.2
Troitsk	0.7	0.3	Makushino	0.5	0.2
Ishim	0.6	0.1	Russkaya Polyana	0.3	0.0
Tatarsk	0.3	−0.1	Barabinsk	0.5	0.0
Slavgorod	**0.2**	**0.0**	Rubtsovsk	0	0.0
Zmeinogorsk	0.0	0.1	Kamen-on-Ob	0	0.1
Rebrikha	−0.1	0.0	Barnaul	−0.1	0.0
Biysk, Zonalnaya	0	0.2	**Average**	**0.6**	**0.3**

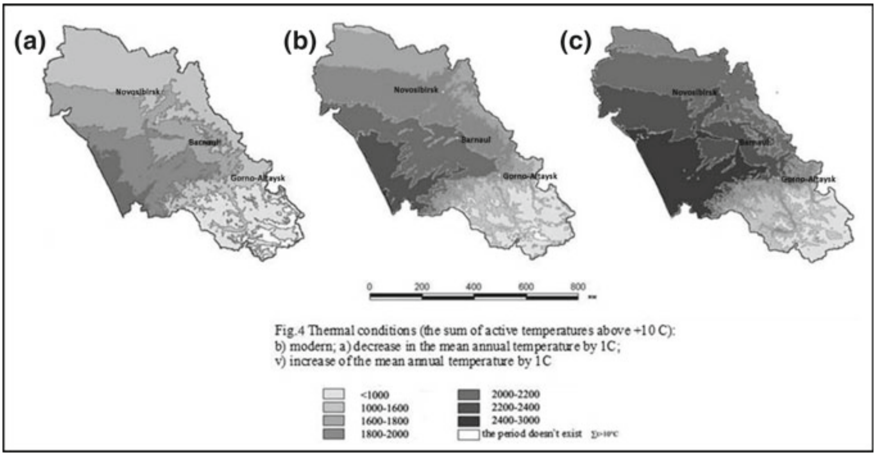


Fig. 3.4 Thermal conditions (the sum of active temperatures above +10 °C): **a** decrease in the mean annual temperature by 1 °C; **b** modern; **c** increase in the mean annual temperature by 1 °C

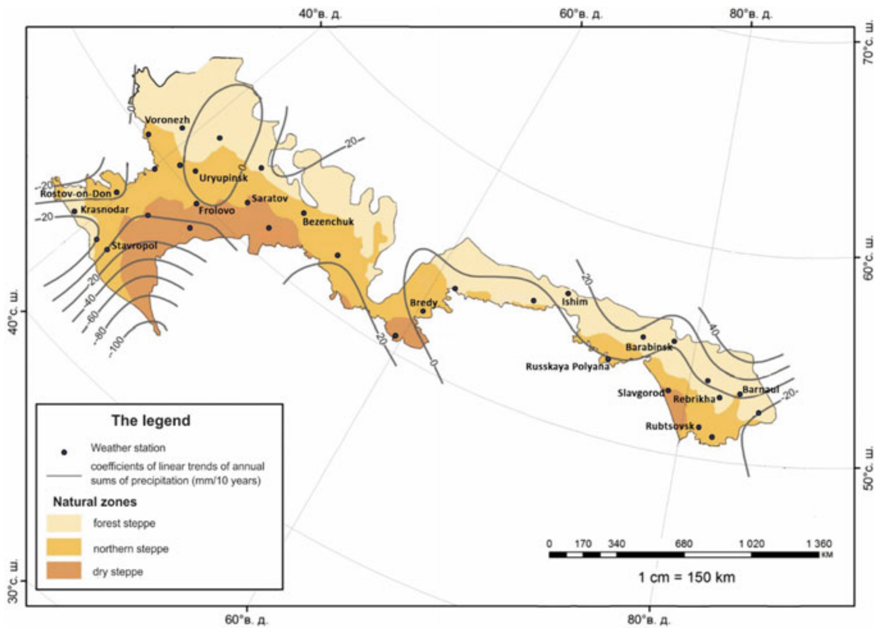


Fig. 3.5 Spatial distribution of coefficients of linear trends of annual sums of precipitation (mm/10 years) in forest steppe and steppe natural zones of Russia, 1966–2012

lar, in the extreme north-east of this zone (40 mm/10 years), where there is a barrier effect of the Kuznetsky Alatau.

Therefore, the most significant reduction in annual precipitation since the second half of the twentieth century has been observed in the western regions of Russia, especially in steppe of the Western Caspian, Azov steppe, forest steppe and steppe natural zones of Altai. These areas are the most important agricultural regions of Russia, and the identified trends will certainly impact the structure and quality of agricultural production.

Average values of moistening coefficient (CH) by Ivanov of forest steppe and steppe landscapes in Russia vary in the range from 20.8–29.2% (Akbulak, Rubtsovsk and Slavgorod) to 69.2% (Zmeinogorsk, Table 4). Values of the hydrothermal coefficient (HTC) in the forest steppe and the steppe vary from 0.4 (Slavgorod) to 1.2 (Zmeinogorsk). According to the range of HTC, the following moistening zones have been identified:

- Insufficiently wet (Krasnodar, Stavropol, Biysk and Zmeinogorsk),
- Dry (Bezenchuk, Frolovo, Uryupinsk, Chertkovo, Rostov-on-Don, Kamen-on-Ob, Barnaul, Rebrikha),
- Very dry (Akbulak, Bredy, Russkaya Polyana, Rubtsovsk),
- Extremely dry (Slavgorod) (Table 3.3).

Table 3.3 Mean values of HTC and CH coefficient of moisture of forest steppe and steppe landscapes of Russia, 1966–2012

№	Weather station	Value of CH/(moistening characteristic)	Value of HTC/(moistening characteristic)
forest steppe			
1	Krasnodar	55.7 (insufficient)	1.0 (insufficiently wet)
2	Kamen-on-Ob	43.2 (insufficient)	0.8(dry)
3	Barnaul	55.5(insufficient)	0.9 (dry)
4	Rebrikha	48.1 (insufficient)	0.9 (dry)
Steppe			
5	Stavropol	57.2 (insufficient)	1 (insufficiently wet)
6	Rostov-on-Don	49.4 (insufficient)	0.9 (dry)
7	Chertkovo	47.3 (insufficient)	0.9 (dry)
8	Uryupinsk	44.7 (insufficient)	0.8 (dry)
9	Frolovo	38.2 (insufficient)	0.7 (dry)
10	Bezenchuk	44.3 (insufficient)	0.8 (dry)
11	Akbulak	29.2 (scanty)	0.5 (very dry)
12	Bredy	40.6 (insufficient)	0.7 (very dry)
13	Russkaya Polyana	41.5 (insufficient)	0.7 (very dry)
14	Biysk, Zonalnaya	59.7 (insufficient)	1.1 (insufficiently wet)
15	Zmeinogorsk	69.2 (insufficient)	1.2 (insufficiently wet)
16	Rubtsovsk	26.6 (scanty)	0.5 (very dry)
17	Slavgorod	20.8 (scanty)	0.4 (extremely dry)

With a general tendency towards reducing the degree of moisture with the increasing continentality of the climate from the western borders of forest steppe and steppe natural zones of Russia to the Altai Krai, there was a significant barrier effect of the Altai and Sayan Mountain ranges, contributing to the increase in the availability of moisture in the territory (Fig. 3.6).

Linear trends of CH and HTC, reflecting the overall long-term trend of moisture variability during 1966–2012, are negative in most parts of the area under study (for example, see weather station Slavgorod, Fig. 3.7), while only for some areas like at the weather stations of Barnaul (Fig. 3.8) and Rebrikha, slightly positive trends are noted.

Thus, in the course of the study of spatio-temporal variability of the degree of moistening of forest steppe and steppe landscapes of Russia for the period 1966–2012, a general trend of increasing aridity has been identified. Against a long-

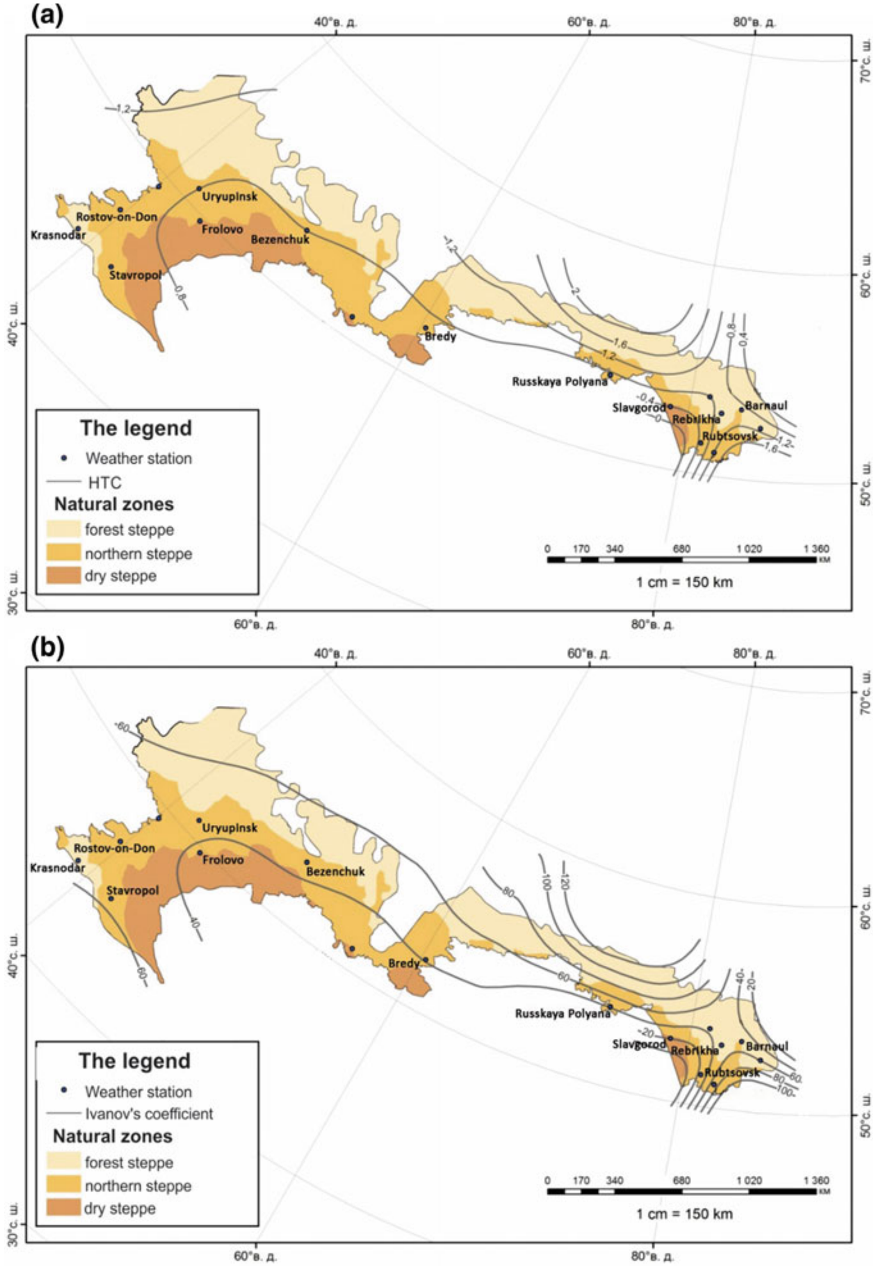


Fig. 3.6 Spatial distribution of HTC (**a**) and CH (**b**) moistening coefficients in forest steppe and steppe natural zones of Russia, 1966–2012

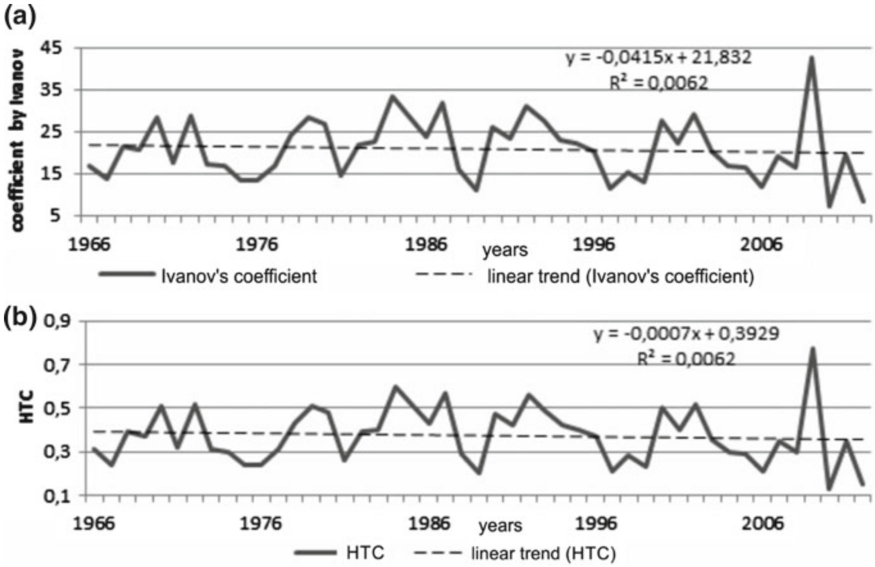


Fig. 3.7 Changes of CH (**a**), HTC (**b**) values from 1966–2012 for Slavgorod

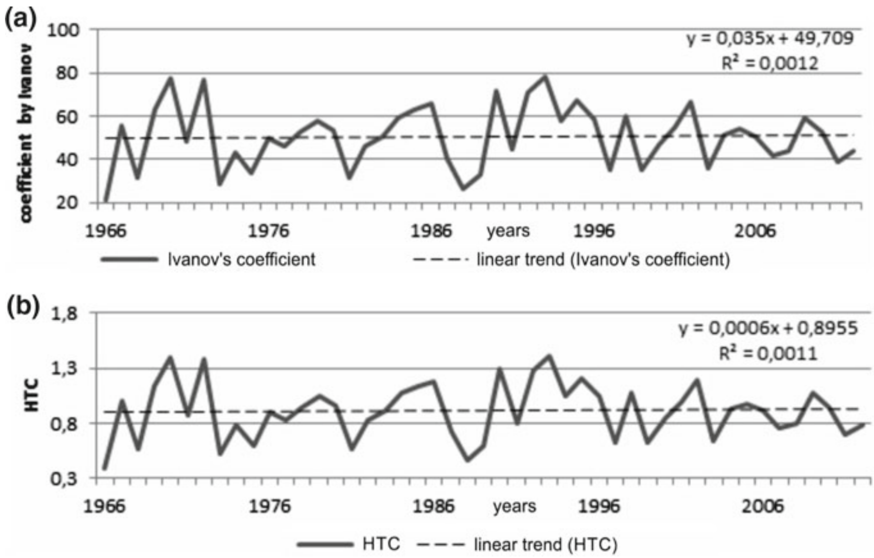


Fig. 3.8 Changes of CH (**a**), HTC (**b**) values from 1966–2012 for Barnaul

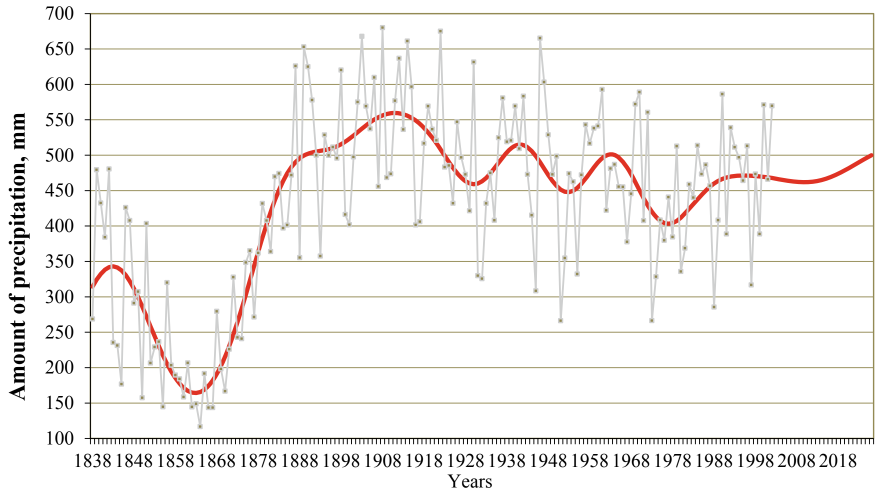


Fig. 3.9 Changes in annual precipitation, weather station in Barnaul, 1838–2028; red line—smoothed by low-pass filter, grey line—the annual value (without correction for wetting)

term negative orientation of linear trends, rhythmic periods of relative reduction and increase in moisture are noted.

The results obtained in the study of relatively short time periods, as in this study (1966–2012), may not correspond to long-term trends, identified on the basis of long-term series of meteorological observations by the different weather stations. Thus, the observed rhythm of wet and dry periods was determined on the basis of the analysis of the distribution of annual precipitation at the Barnaul weather station for the period 1838–2028 (Fig. 3.9; Kharlamova and Revyakin 2006; Kharlamova 2010). According to these observations, beginning in 2007, there was a tendency of an increasing moisture content, which can be preserved in the coming years.

However, the peculiarity of modern climate change, beginning from the middle of the twentieth century, is the change in the ratio of heat and moisture supply. Equal amount of precipitation at the beginning and at the end of the twentieth century provided different moisture, because at a higher temperature level, the moisture content decreases. And if the rate of warming continues to increase in the coming years, the increasing level of precipitation, projected by 2028 (Fig. 3.9), may not be sufficient to increase the overall moisture content.

3.4 Conclusions

The spatio-temporal variability of the thermal regime and the humidification of the Kulunda steppe indicate an appreciable increase in the annual air temperature (an average of 0.4 °C/10 years) during the almost 50-year period of 1966–2012, especially in the winter season. This concurs with an increase in the aridity of forest steppe and steppe landscapes, where the main agricultural areas are concentrated. Trends of annual precipitation and coefficients of humidification by Ivanov (moistening coefficient, CH) and Selyaninov (hydrothermal coefficient, HTC) are negative practically for the whole territory. The most noticeable decrease in annual amount of precipitation and moisture since the second half of the twentieth century has been observed in western regions, especially in steppe regions of the Western Caspian, Azov steppes, forest steppe and steppe regions of Kulunda in the Altai Krai. The problems in agriculture caused by climatic changes of a regional and global scale are common for many regions. Therefore, the results of research on this topic on the example of the South Siberian agro-steppe are very relevant beyond this study region.

References

Federal Service for Hydrometeorology and environmental monitoring (Rosgidromet) (2012) Metody otsenki posledstvii izmeneniia klimata dlia fizicheskikh i biologicheskikh sistem [Methods for assessing climate change impacts on physical and biological systems]. Planet, Moscow (in Russian)

Federal Service for Hydrometeorology and environmental monitoring (Rosgidromet) (2014) Vtoroi otsenochnyi doklad Rosgidrometa ob izmeneniiakh klimata i ikh posledstviiakh na territorii Rossiiskoi Federatsii - obshchee reziume [The second assessment report Hydromet about climate change and its consequences on the territory of the Russian Federation - General Summary]. Rosgidromet, Moscow (in Russian)

Keltchevskaya LS (1971) Processing methods of observation in agroclimatology: methodical and training Manual. Leningrad (in Russian)

Kharlamova NF (2010) Long-term climate change in the Russian hinterland (The Altai Krai). News Altai State Univ 3/1(67): 133–140

Kharlamova NF (2013a) Assessment and forecast of modern climate change of the Altai region: monograph. Publishing House of the Alt, University Press, Barnaul

Kharlamova NF (2013b) The climate of the Altai Territory: textbook. Publishing House of the Alt, University Press, Barnaul

Kharlamova NF, Bondarovich AN, Kozlova DS, Plekhova AV (2014) Variability of moistening of the territory of forest steppe and steppe zones of the Altai Territory during 1982–2013. Geogr Nat Resour Siberia 18:206–215

Kharlamova NF, Kozlova DS (2015) Variability of the thermal regime and moistening of Russian forest steppe and steppe natural zones 1966–2012. Geogr Nat Siberia 20:169–181

Kharlamova NF, Revyakin VS (2006) Regional climate and environmental chance in Central Asia. In: Vogtmann H, Dobretsov N (eds) Environmental security and sustainable land use—with special reference to Central Asia. NATO Security through Science Series - C: Environmental Security. Springer, Dordrecht, pp 19–26

Kharlamova NF, Silanteva MM (2011a) Current status and trends of climate change in Kulunda. News Altai State Univ 3/2(71):50–55

Kharlamova NF, Silanteva MM (2011b) Dependence of the yield of grain crops in regions of Kulunda on climatic factors. News Altai State Univ 3/2(71):88–94

Mikhailova LA, Kharlamova NF (2006) GIS modeling of climatic parameters on the example of the Siberian region. Polzunovsky Gazette 4–2:113–118

Mikhailova LA, Kharlamova NF, Mikhailov NN (2008) Geoinformation technologies in the study of regional climate changes. In: Acad. Kotlyakov VM (ed) Environmental changes in the Commonwealth countries in the current climate change. Media-Press, Moscow, pp 96–101

Selyaninov GT (1955) Climatic zoning of the USSR for agricultural purposes/Coll of Memory of L.S. Berg, Moscow/Leningrad, Nauka, pp 29–89

Shumova NA (2005) Forecast of the impact of possible climate changes on hydrothermal conditions and harvest crops and steppe zones/Assessing the impact of changes in land water regime on terrestrial ecosystems. M, pp 71–107

Shumova NA (2007) Vulnerability assessment of hydrothermal conditions and zonal boundaries of arid territories under different scenarios of climate change. Arid Ecosyst 13(32):34–46

Stadler SJ (1987) Aridity indexes. In: Oliver JE, Fairbridge RW (eds) The encyclopedia of climatology. Van Nostrand Reinhold Company, New York, pp 102–106

Chapter 4
Vegetation Patterns and Ecological Gradients: From Forest to Dry Steppes

N. Lashchinsky, A. Korolyuk and K. Wesche

Abstract Vegetation patterns and plant communities associated with them are determined on the regional scale based on an analysis of remote sensing data and ground information. Three main vegetation patterns are described in dependence on ecological factors: geological substrate (loess vs. sand), relief, precipitation and warmness. The first two patterns are characterized by the same substrate (loess) but different relief and consist of dry grasslands in combination with birch forests. The first pattern on elevated plains with extensive gully systems looks at forest patches in the form of dendritic or amoeba-like contours in a matrix of steppes and arable land. The second pattern on low-lying plains with poor drainage is patchy with numerous rounded forest groves, locally called 'kolok' forests, embedded in a steppe matrix. The third one differs mostly by substrate (sand) and is represented by pine forests in combination with psammophytic steppes. Each pattern is composed of different vegetation types (forests and grasslands) and distributed more or less throughout all of the Kulunda area. Nine types of forest ecosystems and four types of grasslands could be distinguished by species composition and their ecological demands. Depending on local climate conditions, combinations of plant communities in each pattern change from west to east on the precipitation gradient and from south to north along the warmness gradient.

Keywords Vegetation pattern · Steppe · Pine forest · Ordination · Ecological gradient · Indicator species

---

N. Lashchinsky (✉) · A. Korolyuk
Central Siberian Botanical Garden SD RAS, Zolotodolinskaya 101, Novosibirsk 630090, Russia
e-mail: nnl630090@gmail.com

K. Wesche
Senckenberg Museum of Natural History, Görlitz, PO Box 300 154, 02806 Görlitz, Germany

German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Leipzig, Germany

International Institute Zittau, Technische Universität Dresden, Markt 23, 02763 Zittau, Germany

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_4

4.1 Introduction

In the first chapter, the Kulunda steppe was introduced as one relatively uniform region and a part of the Eurasian steppe zone. In this chapter, we will discuss Kulunda vegetation on a finer scale and describe its spatial structure depending on different ecological gradients. If on the continental scale climate is the main factor of vegetation type distribution, then on the regional level there are few ecological factors equally important for the vegetation spatial structure. Vegetation structure and composition reflect relief, climate and geological conditions, and plant community composition is influenced by numerous ecological factors including human impact.

The vegetation of the Kulunda region has been highly transformed by human activity. For ecologically sustainable land management, knowledge on the natural or so-called potential vegetation is, however, highly relevant. It is also important for an understanding of relationships between vegetation and environmental conditions—sound knowledge on these relationships allows us to predict vegetation responses to changes in climate, soil, etc.

In spite of the massive alterations brought by the human colonization of the Kulunda region, it is still possible to find few remnants of the natural or of comparatively undisturbed vegetation. Here, we combined available satellite images with ground information taken from the literature and obtained them in own field research. We mostly focused on zonal vegetation and excluded communities such as riparian ecosystems, different mire types, wet meadows and vegetation on strongly saline soils. Based on this material, we described spatial patterns in the zonal vegetation across the entire Kulunda region, and we assessed the key ecological factors responsible for the vegetation diversity.

The most important of these ecological factors are substrate, relief and local climate. According to differences in relief and surface geological substrate, three main classes of patterns in spatial vegetation structure could be distinguished. Each pattern comprises a limited number of vegetation types, the most contrasting of which are forests and steppes.

4.2 Main Vegetation Patterns and the Associated Plant Communities

The zonal vegetation on plains covered by the aeolian loess-like deposits comprises dry open grasslands devoid of trees (steppe) and deciduous forests. Depending on relief, these two types have two different spatial vegetation patterns each.

The elevated plains in the eastern part of Kulunda close to the Ob River plain surface are well drained by extensive gully systems. There, all flat well-drained surfaces are covered by steppe-like communities, while forests occur on gully bottoms or on north- and east-oriented slopes along the gullies. On satellite images, these forest

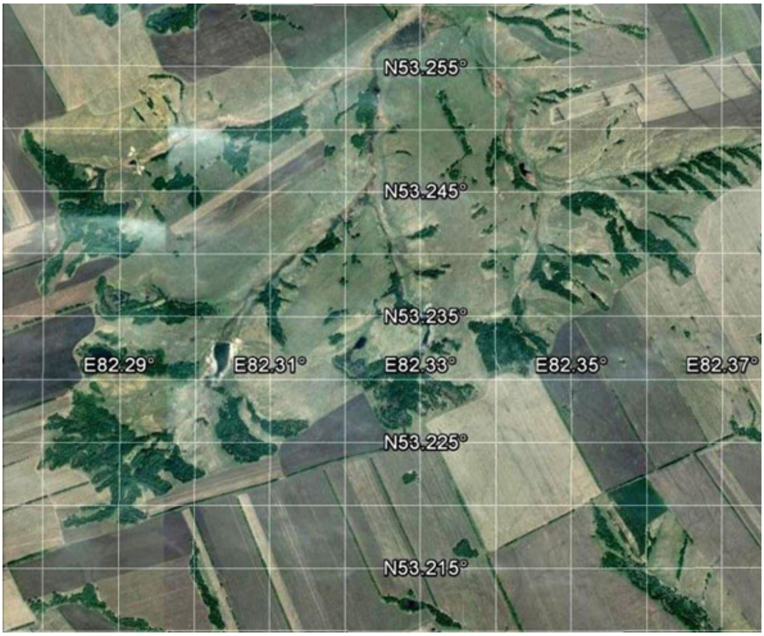


Fig. 4.1 Satellite image of class 1 of patterns in spatial vegetation distribution

patches form dendritic or amoeba-like contours in a matrix of steppes and arable land (Fig. 4.1).

On low-lying plains with poor drainage in the western part of Kulunda, suffusion is very common and produces numerous small (typically 20–200 m in diameter) rounded depressions. Like in the first case, all drained flat surfaces are occupied by steppe and forests are in depressions. The whole picture from above is patchy with numerous rounded forest groves, locally called ‘kolok’ forests, embedded in a steppe matrix (Fig. 4.2).

In both cases, the ratio between forest and steppe is strictly determined by relief features—length of the gullies, or size and amount of the depressions.

The third vegetation pattern is associated with old systems of parallel drainage channels filled with alluvial sand deposits. The mesorelief of these former channels was shaped by wind in the form of dune fields. Here, the main vegetation type is pine forest with Scots pine (*Pinus sylvestris*). Grasslands in this case covered small areas, and these are secondary stands formed after fires or logging. The small-scale vegetation structure is quite monotonous with small openings in an otherwise-forested landscape (Fig. 4.3).

Fig. 4.2 Satellite image of class 2 of spatial vegetation distribution

Within each main vegetation pattern, three forest units can be distinguished depending on the geographical position. Each type has some characteristic features in terms of structure and especially in species composition. Tables 4.1, 4.2 and 4.3 briefly summarize characteristics of structure and species composition for each forest unit.

Non-forest vegetation is represented by four main types of dry grasslands (Table 4.4). In the northern part of the forest steppe, meadow steppes represent the zonal types of grasslands. These communities are characterized by the dominance of mesoxerophytic perennial forbs (*Galatella biflora*, *Filipendula vulgaris*, *Fragaria viridis*, etc.) and rhizomatous grasses (*Poa angustifolia* and *Calamagrostis epigeios*). Bunch grasses such as *Festuca pseudovina*, *Stipa pennata* and *Koeleria cristata* may be locally abundant. Because these communities grow on slightly saline soils, halotolerant plants are often present (*Artemisia nitrosa*, *Artemisia rupestris*, *Iris halophila*, *Limonium gmelinii*, *Pedicularis dasystachys*, etc.).

Bunch-grass steppes with many forbs are widely distributed in the southern part of the forest-steppe zone and in the northern part of the steppe zone. This is the most species-rich type of dry grasslands in Western Siberia. Communities usually are polydominant, with abundant bunch grasses (*Festuca valesiaca*, *Stipa capillata*, *Koeleria cristata*, *Stipa pennata*, *S. zalesskii*) and forbs (*Fragaria viridis*, *Filipen-*

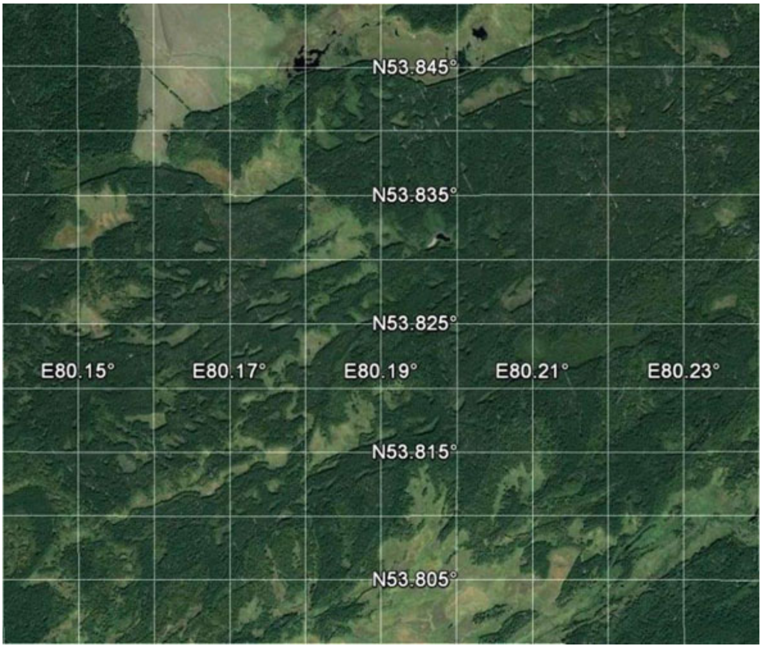


Fig. 4.3 Satellite image of class 3 of pattern in spatial vegetation distribution

dula vulgaris, *Galatella biflora*, *Artemisia spp.*, *Thymus marschallianus*, etc.). These steppes are also characterized by a high abundance of mesoxerophytic grasses and sedges (*Poa angustifolia*, *Calamagrostis epigeios*, *Carex praecox*).

Typical bunch-grass steppes are widespread in the steppe zone, especially in its southern part. *Stipa capillata* and *Festuca valesiaca* are significant dominant species of the upper and lower herb layers, respectively. Among these dominant species, common steppe xerophytes grow: *Artemisia frigida*, *Koeleria cristata*, *Artemisia austriaca*, *Carex supina*. These plant communities show the lowest species numbers among the analysed steppes, mainly because of dry conditions and omnipresent overgrazing.

Sandy steppes inhabit alluvial sand deposits in the steppe zone. They form mosaics with dry pine forests. Sometimes psammophytic grasslands are formed after fires and clearcuttings. Among the abundant species are xerophytic plants (*Festuca valesiaca*, *Artemisia frigida*, *Stipa capillata*, *Carex supina*) and species preferring sandy soils (*Stipa borysthenica*, *Cleistogenes squarrosa*, *Artemisia marschalliana,* etc.).

Table 4.1 Main characteristics of forest communities of the first class of vegetation pattern (species taxonomy follows Cherepanov 1995)

Community type	Dominant tree species	Average canopy closure (%)	Average canopy height (m)	Average tree diameter (cm)	Shrub layer	Herbaceous layer		Moss layer	Species richness (number of vascular plant species per 400 m^2)	Indicator species
					Cover (%) and main species	Height (cm)/cover (%)	Dominant species	Cover (%) and main species		
Ravine forest unit 1	*Betula pubescens*, *Populus tremula*	60	21	29	20 *Caragana arborescens*, *Salix cinerea*	74/75	*Brachypodium pinnatum*, *Rubus saxatilis*, *Angelica sylvestris*, *Filipendula ulmaria*	Absent	46	*Salix cinerea*, *Ribes nigrum*, *Poa palustris*, *Filipendula ulmaria*, *Cirsium setosum*, *Urtica dioica*, *Crepis sibirica*, *Geranium pratense*, *Equisetum pratense*, *Stachys palustris*, *Alopecurus pratensis*, *Ranunculus auricomus*, *Paris quadrifolia*, *Trollius asiaticus*, *Carex cespitosa*, *Ranunculus repens*
Ravine forest unit 2	*Betula pendula*, *Populus tremula*	60	20	30	45 *Caragana arborescens*	43/60	*Brachypodium pinnatum*, *Rubus saxatilis*, *Iris ruthenica*, *Lathyrus vernus*, *Pteridium aquilinum*	Absent	56	*Padus avium*, *Phlomoides tuberosa*, *Silene nutans*, *Viola hirta*, *Cirsium serratuloides*, *Helictotrichon pubescens*
Ravine forest unit 3	*Betula pendula*, *Populus tremula*, *Betula pubescens*	60	19	26	35 *Caragana arborescens*	44/40	*Calamagrostis epigeios*, *Carex supina*, *Poa angustifolia*, *Fragaria viridis*, *Pteridium aquilinum*	Absent	40	*Bromopsis inermis*, *Sambucus sibirica*, *Taraxacum officinale*, *Potentilla canescens*, *Elymus caninus*

Table 4.2 Main characteristics of forest types for the second pattern

Community type	Dominant tree species	Average canopy closure (%)	Average canopy height (m)	Average tree diameter (cm)	Shrub layer	Herbaceous layer		Moss layer	Species richness (number of vascular plant species per 400 m^2)	Indicator species
					Cover (%) and main species	Height (cm)/cover (%)	Dominant species	Cover (%) and main species		
Birch 'kolok' forest unit 4	*Betula pendula*, *Populus tremula*	60	19	24	Occasional	46/70	*Calamagrostis epigeios*, *Brachypodium pinnatum*, *Iris ruthenica*, *Rubus saxatilis*	Absent	47	*Artemisia macrantha*, *Vicia megalotropis*
Birch 'kolok' forest unit 5	*Betula pendula*, *Populus tremula*	60	17	20	Occasional	50/60	*Calamagrostis epigeios*, *Carex praecox*, *Poa angustifolia*, *Rubus saxatilis*	Absent	43	*Sedum telephium*, *Lathyrus tuberosus*
Birch 'kolok' forest unit 6	*Betula pendula*, *Populus tremula*	60	14	18	10 *Rosa laxa*	34/40	*Calamagrostis epigeios*, *Carex supina*, *Poa angustifolia*, *Peucedanum morisonii*, *Carex praecox*	Absent	36	*Spiraea crenata*, *Rosa laxa*, *Ribes aureum*, *Artemisia dracunculus*, *Chenopodium album*, *Asparagus officinalis*, *Artemisia commutata*

Table 4.3 Main characteristics of forest types for the third pattern

Community type	Dominant tree species	Average canopy closure (%)	Average canopy height (m)	Average tree diameter (cm)	Shrub layer	Herbaceous layer		Moss layer	Species richness (number of vascular plant species per 400 m^2)	Indicator species
					Cover (%) and main species	Height (cm)/cover (%)	Dominant species	Cover (%) and main species		
Pine forest unit 7	*Pinus sylvestris*	60	24	28	8 *Caragana arborescens*	20/25	*Vaccinium vitis-idaea*, *Calama-grostis epigeios*, *Iris ruthenica*, *Carex ericetorum*	80 *Pleurozium schreberi*, *Dicranum polysetum*	20	*Carex ericetorum*, *Chimaphila umbellata*, *Vaccinium vitis-idaea*, *Dicranum polysetum*, *Pleurozium schreberi*, *Ptilium crista-castrensis*
Pine forest unit 8	*Pinus sylvestris*, *Betula pendula*, *B. pubescens*	60	24	36	8 *Caragana arborescens*	34/70	*Rubus saxatilis*, *Brachy-podium pinnatum*, *Iris ruthenica*, *Equisetum pratense*	5 *Pleurozium schreberi*	47	*Sorbus sibirica*, *Agrimonia pilosa*, *Fragaria vesca*, *Geranium sylvaticum*, *Orthilia secunda*, *Dryopteris carthusiana*, *Platanthera bifolia*

(continued)

Table 4.3 (continued)

Community type	Dominant tree species	Average canopy closure (%)	Average canopy height (m)	Average tree diameter (cm)	Shrub layer	Herbaceous layer		Moss layer	Species richness (number of vascular plant species per 400 m^2)	Indicator species
					Cover (%) and main species	Height (cm)/cover (%)	Dominant species	Cover (%) and main species		
Pine forest unit 9	*Pinus sylvestris*	40	18	28	absent	26/20	*Carex supina*, *Koeleria glauca*, *Festuca beckeri*, *Stipa borys-thenica*	Occasional	28	*Pulsatilla patens*, *Alyssum turkestanicum*, *Allium nutans*, *Stipa anomala*, *Arabidopsis thaliana*, *Gypsophila paniculata*, *Cleistogenes squarrosa*, *Artemisia marschalliana*, *Syrenia siliculosa*, *Silene borysthenica*, *Silene chlorantha*, *Kochia laniflora*, *Jurinea cyanoides*, *Koeleria glauca*, *Festuca beckeri*, *Scorzonera ensifolia*

Table 4.4 Main characteristics of steppe communities (IV = indicator value composed of square root ($f * c$), f—frequency (%), c—average cover (%)

Community type	Dominant species (IV more than 20)	Codominant species (IV from 10 to 20)	Total cover (%)	Species richness (number of vascular plant species per 100 m^2)	Indicator species
Meadow steppes and xeric meadows unit 10	*Galatella biflora*, *Filipendula vulgaris*, *Poa angustifolia*, *Fragaria viridis*, *Calamagrostis epigeios*	*Festuca pseudovina*, *Elytrigia repens*, *Peucedanum morisonii*, *Artemisia pontica*, *Carex praecox*	80	38	*Agrostis vinealis*, *Artemisia macrantha*, *Eremogone longifolia*, *Filipendula stepposa*, *Fragaria viridis*, *Galatella biflora*, *Galium boreale*, *Hieracium umbellatum*, *Inula britannica*, *Lathyrus pratensis*, *Lathyrus tuberosus*, *Lupinaster pentaphyllus*, *Plantago maxima*, *Poa urssulensis*, *Sanguisorba officinalis*, *Serratula coronata*, *Seseli strictum*, *Tanacetum vulgare*, *Thalictrum simplex*

(continued)

Table 4.4 (continued)

Community type	Dominant species (IV more than 20)	Codominant species (IV from 10 to 20)	Total cover (%)	Species richness (number of vascular plant species per 100 m^2)	Indicator species
Typical bunch-grass steppes with many forbs unit 11	*Festuca valesiaca*	*Poa angustifolia*, *Fragaria viridis*, *Filipendula vulgaris*, *Stipa capillata*, *Koeleria cristata*, *Calamagrostis epigeios*, *Stipa pennata*, *Galatella biflora*, *Stipa zalesskii*, *Artemisia pontica*, *Artemisia glauca*, *Thymus marschallianus*, *Carex praecox*, *Artemisia austriaca*, *Phleum phleoides*	70	43	*Achillea nobilis*, *Helictotrichon desertorum*, *Oxytropis pilosa*, *Seseli ledebourii*, *Stipa zalesskii*, *Tephroseris integrifolia*

(continued)

Table 4.4 (continued)

Community type	Dominant species (IV more than 20)	Codominant species (IV from 10 to 20)	Total cover (%)	Species richness (number of vascular plant species per 100 m^2)	Indicator species
Typical bunch-grass steppes with few forbs unit 12	*Stipa capillata*, *Festuca valesiaca*	*Artemisia frigida*, *Koeleria cristata*, *Artemisia austriaca*, *Carex supina*	63	21	None
Sandy steppes unit 13	*Festuca valesiaca*, *Stipa borysthenica*	*Artemisia frigida*, *Stipa capillata*, *Carex supina*, *Cleistogenes squarrosa*, *Artemisia marschalliana*	53	30	*Artemisia marschalliana*, *Astragalus onobrychis*, *Centaurea adpressa*, *Chenopodium acuminatum*, *Cleistogenes squarrosa*, *Gypsophila paniculata*, *Helichrysum arenarium*, *Kochia laniflora*, *Koeleria glauca*, *Scorzonera ensifolia*, *Silene borysthenica*, *Stipa borysthenica*

4.3 Overview of Vegetation and Vegetation–Environment Relationships

Each plant community was characterized by sampling a set of vegetation relevés, and for each relevé, mean annual temperature and precipitation were retrieved from the WorldClim database (Hijmans et al. 2005). Plant species indicator values for southern Siberia (Tsatsenkin et al. 1974; Korolyuk 2006) were also employed. These indicator values represent the ecological optimum of a given species along gradients of both moisture and soil fertility. Average indicator values for moisture and fertility were calculated for every relevé as the average indicator values of all species registered within the plot.

Ordination of relevés was used to determine the main geographical and ecological patterns in steppe vegetation. Species found in less than five relevés were excluded from the analysis. Cover values of species were transformed to ordinal scale. The data set was stored and managed in IBIS (Integrated Botanical Information System) (Zverev 2007). For the ordination, we used canonical correspondence analysis (CCA) with the standard setting as implemented in the PAST software (Hammer et al. 2001).

The respective ordination plot shows a relatively clear differentiation of plant communities (Fig. 4.4). All pine forests cluster in the lower part of scattergram. The most separate position is held by pine forests of the seventh vegetation unit. This is explained by their species composition with a high share of boreal forest species (*Chimaphila umbellata*, *Vaccinium vitis-idaea*) and a well-developed moss layer. In this respect, pine forests of the seventh unit resemble true taiga forests typically found far north of the Kulunda region. Pine forests of the ninth unit also are well separated from all other forests but are close to sandy steppes. The similarity between sandy steppes and southern pine forests is based on a group of species well adapted to dry conditions (xerophytes) and/or to sandy substrate (psammophytes), which are typical for both units (*Artemisia marschalliana*, *Gypsophila paniculata*, *Koeleria glauca*, *Scorzonera ensifolia*, *Silene borysthenica*, *Stipa borysthenica*). Together these two types create a successional series triggered by fires or logging. Pine forests of the eighth unit are close to slope deciduous forests in the ordination plot. Both of these grow on relatively moist, yet well-drained soils and contain diagnostic species of the class Brachypodio pinnati–Betuletea pendulae. They represent the zonal vegetation of the West Siberian forest-steppe zone (*Brachypodium pinnatum*, *Rubus saxatilis*, *Iris ruthenica*).

Communities of deciduous forests are much closer to each other in the scattergram. Compared to pine forests, deciduous forests of gully slopes are characterized by higher species richness values but by lower mean annual temperatures. Birch 'kolok' forests are intermediate between slope deciduous forests and steppe units. Within units, both slope and 'kolok' are well differentiated along a moisture gradient. Both types of deciduous forests are placed close to each other due to the shared presences of a relatively large group of common mesophyte and xeromesophyte forest species (*Lathyrus pisiformis*, *Artemisia latifolia*, *Fragaria viridis*, etc.).

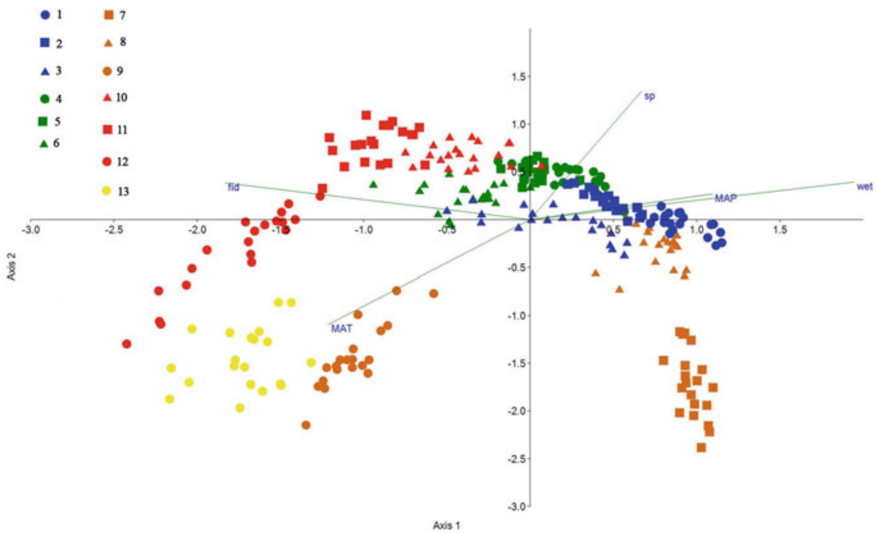


Fig. 4.4 Scatterplot of canonical correspondence analysis of relevés. Numbers correspond to vegetation units. Eigenvalues (%): 1 axis—50.9, 2 axis—26.1. Plant communities: 1—ravine forest, 2—ravine forest, 3—ravine forest, 4—birch 'kolok' forest, 5—birch 'kolok' forest, 6—birch 'kolok' forest, 7—pine forest, 8—pine forest, 9—pine forest, 10—meadow steppes and xeric meadows, 11—typical bunch-grass steppes with many forbs, 12—typical bunch-grass steppes with few forbs, 13—sandy steppes. Abbreviations: fid—soil fertility, MAP—mean annual precipitation, MAT—mean annual temperature, sp—number of species per relevé, wet—soil moisture

Steppe communities occupy the left part of the scattergram. They are associated with the driest habitats (low values of precipitation and soil moisture) on productive soils (highest values of soil fertility). Within this group, all steppe units are well differentiated along gradients of both moisture and soil fertility. Meadow steppes and xeric meadows are quite close to dry 'kolok' forests in the scattergram. This reflects the fact that in forest-steppe landscapes, these communities grow in close vicinity and share a group of light-demanding mesoxerophyte species (*Artemisia macrantha*, *Filipendula stepposa*, *Galatella biflora*, *Lathyrus pratensis*, *Lathyrus tuberosus*, *Lupinaster pentaphyllus*). The most distinct position among steppe units in the scattergram is held by sandy steppes close to southern pine forests as discussed above.

Available climatic data for Kulunda from the WorldClim database (Hijmans et al. 2005) show that there is a clear gradient of mean annual temperature from south to the north (Fig. 4.5) and also of annual precipitation from west to east (Fig. 4.6).

For all three vegetation patterns, composition of plant communities changes significantly along these climatic gradients. The first pattern which occurs close to the Ob River mainly shows a west-east gradient, while the second, eastern pattern displays a more pronounced south-north gradient. Because ribbon pine forests stretch from south-west to north-east across the whole Kulunda region, they show both gra-

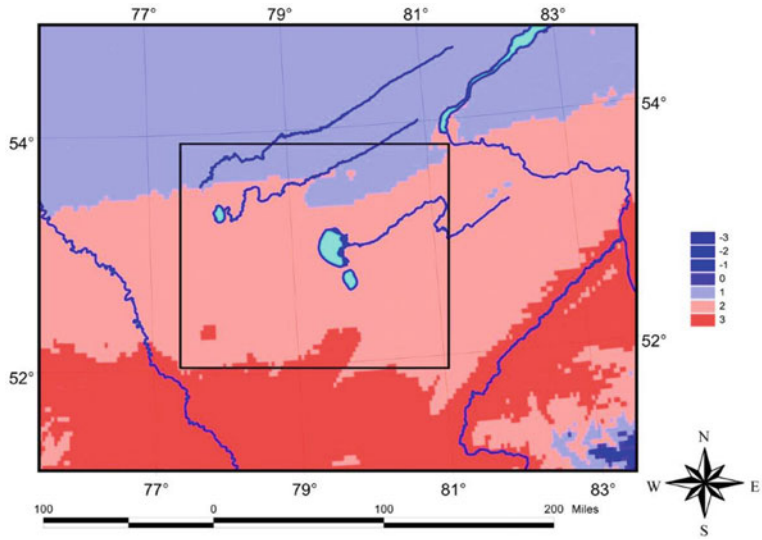


Fig. 4.5 Spatial patterns of mean annual temperature across Kulunda (based on WorldClim data). Colours correspond to the mean annual temperatures in °C. Black square indicates the study area

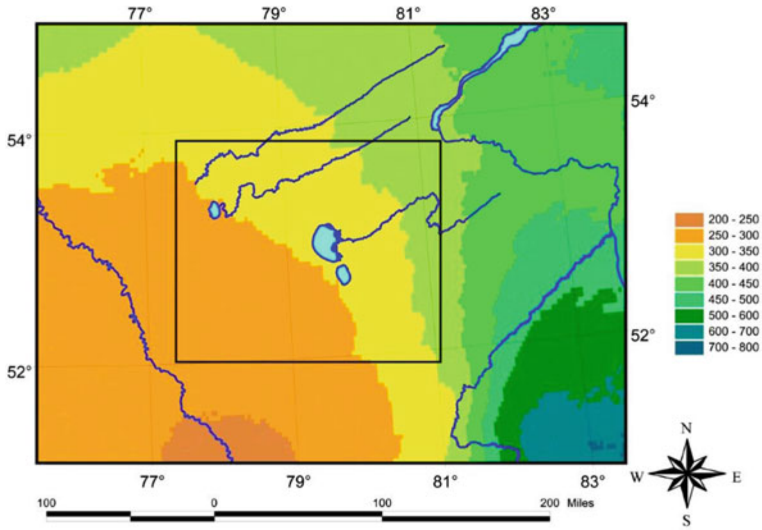


Fig. 4.6 Spatial patterns of mean annual precipitation totals across Kulunda (based on WorldClim data). Colours correspond to the annual amount of precipitation in mm. Black square indicates the study area

dients. In addition, it should be mentioned that ecological factors such as salinity and level of ground water also play a significant role in vegetation differentiation. This may result in the formation of azonal vegetation which is not described in the present chapter.

References

Cherepanov CK (1995) Sosudistye rasteniia Rossii i sopredel'nykh gosudarstv (Higher vascular plants of Russia and contiguous countries). Mir i sem'ya, St. Petersburg (in Russian)

Hammer Ø, Harpe DAT, Ryan PD (2001) PAST: paleontological statistics software package for education and data analysis. Palaeontol Electronica 4(1):1–9

Hijmans RJ, Cameron SE, Parra JL, Jones PG, Jarvis A (2005) Very high resolution interpolated climate surfaces for global land areas. Int J Climatol 25:1965–1978

Korolyuk AY (2006) Ekologicheskie optimumy rastenii iuga Sibiri (The ecological optimum of South Siberian plants). Botanicheskie issledovaniia Sibiri I Kazakhstana 12: 3–28 (in Russian with Engl. abstr.)

Tsatsenkin IA, Dmitriyeva SI, Belyayeva NV, Savchenko IV (1974) Metodicheskie ukazaniia po ekologicheskoi otsenke kormovykh ugodii lesostepnoi i stepnoi zon Sibiri i Dal'nego Vostoka po rastitel'nomu pokrovu (Handbook for Ecological Assessment of Fodder Lands in the Forest-Steppe and Steppe Zones of Siberia Based on Vegetation Traits). VNIIK, Moscow (in Russian)

Zverev AA (2007) Informatzionnye tekhnologii v issledovaniiakh rastitel'nogo pokrova (Information technologies in studies of vegetation: tutorial). TML-Press, Tomsk (in Russian)

Chapter 5
Soils of the Central and Western Steppes of the Altai Krai

A. Mizgirev, M. Zierdt, P. Illiger, A. E. Kudryavtsev, A. A. Bondarovich, E. Stephan and G. Schmidt

Abstract The World Reference Base for Soil Resources (WRB) was chosen as the soil classification system for the pedological work of the KULUNDA project. The in-depth analysis and evaluation of anthropogenic soil changes required the use of historical information based on the Russian soil classification system. The soil map of Altai Krai (KGKRF in Soil map of the Altai Territory and the Altai Republic 1986, scale 1:500,000. Novosibirsk, 1992; Kovda and Rozanov in soil science—types of soils, their geography, and use. Moscow, 1988) and the results of a soil science expedition to the Altai Krai in 1954 and 1955 published as "The Soils of Altai Krai" in 1959 (Akademiya Nauk SSSR 1959) worked as reference database. This historical soil information had to be converted to the WRB system to make it comparable to current soil information. An unequivocal conversion and transformation were not always possible resulting in loss of information and data uncertainty. Especially, the information regarding spatial distribution and area percentage of soil groups was affected by having an impact on the analysis of soil changes over time. The article describes the challenges of converting soil information and possible ways of handling them.

Keywords WRB · Agriculture · Landuse change · Soil degradation · Soil mapping

A. Mizgirev (✉)
Institute of Agricultural and Nutrition Sciences, Martin-Luther-Universität Halle-Wittenberg, Von-Seckendorff-Platz 4, 06120 Halle, Germany
e-mail: alexander.mizgirev@landw.uni-halle.de

M. Zierdt (✉) · P. Illiger · E. Stephan · G. Schmidt
Institute of Geosciences and Geography, Martin-Luther-Universität Halle-Wittenberg, Von-Seckendorff-Platz 4, 06120 Halle, Germany
e-mail: michael.zierdt@geo.uni-halle.de

A. E. Kudryavtsev
Faculty of Agronomy, Altai State Agrarian University, Prospect Krasnoarmeiski 98, 656049 Barnaul, Russian Federation

A. A. Bondarovich
Faculty of Geography, Altai State University, Prospect Lenina 61, 656049 Barnaul, Russian Federation

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_5

5.1 Introduction

The dominant soil groups of the research region are the result of a soil development under high continental climate along a vegetation gradient from forest steppe to typical steppe to dry steppe. Late Pleistocene deposits like loess and loess derivatives are the parent material of the pedogenesis. The short vegetation period and large annual temperature amplitude are the important preconditions for the pedogenesis in the region (Rosanov and Karmanov 1959; Kovda and Rozanov 1988). They vary along a northeast–southwest gradient. While the annual precipitation amounts between 500 and 600 mm/a in the northeast, it is much lower in the southwest with values between 250 and 300 mm/a. With the reduced water supply, the biomass production of the vegetation decreases. Less organic matter means reduced humus horizons and decreased humus content in the soils. Therefore, Chernozems and Kastanozems of different varieties are typical for this climate and vegetation gradient. Because of their good water and nutrient storage capacities, these soils are the foundation for the region's intensive agriculture. Solonetz and Solonchaks are common too, depending on geological and morphological characteristics in the region. Their percentage is less than 25% in the region and they are usually not used for agriculture.

Systematic soil mapping of the region was already started at the end of the nineteenth century and reached its peak with the soil surveys of the Virgin Lands Campaign. In 1959, the summary of the soil surveys of the 1950s was published with the title "The Soils of the Altai Krai" by the Academy of Sciences of the Soviet Union. Based on this work and the results of further soil surveys during the following years, the Committee of Geodesy and Cartography of the Russian Federation published the soil map of the Altai Krai at 1:500,000 scale. Both publications are an essential foundation for the soil degradation research of the KULUNDA project.

Comparing analyses of soil characteristics and soil states are an important approach to evaluate the effects of land use on soils. Historically, different countries developed different soil classification systems and methods which are now problematic for research regarding land use effects on soil quality. Not only the classification but also the field and analytical methods used for soil characterization differ, which makes it difficult—sometimes even impossible—to compare historic data with current soil information. The following material offers not only a description of the soils of the western Altai Krai but also a discussion of problems of converting information from soil maps and of comparing laboratory methods to determine soil characteristics. Exemplified approaches will be presented.

5.2 Converting Soil Information from the Russian Soil Classification System to the WRB Standard

The necessity to transform soil information from the Russian Soil Classification System and pedological field and laboratory research arose from the agreement to use the "World Reference Base for Soil Resources" (FAO 2014) as a reference system for the work of the KULUNDA project. First steps were taken to compile Russia's soil information and make it useable for an international context as early as in the 1980s. This was done for the project GLASOD—Global Assessment of Soil Degradation (Oldeman et al. 1991) which had the global evaluation of soil degradation as its goal (Stolbovoi and Fischer 1997). Stolbovoi provided an updated version of the Russian soil information for the FAO World Soil Map in 2000. The conversion was based on Russia's Soil Map at 1:2,500,000 scale.

Unfortunately, for the KULUNDA project, this scale is too small for a sufficiently differentiated depiction of the varying soil groups and soil characteristics in the western Altai Krai. The conversion of soil information with a higher resolution was required. The soil map of the Altai Krai at 1:500,000 scale seemed suitable (Kovda 1973; Kovda and Rozanov 1988). It was published by the Committee of Geodesy and Cartography of the Russian Federation (Komitet po geodezii i kartografii Rossiiskoi Federatsii (KGKRF)) in 1992.

5.2.1 Depiction of Different Classifications

The usage of the higher-resolution soil map of the Altai Krai required a new and differentiated conversion of the soil groups into the WRB format. The comparison of both soil maps for the Altai Krai revealed some differences regarding the soil groups based on the Russian Soil Classification System. The map at 1:2,500,000 scale did not depict ten soil subgroups which are contained in the legend of the map at 1: 500,000 scale (see Table 5.1). This kind of generalization loss was corrected for the soils of the chosen research regions. In this process, overall 40 soil groups and soil subgroups were identified and translated into the WRB in the research regions.

The comparison of soil profile descriptions in both map legends showed some differences, too (see Table 5.1 and Chap. 2). The reason for the differences was that the profile descriptions of the soil map at 1:500,000 scale from Kovda (1973) were based on the soil classification system for the legend of the FAO World Soil Map but the Stolbovoi (2000) used the since 1974 developed WRB soil classification (see Table 5.1). The use of these data sets results at least in the different allocation of qualifiers for some soil groups. But it might even result in a different spatial allocation of soil groups which would lead to a completely different depiction of the soil distribution. The further usage of such soil maps holds quite some uncertainty for a comparing analysis and evaluation of soil degradation phenomena.

Table 5.1 Comparison and conversion of soil information of the research region with different scale references (Mizgirev 2013)

Name Russian	Name Transliterated	Name Englisch	Type_Profile (Kovda 1973; Kovda and Rozanov 1988)	Type_Profile (Stolbovoy 2000)
Черноземы оподзоленные	Chernozemy opodzolennye	Chernozems podzolized	Ah/AB/Bt,f,al/Bca/Cca	A1-A1B-Bt-Bca-Bcca-Cca
Черноземы выщелоченные	Chernozemy vyshelochennye	Chernozems leached	Ah/AB/Bt/Bca/Cca	A1-A1B-Bt-Bca-Bcca-Cca
Черноземы типичные	Chernozemy tipichnye	Chernozems typical	Ah/AB/Bca/BCca/Cca	A1-A1Bca-Bca-BCca-Cca
Черноземы обыкновенные	Chernozemy obyknovennye	Chernozems ordinary	Ah(Aca)/ABca/Bnca/BCcs	A1-A1Bca-Bca-BCca-Cca-Cs
Черноземы обыкновенные карбонатные	Chernozemy obyknovennye karbonatnye	Chernozems ordinary calcareous		A1ca,z-A1Bca,z-BCca,z-Cca
Черноземы обыкновенные солонцеватые	Chernozemy obyknovennye solontsevatye	Chernozems ordinary solonetzic		A1-A1Bslca-Bsl,ca-Cca
Черноземы южные	Chernozemy yuzhnye	Chernozems southern	Ah(Aca)/AB(ABca)/Bca/BCca/Cca/Ccs/Cca	A1ca-A1Bca,sl-BCs-Cs
Черноземы южные солонцеватые	Chernozemy yuzhnye solontsevatye	Chernozems southern solonetzic		A1-A1Bslca-Bsl,ca-Cca
Лугово-черноземные	Lugovo-chernozemnye	Meadow-chernozemics	Ad/AB/Bca/Cg	A1-A1B-B-Bca-Cca(Cca,g)
Лугово-черноземные солонцеватые	Lugovo-chernozemnye solontsevatye	Meadow-chernozemics solonetzic	Ad/AB/Bca/Bna/Cg	A1-A1Bsl,ca-Bsl,ca-Cca(g)
Лугово-черноземные засоленные	Lugovo-chernozemnye zasolennye	Meadow-chernozemics saline	Ad/AB/Bca/Bsa/Cg	A1-A1Bsl,ca-Bsl,ca-Cca(g)
Темнокаштановые	Temnokashtanovye	Chestnuts dark	A/AB1/AB2/Bca/Bcs/C	A1-A1B-Bca-Bca,cs-Ccs
Каштановые	Kashtanovye	Chestnuts	A/AB/Bt/Bca/Bcs/C	A1-B-Bca,cs-BCcs-Ccs
Светлокаштановые	Svetlokashtanovye	Chestnuts light	A/E/Bt/Bca/Bcs/C	A1-B-Bca-Bcs-Ccs

(continued)

Table 5.1 (continued)

Name Russian	Name Transliterated	Name Englisch	Type_Profile (Kovda 1973; Kovda and Rozanov 1988)	Type_Profile (Stolbovoy 2000)
Каштановые солонцеватые	Kashtanovye solontsevatye	Chestnuts solonetzic	A/AB/Bt/Bca/Bcs/Bna/C	
Светлокаштановые солонцеватые	Svetlokashtanovye solontsevatye	Chestnuts light solonetzic	A/E/Bt/Bca/Bcs/Bna/C	
Луговато-каштановые	Lugovato-kashtanovye	Meadow-chestnuts	Ad/AB/Bca/Bcs/Cg	A1-B-Bca-Cca(Cca,g)
Луговато-каштановые солонцеватые	Lugovato-kashtanovye solontsevatye	Meadow-chestnuts solonetzic	Ad/AB/Bca/Bcs/Bna/Cg	A1-A1Bsl-Bca-BCca(cs)-Ccs(g)
Луговато-каштановые засоленные	Lugovato-kashtanovye zasolennye	Meadow-chestnuts saline	Ad/AB/Bca/Bcs/Bsa/Cg	
Болотные низинные торфянисто- и торфяно-глеевые	Bolotnye nizinnye torfyanisto- i torfyano-gleevye	Peats low moor gleyic and peats boggy gleyic	T1/(T2/)G	
Лугово-болотные	Lugovo-bolotnye	Meadow-boggy	Ad(T)/G	(O)-Av-A1g-Bg-G
Лугово-болотные засоленные	Lugovo-bolotnye zasolennye	Meadow-boggy saline	Ad,na(Tna)/G	A1(sl)-A1B(sl)-Bca,(cs),(s),(g)-Cg,ca,(cs),(s)
Луговые	Lugovye	Meadows	Ad/A/AC/Cg	A1-A1B-Bg,ca-Cg,ca
Луговые засоленные	Lugovye zasolennye	Meadows saline	Ad/A/ACna/Cg	A1(sl)-A1B(sl)-Bca,(cs),(s),(g)-Cg,ca,(cs),(s)
Солоди луговые	Solodi lugovye	Meadows differentiated and solodic	Ad(T)/Eg/Bt,g/Bca,g/Bcs,g/Bsa,g/Cg(G)	A1-A2(A1A2)-Bt,(g)-Bca,(g)-Cg
Солонцы лугово-черноземные	Solontsy lugovo-chernozemnye	Meadow-chernozemics solonetzic	Ad/(Ah/)E/Bna/Bca/Bcs/Bsa/C	

(continued)

Table 5.1 (continued)

Name Russian	Name Transliterated	Name Englisch	Type_Profile (Kovda 1973; Kovda and Rozanov 1988)	Type_Profile (Stolbovoy 2000)
Солонцы лугово-черноземные засоленные	Solontsy lugovo-chernozemnye zasolennye	Meadow-chernozemics solonetzic and saline		
Солонцы лугово-каштановые	Solontsy lugovo-kashtanovye	Meadow-chestnuts solonetzic	Ad/(Ah/)E/Bna/Bca/Bcs/Bsa/C	
Солонцы лугово-каштановые засоленные	Solontsy lugovo-kashtanovye zasolennye	Meadow-chestnuts solonetzic and saline		
Солончаки типичные	Solonchaki tipichnye	Solonchaks typical	Asa/ACsa/Csa	
Солончаки луговые	Solonchaki lugovye	Solonchaks meadow	Ad,sa/ACsa/Csa	
Аллювиальные луговые насыщенные	Allyuvial’nye lugovye nasyshennye	Alluvials meadow saturated	Ad/A/AC/Cg	A1-B-Bg-CDg
Аллювиальные луговые насыщенные засоленные	Allyuvial’nye lugovye nasyshennye zasolennye	Alluvials meadow saturated saline	Ad/A/ACna/Cg	
Аллювиальные лугово-болотные	Allyuvial’nye lugovo-bolotnye	Alluvials swamp meadow	Ad(T)/G	

(continued)

Table 5.1 (continued)

Name Russian	Name Transliterated	Name Englisch	Group_WRB (FAO/IIASA/ISRIC/ISSCAS/ JRC 2012)	Qualifier WRB	Code_wrb
Черноземы оподзоленные	Chernozemy opodzolennye	Chernozems podzolized	Phaeozem	Luvic	PHlv
Черноземы выщелоченные	Chernozemy vyshelochennye	Chernozems leached	Chernozem	Luvic	CHlv
Черноземы типичные	Chernozemy tipichnye	Chernozems typical	Chernozem	Haplic	CHha
Черноземы обыкновенные	Chernozemy obyknovennye	Chernozems ordinary	Chernozem	Haplic	CHha
Черноземы обыкновенные карбонатные	Chernozemy obyknovennye karbonatnye	Chernozems ordinary calcareous	Chernozem	Haplic	CHca
Черноземы обыкновенные солонцеватые	Chernozemy obyknovennye solontsevatye	Chernozems ordinary solonetzic	Chernozem	Luvic	CHlv
Черноземы южные	Chernozemy Yushnye	Chernozems southern	Chernozem	Calcic	CHca
Черноземы южные солонцеватые	Chernozemy Yushnye solontsevatye	Chernozems southern solonetzic	Chernozem	Calcic, Luvic	CHcalv
Лугово-черноземные	Lugovo-chernozemnye	Meadow-chernozemics	Phaeozem	Haplic	PHha
Лугово-черноземные солонцеватые	Lugovo-chernozemnye solontsevatye	Meadow-chernozemics solonetzic	Phaeozem	Luvic	PHlv
Лугово-черноземные засоленные	Lugovo-chernozemnye zasolennye	Meadow-chernozemics saline	Phaeozem	Luvic	PHlv

(continued)

Table 5.1 (continued)

Name Russian	Name Transliterated	Name Englisch	Group_WRB (FAO/IIASA/ISRIC/ISSCAS/JRC 2012)	Qualifier WRB	Code_wrb
Темнокаштановые	Temnokashtanovye	Chestnuts dark	Kastanozem	Haplic	KSha
Каштановые	Kashtanovye	Chestnuts	Kastanozem	Haplic	KSha
Светлокаштановые	Svetlokashtanovye	Chestnuts light	Kastanozem	Haplic	KSha
Каштановые солонцеватые	Kashtanovye solontsevatye	Chestnuts solonetzic	Kastanozem	Luvic	KSlv
Светлокаштановые солонцеватые	Svetlokashtanovye solontsevatye	Chestnuts light solonetzic	Kastanozem	Luvic	KSlv
Луговато-каштановые	Lugovato-kashtanovye	Meadow-chestnuts	Phaeozem	Haplic	PHha
Луговато-каштановые солонцеватые	Lugovato-kashtanovye solontsevatye	Meadow-chestnuts solonetzic	Phaeozem	Luvic	PHlv
Луговато-каштановые засоленные	Lugovato-kashtanovye zasolennye	Meadow-chestnuts saline	Phaeozem	Luvic	PHlv
Болотные низинные торфянисто- и торфяно-глеевые	Bolotnye nizinnye torfyanisto- i toryano-gleevye	Peats low moor gleyic and peats boggy gleyic	Histosol	Terric	HStr
Лугово-болотные	Lugovo-bolotnye	Meadow-boggy	Gleysol	Mollic	GLmo
Лугово-болотные засоленные	Lugovo-bolotnye zasolennye	Meadow-boggy saline	Gleysol	Mollic	GLmo
Луговые	Lugovye	Meadows	Gleysol	Umbric	GLum

(continued)

Table 5.1 (continued)

Name Russian	Name Transliterated	Name Englisch	Group_WRB (FAO/IIASA/ISRIC/ISSCAS/JRC 2012)	Qualifier WRB	Code_wrb
Луговые засоленные	Lugovye zasolennye	Meadows saline	Gleysol	Umbric	Glum
Солоди луговые	Solodi lugovye	Meadows differentiated and solodic	Planosol	Mollic	PLmo
Солонцы лугово-черноземные	Solontsy lugovo-chernozemnye	Meadow-chernozemics solonetzic	Solonetz	Gleyic	SNgl
Солонцы лугово-черноземные засоленные	Solontsy lugovo-chernozemnye zasolennye	Meadow-chernozemics solonetzic and saline	Solonetz	Gleyic	SNgl
Солонцы лугово-каштановые	Solontsy lugovo-kashtanovye	Meadow-chestnuts solonetzic	Solonetz	Gleyic	SNgl
Солонцы лугово-каштановые засоленные	Solontsy lugovo-kashtanovye zasolennye	Meadow-chestnuts solonetzic and saline	Solonetz	Gleyic	SNgl
Солончаки типичные	Solonchaki tipichnye	Solonchaks typical	Solonchak	Haplic	SCha
Солончаки луговые	Solonchaki lugovye	Solonchaks meadow	Solonchak	Gleyic	SCgl
Аллювиальные луговые насыщенные	Allyuvial'nye lugovye nasyshennye	Alluvials meadow saturated	Fluvisol	Umbric	FLum
Аллювиальные луговые насыщенные засоленные	Allyuvial'nye lugovye nasyshennye zasolennye	Alluvials meadow saturated saline	Fluvisol	Thionic	FLti
Аллювиальные лугово-болотные	Allyuvial'nye lugovo-bolotnye	Alluvials swamp meadow	Fluvisol	Umbric	FLum

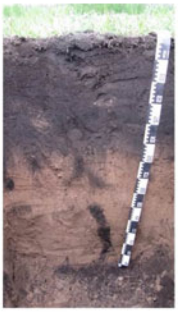
5.2.2 *Exemplified New Examination and Description of Soil Horizons of Selected Soil Profiles*

Additional to the analysis of existing maps, soil profiles were examined in the field and described based on the WRB soil classification system. A soil profile database was built for the research regions which is accessible here: http://www.sibessc.uni-jena.de/. Samples were taken from the described profiles. The samples were analyzed to determine soil characteristics like organic matter, texture, aggregate stability, carbonate content, bulk density, pH value, etc. The analyses were conducted in the laboratories of the Altai State University, the Agrarian State University of the Altai Krai as well as the Institute of Water and Ecological Problems of the Siberian Department of the Russian Academy of Sciences.

The purpose of the examinations was the comparison of current results with data of earlier soil surveys and the evaluation of type and intensity of agricultural land use effects on the soils. The pedological analyses produced a multitude of new data about the soil characteristics of the examined profiles. Figure 5.1 presents profile examples of the widespread soil groups Haplic Chernozem and Haplic Kastanozem.

Profile - Datasheet

Name/No.	202
Date	28-05-2014
Editor	Illiger/Stephan/Mizgiriev
Position	81,637673 - 52,900049
Altitude	247 m
Inclination/ Exposition	< 1°
Usage	Extensive Pasture, Hay Meadow
Notice	West of Perwomayskij, no tilling since 1960s
Soil Type	Haplic Chernozem



Horizon Symbol	Ah	AC	C		
Lower edge (cm)	45	60	60+		
Grain Size	Ut2	Ut2	Ut3		
Soil Colour	10YR 2/1	mix	10YR 5/4		
Moisture (FDR)	31,4%	26,2%	27,0%		

Laboratory Results

Horizon	Depth (cm)	Bulk Density (g/cm³)	SOM (%)	pH H_2O	Elec. conduc. (µS/cm)	$CaCO_3$ (%)	SOC (%)	C/N
Ah	15	1,09	5,85	6,8	251	0,09	3,33	10,6
Ah	30	1,14	4,79	7,3	246	0,28	2,72	10,5
C	60	1,34	2,3	7,7	592	0,18	1,31	13,0

Profile - Datasheet

Name/No.	73
Date	17.09.2012
Editor	Illiger/Stephan/ Schmidt/Holzweißig
Position	N5769406.13E424631.51
Altitude	137m
Slope/ Exposition	>1
Usage	Field/ Pea
Notice	Amazone test field; Poluyamkij/ Condor
Soil Type	Haplic Kastanozem

Horizon Symbol	Ah	AC	Ckc	C
Lower edge	30	45	90	120+
Soil Moisture	dry	dry	dry	dry
Grain Size Fraction	SLSi (Uls)	SLSi (Uls)	SL (Ls2)	LS (Sl4)

Laboratory Results

Horizon	Depth (cm)	Bulk density (cm³)	organic Matter (%)	pH H2O	Conductance (µS/cm)	CaCO3 (%)	TC (%)	C/N
Ah	15	1,17	4,68	8,56	398,7	0,43	1,75	12,4
AC	30	1,27	4,27	7,32	127,5	0,23	1,45	9,6
Ckc	60	1,31	3,55	7,9	355,7	11,66	3,1	25,4
C	120	1,46	1,86	8,17	268,0	5,43	1,15	10,4

Fig. 5.1 Examples of standard profile datasheets of the KULUNDA project's soil survey (left Haplic Chernozem, right Haplic Kastanozem)

5.3 Comparability of Analytical Methods Used for Soil Characterization

The intended comparison presumes that the laboratory analyses were conducted using the same methods and the evaluation of the results was based on the same classification system. But the analytical methods for numerous soil characteristics have changed repeatedly in the past and are now more advanced. This presents one of the biggest challenges for converting soil information from the Russian soil classification system into the WRB classification system and using the data of earlier soil surveys for comparisons.

Soil characteristics texture and soil organic matter are especially problematic. The Russian particle-size classification system uses different classification limits and the determination of the humus content uses a completely different analytical method. Comprehensive comparative analyses were required. For instance, soil organic matter analyses have been performed with different methods. They showed mismatching and not comparable results, which is based on the differences in the analytical method. Using this data to analyze changes over time would result in misinterpretations.

5.3.1 Texture

Texture is a fundamental physical soil characteristic which influences the hydraulic properties and erodibility of soils. Figure 5.2 compares the Russian and international particle-size classification. The limits of the particle-size classes are lower in the Russian system than in the international classification.

The usage of texture data derived from different classification methods might result in erroneous evaluations of soil erodibility or water storage capacity. As an example, the infiltration capacity of sandy soil is underestimated if the Russian particle-size classification system is used because the maximal size of its sand class is 1 mm. Depending on the number of particles between 1 and 2 mm in the soil, pore space and pore diameter might be less than thought.

The differences between the classification systems are even greater regarding the definition of textural classes based on the particle-size distribution. While the definition for clay is almost identical, the particle-size distribution of silts and loams

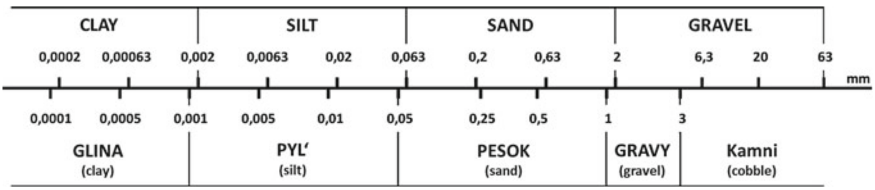


Fig. 5.2 Comparison of the Russian and the international particle-size classes. *Source* FAO (2014), Kovda and Rozanov (1988), Mizgirev et al. (2015) and Scheffer and Schachtschabel (2000)

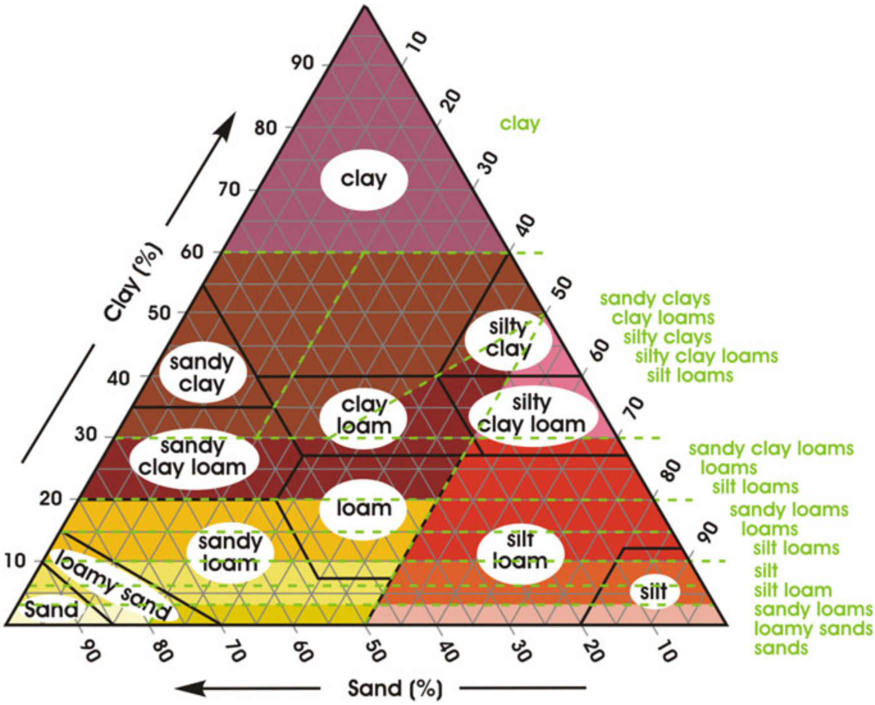


Fig. 5.3 Combined display of textural classes based on the Russian and international texture classification system (underlying color—international classification, green Russian system). *Source* FAO (2014), Kovda and Rozanov (1988) and Mizgirev et al. (2015)

differs widely between the two systems (see Fig. 5.3). The comparability of soil information depends on textural classes, which make it almost impossible to convert data from one system to the other. For this reason, the standardized evaluation of the erosion susceptibility of locations based on older and current data and the evaluation of land use effects is affected by high uncertainty (Mizgirev 2013; Mizgirev et al. 2015).

5.3.2 Soil Organic Matter, Humus, Organic Carbon

The organic substances in soils that are left after decomposition of organic matter are called humic substances. That is why in literature, the term "humus" is often used synonymously with "organic substance." The amount of organic substance or humus besides texture is an important soil characteristic for classifying them into soil groups. As well the direct comparison of soil organic matter data with different time references allows an assessment of soil degradation under different land use types.

Traditionally, the determination of all organic carbon compounds is done in the Slavic speaking region by the wet-combustion method according to Tyurin. Dry-combustion in a muffle oven (also called loss by combustion) and elemental analysis are the common methods in the USA and Western Europe. Higher or lower results due to the usage of different analytical methods might result in the different classification of soils. These analytical differences limit the comparability of data. This is a problem because the data collected in the project cannot be easily compared with data from Russian soil surveys.

For this reason, new determinations of soil organic matter were made in connection with the exemplified new examination and description of soil horizons of selected soil profiles in the project (see Chap. 19). The method of chrono-sequences was then used to assess soil degradation by land use.

5.4 Soil Map of the Altai Krai Based on the WRB Soil Classification System

Due to its location in the high continental region of southern Siberia, the Altai Krai has the typical soil pattern of steppe regions. Along a climatic northwest–southeast gradient, the landscape changes by the transition from the forest steppe with typical Chernozems in the east of the Altai Krai to the light Kastanozems of the dry steppe in the southwest. About 71% of the Altai Krai's soils are Chernozems and Kastanozems (see Fig. 5.4). Solonetz, Gleysols, Fluvisols, and Histosols are taking up smaller areas.

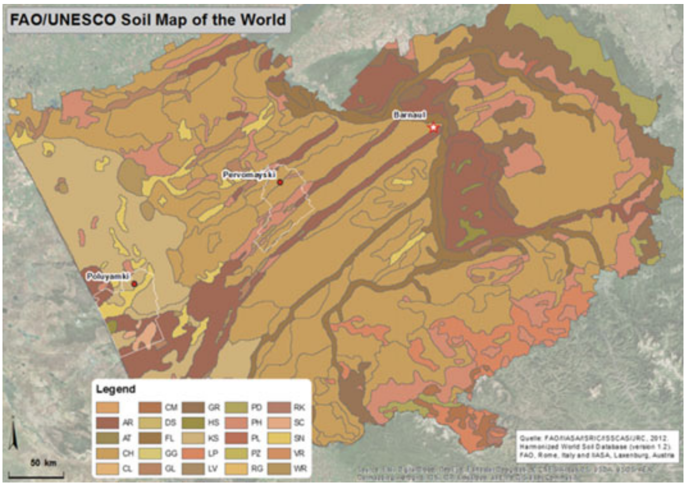


Fig. 5.4 Soil map of the Altai Krai based on the WRB soil classification map at 1:5 million scale. *Source* FAO (2007, 2014)

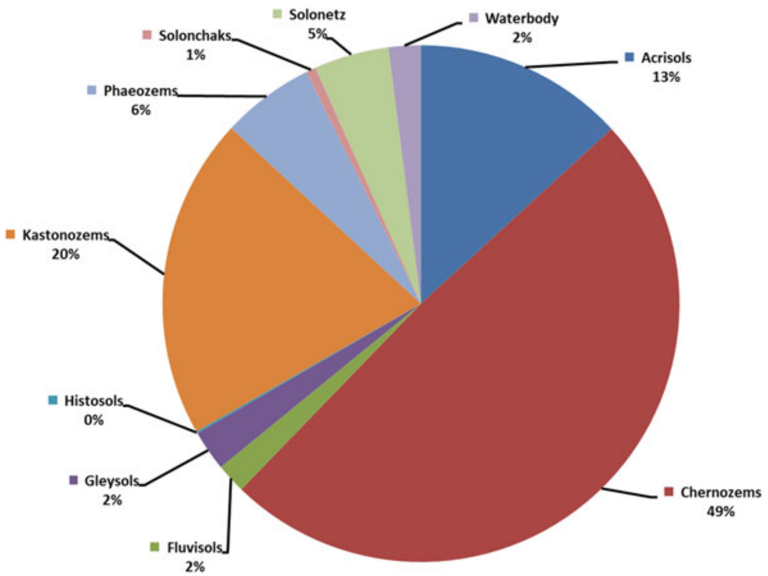


Fig. 5.5 Percentage of the soil groups of the research region. *Source* FAO/IIASA/ISRIC/ISSCAS/JRC (2012)

Work of the KULUNDA project was concentrated on the area to the west of the Ob River and north of the Aley River. It borders at the Novosibirsk region in the north and Kazakhstan in the west. The total of the research region is 77,427 km^2. 69% of the region's soils are Chernozems (49%) and Kastanozems (20%) (see Fig. 5.5) which is very similar to the soil distribution of whole Altai Krai. Acrisols (13%), Phaeozems (6%), and Solonetzes (5%) are other soils of this area.

The soil patterns of the districts, where the test areas are located, are different depending on the local conditions. Figure 5.6 displays the integration of the soil maps of the Rayons Mamontovskiy and Mikhaylovskiy at 1:500,000 scale into the FAO World Soil Map at 1:5,000,000 scale. The much more detailed soil patterns due to the different scaling are clearly visible.

The soil pattern of the Mikhaylovskiy Rayon at 1:500,000 scale shows not only a large variety but also a different percentage of soils in comparison with the research region (see Fig. 5.7). Here, only 26% of the soils are Chernozems but the portion of Solonetzes is with 20% almost four times higher than in the research region. The displayed percentage of Podzoluvisols is about 14% and the Kastanozem portion is the same in the Mikhaylovskiy Rayon as in the whole research region.

The soil map at 1:500,000 scale was converted into the WRB classification system for the districts of the test areas. The comparison with the FAO World Soil Map at 1:5,000,000 scale exemplified by the Mikhaylovskiy Rayon shows clearly a less detailed soil pattern for the small-scale map (six soil groups are displayed). The large-scale map displays the soil pattern much more detailed with eleven soil groups

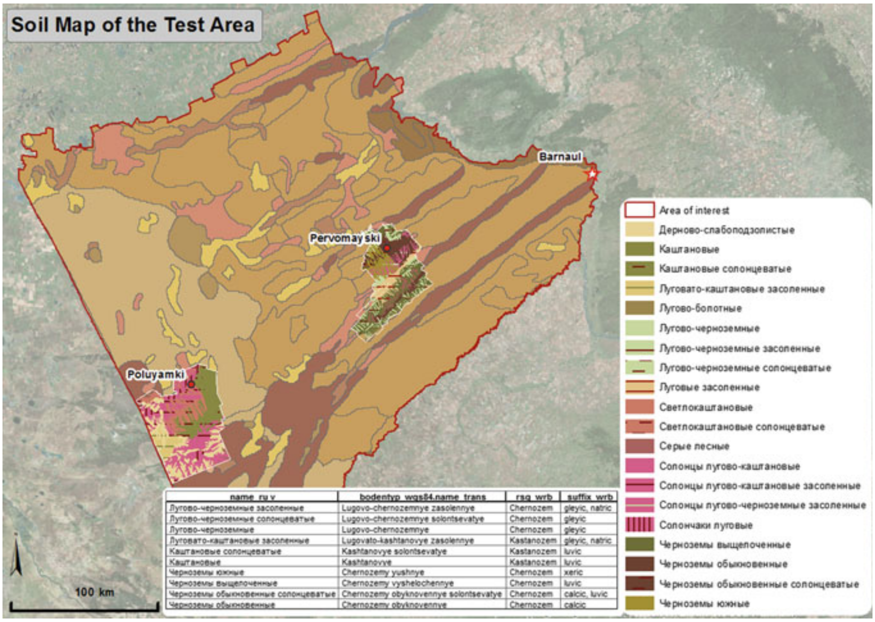


Fig. 5.6 Integration of the soil map at 1:500,000 scale into the FAO World Soil Map of the research area (Mizgirev 2013)

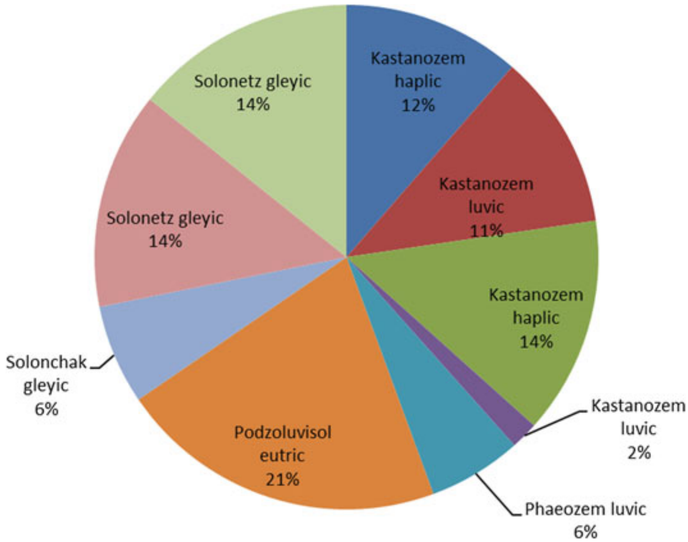


Fig. 5.7 Percentage of the different soil units in the Mikhaylovskiy Rayon. *Source* Kovda and Rozanov (1988); KGKRF (1992)

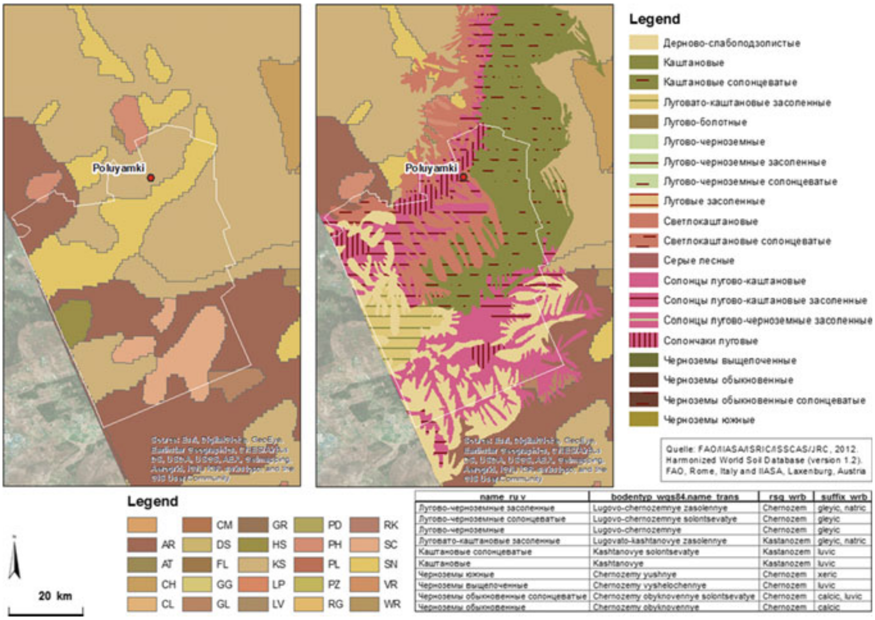


Fig. 5.8 Segments of the FAO World Soil Map (FAO/IIASA/ISRIC/ISSCAS/JRC 2012) and the soil map of the Altai Krai (KGKRF 1992) exemplified by the Mikhaylovskiy Rayon (Mizgirev 2013)

(which are 18 soil groups according to the Russian soil classification system) (see Fig. 5.8). This map reveals that besides Solonetzes a multitude of subgroups of Kastanozems and Chernozems with different saline properties exist which is not shown in the generalized world soil map.

The comparison of both differently scaled maps of the Mikhaylovskiy Rayon does not only reveal the higher degree of differentiation by the map at 1:500,000 scale, it also shows that each map displays soil groups which cannot be found in the other map. The reason is probably not the different map scaling (see Table 5.2), but rather a different interpretation of the soil data for the different soil profiles. The most significant result of the comparison of both soil maps is the absence of Chernozems in the FAO soil map at 1:5,000,000 scale. Here, 24% of the soils are classified as Acrisols.

5.5 Conclusions

The research of the soil pattern and soil characteristics in the Altai region posed a challenge for all parties involved because the comparative analyses of the soil state were based on pedological data of historic Russian soil surveys and new, current

Table 5.2 Comparison of the area of the soil groups in the Mikhaylovskiy Rayon in the soil maps at 1:500,000 scale (KGKRF 1992) and 1:5,000,000 scale (FAO 2012)

Soil (Kovda and Rozanov 1988, KGKRF 1992)	KGKRF_translated to FAO (1:500,000)	Area [%]	FAO WRB (1:5 Mill)	Area [%]
Chernozems leached	Chernozem Luvic	12.8	**Chernozems**	**0.0**
Chernozems ordinary	Chernozem Haplic	7.2		
Chernozems ordinary Solonetzic	Chernozem Luvic	1.9		
Chernozems southern	Chernozem Calcic	5.5		
	Chernozems	**27.4**		**0.0**
Meadow-boggy	Gleysol Mollic	0.2	**Gleysols**	**0.4**
Meadows saline	Gleysol Umbric	4.1		
	Gleysols	**4.3**		**0.4**
Chestnuts	Kastanozem Haplic	7.0	**Kastanozems**	**41.0**
Chestnuts solonetzic	Kastanozem Luvic	4.3		
Chestnuts light	Kastanozem Haplic	8.6		
Chestnuts light Solonetzic	Kastanozem Luvic	1.1		
	Kastanozems	**21.0**		**41.0**
Meadow-chestnuts saline	Phaeozem Luvic	3.7	**Phaeozems**	**0.4**
Meadow-Chernozemics saline	Phaeozem Luvic	2.2		
Meadow-Chernozemics solonetzic	Phaeozem Luvic	3.6		
	Phaeozems	**9.4**		**0.4**
Sod-podzolics	**Podzoluvisol Eutric**	**14.0**	**Podzoluvisosl**	**0.0**
Solonchaks meadow	**Solonchak Gleyic**	**3.9**	**Solonchaks**	**12.5**
Meadow-chestnuts solonetzic	Solonetz Gleyic	8.6	**Solonetzs**	**18.0**
Meadow-chestnuts Solonetzic and saline	Solonetz Gleyic	8.8		
Meadow-Chernozemics solonetzic and saline	Solonetz Gleyic	2.6		
	Solonetzs	**19.9**		**18.0**
	Acrisols		**Acrisols**	**24.8**
	Histosols		**Histosols**	**3.0**

pedological data. The different soil classification systems and analytical methods were especially problematic. A multitude of Russian soil data going back to the 1950s was available for the researchers. But to use these data for comparative analyses, the data had to be converted which always results in loss of information and is not possible for each soil characteristic (analytic). By remapping, soil information can be collected and used for corrections. But due to the size of the research area and given time constraints, only very localized soil surveys and corrections were possible.

References

Akademiya Nauk SSSR (ed) (1959) Pochvy Altaiskogo Kraia [The soils of the Altai Krai]. Academy of Sciences of the Soviet Union, Moscow [in Russian]

FAO—Food and Agriculture Organization of the United Nations (2007) Digital soil map of the world. Rome

FAO—Food and Agriculture Organization of the United Nations (2014) World reference base for soil resources 2014. International soil classification system for naming soils and creating legends for soil maps. In: World soil resources reports. 106. Rome

FAO/IIASA/ISRIC/ISSCAS/JRC (2012) Harmonized world soil database (version 1.2). FAO, Rome, Italy and IIASA, Laxenburg, Austria

Komitet po geodezii i kartografii Rossiiskoi Federatsii (KGKRF) (1992) Pochvennaia karta Altaiskogo Kraia i Respubliki Altai 1986 g., M. 1:500,000 [Soil map of the Altai Territory and the Altai Republic 1986, scale 1:500,000]. Novosibirsk: [in Russian]

Kovda VA (1973) Osnovy ucheniia o pochvakh - obshchaia teoriia pochvoobrazovatel'nogo protsessa [The principles of pedology—general theory of soil formation], 2nd volume. Moscow. [in Russian]

Kovda VA, Rozanov BG (1988) Pochvovedenie - Tipy pochv, ikh geografiia i ispol'zovanie [Soil science—types of soils, their geography and use], 2nd volume. Moscow. [in Russian]

Mizgirev A (2013) Konzeption eines Web-GIS mit transkribierten Kartenelementen für das KULUNDA-Projekt [Conception of a web GIS with transcribed map elements for the KULUNDA project]. Diploma Thesis, Martin Luther University Halle-Wittenberg. [unpublished, in German]

Mizgirev A, Thürkow D, Zierdt M (2015) Konzeption eines WebGIS zur bilingualen Transformation geographischer Namen [Conception of a WebGIS for the bilingual transformation of geographical names]. Kartographische Nachrichten 3:139–145 [in German]

Oldeman LR, Hakkeling RTA, Sombroek WG (1991) World map of the status of human-induced soil degradation: An explanatory note. Wageningen: International Soil Reference and Information Centre; Nairobi: United Nations Environment Programme

Rosanov AN, Karmanov II (1959) Sistematika Potchv Altaiskogo Kraia [Systematics of soils of the Altai Region]. In: Akademii Nauk SSSR (ed) Pochvy Altaiskogo Kraia. Academy of Sciences of the Soviet Union, Moscow, pp 27–31 [in Russian]

Scheffer F, Schachtschabel P (2000) Lehrbuch der Bodenkunde [Textbook of Soil Science]. Spektrum Akademischer Verlag, Heidelberg, Berlin [in German]

Stolbovoy V, Fischer G (1997) A new digital georeferenced database of soil degradation in Russia, IIASA Interim Report, IR-97-084/November, Laxenburg

Stolbovoy V (2000) Soils of Russia: correlated with the revised legend of the FAO soil map of the world and world reference base for soil resources, IIASA Research Report, RR-00-13, June, Laxenburg

Chapter 6
800 Years of Agricultural Land-use Change in Asian (Eastern) Russia

A. V. Prishchepov, F. Schierhorn, N. Dronin, E. V. Ponkina and D. Müller

Abstract Asian (Eastern) Russia is a globally important agricultural region but has received little attention in the literature. This book chapter evaluates the history of agricultural development in Asian Russia, often colloquially called Siberia, which is a vast region that stretches from the Ural Mountains to the Pacific Ocean. First, we summarize agro-environmental conditions across the region. Second, we present the dynamics of land use, crop and milk yields from medieval times until recent years and discuss the major underlying causes that bring about the observed changes in the extent and intensity of agricultural production. We then briefly discuss untapped agricultural potentials in the region regarding expanding cultivated areas and particularly regarding increasing productivity in crop and livestock production.

A. V. Prishchepov (✉)
Department of Geosciences and Natural Resource Management, University of Copenhagen, Øster Voldgade 10, 1350 København K, Denmark
e-mail: alpr@ign.ku.dk

Institute of Environmental Sciences, Kazan Federal University, Tovarishcheskaya str.5, Kazan 420097, Russia

A. V. Prishchepov · D. Müller
Institute of Steppe of the Ural Branch of the Russian Academy of Sciences, Pionerskaya str.11, Orenburg 460000, Russia

F. Schierhorn · D. Müller
Leibniz Institute of Agricultural Development in Transition Economies (IAMO), Theodor-Lieser-Strasse 2, 06120 Halle (Saale), Germany

N. Dronin
Department of Geography,
Moscow State University, Leninski Gory, GSP-2, Moscow 119992, Russia

E. V. Ponkina · D. Müller
Faculty of Mathematics and Information Technology, Altai State University, Lenina ave. 61, Barnaul, Altai Krai 656049, Russia

D. Müller
Geography Department, Humboldt Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany

Integrative Research Institute on Transformations of Human-Environment Systems (IRI THESys), Humboldt Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_6

We particularly focus attention on socio-economic and environmental impediments that limit uncovering such production potentials in the region.

Keywords Historical land use change · Drivers · Agricultural potential · Yield gap · Expansion · Abandonment

6.1 Introduction

Russia holds enormous land resources suited for both crop and livestock production. However, the geographic distribution of land resources that are suitable for agriculture is uneven across Russia; approximately two-thirds of the 75 million hectares (Mha) of cultivated croplands and 26% of total livestock production in 2013 were located in Western (European) Russia (Bartalev et al. 2016; Rosstat 2016). Consequently, most scientific studies have examined agricultural land-use change and production opportunities in European Russia (de Beurs and Ioffe 2014; Ioffe and Nefedova 2004; Prishchepov et al. 2013; Schierhorn et al. 2014), with only a few exceptions focusing on all of Russia (Dronin and Kirilenko 2010; Dronin and Bellinger 2005; Meyfroidt et al. 2016; Nefedova 2011; Savin et al. 2001; Swinnen et al. 2017) or specific parts of Asian Russia[1] (Horion et al. 2016; Kühling et al. 2016; Pavlova et al. 2014; Tchebakova et al. 2011; Wegren et al. 2015; Wright et al. 2012). However, Asian Russia has not yet been analyzed as a whole. Consequently, little is known in English literature about historic agricultural development beyond the Ural Mountains. This is unfortunate because Asian Russia is truly unique, and agriculture only started to expand to the region in the mid-nineteenth century (Dronin and Bellinger 2005; Riasanovsky 2000; Treadgold 1957).

Asian Russia experienced multiple fluctuations regarding agricultural land use during the nineteenth and twentieth centuries, such as the Great Siberian Migration of 7–8 million people over the Urals during the mid-nineteenth and early twentieth centuries, which had striking parallels with the migration from Europe across the Atlantic to the USA and related massive cropland expansion in the US Great Plains. The agricultural expansion associated with the Great Siberian Migration was interrupted by the colossal sociopolitical disturbances of World War I (WWI) (1914), Bolshevik revolution (1917) and the Civil War (1917–1923). After 1923, the gradual cropland expansion continued with the perturbation caused by WWII. Another much larger wave of cropland expansion in Asian Russia started in 1954, when the Soviet government enacted the Virgin Lands Campaign, during which 13.6 Mha was ploughed up in Asian Russia alone from 1954 to 1963 (Durgin 1962; Josephson et al. 2013). Finally, another shocking event that affected cropland expansion was the breakup of the Soviet Union in 1991 and disintegration of state-command economy, which resulted in massive cropland and managed grassland abandonment

[1]This vast region, hereafter labelled Asian Russia, is also often called colloquially Eastern, Asiatic Russia or Siberia.

during the mid-1990s. Consequently, agricultural production started to recover only around 2000 in Asian Russia. Both cropland extent and livestock numbers are currently much lower than those before 1991 (Rosstat 2016; Schierhorn et al. 2016), and current productivity levels in crop and livestock production fall short of the levels in industrialized countries (Schierhorn et al. 2016). This suggests that Russia possesses enormous untapped agricultural potentials, both by bringing idle croplands and grasslands back into production and by increasing agricultural productivity (Saraykin et al. 2017; Savin et al. 2001; Schierhorn et al. 2014; Swinnen et al. 2017). Moreover, Russia may also possess suitable land resources that were not used before and could, in theory, be brought into agricultural production (Tchebakova et al. 2011).

In this chapter, we will first describe the agro-environmental conditions of Asian Russia. Then, we will provide a brief historical summary of agricultural development over 800 years, structured by major political milestones. Finally, we will discuss the agricultural production potentials of Asian Russia.

6.2 Geographic Description of the Asian Russian Agricultural Rim

Asian Russia occupies a large part of the Eurasian landmass, stretching from the Urals to the Pacific Ocean. The Russian Far East[2] is also included in our regional definition of Asian Russia. Asian Russia covers approximately 77% of the Russian territory or 13 million km^2. Taken alone, Asian Russia would be the largest country on earth by a large margin. In the north, Asian Russia is limited by the Arctic Ocean, and in the south, it borders Mongolia, China and Kazakhstan. Asian Russia is subdivided into several natural sub-regions: Western Siberia, Eastern Siberia, Pribaikalje and Zabaikalje (Transbaikal or Dauria), North-Eastern Siberia, and Southern Siberia with the Altai and Sayan Mountain ranges, and the Far East (Fig. 6.1).

The elevation of Asian Russia varies markedly. To the west, the area is characterized by a flat and unbroken landscape over hundreds of kilometres called the West Siberian Plain. Over half of the territory of the West Siberian Plain (or the Western Siberia sub-region) is lowlands with elevations below 100 m (more details about agro-climatic conditions for Western Siberia you may find in this book in Chap. 8 by Frühauf & Borisenko). In the Central Siberian Plateau, more rugged terrain can be found with elevations up to 1700 m; the elevation reaches up to 3000 m towards the eastern edges. In the south of Siberia, the Sayan Mountains rise up to 3100 m and form the border with the Mongolian People's Republic.

The climatic conditions vary considerably across Asian Russia. Given its severe and long winters, the largest part of Asian Russia currently is not suited for crop and livestock production, except transhumance reindeer herding in parts of North-Western Siberia. Agriculture stretches across the southern part of Western and East-

[2]Far East consists of the Amur, Kamchatka, Khabarovsk, Magadan, Primorje and Sakhalin provinces, plus the Jewish and Chukotka autonomous regions—Fig. 6.1.

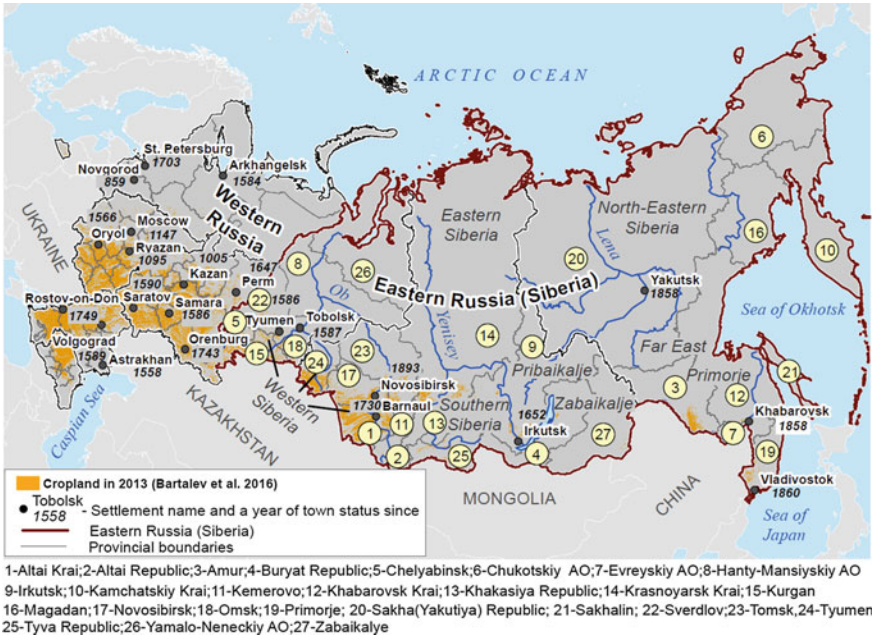


Fig. 6.1 Russia and Asian Russia

ern Siberia with an additional agricultural spot around Yakutsk. By 2013, 68 Mha or 5% of the entire Asian Russian landmass was designated for agriculture, of which 21.8 Mha was used for crops. Within the cropland areas (Fig. 6.1), the lowest average monthly temperature is −12 °C in February and the highest is 18 °C in July. For comparison, the lowest average monthly temperature in the cropland belt in European Russia is −9 °C and the highest is 20 °C. There are approximately 121 days with temperatures over 10 °C in the Asian Russian agricultural belt compared to 150 days in European Russia (Afonin et al. 2008). Regarding the number of days with temperatures above 10 °C, some Asian Russian provinces that specialize in wheat production (e.g. southern Tyumen, Kurgan, Altai Krai) (Fig. 6.1) can be compared with provinces in non-fertile areas (non-Chernozem Russia). However, soil suitability for wheat production is much better in Western Siberia.

The average annual precipitation is 383 mm in the agricultural belt of Asian Russia, in contrast to 454 mm in European Russia. The drought intensity, measured by Selyaninov's Hydrothermal Coefficient (HTC)- an index, which reflects drought/excessive precipitation conditions and which combines precipitation with the temperature during the vegetation period, is 1.2 on average for Asian Russia and 0.9 for European Russia (values of the HTC of over one indicate excessive precipitation, and the lower the value, the higher the drought intensity, whereas values below 0.5 indicate severe drought).

6.3 Vast Idle Land Reserves in Asian Russia by 1917

Asian Russia has been occupied by nomads and hunters and gatherers for centuries with very little agricultural activity and low output. In search of fur to trade with the Hanseatic League, merchants and hunters from the Novgorod Republic crossed the Ural Mountains and reached the valleys of the lower Ob River, settling in some parts of northern Siberia as early as the twelfth century (Treadgold 1957). The Mongol conquest of the Eastern Slavs Duchies, which occupied the Russian plain, temporally stopped the further penetration of Eastern Slavs into Siberia. By freeing themselves from the Mongol yoke, the Moscow Duchy first enlarged its territory at the expense of the forest-steppe frontiers of European Russia. Later, they conquered the free city of Novgorod with the Yugorian lands in Siberia. By 1554, the Moscow Great Duke Ivan IV (Ivan the Terrible) already featured the name 'the Ruler of Siberia', among other titles (Treadgold 1957). Later, from 1581 to 1585, the Cossack Yermak continued the conquest of Siberia. Their establishment of the Muscovite towns Tobolsk (1590), Tomsk (1604) and Yeniseysk (1618) and further penetration towards the Pacific reflect the rapid conquest of Siberia in the late medieval period (Fig. 6.1).

However, the main interest of Russians in Asian Russia was on hunting and fur trade, which was in high demand on domestic and international markets. Later, gemstones and precious metals became other important stimuli for Russians to conquer Asian Russia. One can easily conclude that the trade of fur of sable was a precursor for Moscow's state enlargement into the Siberian territory. Even 300 years after the conquest of Siberia by Yermak, Siberia was primarily an exploitative source of fur, gemstones and metals.

The economic interests to utilize Asian Russia's agricultural potentials remained very low until the mid-nineteenth century. The Amur province and the Russian Far East (Fig. 6.1) were the only regions in Asian Russia where agriculture was well advanced before the resettlement of Russians by Bohai, Koreans, and Mohe-Nuzhen already in the twelfth century, primarily in some parts of the Amur floodplains (Okladnikov 1959). In the rest of Asian Russia, agriculture was likely concentrated in the vicinity of military outposts and mining towns to satisfy the needs of Russian settlers for cereals, such as rye and wheat, which are the main ingredients for bread, a key staple food (Forsyth 1992; Okladnikov 1959; Treadgold 1957). Siberia, being at the outer Russian frontier, also became infamously known for the resettlement of convicts and nobles who had fallen under the Tsar's disgrace (Forsyth 1992; Treadgold 1957). By 1815, approximately 42 million people lived in Russia, and only 1.1 million of those people lived in the territory of Asian Russia, of which only 430,000 were natives (Blackwell 1968; Okladnikov 1968a; Treadgold 1957). Assuming it would require about 4.4 ha of managed agricultural lands (crops, hayfields, pasturelands) per capita to satisfy the demands for agricultural products, including about 1 ha of cropland (Dronin and Bellinger 2005; Okladnikov 1968a), only approximately 0.67 Mha of land were needed for such land-use intensity around 1815 in Asian Russia (we exclude natives from the calculation because they were not dependent on grain as a source of staple food).

There were also calls for resettlement in Asian Russia and inquiries for the employment of state peasants during the nineteenth century for all kinds of services. The calls particularly addressed the peasants in the temperate and forest steppe of European Russia, who were increasingly short on land (Okladnikov 1968b; Treadgold 1957). Asian Russia also attracted those who wanted to practice religions that deviate from the main course of the Russian Orthodox Church, such as old believers, those who escaped from the serfdom, or those who ran into problems with the law. In this regard, Siberia served as a free Utopian land to restart life. Local administration in Asian Russia had no desire to send back the 'unofficial' settlers because it would impose extra administrative and financial costs and because Asian Russia was labour insufficient at that time (more on that in Chap. 8 by Frühauf & Borisenko).

Approximately, 1.2 million people immigrated from 1815 until 1860, of which 350,000 were exiles and prisoners, and 200,000 were so-called unofficial settlers, who searched for better living conditions in Asian Russia (Okladnikov 1968a; Treadgold 1957). Consequently, the total population in Asian Russia (including natives) increased from 1.1 million in 1815 to 2.9 million in 1860 (Treadgold 1957). This implies that the cropland demand in Asian Russia also more than doubled from 1815 to 1860 to approximately 2.3 Mha (assuming the same land-use intensity of 4.4 ha per capita, of which 1 ha is required for cropland). Cropland expansion occurred primarily in the contemporary Chelyabinsk, Kurgan, Tyumen, Omsk, Novosibirsk provinces, and in the Altai Krai; these areas are part of the fertile Chernozem (Black Earth) belt of Western Siberia.

The dynamics of migration to Asian Russia intensified after 1861 when the serfdom of Russian peasants was abolished, and peasants were able to move freely (Riasanovsky 2000). Moreover, Russia reached the Black Sea by the mid-nineteenth century and thereby cleared the space from all the troubles associated with the invasion of nomads or Turks. When Russia conquered the Caucasus and Central Asia a few decades later, large areas of idle and fertile steppe soils from Austria-Hungary to Mongolia were in the hands of the Russian Empire and could be ploughed up, including many areas that were wild and had never been used for ploughing.

Despite the vast and fertile land resources in the steppes of European Russia, the country continued to suffer from food insecurity and land scarcity in parts of the densely populated temperate European Russia. The Russian population grew dramatically, rising from 118 to 179 million people between 1880 and 1914. Colonists who were invited to use the idle Chernozem soils in the south of European Russia were mainly large estate owners, and they produced crops for sale on the markets, a stark difference to the predominant semi-subsistence and household-based production in earlier times (Parker 1969). While 50% of the cereal production in southern Russia was exported in the 1860s, the export share of cereals increased to 80% by the beginning of the twentieth century, limiting the production that was available for domestic consumption (Chelinstvev 1928; Dronin and Bellinger 2005).

Complementary to the frequently cultivated rye in the north, wheat in the south, and flax and hemp as industrial crops, new crops were introduced, such as sugar beet, cotton and maize, which created additional pressure on land-use systems and contributed to the rapid disappearance of the steppes (Parker 1969). However, the grain yields remained low and only comprised 6–7 decitons (dt, equivalent to 100 kg)/ha or approximately half of what was achieved in Europe by that time. One reason for this difference was low mineral and fertilizers inputs in most areas of Russia. To sum up, despite vast areas, the peasantry in European Russia suffered from low productivity and land scarcity towards the end of the nineteenth and the beginning of the twentieth centuries. The population required more land for agricultural production, and many people moved to Asian Russia in search of new opportunities in agriculture.

The combination of cropland scarcity and low yields resulted in a sequence of unrest across European Russia from 1905 until 1907, which induced the Russian Imperial government to develop resettlement and cropland expansion programs in Asian Russia. One initiative was, for example, Pyotr Stolypin's agrarian reform, which fostered the migration of Russians towards Asian Russia from 1906 to 1914. The population in Asian Russia increased from 5.7 to 9.3 million people between 1897 and 1911, whereas the native population grew much less, ranging from 870,000 to 972,000 people (Treadgold 1957). By 1913, the population of Asian Russia was comprised of 10 million people out of the 125 million that lived in what is currently Russian territory. After 1913, further migration of peasants from European Russia discontinued due to the start of World War I (WWI), and cropland expansion also nearly stopped until the mid-1920s.

The year 1913 had the best economic performance in the history of Imperial Russia, and this year later served as the benchmark to compare agricultural performance during Soviet times. By 1913, the cropland extent reached 10 Mha and nine million heads of livestock were reared in Asian Russia (Fig. 6.2a, b). In 1913, the greatest cropland extent of 2 Mha (of which 90% was used for the production of grains) was recorded in the province that is currently called Altai (more details about historical agricultural development in Altai Krai you may find in Chap. 8 by Frühauf & Borisenko). The highest share of croplands in Asian Russia (18% of total area) was reported for Kurgan oblast and the lowest share (1%) was in the Amur province at

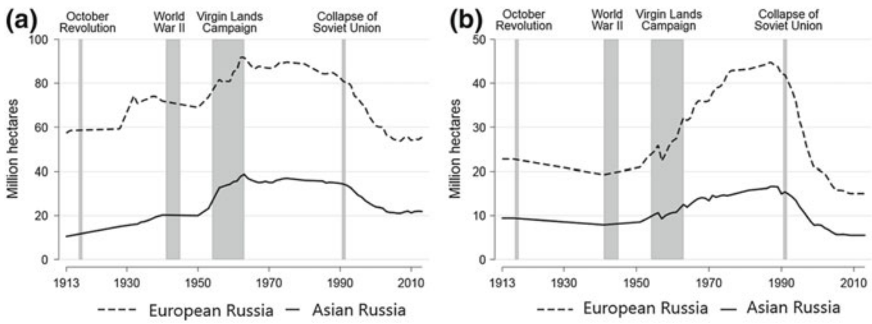


Fig. 6.2 Dynamics of sown areas (**a**) and livestock numbers (**b**) for European Russia and Asian Russia from 1913 until 2013. Source of statistics for 1913, 1928–1938, 1940, 1950, 1953–2013: USSR CDNEAGosplan (1939), USSR SSPH (1957, 1959), USSR SSPH (1960–1963), USSR CSD (1965–1976), USSR CSD (1981–1988), USSR CSD (1990). *Source* Rosstat (2016)

the Asian edge of Russia. After 1913, the militarization of the economy and the loss of established international markets due to WWI resulted in colossal fluctuations in grain supplies within the country. Despite continuing grain production after 1914 in Asian Russia, domestic trade connections between Asian Russia and European Russia were partly interrupted during the war. This also disrupted the stable grain supply in cities in European Russia, which led to revolts in the army and social unrest, and eventually, it led to the overthrow of the Imperial Government in 1917 and the rise of the Bolsheviks.

6.4 Agricultural Collapse After 1917 and Poor Performance of the Collectivized Farming Until 1953

The year of 1917 was associated with deepened turmoil in agricultural production caused by WWI. The October revolution in 1917 and the subsequent Civil War further led to a strong reduction in agricultural output across Russia. The nationalization and redistribution of land assets of former nobility and landholders following Vladimir Lenin's Decree on Land in 1918 did not help to solve the food insecurity issues. Large numbers of the male urban labour force were procured to support the Red Army (fighting for the Bolsheviks) and the White Forces (the anti-Bolsheviks) in the Civil War (1917–1923), but many of them fled to their villages. As a result, the urban population decreased by one-third and primarily heavily hit European Russia (Dronin and Bellinger 2005). During the war, the production of civilian products almost completely ceased, including the production of agricultural equipment and fertilizers (Dronin and Bellinger 2005). Another negative impact was the collapse of trade between urban and rural areas. De facto, the semi-agrarian Russia in rural areas returned to complete self-sufficiency regarding agricultural production and regarding products for daily use, such as smelting, construction, and local textile production. During the Civil War, agricultural production contracted dramatically. For instance, wheat production fell by 30% from 1917 until 1920 across Russia (Dronin and Bellinger 2005). In Asian Russia, some studies indicate crop production decline by 17% due to a lower share of crops destined for export compared to European Russia (Dronin and Bellinger 2005), while other studies showed sown areas declined by 1922 by half of what was cultivated in 1913 (Okladnikov 1968c). A reduction of livestock by 35% impacted meat and dairy supply and also the supply of organic fertilizers and draft power.[3] The procurement of butter for the export, what Siberia became

[3]We should note that our numbers for the period 1917–1920 differ from the reports of other scholars, who indicated more drastic decreases in sown areas and livestock numbers for the Civil War period (Dronin and Bellinger 2005; Okladnikov 1968c). We used official statistics on agricultural developments from various sources. The official statistics between 1917 and 1940 are questionable because of potential manipulation by the government. We cannot avoid such bias, as we wanted to use systematically collected data. All other official statistics, e.g., after 1953, are considered to better reflect agricultural dynamics.

famous for during the late Tzarist time, contracted by 13 times from 1917 until 1922 (Okladnikov 1968c). Consequently, the productivity of the land also decreased.

The period of the Civil War was characterized by drastic food shortages in the cities, which forced the Bolsheviks to develop measures of expropriation of agricultural products in rural areas. However, the fall in agricultural production was complemented by the drought in 1921, which deepened the food crisis, even in major breadbaskets, including the Volga region, where millions faced death by starvation. The famine of 1921 forced the Soviet government to develop extraordinary measures, such as the liberalization of trade and agricultural production via the so-called New Economic Program (NEP), which existed until 1929. However, the NEP did not resolve the inadequate provision of the food supply. Often, farmers sold a surplus production only at very high prices, but such prices were rarely paid. At the same time, the collectivized system could not supply the farmers with sufficient inputs, primarily machinery and fertilizers. By 1929 when the NEP ended, agricultural production had slightly recovered according to official statistics, and cropland area was officially back at the level of 1913 in European Russia and was even higher in Asian Russia (Fig. 6.2a) (Dronin and Bellinger 2005; Okladnikov 1968c). However, the livestock numbers continued to decline (Fig. 6.2b). The decision about cessation of the NEP was partially determined by the necessity of rapid industrialization of the Soviet economy and a strong desire to be able to export grain to obtain the means to buy machinery for the Soviet industry from abroad, but also with the hope that collectivized large-scale agricultural production will be efficient and supply the cities. Just in one year collectivized farms raised from 7.7% (1929) to 74% (1930) in the Central Black Earth region (Dronin and Bellinger 2005). By mid-1931, the Soviet government reported successful (forced) completion of the collectivization program.

The period of 1931–1940 was characterized by cropland expansion, primarily in Asian Russia (1 Mha in European Russia and 4 Mha in 4.5 Mha or by 22% in Asian Russia) (Fig. 6.2a). At the same time, livestock production continued to decline despite special programs, such as ‘On the development of the socialistic livestock’ (1931). The massive slaughtering of livestock was most likely a reflection of the peasants about forced collectivization. A further decrease in livestock numbers subsequently affected crop productivity due to a lack of organic fertilizers, lack of horsepower for ploughing and disruption of crop rotation practices. It has been reported that the yields were as low as 7 dt/ha, and even lower than those during the pre-revolutionary time. Famines, including the catastrophic famine of 1932–1933, heavily affected Russia.

The period of World War II (WWII) (in the case of the Soviet Union, a Great Patriotic War, which lasted from 1941 to 1945) had a devastating impact on agricultural production, especially in European Russia, where major breadbaskets were occupied by the Nazis. In response, production shifted to the inner parts of Russia. Due to labour and financial means’ shortage, the drop in the crop production has also been observed in Asian Russia (Fig. 6.2a). For instance, in Altai and Krasnoyarsk Krai, Novosibirsk and Omsk provinces sown areas contracted by 25% from 1940 to 1943 (Okladnikov 1968d). A drop in livestock numbers, with cattle numbers reduced by 20% and horses by 55%, also negatively impacted the productivity of the agricultural sector (Dronin and Bellinger 2005). In turn, the shortage of grain for fodder sequentially affected the productivity of livestock and livestock numbers.

After the end of WWII, cultivated areas slowly started to expand again and livestock numbers slightly increased. By 1950, the extent of sown areas was lower in European Russia and reached the same numbers in Asian Russia compared to 1940 (Fig. 6.2a). However, the livestock sector, including milk production, in particular, continued to suffer from a lack of fodder crop and the poor genetic condition of the herds, which compromised the supply of the population for milk and meat (Fig. 6.2b). The measures to optimize agricultural production, such as merging unsuccessful collective farms with successful ones, were not enough to resolve the chronic problems of Soviet farming, and they resulted in the agriculture policy measures after 1953 that are described below.

6.5 Expansionist Agriculture in the Soviet Union After 1953

By 1953, the Soviet Union was under pressure to increase its agricultural production, both grain and milk yields (Fig. 6.3a, b) to meet the growing domestic food demand and improve national food security, particularly meat and milk consumption (Dronin and Kirilenko 2010; Josephson et al. 2013; Prishchepov et al. 2015). Nutritious feed crops rather just hay should be produced to improve meat and milk production. The agricultural sector recovered only slowly in the aftermath of WWII, and the country was marred by repeated famines. The government responded by paying more attention towards boosting agricultural production, particularly in the face of emerging political isolation from the West (Prishchepov et al. 2015). Wheat, milk yields and meat production per capita in the Soviet Union, however, remained far below the average yields in the Western countries, including the USA. For example, spring wheat generated only 7 dt/ha by 1953 in Asian Russia (Fig. 6.3a, b), and interestingly, even less in European Russia (6 dt/ha). Hence, land productivity remained at the level of the best production year of the Russian Empire, 1913. Between 1913 and 1953, the croplands area in Asian Russia expanded from 10 to 20 Mha. However, production was very extensive, without much consideration to advancing technologies to raise yields. By 1953, livestock numbers in Asian Russia were also the same as in 1913 with nine million heads.

The Soviet state produced only 29.8 million tons (Mt) of cereals in 1953, less than the 1940 pre-war level of 35.6 Mt (Josephson et al. 2013). Another collectivization campaign from 1946 to 1953 in the newly acquired areas of what today constitutes Belarus, Ukraine, and the Baltic States, also failed to substantially increase domestic wheat supply (Josephson et al. 2013). Therefore, the ways of increasing agricultural production and food security became a top political priority and the subject of bitter political debate. The debate featured the potential successors of Josef W. Stalin after his death in 1953, namely the group around Nikita Khrushchev, the First Secretary of the Central Committee, and Georgy Malenkov, Chairman of the Council of Ministers. In their struggle for power, the question of the future orientation of agricultural policy

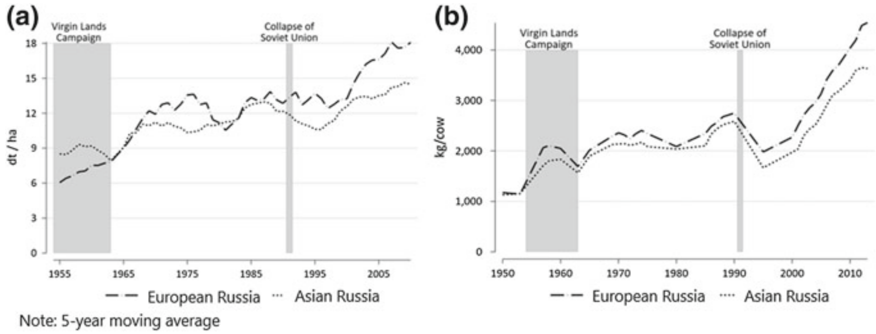


Fig. 6.3 Dynamic of spring wheat yields in dt/ha (1 dt = 100 kg) (**a**) and milk yields (kg/cattle) (**b**) separately for European and Asian Russia from 1955 till 2010 (wheat yield) and 1950 till 2013 (milk yield) with moving average of five years. Source of statistics for 1955–2013: USSR SSPH (1957, 1959), USSR SSPH (1960–1963), USSR CSD (1965-1976), USSR CSD (1981–1988), USSR CSD (1990). *Source* Rosstat (2016)

played a key role (Josephson et al. 2013; Prishchepov et al. 2015). Malenkov advocated increasing yields by greater use of fertilizer and modern farming technology on the existing arable land in the so-called old agricultural areas in European Russia, in combination with an optional expansion of up to 14 Mha of cropland in areas with medium crop suitability (McCauley 1976; Prishchepov et al. 2015). Khrushchev, in contrast, favoured a policy of extending maize cultivation in the former main wheat and rye growing areas in Ukraine and European Russia (McCauley 1976). Wheat cultivation, in return, would be expanded in the Eurasian Steppe, where vast stretches of land had never been used for arable farming before. This strategy, Khrushchev argued, would exploit the high natural fertility of the dry and semi-dry steppe soils (Durgin 1962; McCauley 1976). Khrushchev's plan prevailed—probably because the Soviet Union lacked sufficient capital reserves to intensify agricultural production in the farming areas in European Russia (Prishchepov et al. 2015); however, it is most likely that agricultural expansion further served to increase the human footprint in scarcely populated Asian Russia (Wein 1980) (more details you may find in Chap. 8 by Frühauf & Borisenko).

In February 1954, Khrushchev announced an ambitious plan for increasing cereal production, which targeted a 40-Mha expansion of cropland and a 35–40% grain production increase within a few years about yields in 1953 (Prishchepov et al. 2015). This plan became known as the Virgin Lands Campaign (hereafter, Campaign). In spring 1954, tractors began ploughing up remained steppes in European Russia (Volgograd, Rostov, Saratov, Bashkiria) as well as large tracts of Asian Russia (Kurgan, Orenburg, Altai Krai, Kemerovo, Novosibirsk, Omsk, Tyumen, Krasnoyarsk, Irkutsk and Chita) (Fig. 6.1) (Durgin 1962; McCauley 1976) and Northern Kazakhstan with the aim to mainly sow wheat. Of the 40 million ha that was scheduled to be brought into cultivation during the Campaign across Soviet Russia and Kazakhstan, 11 million had already been ploughed up in 1954 (Durgin 1962; Josephson et al. 2013;

Prishchepov et al. 2015). While many of these newly ploughed areas were not sown and some were sown but not harvested due to a lack of equipment, the year 1954 allowed procurement of an additional 14.7 Mt of grain, thanks to good weather conditions. This promising early success encouraged further expansion. However, subsequent years brought about colossal losses due to a sequence of droughts and shattered the initial belief of having at least two to three good harvests every five years. In 1957, again a year with bad harvests due to droughts, cropland expansion virtually came to a halt. Following another disastrous drought in 1963, when the grain yields averaged only 3 dt/ha, an amount insufficient to provide enough seeds for the following year, the Campaign ended (Prishchepov et al. 2015). Overall, 45 Mha of steppes lands were converted to cropland from 1953 to 1964 across Soviet Russia and Kazakhstan. Approximately 13.6 Mha of Asian Russian steppes were ploughed up by 1964 and cropland expansion was most widespread in the oblast Altai Krai with 2.8 Mha (Fig. 6.2a) (the nuances about the Campaign across Western Siberia and Altai Krai are in Chap. 8 by Frühauf & Borisenko).

However, the Campaign resolved the food security issue only partially. Each hectare ploughed in the virgin steppes allowed for the procurement of only 4.4 dt of grain per year on average, which increased total Soviet grain production only by 20% instead of the planned 35–40%. However, milk yields almost doubled during the Campaign, possibly due to the extra supply of feed grain produced in Campaign area and because of the substitution of grain production with more nutritious feed crops in temperate European Russia (Fig. 6.3b). Nevertheless, the failure of the Campaign was also one of the reasons for the dismissal of the general secretary of the Communist Party, Nikita Khrushchev. The Soviet Union even had to start importing grain from its political enemies, Canada and the USA. Given drastically increasing livestock numbers since the late 1950s (Fig. 6.2b) and ensuring the growth of milk yields (Fig. 6.3b), Soviet grain imports reached almost the same amount of grain than was produced across the entire Campaign area. Moreover, the environmental costs of the Campaign were tremendous, as it resulted in massive soil erosion, causing yields to remain low for years to come, the disappearance of steppe-dependent habitat, and substantial soil carbon release (Bekenov et al. 1998; Prishchepov et al. 2015; Suleimenov et al. 2012). Khrushchev later conceded that the steppes could instead serve as extensive livestock grazing systems (Einaudi 1964), but it was too late to turn around.

However, certain areas in Asian Russia enabled the procurement of more grain because of cropland expansion and increasing yields; for example, when precipitation ranged from 600 to 400 mm, spring wheat yields rose from 7.5 to 8.6 dt/ha on average by the end of the Campaign (Fig. 6.3a). At the same time, cropland in more marginal areas, such as at the southern edge of Northern Kazakhstan, where the annual average precipitation can fall below 200 mm per year, spring wheat yields remained as low as 3–4 dt/ha (ASK 2003; Prishchepov et al. 2015). This suggests that the opponents of Khrushchev, who favoured raising yields through higher land-use intensity and only increasing cropland by a mere 14 Mha in areas with good soil quality (instead of the 45 Mha put forward in the Campaign), would have had probably made the better choice to increase agricultural output.

After the end of the Campaign in 1964, cropland extent in Asian Russia remained almost stable at approximately 35–36 Mha until the collapse of the Soviet Union (Fig. 6.2a). In contrast, croplands in Kazakhstan expanded by another 8 Mha from 1964 to 1980, arguably because nearly all accessible land in Asian Russia, including in many marginal areas, was already ploughed up by 1964.

Another interesting point is that yields were continuously increasing after the end of the Campaign until the end of the Soviet Union in Asian Russia. Average spring wheat yields increased from 9.5 dt/ha in the 1960s to 11 dt/ha in the 1970s and to 12 dt/ha in the 1980s (Fig. 6.3a). However, these yields still lagged far behind biologically attainable yields (Swinnen et al. 2017) and milk yields were low. The increment of only 1 dt/ha per decade in Asian Russia was low despite growing intensification of agricultural production, such as an increase of fertilizers' inputs and mechanization of farming.

As noted previously, livestock production was a key focus of Soviet agricultural and social policies. Since 1927 and until 1953, there has been little increase in livestock numbers in European and Asian Russia (Fig. 6.2b). However, demand for livestock products was growing in this period, mainly due to the 36% growth of the population (Fig. 6.3b). Approximately 37% of the croplands were dedicated to producing livestock fodder to satisfy the demand for beef and dairy products. Fuelled with capital from oil and gas revenues of the Soviet Union, the investments into large agro-complexes since the 1970s, which featured a symbiosis between crop and livestock production, facilitated the growth of livestock production (Fig. 6.2b). As a result, livestock numbers in Asian Russia increased by 36% from 1950 to 1970 and increased another 19% from 1971 to 1988 (Fig. 6.2b). Livestock then slightly decreased until 1991, which coincides with the drop in world oil prices. This also reflects economic stagnation in the Soviet Union before the collapse; however, we should also acknowledge the increase in productivity, e.g. in milk yields, over this period, both in European and in Asian Russia.

6.6 Collapse of Agricultural Production After 1991 and Recent Recovery

The transition from a state-command to a market-driven economy following the demise of the Soviet Union in 1991 went hand in hand with the collapse of Soviet-time trade arrangements. This was particularly critical for the West Siberian bread-baskets, such as Altai Krai, a region that is located equally far from the ports of European Russia and those of the Russian Far East, approximately 5000 km in each direction. The vast discrepancy between guaranteed output prices until 1991 and the production costs of agricultural commodities surfaced after the collapse of state support, particularly in the heavily subsidized livestock sector, where state support decreased by 95% (Prishchepov et al. 2013). Subsidy cuts resulted in the reduction of livestock numbers in Asian Russia by more than half from 1990 to 2000

(Fig. 6.2b) and were associated with massive contraction of the area used for fodder crops (Fig. 6.2a), pasturing and hay cutting. Thus, the inefficient, but socially and thus politically important, livestock sector had been exceptionally affected, as was the ability to supply sufficient beef and milk products for the diet of the Russian people from domestic production (Schierhorn et al. 2016).

The unfortunate situation was also due to the infrastructure constraints inherited from Soviet times. To ensure that fodder crop production would not reduce the production of other agricultural commodities, such as wheat, the Soviet Union imported considerable amounts of highly nutritious fodder crops (e.g. maize) and high-quality wheat from the USA and Canada. To facilitate these imports, infrastructure development in the ports of Nahodka and Vladivostok in the Russian Far East (Fig. 6.1) focused on unloading capacities for imported grain. However, the current port infrastructure is inept for exporting large wheat surplus if the yield gaps are closed or if a surplus arises via cropland expansion. Moreover, many grain processing industries (mills and silages) have developed around the breadbaskets, such as Altai Krai. The high transportation costs reduce the profits from exporting.

From 1991 to 1995, wheat and milk yields dropped in Asian Russia, but then started to recover (Fig. 6.3a, b). In total, 1991–2000 cropland declined by 11 Mha or by 30% in Asian Russia while cropland in European Russia declined by 20 Mha or 26% (Fig. 6.2a). The cropland abandonment rate during this period reached 77% in Zabaikalje and even 84% in Tyva Republic. Krasnoyarsk province (1.27 Mha abandoned), followed by Zabaikalje (1.18 Mha) and Altai Krai (1.0 Mha), contributed the most to total abandonment between 1991 and 2000. The net reduction of agricultural land continued until 2007 when cropland extent reached its low point due to 13.7 Mha of cropland abandonment in Asian Russia or 37% of all croplands that were cultivated in 1991 compared to 31% of abandoned croplands in European Russia (Fig. 6.2a). Interestingly, the extent of abandonment in Asian Russia is almost equal to the same amount of land that was ploughed up during the Campaign from 1954 to 1963. The spatial distribution of abandoned croplands suggests that areas with excessive and deficient precipitation and areas with shorter growing periods were more likely to be abandoned. The areas with a high concentration of abandoned lands also coincided with a low population density and a higher decrease in birth rates (Meyfroidt et al. 2016; Nguyen et al. 2018).

After 2008, croplands started to expand again across Asian Russia. By 2013, approximately 0.83 Mha of abandoned croplands in Asian Russia were brought back into cultivation compared to 1.7 Mha in European Russia. Recultivation primarily occurred in the Amur, Kemerovo, Altai Krai and Omsk provinces and was particularly pronounced in the natural and economically suitable areas that enjoy better physical access to local and international markets (e.g. in the Amur region) and are endowed with favourable agro-environmental conditions. The increasing recultivation rates are associated with economic recovery, the rapidly growing purchasing power of consumers, the rebounding purchasing power and thus demands livestock products from Russian consumers, and the re-emerging trade partnerships with countries of the former Soviet Union as well as globally, as also witnessed by Russia's accession into the World Trade Organization (WTO) in 2012. New export markets opened up, such as in Southeast Asia, and more particularly, trade with China boomed. For instance, the sown area for soybeans in the Amur region increased five times from 0.16 to 0.8 Mha (2000–2014), which was driven by growing demand in neighbouring China (Rosstat 2016). From 2000 to 2013, milk yields dramatically increased almost 1500 kg/cow per decade and became three times higher compared to the 1950 level. Yet milk yields in Asian Russia are roughly twice as low compared to EU-15.

Another development that contributed to the recovery of agriculture in Asian Russia has been the changing policy framework. Since 2016, new laws on efficient land use and incentives for the reclamation of abandoned land pressured the provincial authorities to provide the legislative and infrastructural framework for recultivation, including dispossession of unused agricultural parcels (Russian Federation 2016). This situation can, to some extent, be labelled a new cropland expansion campaign. However, the success of this new campaign is unclear because of the ongoing stagnation of the Russian economy in 2016 and 2017 and the lack of infrastructure to store and process agricultural commodities destined for export markets. The prospects of beef sector recovery are also blurry because of the deteriorating purchasing power of many domestic consumers in the mid-2010s. By 2013, the livestock numbers in Asian Russia were only 50% of the number in the year 1913 and only one-third of those in 1991 (Fig. 6.2b).

6.7 Prospects for Agricultural Development in Asian Russia

Asian Russia stretches across a vast area of 6000 km in length from the Urals to the Pacific Ocean, yet only harbours 34 Mha of croplands, of which 23 Mha were cultivated and 11 Mha remained abandoned in 2013. Crop production could, in theory, be increased by bringing formerly used land back into cultivation, by converting thus far unused land into cropland, e.g. by reclaiming floodplains and marshlands in the northern edge of the Asian Russian grain belt, as well as by improving yields on existing fields. However, exemplary studies on recultivation of abandoned lands across former Soviet Union countries suggest that recultivation will not be a widespread phenomenon considering the 2017 prices for agricultural commodities in Asian Russia (Meyfroidt et al. 2016; Nefedova 2011; Saraykin et al. 2017; Schierhorn et al. 2014; Swinnen et al. 2017). Moreover, socio-economic constraints, such as the availability and quality of skilled labour, oftentimes inadequate infrastructure (particularly, the lack of tarred roads and modern storage facilities), and the adverse investment climate counterbalance incentives to invest into raising agricultural productivity and recultivation (Meyfroidt et al. 2016; Swinnen et al. 2017). Moreover, the produced crops should meet the market demand, as any further cropland expansion can crush down the current prices; a diversification of crops driven by internal and external market demand and land-use policies can be a solution.

Unfortunately, current agricultural and land-use policies in Russia pay little attention to environmental costs associated with the re-use of abandoned lands (such as the loss of carbon and biodiversity) (Bukvareva et al. 2015). However, abandoned croplands offer rare opportunities to restore part of the fragmented remaining areas of virgin steppes, which were largely converted to croplands during the nineteenth and twentieth centuries in Asian Russia (Kamp 2014; Kamp et al. 2015). Land-use policies of the Russian provinces at present reinforce the utilization of all arable lands, regardless of whether some lands are of high environmental value or are socio-economically marginal. One example is the southern edge of the Western Siberian grain belt in the Altai Krai, where wheat yields vary from 7 to 10 dt/ha and soils were heavily degraded during the Campaign period. Efforts to restore the steppes at the expense of croplands are still considered by many as an invasion of weeds and a loss of tax money, which was a common notion that was repeatedly heard from the local authorities. However, it is clear that steppe restoration may provide ample societal benefits regarding carbon storage, improvements of soil fertility and habitat provision for many bird and mammal species (Bekenov et al. 1998; Kamp et al. 2015). Moreover, alternative options, and in particular extensive livestock rearing, may combine agricultural production with environmental benefits, including the suppression of grassland fires. Such initiatives may also strengthen environmental awareness and benefit tourism.

Asian Russia also has prospective regions with potential land reserves that have not been used before, which are, for instance, in the Tyumen, Krasnoyarsk, Khabarovsk, Amur and Primorje provinces. However, such land reclamation and amelioration programs would require large investments for clearing land from the forest, liming and other amelioration works. High reclamation costs and poor soil quality may reduce expected economic returns in these areas and thus the incentives for reclamation (Tchebakova et al. 2011). However, with improvements in farming technology and higher prices for agricultural commodities, many of these areas may become attractive investment targets for the densely populated countries bordering the Russian Far East, namely Japan, the Koreas, and, last but not least, China (Wegren et al. 2015; Zhou 2017).

Increasing crop productivity may also contribute to the agricultural development in Asian Russia. Higher crop yields can be attained with agronomics measures and better cultivars but also by a strict fulfilment of currently available technologies (Prishchepov et al. 2019). For example, higher input applications will reduce nutrient shortages, and capital investments, such as into no-till machinery, may allow for high yields without compromising soil fertility (Bavorova et al. 2017; Ponkina et al. 2012). In the livestock sector, the shift to intensive feedlot-based production may raise productivity and could be apt for Asian Russia.

At the same time, in some areas, crop yields can be doubled or even tripled, such as in the Far East, where existing wheat yield gaps are 1.5 t/ha for 75% of yield potential based on observations from agrometeorological stations and reported cultivar capacity (Savin et al. 2001; Swinnen et al. 2017). Assuming a wheat yield growth of 1 dt/ha per decade in Asian Russia, a very long period would be required to close the yield gap under the current technologies. However, yield increment may follow a non-linear path, for instance following the example of yield growth in Canada along with 2 dt/ha in 10 years by advancing cultivation practices (Ministry of Agriculture and Agri-Food of Canada 2013). At the same time, a full closure of

75% of yield is not realistic in a short period; with current yield increments, closure would require another 100 years or so.

Some reduction of yield gaps is realistic because much improvement can be achieved by better education of farmers in improving current production practices. Production can arguably be increased further by introducing new, emerging technologies, such as new cultivars, precision farming, and better sowing and harvesting machinery that also reduce post-harvest losses (Prishchepov et al. 2019). To achieve such innovations, substantial investments into research and development will be necessary, which can only be brought about by investments from both private companies and with additional support from governmental authorities by enabling policies, improving extension services, and investing into research.

Productivity gaps can also be substantially reduced in the livestock sector, which contributed 50% to total revenue from agricultural production in Asian Russia in 2011. The beef production relies on the production of fodder crops and the management of grasslands for haymaking and grazing. While there is general agreement about statistics on sown areas and their suitability to track the dynamics of croplands, the actual surface and location of the vast extent of grasslands in Asian Russia are fuzzy due to the definition of what constitutes ‘grassland’ and due to the lack of apt surveying technologies for grassland resources. Official statistics indicate that approximately 35 Mha of grasslands were used for hay cutting and grazing by 1989 in Asian Russia (in European Russia-44.5 Mha) (GKS SSSR 1991). Keeping in mind the drastic decrease of livestock following the demise of the Soviet Union after 1990 (approximately 35% of livestock decline from 1991 to 2013 both in European and in Asian Russia) (Fig. 6.2b), we may assume a decline of grassland use in a similar proportion to the decrease in numbers of grazing livestock (15 Mha of abandoned grasslands in European Russia and 12 Mha in European Russia). However, the more productive grasslands are likely overused, mainly those close to settlements and livestock farms, whereas more remote grassland areas are often still pristine, used only sporadically, or continue to be abandoned. However, livestock productivity also increased over time, and thus potential fodder intake intensity per head of livestock also increased since 1990.

Last but not least, the policies so far paid little attention to the projected adverse impacts of climate change, particularly in Western Siberia, where the increase of temperature is expected to be 2.5 times higher compared to the average numbers around the world (Belyaeva and Bokusheva 2017; Roshydromet 2014). A doctrine on preventive measures to mitigate the negative impacts of climate change has been developed, but the actual mechanisms, such as the development of drought-tolerant crop varieties and promotion of technologies preserving the moisture in soils, are far from adequate development; thus, there is room for improvement.

6.8 Concluding Remarks

We described the historical development of land use in Asian Russia from the twelfth century to 2017. By linking agricultural use to major socio-economic and political developments in Russia, we showed that agricultural land use in Asian Russia was negligible until the mid-nineteenth century but then started to rapidly expand until 1964. Early, yet moderate, cropland expansion was caused by the Great Siberian Migration from European Russia to Asian Russia. Since 1953, major policy interventions until 1988 were paramount in harnessing existing production opportunities, and they helped turn Asian Russia into a major breadbasket. However, agricultural expansion in the course of the controversial Virgin Lands Campaign, which was enacted to relieve food shortages in the Soviet Union, generated half of the expected increase in agricultural production at very high economic and environmental costs per additional unit of production. The Virgin Lands Campaign also contributed to substantive and long-lasting negative environmental impacts, such as topsoil degradation and biodiversity decline; these factors compromised crop productivity, and farmers in the regions have had to bear their legacies up to the present day.

The example of Asian Russia also vividly demonstrated the rapid response of agricultural land use to major sociopolitical disruption, that is, the dissolution of the Soviet Union in 1991. Partly as a result of the ensuing downturn, Russia as a whole, but also Asian Russia, possesses ample opportunities to raise agricultural output by recultivating some of the abandoned croplands and returning in use massively abandoned grasslands, increasing land productivity, and increasing output from the livestock sector both through expansion of grazing land as well productivity improvements. However, several challenges in harnessing these opportunities loom large in the region, particularly in a labour-intensive livestock sector, such as the shrinking and aging population, outmigration of youth, inadequate infrastructure connecting this vast region, negative projections of climate change and environmental challenges like land degradation, which impede the uncovering of these potentials. The environmental consequences of agricultural expansion should also be weighted since the current land-use policy measures do not adequately reflect such impacts.

Acknowledgements We acknowledge funding made available through the BMBF KULUNDA project and ERA.Net Russia Plus Project N.559. The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University. We also acknowledge funds from the Russian Foundation for Basic Research, grant N. 18-45-030039.

References

Afonin AN, Greene AN, Dzyubenko SL, Frolo NI (2008) Interactive agricultural ecological atlas of Russia and neighboring countries. Economic plants and their diseases, pests and weeds

ASK (2003) Republic of Kazakhstan: 50 years since the beginning of virgin lands campaign. Statistical digest 1953–2003 (Respublika Kazahstan: 50-Let Nachala Osvoenija Celinnyh i Zalezhnyh Zemel'. Statisticheskij Sbornik 1953-2003). Almaty

Bartalev SA, Plotnikov DE, Loupian EA (2016) Mapping of arable land in Russia using multi-year time series of MODIS data and the LAGMA classification technique. Remote Sens Lett 7:269–278. https://doi.org/10.1080/2150704X.2015.1130874

Bavorova M, Imamverdiyev N, Ponkina E (2017) Farm-level economics of innovative tillage technologies: the case of no-till in the Altai Krai in Russian Siberia. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-017-9268-y

Bekenov AB, Grachev IA, Milner-Gulland EJ (1998) The ecology and management of the Saiga antelope in Kazakhstan. Mammal Rev 28:1–52. https://doi.org/10.1046/j.1365-2907.1998.281024.x

Belyaeva M, Bokusheva R (2017) Will climate change benefit or hurt Russian grain production? A statistical evidence from a panel approach. Discuss. Pap Inst Agric Dev Transit Econ 161:1–25

Blackwell W (1968) Beginnings of Russian industrialization, 1800-1860. Princeton University, Princeton, NJ

Bukvareva EN, Grunewald K, Bobylev SN, Zamolodchikov DG, Zimenko AV, Bastian O (2015) The current state of knowledge of ecosystems and ecosystem services in Russia: a status report. Ambio 44:491–507. https://doi.org/10.1007/s13280-015-0674-4

Canada A, A-FC of (2013) Wheat sector profile—part one: overview (November 2010) (report)

Chelinstvev AN (1928) Russian agriculture before revolution. (Russkoe selskoe khozjaistvo pered revolutsiei). Novij Agronom, Moscow

de Beurs KM, Ioffe G (2014) Use of Landsat and MODIS data to remotely estimate Russia's sown area. J Land Use Sci 9:377–401. https://doi.org/10.1080/1747423X.2013.798038

Dronin NM, Bellinger EG (2005) Climate dependence and food problems in Russia, 1900–1990: the interaction of climate and agricultural policy and their effect on food problems, NED-New edition, 1. ed. Central European University Press

Dronin N, Kirilenko A (2010) Climate change, food stress, and security in Russia. Reg Environ Change 11:167–178. https://doi.org/10.1007/s10113-010-0165-x

Durgin FAJ (1962) The virgin lands programme 1954-1960. Sov. Stud. 13:255–280

Einaudi G (1964) Khrushchev reported planning to give up Virgin-Land Farms. N. Y. Times 2

Forsyth J (1992) A history of the peoples of Siberia: Russia's north Asian colony, 1581-1990. Cambridge University Press, Cambridge, New York

Gks SSSR (1991) Narodnoye Khozyaistvo SSSR v 1990. Finansi i Statistika, Moscow

Horion S, Prishchepov AV, Verbesselt J, de Beurs K, Tagesson T, Fensholt R (2016) Revealing turning points in ecosystem functioning over the Northern Eurasian agricultural frontier. Glob Change Biol 22:2801–2817. https://doi.org/10.1111/gcb.13267

Ioffe G, Nefedova T (2004) Marginal farmland in European Russia. Eurasian Geogr Econ 45:45–59

Josephson P, Dronin N, Mnatsakanian R, Cherp A, Efremenko D, Larin V (2013) An environmental history of Russia, New edn. Cambridge University Press, Cambridge, New York

Kamp J (2014) Land management: weighing up reuse of Soviet croplands. Nature 505:483. https://doi.org/10.1038/505483d

Kamp J, Oppel S, Ananin AA, Durnev YA, Gashev SN, Hölzel N, Mishchenko AL, Pessa J, Smirenski SM, Strelnikov EG, Timonen S, Wolanska K, Chan S (2015) Global population collapse in a superabundant migratory bird and illegal trapping in China. Conserv Biol n/a-n/a. https://doi.org/10.1111/cobi.12537

Kühling I, Broll G, Trautz D (2016) Spatio-temporal analysis of agricultural land-use intensity across the Western Siberian grain belt. Sci Total Environ 544:271–280. https://doi.org/10.1016/j.scitotenv.2015.11.129

McCauley M (1976) Khrushchev and the development of soviet agriculture. The virgin land programme 1953-1964. Holmes & Meier, New York

Meyfroidt P, Schierhorn F, Prishchepov AV, Müller D, Kuemmerle T (2016) Drivers, constraints and trade-offs associated with recultivating abandoned cropland in Russia, Ukraine and Kazakhstan. Glob Environ Change 37:1–15. https://doi.org/10.1016/j.gloenvcha.2016.01.003

Nefedova TG (2011) Agricultural land in Russia and its dynamics. Reg Res Russ 1:292–295. https://doi.org/10.1134/S2079970511030099

Nguyen H, Hölzel N, Völker A, Kamp J (2018) Patterns and Determinants of Post-Soviet Cropland Abandonment in the Western Siberian Grain Belt. Remote Sens 10(12):1973. https://doi.org/10.3390/rs10121973

Okladnikov AP (1959) Dalekoe proshloe Primor'ja. Vladivostok

Okladnikov AP (1968a) History of Siberia. Siberia as a part of Feudal Russia. Volume II., History of Siberia since early until modern times (In five vlumes). Istorija Sibiri s drevnejshih vremen do nashih dnej (v 5 tomah). Nauka, USSR Academy of Science, Leningrad, USSR

Okladnikov AP (ed) (1968b) History of Siberia since early until modern times (In five vlumes). Istorija Sibiri s drevnejshih vremen do nashih dnej (v 5 tomah). Nauka, USSR Academy of Science, Leningrad, USSR

Okladnikov AP (1968c) Siberia during the period of building the socialism. Volume IV., History of Siberia since early until modern times (In five vlumes). Istorija Sibiri s drevnejshih vremen do nashih dnej (v 5 tomah). Nauka, USSR Academy of Science, Leningrad, USSR

Okladnikov AP (1968d) Siberia during the period of the completion of socialism and transitioning toward communism., History of Siberia since early until modern times (In five vlumes). Istorija Sibiri s drevnejshih vremen do nashih dnej (v 5 tomah). Nauka, USSR Academy of Science, Leningrad, USSR

Parker WH (1969) An historical geography of Russia. Aldine Publishing Company

Pavlova VN, Varcheva SE, Bokusheva R, Calanca P (2014) Modelling the effects of climate variability on spring wheat productivity in the steppe zone of Russia and Kazakhstan. Ecol Model 277:57–67. https://doi.org/10.1016/j.ecolmodel.2014.01.014

Ponkina E, Bavorova M, Prishchepov AV, Kovaleva I (2012) Positive quantitative analysis of farms regarding natural conditions, structure, production program, factor endowment, productivity, economic success and income

Prishchepov AV, Müller D, Dubinin M, Baumann M, Radeloff VC (2013) Determinants of agricultural land abandonment in post-Soviet European Russia. Land Use Policy 30:873–884. https://doi.org/10.1016/j.landusepol.2012.06.011

Prishchepov AV, Petrick M, Müller D, Schierhorn F, Kraemer R, Kurganova I, Kopsidis M (2015) Sixty years of the virgin lands campaign in Russia and Kazakhstan: an assessment from an economic, ecological and political perspective. IAMO Yearb. 2015Leibniz Inst Agric Dev Transit Econ IAMO 39–57

Prishchepov AV, Ponkina E, Sun Z, Müller D (2019) Revealing the determinants of wheat yields in the Siberian breadbasket of Russia with Bayesian networks. Land Use Policy 80:21–31. https://doi.org/10.1016/j.landusepol.2018.09.038

Riasanovsky NV (2000) A history of Russia, 6th edn. Oxford press, New-York, Oxford

Roshydromet (2014) Second Roshydromet assessment report on climate change and its consequences in Russian Federation. General Summary. Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet), Moscow, Russia

Rosstat (2016) Central statistical database

Russian Federation (2016) Federal law "on amendments to certain legislative acts of the Russian Federation in terms of improving the procedure of withdrawal of agricultural plots from agricultural land which are not used for their intended purpose were used with violation of the legislation of the Russian Federation" (O vnesenii izmenenij v otdel'nye zakonodatel'nye akty Rossijskoj Federacii v chasti sovershenstvovanija porjadka iz"jatija zemel'nyh uchastkov iz zemel' sel'skohozjajstvennogo naznachenija pri ih neispol'zovanii po celevomu naznacheniju ili ispol'zovanii s narusheniem zakonodatel'stva Rossijskoj Federacii). Approved Federal Council 29th June 2016. Retrieved from http://publication.pravo.gov.ru/Document/View/0001201607040150?index=0&rangeSize=1

Saraykin V, Yanbykh R, Uzun V (2017) Assessing the potential for Russian grain exports: a special focus on the prospective cultivation of abandoned land. In: Gomez y Paloma S, Mary S, Langrell S, Ciaian P (eds) The Eurasian wheat belt and food security. Springer International Publishing, Cham, pp 155–175. https://doi.org/10.1007/978-3-319-33239-0_10

Savin IY, Stolbovoy V, van Diepen CA (2001) Crop growth simulation model wofost and its application for land productivity analysis in Russia. V.V. Dokuchaev Soil Science Institute, Russian Academy of Agricultural Science

Schierhorn F, Müller D, Prishchepov AV, Faramarzi M, Balmann A (2014) The potential of Russia to increase its wheat production through cropland expansion and intensification. Glob Food Secur 3:133–141. https://doi.org/10.1016/j.gfs.2014.10.007

Schierhorn F, Meyfroidt P, Kastner T, Kuemmerle T, Prishchepov AV, Müller D (2016) The dynamics of beef trade between Brazil and Russia and their environmental implications. Glob Food Secur. https://doi.org/10.1016/j.gfs.2016.08.001

Suleimenov M, Saparov A, Akshalov K, Kaskardaev Z (2012) Land degradation Issues in Kazakhstan and measures to address them: research and adoption. Pedologist: 373–381

Swinnen J, Burkitbayeva S, Schierhorn F, Prishchepov AV, Müller D (2017) Production potential in the "bread baskets" of Eastern Europe and Central Asia. Glob Food Secur. https://doi.org/10.1016/j.gfs.2017.03.005

Tchebakova NM, Parfenova EI, Lysanova GI, Soja AJ (2011) Agroclimatic potential across central Siberia in an altered twenty-first century. Environ Res Lett 6:045207. https://doi.org/10.1088/1748-9326/6/4/045207

Treadgold DW (1957) The great Siberian migration government and peasant in resettlement from emancipation to the First World War. Princeton University Press, Princeton

Wegren SK, Nikulin AM, Trotsuk I (2015) Russia's tilt to Asia and implications for agriculture in the Far East. Eurasian Geogr Econ 56:127–149. https://doi.org/10.1080/15387216.2015.1066263

Wein N (1980) Twenty-five years of new land (Fünfundzwanzig Jahr Neuland). Geogr Rundsch 32:32–38

Wright CK, De Beurs KM, Henebry GM (2012) Combined analysis of land cover change and NDVI trends in the Northern Eurasian grain belt. Front Earth Sci 6:177–187. https://doi.org/10.1007/s11707-012-0327-x

Zhou J (2017) Chinese agrarian capitalism in the Russian Far East. Third World Themat. TWQ J. 0, 1–21. https://doi.org/10.1080/23802014.2016.1327795

Chapter 7
Russian Settlements and the Beginning of Agriculture in Southwestern Siberia Until After World War II

M. Frühauf and M. A. Borisenko

Abstract In this publication, the main stages of settlement and land use development in southwestern Siberia since the eighteenth century are presented with a special focus on the Altai Krai. The Altai Krai was and is an important agrarian region in Russia. During the eighteenth century, Russians founded settlements along the river Ob. Migrating peasants from Russia's European part began to populate the steppe in the nineteenth century. Due to religious freedom and governmental provisions like tax breaks and exemption from military service as well as the rising demand for agricultural products, number of settlements and agricultural land use grew rapidly. In the Altai Krai, a new epoch began in the twentieth century due to the usage of machinery, a developing infrastructure, and the Stolypin agrarian reforms. In the aftermath of World War I, the Bolshevik Revolution, and the subsequent Russian Civil War, the yield of livestock farming and crop production decreased significantly. After the Bolsheviks seized power in 1917, conditions for settlement development and land use changed. Important was the rising number of settlements during the 1920s, the reform of land ownership, and the increasing size of fields.

Keywords Siberia · Agrarian land use development · Historical stages · Settlement · Altai Krai · Stolypin reforms · Bolshevik revolution · Land use change · Political causative factors

M. Frühauf (✉)
Institute of Geosciences and Geography, Martin-Luther-Universität Halle-Wittenberg, Von-Seckendorff-Platz 4, 06120 Halle, Germany
e-mail: manfred.fruehauf@geo.uni-halle.de

M. A. Borisenko (✉)
Faculty of Geography, Altai State University, Prospect Lenina 61, 656049 Barnaul, Russian Federation
e-mail: maxi.borisenko@mail.ru

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_7

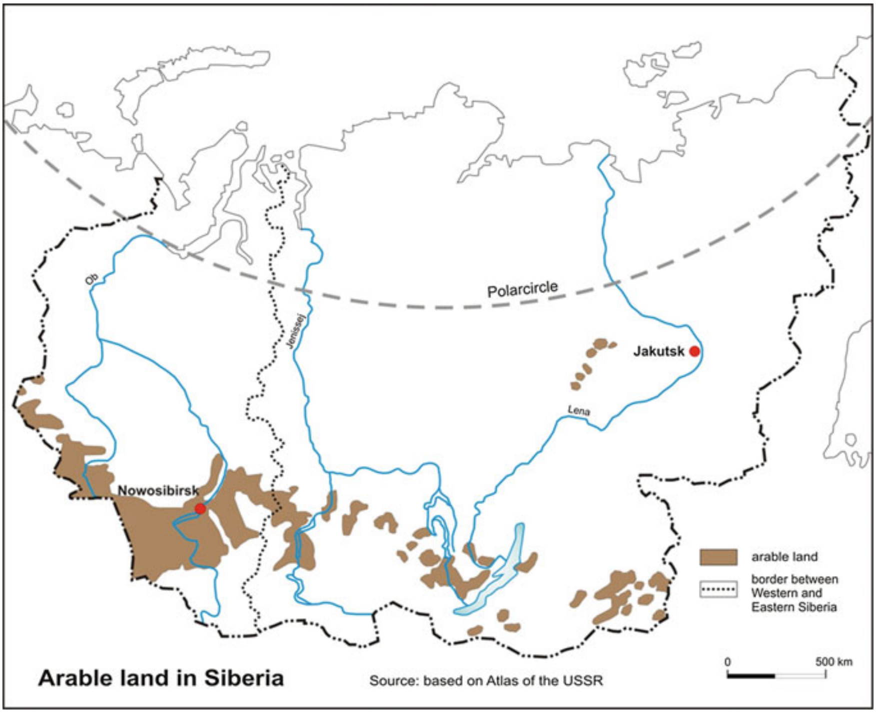


Fig. 7.1 Arable land in Siberia. *Source* Wein (1999), modified

7.1 Siberia's Agrarian Land Resources

Siberia contains an area of 13 million km^2, but only 5% (650,000 km^2) of it is used for agriculture (Halicky and Kulizhsky 2015). Agriculture in Siberia mainly is concentrated on the south of West Siberia lowland in the steppe triangle between Omsk-Novosibirsk and Barnaul as capital of the Altai Krai (Fig. 7.1). This steppe zones (steppe and forest steppe) make up 21% of altogether territory of Western Siberia (Wein 1999). Some 15.1 million inhabitants live in this area (Pleschakova and Drobischev 2002).

With an area of 360,000 km^2, the Southwestern Siberian agricultural triangle constitutes the biggest agrarian region of Siberia. 55% of the land are used for tillage, 25% for pasturage, and 20% are grassland (N.N 2005). This widespread agricultural use of the land stems from its favourable climatic (a normal frost-free period of more than 90 days, Meyer et al. 2008) and soil conditions. Overall, three-quarters of the soils in the area are Chernozems.

The proportion of agricultural production of Western Siberia in the agricultural production of Russia amounts to approximately 11% (N.N 1997). But on the other hand, this cultivated land belongs at the same time to the areas that are intensively prone to and affected by different processes of soil degradation and desertification (Wein 1999; Meyer et al. 2008).

Within the agricultural triangle, the area of the Altai Krai (Fig. 7.2), especially the Kulunda Steppe, is of great importance. Its history is exemplary of the relationship between land usage and settlement development. Currently, the Altai Krai is the second most important grain-producing region in Russia behind the Orenburg region.

As shown in Fig. 7.2, the administrative district of Altai Krai (population: 2.4 million, capital: Barnaul) is situated in the Russian foreland of the Altai Mountains with an area of approximately 169,000 km^2. Most of this area (100,000 km^2) forms the north-eastern corner of the Kazakh Steppe which is part of the Eurasian Steppe.

The history of the agrarian land development in Siberia—especially in southwestern Siberia—is very different in comparison with Russia's European area. Siberia's agrarian development was much more driven by the social upheavals and political decisions in Russian and Soviet history (Okladinov 1968; Nikonov and Schulze 2004). Differences are observable in the extent to which agriculture was used, its overall productivity, and its significance for the region's development. Due to these differences, a stark contrast has emerged between the agrarian regions west of the

Fig. 7.2 The Altai Krai and the ecoregions of the Kulunda Steppe. *Source* Illiger et al. (2014), modified

Urals and the agricultural areas in Siberia in terms of the types of intensive development the regions underwent and when these occurred. These unique histories resulted in diverging socio-economic and ecological impacts on each respective region.

7.2 The Development of Population, Settlements, and Land Use Until the Bolshevik Revolution

The first Russian settlements were located either close to fortresses or along the river Ob in today's Altai Krai. At the beginning of the eighteenth century, Russian settlements were founded in the Altai region in proximity to a chain of fortresses along the border of the Russian Empire constructed by Siberian Cossacks. Almost all settlements along the Ob were situated on the eastern shore to be more protected from attacks by nomads (Anashkin 1995). In the first half of the eighteenth century, 206 settlements were founded, and in the subsequent half, another 348 new settlements were reported. Only some areas in the west and southeast of the Altai were not populated by the end of the eighteenth century (Koldakov 2011).

Peasants from Russia's European part arrived in the fertile forest steppe and steppe in the late eighteenth and early nineteenth century. The promise of freedom of religion made by Tsarina Katharina II attracted German Mennonites to settle in the region as well. In the wake of the arrival of the new settlers, the steppe region was seized from the Khans of the Turks by the Russian Empire.

The migration of peasants followed the 'Siberian Trek' along the northern border of the steppe of the Altai region (Stadelbauer 1986). In Russia's European part, peasants were bound to their landowner as serfs until 1861, but in Siberia, the system of serfdom did not exist in this form. Therefore, in the second part of the nineteenth century, many peasants chose to settle in Siberia. The demand for agricultural products increased and more farms had to cultivate land (Moon 2013). As early as 1843, the Russian government promoted the eastward expansion by giving 38 ha plots to each new settler. Because of the religious freedom but also due to further government provisions like tax breaks and exemption from military service (Nikonov and Schulze 2004), land cultivation was expedited and later got another push by the land acquisition ruling of 1865 (Vinokurov and Suchodolov 1996). About 350,000 peasants migrated within the next years, and Siberia's population and settlements grew rapidly. By 1897, 5.75 million people lived in Siberia with 90% of the population coming from Russia's European part (Wein 1999).

In the Russian Altai Mountains and their foreland, the population increased from 432,000 to 1.3 million between 1862 and 1897 (Jakutin 2005). A multitude of new settlements was founded in the second half of the nineteenth century.

Due to this influx of peasants, the Altai region became one of the main agricultural producers of Siberia (Nikulina 2015) (Fig. 7.3).

The agricultural productivity in Siberia became much more efficient in the second half of the nineteenth century. The annual grain production in western Siberia

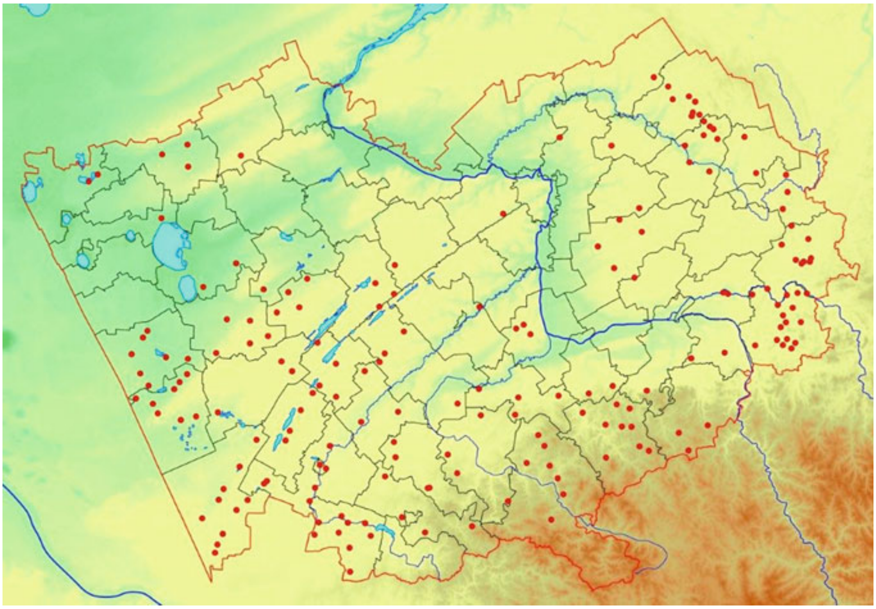


Fig. 7.3 Settlements founded in the Altai Krai between 1850 and 1899 *Source* Bulygin (2000)

rose from 1.4 million t to more than 7 million t between 1850 and 1900 (Naumov 2006; Łukawski 1981) due to the development of a proper land management system: Although no fertilizers were used in this period, two methods were applied to maintain soil fertility. First, the traditional crop rotation system continued to be used and second, they also began rotating used land (Lipinskaya 1998). After a couple of seasons, a field was left fallow and another piece of land was used. The application of this system was feasible because of the vast amount of land available in Siberia at that time. The rapid development of agriculture resulted in a production surplus at the end of the nineteenth century, and part of the surplus, mainly grains, was sent to Russia's European part (Halicki and Kulizhsky 2015).

But the agrarian development in these landscapes also caused ecological problems with significant socio-economic impact. The first huge, historically known disasters in Russia caused by desertification and land degradation occurred in 1891 and at the beginning of the twentieth century (Bragina 2003). Thirty million people were affected in Russia and South Siberia by catastrophic droughts (Timirjazev 1941, 1948).

At the turn of the twentieth century, a new epoch began in the Altai Krai. Usage of machinery started to replace manual labour and transport shifted from waterways to railways. The construction of the Trans-Siberian Railway as well as the Stolypin agrarian reforms (1906) pushed the settlement and agrarian development of Siberia even further (Voronov 2003). By 1908, the number of migrants was 17 times higher than three years earlier. 37,000 new settlers had arrived in the Altai region in 1905.

By 1908, this number had grown to 650,000. More settlements were founded, and land cultivation intensified even more during the Stolypin agrarian reforms between 1906 and 1914. The reforms made it easier for peasants to acquire and own land individually (Voronov 2003). During the Stolypin reforms, 250,000 peasants from Russia's European part took their chance each year and arrived in the Altai region (Anashkin 1995).

By then, agricultural land was managed by village communities. Siberia's agricultural production could keep up with the growing food demand of its population (Moon 2013). From 1897 to 1914, Siberian population increased by 73% to 2.6 million people (Anashkin 1995), and the land under cultivation doubled (Voronov 2003).

In 1912, more than 800,000 new settlers had arrived in southwestern Siberia, especially in the Altai region, as illustrated in Fig. 7.4.

The map in Fig. 7.4 from the beginning of the twentieth century shows that the area in the Altai foreland was one of the most densely populated regions in southwestern Siberia. Within seven years between 1906 and 1913, about 600 new settlements were founded. The Kulunda Steppe is of importance within the Altai foreland because, due to the massive migration, a multi-ethnic population of Russians, Ukrainians,

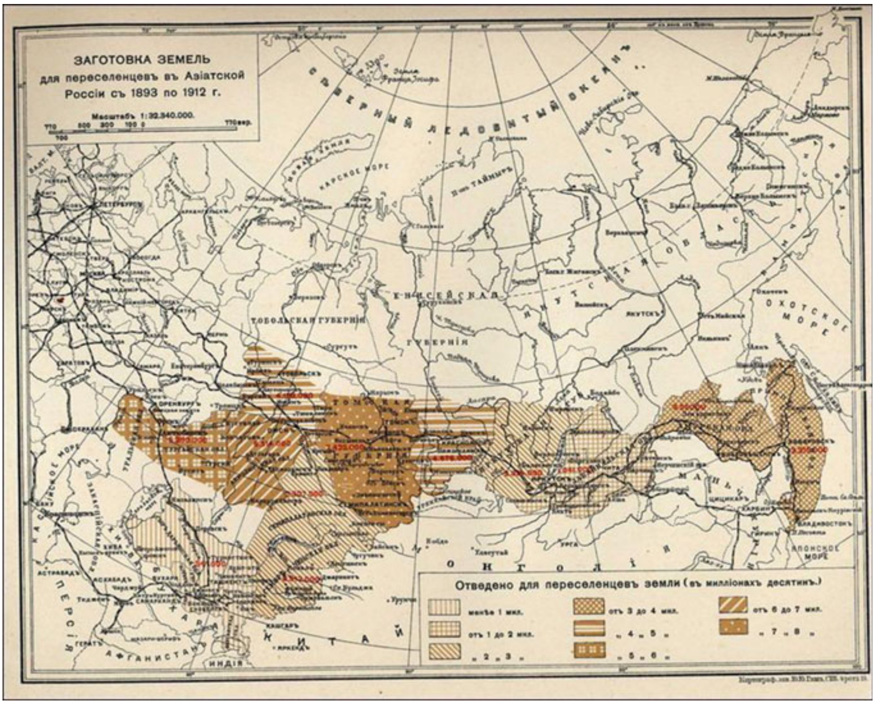


Fig. 7.4 Placement of immigrants in the Asian part of Russia from 1893 to 1912. *Source* Archive Altai State University

Germans, and Kazakhs lived here (N.N. 2007). In 1908, immigrants from Central Russia founded the town Slavgorod which quickly became a centre of production and trade. About 400 villages existed within the 40–50 km vicinity of Slavgorod (Nikulina 2015). During the Stolypin reforms, Germans were resettled, and thus, their population totalled about 17,000 between 1907 and 1914 in 124 settlements scattered throughout the Slavgorod district.

At the start of the twentieth century, 53% of the population of the Kulunda Steppe were German, 36% were Ukrainian, and 9% were Russian (Matis 2008). After the Revolution in 1917, most of Siberia's Germans lived in the Altai foreland. 36,000 Germans lived in what is now the Altai Krai with 32,000 living in the former Slavgorod district which now consists of the districts Blagoveshchensk, Burlinsky, Kulundinsky, German, and Slavgorod (Matis 2008).

By the time of the First World War, most of the area's arable land was in use. Cattle breeding—both by Russians and by natives—was another important part of agriculture (Forsyth 1994).

As illustrated in Fig. 7.5, most of the settlements were founded in the northwestern and central parts of the Altai region—the fertile steppe areas. The northwest became the preferred area for Germans to settle and was one of the most populated areas in southwestern Siberia (Fig. 7.5).

By 1910, about 323,000 km^2 of farmland were in use for food production in Siberia, resulting in an annual million-ton surplus of wheat (Lincoln 1994). Com-

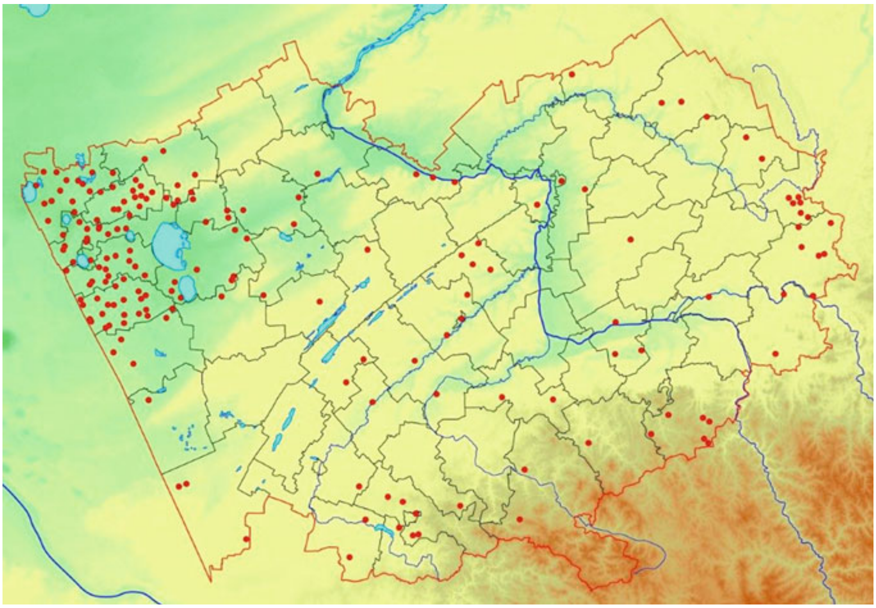


Fig. 7.5 Settlements founded between 1900 and 1918 in the Altai Krai *Source* Bulygin (2000)

pared with other areas of Russia, Siberia's agriculture was quite technologically advanced around the turn of the century.

With the new settlements and conversion of steppe to agricultural land, agrarian production grew steadily. By 1913, 30.4% of globally traded grain came from Russia making the Russian Empire the top global grain exporter. In Siberia, arable fields and pastures were larger and farming equipment was better than in Russia's European part. In 1911, while their European Russian counterparts were still threshing their grain by hand, Siberian peasants had an impressive collection of 37,000 mowing machines and 39,000 horse-drawn rakes (Lincoln 1994).

The livestock was also different in Siberia (as shown by Wein 1999; based on research of Vinokurov and Suchodolov 1996). A comparison between the Siberian governorate Tomsk and central Russia showed the amount of horses, cattle, and hogs per capita was three times higher in Siberia. The livestock of the Siberian peasants was high even in international comparison. In Germany, the average stock of horses was 7 per 100 persons, in the USA it was 25 per 100 persons, and in Canada 41 per 100 persons, but in Siberia the stock was 56 horses per 100 persons.

The meat, milk, and butter production were also quite efficient in comparison with other parts of Russia during this time. Russia became the second biggest butter global exporter (behind Denmark) in 1913. It earned twice as much by exporting butter than by exporting gold (Wein 1999). Because of its efficient farming, Siberia became an agricultural surplus area at that time.

The heyday of Russian agriculture ended with World War I, especially with the Bolshevik Revolution (1917) and its aftermath (Stadelbauer 1986; Nikonov and Schulze 2004).

7.3 From the Bolshevik Revolution to the Stalin and Khrushchev Era

In the aftermath of World War I, the Bolshevik Revolution, and the subsequent Russian Civil War, the yield of livestock farming and crop production decreased significantly. Crop production fell by as much as 61% between 1917 and 1922 (Goryushkin 1966). The butter production in 1921 was merely 3% of butter production in 1913 (Wein 1999).

After the Decree of Land was passed by the Bolsheviks in October 1917, land proprietorship was abolished. The land estates with their land, livestock, and farming equipment were confiscated, and the land was distributed to the peasants who cultivated it. But the productivity of the resulting small farms was very low. Forced grain requisition plus crop failure resulted in the Great Russian Famine of 1921/1922 claiming millions of lives. The area used for grain production was reduced by one-third between 1913 and 1921, and the overall agricultural output sank to one-third of the pre-war level (Hughes 2003; Łukawski 1981).

In 1922, Lenin proposed the New Economic Policy (NEP). Under the NEP between 1922 and 1928, private property was allowed again on a small scale to stimulate the country's economy (Goryushkin 1966). The forced grain requisition was replaced by a tax and peasants could privately sell their surplus. Thus, the food situation stabilized. By the end of the 1920s, the Soviet Union's grain production was 100% higher and meat production was 175% higher than in 1921 (Nikonov and Schulze 2004). In this time, three-quarters of all cultivated land were owned by medium-size farms. They generated 80% of Siberia's agrarian products. The remaining land was owned by small and large farms, and the first farming cooperatives were established during this time. In comparison with 1913, the Soviet Union's area of crop farming had increased by 12% and cattle farming by 14% (Okladnikov 1968).

In the Altai Krai, 25,000 km^2 were used for agriculture at the beginning of the Bolshevik Revolution. Here, too, the area of cultivated land was expanded during the 1920s to a total of 37,000 km^2 by 1940 (Jakutin 2005).

More than 5000, mostly smaller settlements existed in the Altai Krai during the 1920s. But due to new political conditions, the boom in building settlements was over and the construction business declined with businesses like wood mills and woodcarvers closing their doors (Kazancev 2004). Under the new political regime, emphasis was mainly placed on congregating in larger settlements. Thus, the Altai Krai remained a predominantly agrarian region until the end of the 1920s when the number of settlements began to decline.

Looking back on the beginning of Soviet rule with the achieved NEP's goal of improving the economic situation, the following must be concluded.

Lenin's successor Stalin disagreed with the NEP and saw it as a contradiction to the ideology of socialism (Hughes 2003). The NEP was abolished in 1928, and collectivization was enforced. Its process was finished in 1937 when over 90% of the farms were incorporated into kolkhozes (collective farms) or sovkhozes (state farms). North America's well-equipped large-scale farms were a model for the new collective and state-owned large-scale farms of the Soviet Union. Stalin's goal was food security, but lower yields due to the collectivization and mismanagement combined with unfavourable natural conditions resulted in the Great Soviet Famine of 1932/33 with millions of deaths (Tauger 2001). Another goal of the collectivization was a more efficient agricultural system to free-up workers for the industrialization of the country. At the time, about 80% of the population still worked in agriculture.

The Altai Krai benefited from the construction of the Turkestano-Sibirsky Railroad in the late 1920s and became one of the largest agrarian-industrial regions of Siberia by the end of the 1930s (Istoriia Altaiskogo kraia).

Between 1939 and 1941, an extensive soil survey was conducted over an area of more than 1,000,000 km^2 throughout the whole Soviet Union. The goal of the survey was to identify areas suitable for further agrarian land development (Josephson et al. 2013). The realization of this mainly politically motivated idea of new land development in western Siberia was interrupted by World War II and its aftermath.

During World War II, complete segments of factories were relocated from the western regions of the Soviet Union, and more than 100 factory segments were moved to the Altai Krai. The war changed the economic structure of the region by enforcing industrial development and establishing new settlements like the mining town Gornyak in 1942 or Yarovove for chemical industry in 1943.

The area of cultivated land was greatly reduced after the end of World War II in the Soviet Union. By the end of the 1940s, an area of only 28,000 km^2 was still in use for agricultural production in the Altai region (Bykov et al. 2014). The implementation of a programme for food security resulted in the expansion of cultivated land, and by 1954, the agrarian area was the same size or even larger than before World War II. In the Altai region, the area of the cultivated land was about 45,000 km^2 and exceeded its pre-war size (Jakutin 2005; Paramonov et al. 1997). However, the goal of food security for the Russia's population could not be met.

7.4 Conclusion

Throughout its 300-year history, the Altai region's land development by Russians went through different stages. At the beginning of the eighteenth century, Russian settlements were founded in the Altai region in proximity to a chain of fortresses along the border of the Russian Empire. In the nineteenth century, founding new settlements was promoted by agricultural industry and trade. Besides the growing mining industry and its importance in the eighteenth century due to the Great Northern War, the agriculture became the basis of the Altai region's economy at the turn of the twentieth century. The massive inflow of peasant accelerated the development of settlements. The evolving infrastructure, like the Altai Railway, and the Stolypin land reforms contributed to the economic upturn of the region. The multi-ethnic population of the Altai region consisted of Russians, Ukrainians, Germans, and Kazakhs.

World War II and its aftermath had a wide influence on the economic structure. About 100 factories moved to the Altai Krai and enforced the industrial development, which had an impact on the cultivated area in this region. A programme for food security was necessary to expand the agrarian area.

During the Soviet period, the settlement network developed in stages. During the 1920s, the number of rural settlements peaked in the Altai Krai. The settlement network did not change much between 1930s and the 1950s during Stalin's regime. What changed was the administration of settlements, kolkhozes, and sovkhozes, and the economic conditions for the people living and working there which was caused by Stalin's oppressive ruling.

References

Anashkin AP (1995) Istoriia Altaia. Chast' I: Uchebnoe posobie [History of the Altai. Part I: textbook]. Barnaul: Izd-vo Alt. un-ta, p 480. (in Russian)

Bragina T (2003) 17 iiunia- Vsemirnii den' borbi s opustinivaniem [June 17—World day of combating desertification]. Ekosvodka, Nr. 285. http://www.seu.ru/svodka/285.htm. Accessed 17 June 2003. (in Russian)

Bulygin, Ju.S. (2000) Spisok naselennykh punktov Altaiskogo kraia: Spravochnik [List of settlements in the Altai Krai: Directory]. Barnaul, 237 p. (in Russian)

Burke M (2012) Russia's Periphery. Virgin Lands. http://russiasperiphery.blogs.wm.edu/centralasia/general/virgin-lands/. Accessed 18 December 2016

Bykov NI, Yeryomin AA, Borisenko MA (2014) Demographic transformation of municipal districts and settlements of Altai Krai in the Post-soviet period. In Madry C (ed) The social transformation of the cities and regions in the post-communist countries. Bogucki Wydawnictwo Naukowe, Poznan, pp 23–33

Čechov AP (1985) Iz Sibiri [From Siberia]. Irkutsk. (in Russian)

Forsyth J (1994) A history of the peoples of Siberia: Russia's North Asian Colony, 1581–1990. Cambridge University Press, Cambridge, p 186

Goryushkin LM (1966) Sel'skoe khoziaistvo Sibiri v vosstanovitel'nyi period (1921–1925). [Agriculture of Siberia in the period of construction of socialism]. In: Ragi S (ed) Sibir' i period stroitel'stva sotsializma. Nauka, Novosibirsk, p 48

Halicki W, Kulizhsky SP (2015) Changes in arable land use in Siberia in the 20th century and their effect on soil degradation. Int J Environ Stud 72(3):456–473

Hughes J (2003) Stalin, Siberia and the crisis of the new economic policy. Soviet and East European studies Series. Cambridge University Press, Cambridge, p 81

Illiger P, Frühauf M, Schmidt G, Meinel T, Belyaew V, Silanteva M, Kasarjyan M (2014) Ökosystemkonversion und ihre Folgen bezüglich der Kohlenstoffsenken-Funktion in der westsibirischen Kulundasteppe [Ecosystem conversion and its consequences for the carbon sink function in the West Siberian Kulunda steppe]. In: Grunewald K, Bastian O, Drozdow A, Grabovsky V (eds), Erfassung und Bewertung von Ökosystemdienstleistungen (ÖSD) – Erfahrungen, insbesondere aus Deutschland und Russland. BfN-Skripten 373, Bonn, pp 300–319. (in German)

Jakutin NB (2005) Erschließungsetappen und aktuelle Probleme der Neulandregion. In: 50 Jahre Neulanderschließung. Vestnik of Altai University at Bernaul. Nr. 1 (13) 2004, pp 38–48. (in Russian)

Josephson P, Dronin N, Mnatsakanian R, Cherp A, Efremenko D, Larin V (2013) An environmental history of Russia. Cambridge University Press, Cambridge

Kazancev VI (2004) K istorii rasseleniia krest'ian na territorii Altaiskogo kraia [On the history of the resettlement of peasants in the Altai Krai] // Nauchnye chtenija pamjati Ju.S. Bulygina: Sbornik nauchnyh statej / pod red. Ju.M. Goncharova. Barnaul, 124 p. (in Russian)

Koldakov DV (2011) Geoinformacionnye tehnologii v izuchenii zaselenija territorii Altaja v XVIII v. [Geoinformation technologies in the study of the settlement of the Altai territory in the 18th c.] // Aktual'nye voprosy istorii Sibiri. Vos'mye nauchnye chtenija pamjati professora A.P. Borodavkina: materialy konferencii / pod red. V.A. Skubnevskogo, K.A. Pozharskoj. Izd-vo Alt. un-ta, Barnaul, 242 s. (in Russian)

Lincoln BW (1994) The conquest of a continent, Siberia and the Russians. Cornell University Press, Ithaca, p 261

Lipinskaya WA (1998) Traditsionnoe sel'skooe khoziastvo russkikh krest'ian v Sibirii na dal'nem vostoke [Traditional farming of Russian peasants in Siberia in the far east]. In: Traditsionnyi opyt prorodopol'zovaniia v Rossii [Traditional experience of the use of nature in Russia]. Nauka. (in Russian)

Łukawski Z (1981) Historia Syberii [History of Siberia]. Ossolineum, Wroclaw, p 174. (in Polish)

Matis VI (2008) Nemcy Altaia (spravochno-bibliograficheskii sbornik) [The Germans of Altai (reference bibliography)]. Barnaul. p 362 (in Russian)

Meyer BC, Schreiner V, Smolentseva EN, Smolentsev BA (2008) Indicators of desertification in the Kulunda Steppe in the south of Western Siberia. Arch Agron Soil Sci 54(6):585–603

Moon D (2013) The plough that broke the steppes. Agriculture and environment on Russia's Grasslands, 1700–1914. Oxford University Press, Oxford

Naumov IV (author), Collins DN (ed) (2006) The history of Siberia. Routledge, Norfolk, p 137
Nikonov AA, Schulze E (2004) Drei Jahrhunderte Agrarwissenschaft in Russland: Von 1700 bis zur Gegenwart [Three centuries of agricultural science in Russia: from 1700 to the present]. IAMO, vol 27. (in German)
Nikulina IN (2015) Istoriia Altaia: personalii, terminy, khronologiia: uchebnoe posobie. Chast' I [History of Altai: personalities, terms, chronology: textbook. Part I]. In: Nikulina IN, Zhiljakov DV, Kungurova EV. Izd-vo AltGTU, Barnaul, 83 s. (in Russian)
N.N. (1997) Okhrana Okruzhayushchey Sredy v Rossiyskoy Federatsii v 1996 godu [Environmental protection in the Russian Federation in 1996]. Goskomstat Rossii, Statisticheskiy Sbornik, Moscow. (in Russian)
N.N. (2005) Stepi Evrazii: Sokhranenie prirodnogo raznoobrfaziia i monitorino sostoianiia ekosistem (Steppe of Eurasia: preservation of biodiversity and monitoring of the ecosystems). The Steppe Institute Press, Orenburg. 168 pp. (in Russian)
N.N. (2007) Kulundinskii rajon: stranicy istorii i sovremennost' [Kulunda region: pages of history and modernity]. Part I. Barnaul: OOO «Azbuka», 461 p. (in Russian)
Official website of the Government of Altai Krai (2016) Istorija Altajskogo kraja. Oficial'nyj sajt Altajskogo kraja: sajt. http://altairegion22.ru/territory/history/. Accessed 11 November 2016. (in Russian)
Okladnikov AP (1968) Istoriia Sibiri s drevneishikh vremen do nashikh dnei, 4 [History of Siberia from ancient times to the present day], Nauka Yay, Leningrad, pp 181, 183–184, 189. (in Russian)
Paramonov EG, Ishutin JN, Simonenko AP (1997) Kulundinskaia Step': Problemy opustynivaniia [Kulunda steppe: problems of desertification]. Altai-University, Barnaul (in Russian)
Pleschakova MV, Drobischev DS (2002) Regionalistika. Utschebnoe posobie [Regional studies]. Moscow. p 24
Stadelbauer J (1986) Die Erschließung Sibiriens: räumliche Gefügemuster eines historischen Prozesses [The opening of Siberia: spatial structural patterns of a historical process]. In: Leptin G (ed) Sibirien: ein russisches und sowjetisches Entwicklungsproblem. Berlin-Verlag Spitz, Berlin, pp 11–33 (in German)
Tauger MB (2001) Natural disaster and human actions in the Soviet Famine of 1931–1933. Carl Beck Papers Russ East Eur Stud 1506:1–65
Timirjazev K (1941) Zemledelie i fisiologiia rastenii [Farming and plant science]. Sel'khozgis, Moscow, p 450. (in Russian)
Timirjazev K (1948) Bor'ba rastenii s zasukhoi [Fighting plants with drought]. Izbran, Moscow. Cotsch, part 2. (in Russian)
Vinokurov MA, Suchodolov (1996) Sibir' v pervoi chetverti XX veka [Siberia in the first quarter of the 20th century]. Verlag, Irtutsk. (in Russian)
Voronov I (2003) Stolypin i russkaia Sibir' [Stolypin and Russian Siberia]. Ekonomika i zhizn' - Sibir', 189 pp. (in Russian)
Wein N (1999) Sibirien [Siberia]. Perthes Regionalprofile. Gotha, Stuttgart: Klett-Cotta. (in German)

Chapter 8
The Virgin Lands Campaign (1954–1963) Until the Breakdown of the Former Soviet Union (FSU): With Special Focus on Western Siberia

M. Frühauf, T. Meinel and G. Schmidt

Abstract The goal of the Virgin Lands Campaign under the leadership of Nikita Khrushchev was an increase in the agricultural production rate to alleviate food shortage in the Soviet Union after World War II. The campaign was targeted at converting the vast steppe, mainly in northern Kazakhstan and the Altai Region, into arable land for grain production. During the 10 years of the Virgin Lands Campaign, 420,000-km^2 steppe were transformed. The largest area was converted in the Kazakh part of the former Soviet Union. This was globally the largest ecosystem conversion of the temperate grassland in the twentieth century, and it had an important demographic dimension as well, which is reflected in the influx of population. The re-settlers found their home in new settlements, which were also the centres of newly established agricultural businesses. The campaign's economic success turned out to be very depended on weather conditions—especially on precipitation. The annual crop yield was extremely variable, and the political goals of the campaign were unattainable. At the same time, increasing soil degradation affected the agricultural land use. After Khrushchev's fall, the new party leaders enforced new land management methods, which addressed the ecological problems, and slowly, yield stability was achieved.

Keywords Virgin land campaigne · Former Soviet Union · Designated Areas · Economuic effects · Altai Krai · Type and Intensity of Land Use · Soil Degradation

8.1 History, Political Motivation, and Realization

The idea of a large-scale expansion of cultivated land in the Soviet Union was revived after the end of World War II with its disastrous results for Soviet agriculture and the

M. Frühauf (✉) · G. Schmidt
Institute of Geosciences and Geography, Martin-Luther-Universität Halle-Wittenberg, Von-Seckendorff-Platz 4, 06120 Halle, Germany
e-mail: manfred.fruehauf@geo.uni-halle.de

T. Meinel
AMAZONEN-WERKE H. Dreyer GmbH & Co. KG, Am Amazonenwerk 9-13, 49205 Hasbergen-Gaste, Germany

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_8

country's food situation. By the end of the 1940s, grain production was only about one-third to half of the pre-war level (Durgin 1962). Even in 1953, the output of 29.8 million t of grain was still below the 1940s' output of 35.6 million t (Josephson et al. 2013). Furthermore, the so-called corn campaign that had been initiated to improve the meat and milk production resulted in a substantial reduction of the area used for grain production in the traditional southern Russian Chernozem region (Eule 1962; Wein 1983). Thus, the Soviet Union became increasingly dependent on grain imports from North and South America. Importing grains was very expensive because the Soviet Union had to pay in foreign exchange. This expense, in addition to the new challenges of the beginning Cold War, put the country's economy under considerable stress.

At first, political decision-makers considered the possibility of an intensification of the grain production in the existing areas. But the industry, still weakened by World War II, did not have the capacity to produce the required amount of mineral fertilizer (Georgiev 1955).

Khrushchev, who was from the Ukrainian agrarian region of the Soviet Union, took over as leader of the Communist Party of the Soviet Union after Stalin's death. He became the leading advocate of the idea of expanding cultivated land which was already part of Stalin's 'Great Plan for the Transformation of Nature'. Khrushchev successfully pushed for a resolution to increase grain production by an agrarian development of new, uncultivated land (in Russian: tselinnye zemli) and previously cultivated land lying idle (tselinnye i zalezhnye) even against criticism from fellow party members (Malenkov) and scientists (McCauley 1976, as cited in Wein 1983). The reclamation of the virgin lands (in Russian: oswoenie tselinnych zemel') began almost immediately in south-western Siberia with a lot of publicity through political propaganda two months after the resolution was adopted (Fig. 8.1).

The Virgin Lands Campaign required tremendous economic efforts because of the insufficient infrastructure in the designated steppe areas. Overall, the Soviet government invested 44 billion roubles, which was 20% of the national budget, in land reclamation between 1954 and 1960 (Durgin 1962).

A great number of people followed the urging of the Komsomol (the youth division of Communist Party) and the prospect of higher wages and moved to the agrarian regions. The number of the re-settlers varies in the literature between 800,000 and 3 million (Wein 1983 and other sources).

At the same time, 500 new socialist large-scale farms (kolkhozes and sovkhozes) and a multitude of new settlements including social infrastructure like hospitals and school were founded in Kazakhstan alone. The most prominent example is the current capital of Kazakhstan. In 1961, the Kazakh city of Akmolinsk was renamed Tselinograd, literally meaning 'Virgin Lands City' which marked the city's role as the centre of the Virgin Lands Campaign. After Kazakhstan's independence from Russia, the city reverted to the name Akmolinsk but only for a short time. Today the capital's name is Astana.

During Khrushchev's rule, some efforts were made not only regarding coming to terms with the Stalin era but also regarding improvements in livelihoods for ordinary citizens working on collective and state-owned farms (Nikonov and Schulze 2004).

Improvements were made regarding economic and social conditions of the peasants. For the first time, the kolkhozes' peasants received a fixed salary and could get an ID card—now they could travel freely at least within the Soviet Union.

8.2 Designated Areas of the Virgin Lands Campaign and Its Economic Effects

Mainly unused steppe and steppe previously used only for pasturing were cultivated during the Virgin Lands Campaign. But some fields lying idle were reclaimed too. These fields were usually located in the proximity of settlements and had been abandoned because of Stalin's enforced collectivization of agriculture and mismanagement before World War II. Within the first year of the Virgin Lands Campaign, 110,000 km^2 had already been cultivated. 50,000 km^2 was converted into arable land just in the Kazakh Soviet Socialist Republic (Fig. 8.2).

The high yields of the newly cultivated land (see Fig. 8.3) were motivation enough for the party's leaders to expand the land reclamation to an area of 300,000 km^2 in 1955 (but only 200,000 km^2 was sown—Durgin 1962).

The goal of the original plan was a land conversion of 130,000 km^2 (McCauley 1976), but due to political demands the land reclamation was expanded further and

Fig. 8.1 Call for the Virgin lands campaign (in Russian: *Osvoenie tseliny*). *Source* N.N. (2017a)—Access: http://t3.gstatic.com/images?q=tbn:ANd9GcT83Th5mJweG2e3xSlb8ged18sClMobS34JZ0p6-brRqWAALRbLO13t.

Fig. 8.2 Crawler tractors converting the grassland. *Source* N.N. (2017b)—Access: http://kazakhsteppe.com/uploads/Threads/zelina_small.jpg.

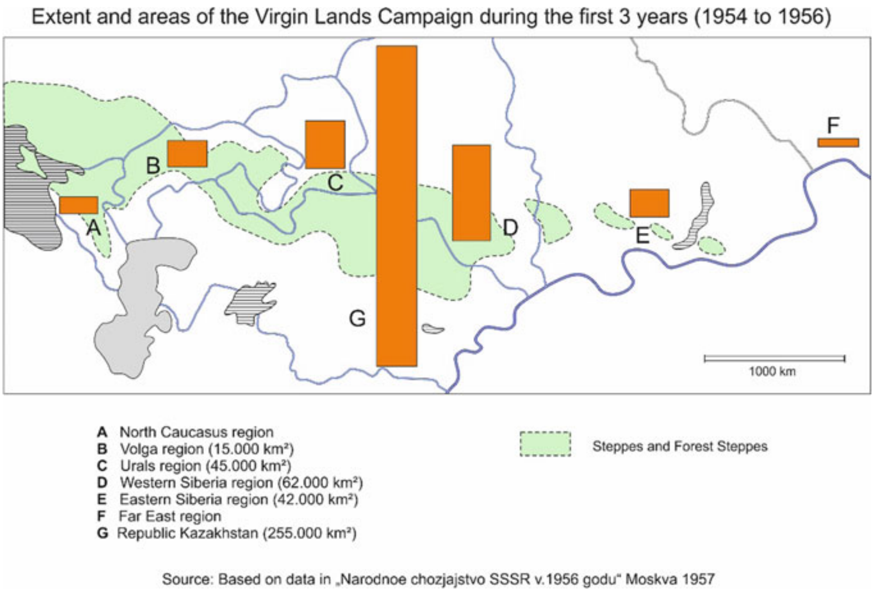


Fig. 8.3 Extent and areas of the Virgin Lands Campaign. *Source* modified according to Narodnoe khoziaistvo SSSR (1957), cited in Meinel (2002)

further (Prishchepov et al. 2015). Soon, land conversion areas could be found everywhere in Russia's steppe (Fig. 8.3).

The largest area with a total of 255,000 km^2 was converted in the Kazakh Steppe located in the north of Kazakhstan (ASK 2003; Kraemer et al. 2015). Furthermore, 62,000 km^2 was transformed into arable land in south-western Siberia, 42,000 km^2 in eastern Siberia, and 45,000 km^2 in the area south of the Urals (Durgin 1962; McCauley 1976; Rostankowski 1979; Wein 1983, 1999; Stadelbauer 1987). By the end of the Virgin Lands Campaign, a large area of 418,000 km^2 had been converted—an all-time-record size totalling the areas of Germany plus Austria—unmatched worldwide! The converted land was mainly located south of and connected to existing agrarian areas. Furthermore, land between smaller, island-like existing agrarian areas was cultivated to connect them and to create larger areas of arable land. This type of land expansion was applied in the typical steppe regions with Chernozems limited in depth (Ah horizon depth between 3 and 4 dm), or in more arid steppe regions with Kastanozems as dominant soil (Meinel 2002).

The land reclamation affected more and more areas of an increasingly continental and arid climate with an average annual precipitation of less than 300 mm (Hahn 1964), and in some regions even less than 250 mm (Fig. 8.4). These agrarian regions struggled with higher evapotranspiration, higher variability of precipitation, higher likelihood of early or late frost, droughts, and wind erosion which affected the length of the growing season and resulted in a higher yield variability, sometimes even complete crop losses (Meinel 2002; Rostankowski 1979). Regions of this climate in the Great Plains in the USA are classified as extremely vulnerable for droughts and are only seldom used for crop production (Späth 1980). The weather conditions were very favourable during the first year of the Virgin Lands Campaign resulting in a high crop yield which was in accordance with the targets of the political plan. At times, the output of the newly converted regions was up to 40% of the overall grain yield in the Soviet Union. But, at least in the beginning, the infrastructure was so limited that most of the unexpected high yield had to be left to rot on the fields because it could not be processed (Durgin 1962; Eule 1962; McCauley 1976).

Soon after the early enthusiasm, a sobering drought followed. Although the converted area had almost doubled in Kazakhstan in 1955, the yield was 38% lower than the year before. In Kazakhstan, the targets of the economic plan could not be met that year because the new land was only partially sown (35%) and yields were regionally quite low with only 1.5–2.5 dt ha^{-1} (Durgin 1962; McCauley 1976).

This disaster was followed by a bumper crop year in 1956 and its success seemed to justify the risks taken in the Virgin Lands Campaign. The Soviet Union produced about 125 million t of grain in that year. But by 1957, drought had struck again to everyone's disappointment. The yield of virgin lands was reduced by 40% and was even less than 50% in Kazakhstan. Although the grain output of 1961 was high, Khrushchev ordered the ploughing of fallowed land and land which had been devoted to grass (McCauley 1976). The weather conditions for grain were favourable in 1962, and the yield was once again high. But in 1963, due to changed weather conditions (especially in the European Chernozem regions), a low yield became a new economic disaster. The average yield was again about 3.1 dt ha^{-1} in the converted

Fig. 8.4 Arable soils in Russia and Kazakhstan. *Source* Meinel (2002)

Kazakh regions (Kazstat 2003). The harvest was not even sufficient for reseeding in the next season (Josephson et al. 2013) and everywhere in the Soviet Union livestock was slaughtered to adapt to the diminished food supply (GKS SSSR 1991; GKS 1956; Prishchepov et al. 2015). This catastrophe required an expensive grain import of 10 million t from Western countries by the Soviet Union. The Soviet government was forced to conclude that the ultimate goals of the Virgin Lands Campaign—establishing an effective buffer against crop failure in traditional agrarian regions and a grain production rate between 160 million t a^{-1} and 180 million t a^{-1} by 1965—were unattainable and action had to be taken. The first measurements were the ousting of Khrushchev and the change of the country's agrarian policy (Josephson et al. 2013).

8.3 The Virgin Lands Campaign in the Altai Krai

The steppes of south-western Siberia and especially the Kulunda Steppe were the second largest converted region of the Virgin Lands Campaign after those in the northern part of today's Kazakhstan.

Until the start of the Virgin Lands Campaign, grain was mainly produced in the forest steppe region but also in typical steppe areas (up to the 400 mm isohyet of annual precipitation) and locally in even more arid steppe areas. The limit of traditionally manageable arable land was exceeded by the extension of the Virgin Lands

Fig. 8.5 Monument of a crawler tractor of the Virgin Lands Campaign in the Komsomolsky farm picture.

Campaign in southern and south-western direction. Here in the Kulunda Steppe, the first steppe conversion of the whole Virgin Lands Campaign was conducted and very much celebrated as a means of propaganda—a fact still evident in the monument of the used crawler tractor (Fig. 8.5).

Between the 1930s and the begin of the Virgin Lands Campaign, the number of settlements decreased from more than 5000 to less than 4000 in the Altai region.

A new settlement structure developed during the Virgin Lands Campaign. The size of the settlements increased, and they were strongly connected to the kolkhozes and sovkhozes. Seventy-eight sovkhozes and 77 kolkhozes with many new settlements were founded in the Altai Krai during the campaign (Fig. 8.6).

At the time, about 13,000 newcomers lived in these at first quite spartan settlements. They arrived mostly from central Russia or what is now Ukraine (Jakutin 2005). Due to the Virgin Lands Campaign, land usage, settlements, and population changed drastically in the Kulunda Steppe (Jakutin 2005).

Within only two years, a total of 29,000 km^2 of unused steppe or steppe only used for pasturing was converted (Orlowski 1955) and the arable area increased by 65% in this part of the Altai foreland (Jakutin 2005).

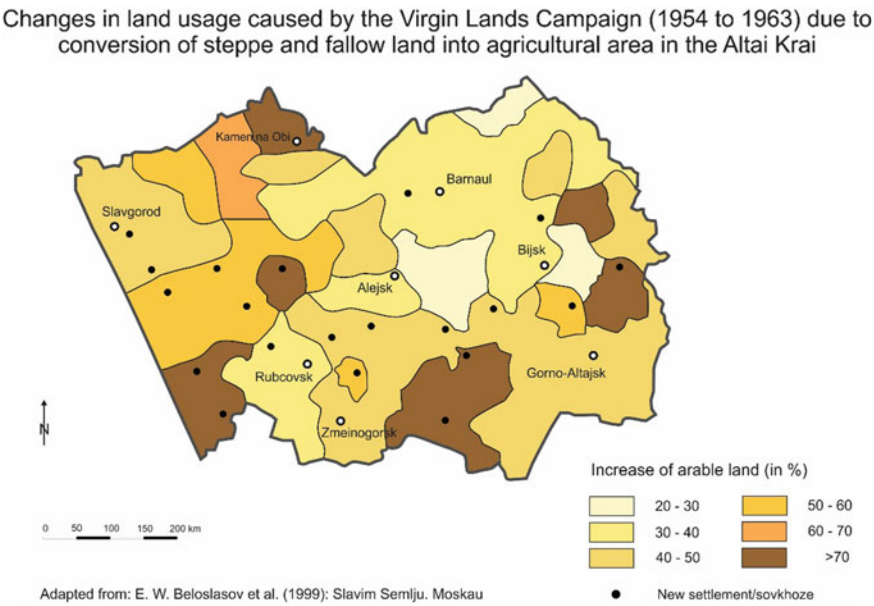


Fig. 8.6 Increase of arable land area during the Virgin Lands Campaign in the Altai Krai Kulunda Steppe. *Source* based on Beloslasov et al. (1999)

According to Meinel (2002), the area of arable land increased in three different ways during this time showing different relations to landscape, existing infrastructure, and previous land usage.

The area of arable land was mainly increased in the western and south-western parts of the region. Here, the dominant soils are (southern) Chernozems, especially dark and light Kastanozems (Meinel 2002). The land reclamation went beyond the 400 mm isohyet into areas with less than 250 mm of annual precipitation. The land conversion affected not just the quasi-natural steppe previously used for pasturage but also previously cultivated land lying fallow. These fields were usually located in the proximity of settlements which were abandoned before or during World War II. The reason for abandonment was usually a low crop yield due to droughts. Most of the abandonments occurred between 1932 and 1936 (Zentralarchiv-Altai Krai 1954)—a time of great political repression which extended even into the agrarian regions.

During the Virgin Lands Campaign, areas with a gradient of more than 10%, occasionally even more than 15%, were converted for the first time (Wein 1999). Most of these areas were in the south-eastern part of the Kulunda Steppe and are characterized by a slightly higher elevation, a hillier topography, and they form the transition zone to the Altai Mountains. Reasons for expanding in this region were a slightly higher precipitation, extended soil management practices due to modern

Fig. 8.7 Large-scale fields with shelterbelts dominate the forest steppe near Barnaul picture.

agrarian machinery, and the targets of land conversion set by the centralized economic plan of the Soviet government.

By the end of the Virgin Lands Campaign, up to 93% of some districts in the steppe and forest steppe of the Altai Krai were converted into arable land (Kowalev and Trofimov 1968). Only few grasslands—unused or used only for pasturing—were left beside the newly created large-scale agrarian steppe areas (Jakutin 2005).

Part of the Virgin Lands Campaign was also a reallocation of already cultivated areas in the surroundings of settlements. The goal was to create large fields with an average area of 100 ha (Fig. 8.7). Even today, this agrarian steppe is still dominated by fields with a standard dimension of 500 m × 2000 m separated by shelterbelts. The orientation of the fields takes into consideration the main wind direction (south-west).

As Durgin (1962), Eule (1962), McCauley (1976), Rostankowski (1979), Wein (1983, 1999) and Stadelbauer (1987) documented for the virgin lands in general, the crop yields vary greatly in the Kulunda Steppe too. The main cause is the annual variation of precipitation during the growth season (Fig. 8.8).

As illustrated in Fig. 8.8, the crop yield of the 'virgin land' Komsomolsky farm is higher than that of the district and the county due to its more favourable precipitation amounts and soil conditions. Located at the border along the forest steppe, the annual precipitation is about 400 mm and the dominant soils are Chernozems (Fig. 8.9) with Ah horizons of an average depth of 4 dm.

In the large steppe areas of the Kulunda Steppe with their lower precipitation rate, the crop yield is much more dependent on the precipitation than in the forest steppe with its higher precipitation and its Chernozems (Frühauf and Meinel 2007).

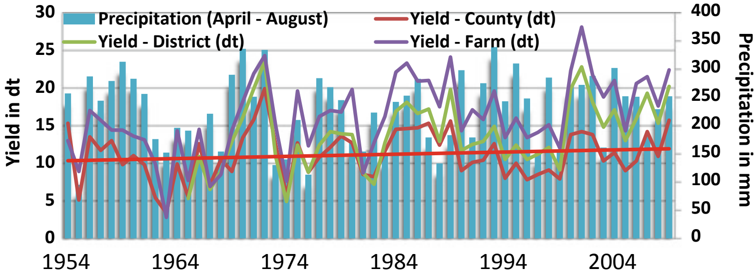


Fig. 8.8 Precipitation and yield data of the Altai Krai, Pavlovsky District, and the Komsomolsky farm in the forest steppe and the yield trend between 1957 and 2010 of the Altai Krai. *Source* Komsomolsky farm intern data

Fig. 8.9 Chernozem of the forest steppe (Komsomolsky farm) picture. *Source* Frühauf (2014)

8.4 Type and Intensity of Land Use as Source of Soil Degradation

Besides existing soils and climatic conditions, knowledge about the type and intensity of used agricultural methods is important for an understanding of crop yield data. During the first years, the same farming technology was used in the virgin lands regions as in the traditional Chernozem regions of the European Soviet Union. The seedbed was prepared by ploughing and subsequent harrowing. Much less fertilizer was provided for the virgin lands regions in comparison with the agricultural regions of the European part of the Soviet Union.

To meet the target of an increased wheat production, summer wheat was planted on the newly cultivated fields for four years in a row putting the soils in the virgin lands region at a high risk of erosion. Thus, devastating dust storms occurred in the regions in 1956. Kostrowski (1959) mentioned dust storms so intense that material from the Kulunda Steppe was transported as far as the distant city Barnaul during the spring 1957.

Dust clouds darkened the sky and lights had been switched on in the affected region during the day (cited by Wein 1983, based on Berg's observations in 1959). Huge drifts of dirt with depths of up to three metres piled up. During the summer, portable windbreak fences had been installed along the railroads to protect the tracks from being buried under the dirt.

An annual loss of 1875 km^2 of newly converted land caused by wind erosion during the first years of the Virgin Lands Campaign was estimated (Wein 1983). At the start of the 1960s, this devastating erosion intensified even more. The damaged area increased from 7000 to 30,000 km^2 between 1961 and 1963. Overall, 130,000 km^2 or 31% of the newly converted areas were negatively affected and the crop yield decreased (Wein 1983).

In the territory of today's Kazakhstan, more than 80% of the virgin lands were damaged by wind erosion by 1963. Repeatedly, more than 10,000 km^2 of sown fields was destroyed in just one year. The effects of this phenomenon showed great similarities to the previous dust bowl events in the prairies of the USA and Canada. But Khrushchev paid little attention to this problem.

Although measurements like planting of shelterbelts and replacing deep tillage with flat cultivation methods were already put in place after 1960, the effects of wind erosion were barely minimized. Own research findings show that soil management technologies were hardly developed any further during the last years. On the contrary, after the breakdown of the central structures in agriculture, the lack of alternatives regarding herbicides, fertilizers, and machinery as well as short-sighted, profit-oriented management resulted in the fallback to outdated, stressful, and yield-reducing soil management methods. Here are some of the characteristics:

- Frequent and too deep ploughing/turning of the fields even in the dry steppe region
- Large-scale burning of straw on the fields
- Insufficient maintenance of fallow land
- Not following the crop rotation sequence because of market situation

- No maintenance of shelterbelts
- No application of erosion protection measurements and dry farming methods
- No application of fertilizers and herbicides (Meinel 2002).

Even the painful experiences of farmers in the Midwest of the USA after the large-scale prairie conversion decades ago and its negative ecologic and socioeconomic consequences were largely ignored by the decision-makers of the Soviet agrarian policy. Meinel (2002) concluded that the Kulunda Steppe is especially vulnerable for droughts and wind erosion due to its natural conditions and the type of soil management methods used in comparison with other Siberian virgin lands regions. He not only emphasized the effects of the used soil management practices on soil desiccation but also pointed out the importance of the summer (Sukhovey) and the winter (Buran) storms which aggravate wind erosion.

8.5 The Time After the Virgin Lands Campaign till the Collapse of the Soviet Union

After Khrushchev's fall, the new party leaders (Brezhnev 1979) enforced new land management methods. Some of them were partially already practiced in North America like dryland farming, as well as crop rotation, land fallowing, and an increased use of fertilizers and agricultural machinery. Land was converted again in the 1970s, but only small areas were transformed (Spaar and Schuhmann 2000), and it did not reach the scale of the Virgin Lands Campaign. The extent of the agricultural area of the former Soviet Union was largest between 1975 and 1980 (Fig. 8.10). The size of virgin lands regions plus the newly converted areas of the 1970s started to decrease in Kazakhstan by the mid-1980s (Fig. 8.10) but remained stagnant in the rest of the Soviet Union until its collapse in 1991 (Prishchepov et al. 2015). Seventy-five per cent of the steppes in the Soviet Union were used for agriculture in the mid-1980s (Plit et al. 1995).

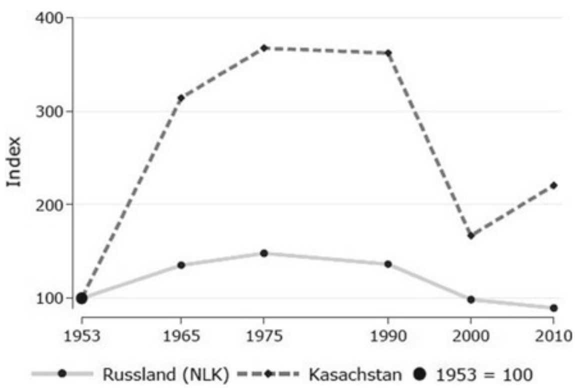


Fig. 8.10 Sown area in 2012 (compared with 1953) in Russian and Kazakh parts of the virgin lands regions. Source: Prishchepov et al. (2015)

Table 8.1 Average crop yields of the Kazakh virgin lands regions

Period	1949–1957	1966–1970	1971–1975	1975–1979
Yields (mill. t)	3.7	20.7	21.7	27.3

Source Wein (1983)

The enforced new land management methods showed some effects regarding a minimization of ecologic problems (McCauley 1976). Wind erosion was drastically reduced in the Kazakh virgin lands regions by the planting of shelterbelts. Very few existed in the Kazakh virgin lands regions up until that point in comparison with the Russian virgin lands regions which was quite surprising because Stalin had already ordered the planting of trees as shelterbelts in agricultural areas in 1948. Although the planting was not successful everywhere, the shelterbelts were eventually beneficial. However, after Stalin's death, the planting plan was neglected.

Slowly, yield stability was achieved. Furthermore, targeted fertilizing supported the increase in the crop yield in the Russian and Kazakh virgin lands regions. The average wheat yield increased from 7.4 dt ha^{-1} during the whole Virgin Lands Campaign (1954–1963) to 8.9 dt ha^{-1} in Kazakhstan. Overall, the amount of produced grain was significantly increased in the Kazakh virgin lands regions (Table 8.1).

The crop yield of the Russian virgin lands regions increased, too, from an average of 6.8 dt ha^{-1} during the Virgin Lands Campaign to an average of 9.4 dt ha^{-1} between 1965 and 1990 which helped to stabilize the grain production even further.

Crop yields of the virgin lands were, however, still lower than the yield of the traditional growing areas in the Chernozem regions of the Northern Caucasus and especially of today's Ukraine. Here, grain amounts of up to 16 dt ha^{-1} were being produced (McCauley 1976; Rostankowski 1979).

The period between 1965 and the late 1980s was a 'phase of intensification' as it is known and it was the most successful and stable time of crop production in the virgin lands regions. Even with a lot of room left for improvement, a functioning soil management system had been developed, which resulted in a stable crop yield and minimized wind erosion. Specialized research institutes had been established and scientific agricultural research had caught up and was now on par with international standards. But the Soviet grain production rate was still too low. One of the fundamental goals of the Virgin Lands Campaign—the self-sufficiency of the country regarding grain—could not be achieved and grain still needed to be imported from Western countries. The imports amounted to between 10 and 16% of the Soviet grain production and required the use of foreign currency.

After the collapse of the Soviet Union, land use in Russia, and in other countries like Kazakhstan, changed radically for the second time within 60 years (Lenk 2005). The changes were caused by shifts in political and social conditions and their retroactive effects influenced land use in western Siberia and the Kulunda Steppe as well. Most of the successful soil management methods of the intensification phase were no longer applied. The central distribution of machinery, seeds, and fertilizer did not exist anymore, and by the 1990s, crop production went back to the usage of old soil management methods with a high risk of erosion.

Although these issues will be detailed further in the next chapter, at this point the following should be noted:

The new socioeconomic conditions led to demographic change and a rural exodus in the area, which resulted in an over-ageing population and in a sharp decline in the number of settlements. In 1989, 1697 settlements existed in the Altai Krai region according to a census from the same year (384 were founded in the eighteenth century, 314 in the nineteenth century, and 996 in the twentieth century (Bulygin 2000; Sel'skie 2011). Only 1598 settlements were counted 21 years later in 2010 (Kazancev 2004; Sel'skie 2011). After the tremendous increase in sown areas because of the Virgin Lands Campaign, the area used for crop production decreased sharply immediately after the collapse of the Soviet Union (Fig. 8.10).

The speed and dimension of the decrease were globally unprecedented (Lyuiri et al. 2010; Kurganova and Gerenyu 2012; Prishepov et al. 2013; Schierhorn et al. 2013; Kraemer et al. 2015). Although radically reduced, Kazakhstan's arable area was still twice as large in 2010 than before the Virgin Lands Campaign (Prishchepov et al. 2015). However, Russia's arable land in 2010 was only 65% the size of the area in 1990 and only 60% of 1965 (Fig. 8.10).

Meanwhile in Kazakhstan, arable land that had been converted for agricultural use after the peak of the Virgin Lands Campaign between 1962 and 1990 was left lying idle. The soils here are of poorer quality than those in the steppe that were converted during the peak of the Virgin Lands Campaign (IAMO 2015).

Irrespective of these facts, evolving social conditions resulted not just in changed land use, ecosystems as well as socioeconomic consequences, but had ecological effects, too. As the studies from Rusalimova et al. (2006) and Schierhorn et al. (2013) show, consequences of these ecological developments do not just include an increased potential of carbon sequestration in these areas. Additionally, findings from these studies point out the potential of the fallow areas for current and future challenges regarding world food problems and future 'bread baskets' (Schierhorn and Müller 2011; Schierhorn et al. 2014; Glauben 2014).

8.6 Conclusion

The review of the main factors and important stages of the agricultural land development of south-western Siberia and especially of the Kulunda Steppe shows clear differences regarding the development of this region in comparison with the European part of Russia and later Soviet Union. The differences are not only Siberia's later development and delayed start of agricultural usage. The agricultural land development was accelerated by political and financial aid, generous support of land acquisition, and political and economic reforms, all of which also motivated peasants and made them more proactive. Here—beyond the Urals—agriculture evolved characterized by high productivity, large-scale fields, and a higher number of livestock and

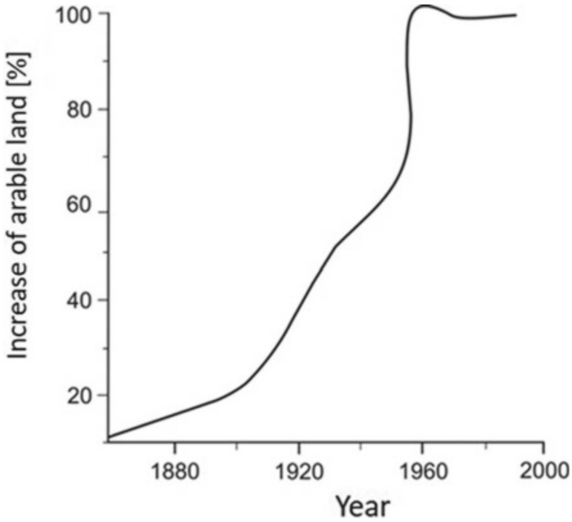


Fig. 8.11 Increase of arable land in Siberia between 1860 and 2000 in (%). *Source* based on Bazhenova and Martanova (2003), Shahgedanova (2003)

machinery. This development was steered by tremendous political upheavals influencing not just type, intensity, and productivity of agriculture but also settlement structures, and general land usage.

Especially in south-western Siberia, the influx of population, number of settlements, and agricultural area increased drastically during the second half of the nineteenth and the first decades of the twentieth century. With the rapidly changing political situation after the Bolshevik Revolution, the framework for population, settlement, and agricultural structures was changed. Many smaller settlements disappeared but the size of the remaining settlements grew after the 1920s. During and after the Virgin Lands Campaign, the number of settlements decreased further while the population was concentrated in larger settlements in agricultural epicentres (sovkhozes and kolkhozes; with long-lasting socioeconomic impacts).

The development of the population, settlements, and agricultural land use demonstrates the relationships between the three and the effects they have on one another.

The magnitude of human interference with the ecosystem during the Virgin Lands Campaign is illustrated by comparing the land expansion in western Siberia with the global average expansion of agricultural land: Agricultural area increased globally by a factor of 2.5 between 1860 and 1970 but by factor 9 in western Siberia at the same time. Only 35% of the steppe were cultivated in 1863 (Jackson 1956; Ioffe et al. 2004; Stepi Evrasii 2005). In 1990, 90% of the steppe in western Siberia were considered as cultivated according to Milanova et al. (1999) and only 2% natural steppe were left (Fig. 8.11).

The data shown in Fig. 8.11 imply that a large-scale land development including founding of settlements and building of streets had occurred in the south-western

Siberian steppe within only 150 years. The area used for agricultural production quintupled between the beginning of the twentieth century and the 1960s.

The Virgin Lands Campaign alone was undoubtedly the major event of the land expansion. The gigantic extent of this land conversion within the short time of only ten years makes the Virgin Lands Campaign a unique ecosystem conversion. It outrivalled even the Prairie conversion in North America between 1909 and 1929 when an area of 130,000 km^2 was transformed into agricultural land (Mitchell 2004). Today, the Virgin Lands Campaign is considered the most radical ecosystem conversion of the twentieth century in the Northern hemisphere (Frühauf and Meinel 2014).

References

ASK (2003) Republika Kazahstan: 50-let nachala osvoenija celinnyh i zalezhnyh zemel'. Statistischeskij sbornik 1953–2003 (Republic of Kazakhstan: 50 Years since the Beginning of Virgin Lands Campaign. Statistical digest 1953–2003). Agency of Statistics of the Republic of Kazakhstan, Almaty (in Russian)

Bazhenova OI, Martanova GN (2003) The problem of Siberian steppe landscape transformation at climate and land-use change. In: Chibilyov AA Steppes of Northern Eurasia, pp 59–61

Beloglasov EV et al (1999) Slavim zemliu (We glorify the earth). Holding Blitz-Inform, Kiev (in Russian)

Brezhnev L (1979) Virgin Lands: two years in Kazakhstan (1954–55). Pergamon Press, Oxford

Bulygin IS (2000) Spisok naselennykh punktov Altaiskogo kraia: Spravochnik. Barnaul – 237s. Demographic transformation of municipal districts and settlements of Altai Krai in the Post-soviet period. In: Madry C (ed) The social transformation of the cities and regions in the post-communist countries. Bogucki Wydawnictwo Naukowe, Poznan, 2014, pp 23–33

Durgin FA Jr (1962) The Virgin Lands Program 1954–1960. Soviet Stud 13(3):255–280

Eule W (1962) Das Problem der Neulandgewinnung in der Sowjetunion (The problem of reclaiming land in the Soviet Union). Dissertation. University of Bonn (in German)

Frühauf M, Meinel T (2007) Desertification in the agricultural used dry steppes in central Asia. In: Proceedings of the international conference soil and desertification—integrated research for the sustainable management of soils in Drylands, 5–6 May 2006, Hamburg, Germany, Organised by Desert*Net Germany and AK BoGeo (http://www.desertnet.de/proceedings/start)

Frühauf M, Meinel T (2014) Ökosystemkonversion in den temperierten Grasländern Südwestsibiriens: Steuerfaktoren, Etappen und Geoökologische Konsequenzen (Ecosystem conversion in the temperate grasslands of southwestern Siberia: key factors, stages and geoecological consequences). Geoöko XXXV(1–2):5–38 (in German)

Georgiev AV (1955) God rabota po osvoeniiu tselinnykh I zalezhnykh zemel' v Altaiskom Krae (A year of work on the development of virgin and fallow lands in the Altai Krai). Publisher, Place [in Russian]

GKS (1956–1990) National Economy of Russian Soviet Federative Socialist Republic. State Statistical Publishing House, Moscow

GKS SSSR (1991) Narodnoe Khoziaistvo SSSR v 1990. Finansi I Statistika, Moscow

Glauben T et al (2014) Eastern breadbasket obstructs its market and growth opportunities. IAMO Policy Brief 16, 1–4. Available at: www.iamo.de/dok/IAMOPolicyBrief16_en.pdf

Hahn R (1964) Klimatische und bodenkundliche Bedingungen der Neulanderschließung in Kasachstan (Climatic and geological conditions of land reclamation in Kazakhstan). Osteuropa 14:260–266

IAMO (2015) Pressemitteilung 07/2015. https://www.iamo.de/presse/pressemitteilungen/artikel/eine-analyse-von-langfristigen-landnutzungsaenderungen-in-nordkasachstan-zeigt-ein-geringes-potenzia/. Accessed (in German)

Ioffe G, Nefedova T, Zaslavsky I (2004) From spatial continuity to fragmentation the case of Russian farming. Ann Assoc Am Geogr 94(4):913–943

Jackson WAD (1956) The Virgin and Idle Lands of Western Siberia and Northern Kazakhstan: a geographical appraisal. Geogr Rev 46(1):1–19

Jakutin NB (2005) Erschließungsetappen und aktuelle Probleme der Neulandregion. In: 50 Jahre Neulanderschließung – Vestnik der Altai-Universität Barnaul. Nr. 1 (13) 2004, pp 38–48 (in Russian)

Josephson P, Dronin N, Mnatsakanian R, Cherp A, Efremenko D, Larin V (2013) An environmental history of Russia. Cambridge University Press, Cambridge

Kazancev VI (2004) K istorii rasseleniia krest'jan na territorii Altaiskogo kraia (On the history of peasant settlement on the territory of Altai Krai). Nauchnye chtenija pamjati Ju.S. Bulygina: Sbornik nauchynh statej/pod red. Ju.M. Goncharova. Barnaul – 124 s

Kazstat (2003) Respublika Kazakhstan: 50 let nachala Tselinnoi kompanii (1953–2002) [Republic of Kazakstan: 50 years of the Virgin Lands campaign (1953–2002)]. Agency of Kazakhstan on Statistics, Almaty

Kowalev RW, Trofimov SS (1968) Allgemeine Charakteristik der Bodendecke Westsibiriens. In: Agrochemische Charakteristik der Böden der UdSSr. Nauka, Moscow (in Russian)

Kostrowski P (1959) Pyl'nye buri v Altaiskikh stepiakh (Dust storms in the Altai steppes). In: Sel'skoe khosiaistvo Sibiri, Omsk 2, pp 35 et seqq (in Russian)

Kraemer R, Prishchepov AV, Müller D, Kuemmerle T, Radeloff VC, Dara A, Terekhov A, Frühauf M (2015) Long-term agricultural land-cover change and potential for cropland expansion in the former Virgin Lands area of Kazakhstan. Environ Res Lett 10(5):054012

Kurganova I, Gerenyu VL (2012) Russian carbon balance update after 20 years of farming system collapse—oral presentation paper by the IAMO FORUM "Land in Transition". Halle, Germany, 20–22 June 2012, Available at: http://www.iamo.de/forum0/forum2012/#.Uv4oLPu2zpM

Lenk M (2005) 50 Jahre Neulandsteppe in Kasachstan: eine kritische Bilanz, Archiv für Naturschutz und Landschaftsforschung (50 years of virgin land steppe in Kazakhstan: a critical balance, archive for nature conservation and landscape research). Archiv für Naturschutz und Landschaftsforschung 44(1):37–62 (in German)

Lyuiri DI, Goryachkin SV, Karavaeva NA, Denisenko EA, Nefedova TG (2010) Dinamika sel'skokhoziaistvennykh zemel' Rossi v XX veke I postagrogennoe vosstanovlenie rastitel'nosti i pochv (Dynamics of agricultural lands of Russia in the 20th century and postagrogenic restoration of vegetation and soils). GEOS, Moscow (in Russian)

McCauley M (1976) Khrushchev and the development of Soviet agriculture: The Virgin Land Programme 1953–1964. Holmes & Meier Publishers Inc, New York

Meinel T (2002) Die geoökologischen Folgewirkungen der Steppenumbrüche in den 50er Jahren in Westsibirien. Ein Beitrag für zukünftige Nutzungskonzepte unter besonderer Berücksichtigung der Winderosion (The geoecological consequences of the steppe ploughing in the 1950s in Western Siberia. A contribution for future usage concepts with special consideration of the wind erosion). Dissertation, Martin Luther University of Halle-Wittenberg (in German)

Milanova EV et al (1999) Land use/land cover change in Russia: mapping and GIS. Land Use Policy 16(3):153–159 (Elsevier Science)

Mitchell JG (2004) Neue Horizonte (New Horizons). Natl Geogr 5:132–161 (in German)

Nikonov AA, Schulze E (2004) Drei Jahrhunderte Agrarwissenschaft in Russland: Von 1700 bis zur Gegenwart (Drei Jahrhunderte Agrarwissenschaft in Russland: Von 1700 bis zur Gegenwart). In: Studies on the Agricultural and Food Sector in Central and Eastern Europe, IAMO 27 (in German)

N.N. (2005) Stepi Evrazii: Sokhranenie prirodnogo raznoobraziia i monitoring sostoianiia ekosistem (Steppe of Eurasia: Preservation of Biodiversity and Monitoring of the Eco-Systems). The Steppe Institute Press, Orenburg (in Russian)

N.N. (2011) Sel'skie naselennye punkty Altaiskogo kraia: statisticheskii sbornik (Rural settlements of the Altai Krai: a statistical anthology). Territorial'nyi organ Federal'noi sluzhby gosudarstvennoi statistiki, Barnaul (in Russian)
N.N. (2017) Access (10.11.2017): http://t3.gstatic.com/images?q=tbn:ANd9GcT83Th5mJweG2e3xSlb8ged18sClMobS34JZ0p6-brRqWAALRbLO13t
N.N. (2017) Access (10.11.2017): http://kazakhsteppe.com/uploads/Threads/zelina_small.jpg
Orlowski NV (1955) Osvoenie tselinnykh i zalezhnykh zemel' v Altaiskom Krae (The development of virgin and fallow lands in the Altai Krai). Akademi Nauk, Moscow (in Russian)
Plit F, Plit J, Zakowski W (1995) Drylands development and combating desertification: bibliographic study of experiences in countries of the CIS. Food and Agriculture Organization of the United Nations, Rome
Prishchepov AV, Müller D, Dubinin M, Baumann M, Radeloff VC (2013) Determinants of agricultural land abandonment in post-Soviet European Russia. Land Use Policy 30:873–884
Prishchepov AV, Petrick M, Müller D, Schierhorn F, Kraemer R, Kurganova I, Kopsidis M (2015) Sechzig Jahre Neulandkampagne in Russland und Kasachstan: Eine Bewertung aus ökonomischer, ökologischer und politischer Sicht (Sixty years of virgin land campaign in Russia and Kazakhstan: An evaluation from an economic, ecological and political point of view). In: IAMO. Jahresbericht 2015, Halle (Saale): IAMO, pp 41–58 (in German)
Rostankowski P (1979) Agrarraum und Getreideanbau in der Sowjetunion 1948–1985 (Agrarian area and cereal cultivation in the Soviet Union 1948–1985). Duncker & Humblot, Berlin (in German)
Rusalimova O, Savenkov O, Smirnova N, Barshukov P (2006) Soil carbon losses from seasonally-frozen soils of agricultural ecosystems in West Siberis from the 20th century. In: Hatano R, Guggenberger G (eds) Symptom of environmental change in Siberian Permafrost Region. Hokkaido University Press, Sapporo
Schierhorn F, Müller D (2011) Russlands Beitrag zur Welternährung – Brachliegende Flächen und niedrige Erträge bieten ungenutztes Potential (Russia's contribution to world food supply—fallow land and low yields offer untapped potential). Forschungsreport 2:18–20 (in German)
Schierhorn F, Müller D, Beringer T, Prishchepo AV, Kuemmerle T, Balmann A (2013) Post-Soviet cropland abandonment and carbon sequestration in European Russia, Ukraine and Belarus. Glob Biogeochem Cycles 27:1175–1185
Schierhorn F, Müller D, Prishchepov AV, Faramarzi M, Balmann A (2014) The potential of Russia to increase its wheat production through cropland expansion and intensification. Glob Food Secur 3:133–141
Shahgedanova M (ed) (2003) The physical geography of Northern Eurasia. Oxford Regional Environments. Oxford University Press, Oxford
Spaar D, Schuhmann P (eds) (2000) Natürliche Grundlagen der Pflanzenproduktion in den Ländern der Gemeinschaft Unabhängiger Staaten und des Baltikums (Natural foundations of plant production in the countries of the Commonwealth of Independent States and the Baltic). Agrimedia, Bergen/Dumme, pp 129–145 (in German)
Späth HJ (1980) Die agro-ökologische Trockengrenze (The agro-ecological dry border). Erdkunde 34:224–231 (in German)
Stadelbauer J (1987) Neuland und Getreideversorgung. Möglichkeiten und Grenzen agrarpolitisch motivierter Raumerschließung in den Steppen der Sowjetunion, der VR China und der Mongolischen VR (Virgin land and grain supply. Possibilities and limits of agricultural policy-driven spatial development in the steppes of the Soviet Union, the People's Republic of China and the Mongolian People's Republic). Freiburger Universitätsblätter 96:129–145
Wein N (1983) Agriculture in the pioneering regions of Siberia. Soviet Geogr 8:67–90
Wein N (1999) Sibirien (Siberia). Perthes Regionalprofile. Klett-Cotta, Gotha, Stuttgart (in German)
Zentralarchiv-Altai Krai (1954) Bericht zur bodenkundlichen Erhebung (1951) des staatlichen Vermessungsamtes des Altai-Krai. Barnaul (unpublished, in Russian)

Chapter 9
Earth Observation and Map-Based Land-Use Change Analysis in the Kulunda Steppe Since the 1950s

S. Hese, N. Kurepina, I. Walde, Yu. M. Tsimbalei and T. G. Plutalova

Abstract The overall aim of this work is to provide land-use and land-cover change information as part of the KULUNDA project to develop sustainable land management policies and practices to stabilize agricultural yields and minimize ongoing degradation and desertification processes. The area under investigation comprises around 80,000 km^2 and belongs to what is thought of as Russia's granary, an essential area in ensuring adequate food supply. Inadequate and outdated cultivation and agricultural management practices have caused ecological and socio-economic problems including soil degradation, desertification and yield losses. The focus of this work is the quantification and assessment of land-use and land-cover changes over time. Multi-temporal and multi-sensor satellite data and historical topographic maps were used to detect changes of specific land-use and land-cover classes. The present work utilizes pixel-based data classification approaches as well as object-based concepts and uses Landsat MSS, TM5, ETM and RapidEye data. For the 1950s, a GIS map layer-based approach is used and calibrated with panchromatic airphotograph data mosaics. Results of the land-use change mapping show an increase in cropland until 1989 of nearly 1 mio ha and a decrease until 2013/2014 of 500,000 ha directly connected to a decrease in grassland and steppe area until 1989 and an increase in grassland until 2013/2014. This study for the first time quantifies the land-cover change over 60 years in the Kulunda steppe region of Russia.

Keywords Landuse change · Landcover · Kulunda steppe · OBIA · Object based · Steppe

S. Hese (✉) · I. Walde · Yu. M. Tsimbalei · T. G. Plutalova
Earth Observation Section, Department of Geography,
Friedrich-Schiller-University Jena, 07743 Jena, Germany
e-mail: soeren.hese@uni-jena.de

N. Kurepina · Yu. M. Tsimbalei · T. G. Plutalova
Institute for Water and Environmental Problems, (IWEB SB RAS),
Barnaul, Russian Federation

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_9

9.1 Introduction

LULC change is a dynamic process that is intensified by human activities (Kühling et al. 2016), which has contributed to approximately 35% of anthropogenic carbon dioxide (CO_2) emissions worldwide (Houghton et al. 2012). The increase in human population and the need for agricultural areas drive the LULC change, which results in social and economic benefits and has inadvertent consequences on the natural environment. The United Nations (UN) has estimated the current global population of over seven billion to rise to over nine billion by 2050. Expanding cropland, intensification of agricultural productivity, or increasing crop yields are needed to meet the projected growth of food demand. Changes in land use entail changes in water, energy and fertilizer consumption, and result in groundwater reduction, degradation, desertification, and biodiversity losses (Foley et al. 2005). The detection of LULC changes is therefore an essential requirement for the valuation of potential environmental impacts and improving land management and planning strategies. The South of Russia is very relevant in terms of agricultural production, biodiversity preservation and carbon sequestration. Its forests, peatlands and steppe soils are one of the important carbon sinks worldwide. The release of the amount of stored carbon would be a relevant source of radiative forcing. Recent and future developments in agricultural land use in this area aggravated this situation (Fleischer et al. 2016). Most of the temperate grassland of the Siberian Kulunda Steppe in the Altai Krai region of Russia was converted into intensely cultivated farmland in the 1950 s following the directives of the 'Virgin Lands Campaign' (in Russian 'Zelina'; Meinel 2002; Stadelbauer 1987). The area under investigation comprises around 80,000 km^2 and belongs to what is thought of as Russia's granary, an essential area in ensuring an adequate food supply for the increasing population. Inadequate and outdated cultivation and agricultural management practices (e.g. using areas with less than 250 mm/year of precipitation for farming) have caused ecological and socio-economic problems including degradation, desertification and yield losses (Meyer et al. 2008). The considerable deficits in current farming and the low efficiency of agricultural land management are, besides climate change, a main driver for future agricultural expansion. An improved land management could reduce soil degradation and other environmental burdens as well as it could lower the need for the reclamation of new agricultural land in areas with high potential for emissions (WWU Münster 2011).

9.2 Status Quo

Land cover is one of the key land surface variables that can be observed with space-based approaches. The benefits of remote-sensing data sources are the high temporal resolution, as well as constant coverage. Multi-spectral Earth-observing satellite data coverage also goes back to the 1970s. Land-cover maps are a key source for detecting and monitoring change processes such as expanding cultivation, deforestation and urbanization, as well as disaster monitoring on a variety of spatial and temporal scales. To detect LULC changes earlier than the 1970, the use of historical maps is essential. A broader use of available historic input data could help to verify or correct assumptions which are used in historic reconstructions (Fuchs et al. 2015). However, the amount of used historic data is limited due to the alignment of inconsistent data sources, different acquisition techniques (aerial photographs, remote sensing, etc.) as well as data formats (hand-drawn, analogue, digital, etc.). One important method for LULC modelling is the Markov–CA model, which incorporates the theories of the Markov chain and the cellular automata (CA). For example, Yang et al. (2014) utilized a CA–Markov model to reconstruct spatial land-use patterns in the 1930s in Zhenlai County, north-east China. The authors reconstructed the spatiotemporal distribution of LULC in 1954 by using topographic maps and physical environmental background maps. The data for the validation of the model were digitized from topographic maps dating back to the 1930s. To be able to make comparisons between the data sets over time, the maps had to be thematically generalized, wherefore the land classes were aggregated into new categories.

Besides the global and continental scales, certain historical reconstructions based on old topographic maps and land-use records have been collected for different local to regional case studies (e.g. Kuemmerle et al. 2006; Van Eetvelde and Antrop 2009; Orczewska 2009; Skaloš et al. 2011; Skokanová et al. 2012; Jawarneh and Julian 2012; Godet and Thomas 2013; González-Puente et al. 2014; Marull et al. 2014). These data sets are good to describe patterns at a fine spatial and thematic detail like human-induced processes (Fuchs et al. 2013). Zanoni et al. (2008), for example, used historical maps to detect island dynamics in a braided river in Italy. The historical maps allow an overview over the changes of the river system over a time period of 200 years (1803–2005). The used maps were scanned with a resolution of 400 or 600 dpi, in order to obtain average pixel dimensions of approximately 1.2 m for the airborne photographs and 3 m for the historical maps. Afterwards, the images were geo-referenced and geocorrected using ‘image-to-map’ warping. An example for the use of historic maps in urban areas is given by Tucci and Gaordano (2011). The authors analysed positional accuracy, uncertainty and feature change detection in historical maps from 1884 to 2005 in Milan (Italy). They proposed a methodology for detecting possible effects of positional uncertainty and inaccuracy on the results of urban change detection analysis at high spatial resolution based on the use of historical maps. Results indicate that some spatial configurations of features are more sensitive to the combined effects of positional accuracy and uncertainty than others. A generalization to other historical maps is not proved yet. However, González-Puente et al. (2014) investigated landscape changes in mountainous areas in north-east Spain. They utilized a historical land-cover map from 1956, which was digitized, generalized and classified within a GIS. Marull et al. (2014) used cadastral land-use maps from 1853 to 1854, digital land-use maps drawn by GIS geo-referencing and photointerpretation from 1956 and land-cover maps from 1993 to 2005 to analyse historical land-use changes in Catalonia (Spain). The results of this study show landscape changes, which are the good examples for global changes in that kind of environment, where a metropolitan fringe dominated by urban sprawl remains is in direct contact with natural protected sites where reforestation prevails after the abandonment of the traditional integrated land-use management. Besides studies about historical LULC changes in urban areas, forests and others, an analysis of steppes (also known as prairies) and grasslands concerning LULC changes is important, because they are significant natural resources which cover about 40% of the land surface (He et al. 2005). However, steppes and grasslands are often facing degradation and desertification, mostly in arid and semi-arid regions caused by human activities and climate change. Because grassland and steppe degradation could have a significant influence on the carbon cycle, as well as regional economy and climate, the monitoring of these areas is very important.

9.3 Data Description

Five different data sets were available for the LULC derivation and change detection (see Table 9.1). For the Pre-Zelina time step (i.e. before the Zelina action in the 1950s) 26 topographic maps for 1938–1947 were used with varying actualization status (Fig. 9.1). Partial coverages of aerial images from 1939 were also used and combined to form seven aerial image mosaics (Fig. 9.1). The satellite images were Landsat 1/2 data for 1975/1976 with 60 m spatial resolution; these images represent the status of the KULUNDA study site after the Zelina action. Intensification and stabilization of the agricultural sector was mapped using the Landsat 4/5 data sets from 1989. In 1991 the breakdown of the Soviet Union led to unstable agricultural conditions and to a return to near-natural conditions in some steppe areas. The data sets from 2000/2001 show this trend. Finally, the current status is represented by a satellite image mosaic acquired by RapidEye in May 2014, and from Landsat 8 images from summer 2013 and 2014.

Table 9.1 Overview of the available data from 1948 to 2014, data types, sensors and spatial resolution

Year	Source	Spatial resolution
1948	26 scanned topographic maps scale 1:200,000 (update status ranging from 1938 to 1947), 727 aerial images mosaicked to form 7 major areas (2017 km^2) from 1939	Aerial images 2 m
1975/1976	Landsat 1/2 June–August	60 m
1989	Landsat 4/5 September	30 m
2000/2001	Landsat 7 May	30 m
2013/2014	RapidEye May 2014, Landsat 8 June–August 2013/2014	RapidEye resampled to 30 m, Landsat 8 30 m

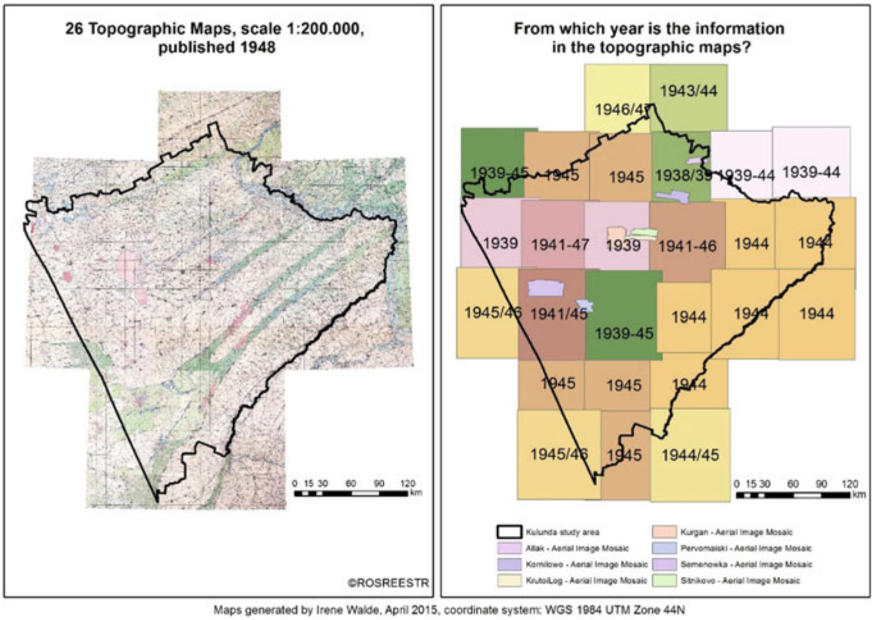


Fig. 9.1 Topographic maps 1:200,000 from 1948 and overview of the used aerial image mosaics with their acquisition date in the Kulunda study area

9.4 Methods

For the historical topographic maps from 1948, a GIS-based modelling approach was developed to estimate cropland extent using several indicators. One satellite mosaic for each year was used to derive the LULC, except for the 2014 status (i.e. a combination of 2013 and 2014 data sets was used). Two data sets with different phenological conditions (Summer 2013 and Spring 2014) were involved.

Di Gregorio (2005) defined *land cover* as 'the observed (bio-)physical cover on the Earth's surface' and *land use* as 'the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it'. For this work, however, a mixture of land-cover and land-use classes is unavoidable due to their mixed occurrence in the study site. For example, while settlements and croplands are pure land-use classes, woody or herbaceous classes contain both land-cover and land-use phenomena. The term *land use/land cover* (LULC) is therefore used in the present paper. Six general LULC classes were selected for study site classification. The classes are limited by the spatial resolution of the satellite images (between 30 and 60 m per pixel). Some of the classes vary in their appearance, such as water with different sediments or cropland in different phenological states; in these cases, such variations were combined into a single class. The characterization of the classes is shown in Table 9.2.

Table 9.2 LULC classes of the KULUNDA study area and their class descriptions

LULC classes	Description
Cropland	Ploughed fields with or without crops, fallow land
Herbaceous	Meadow, rangeland, steppe, deforested areas
Salt/sediments	Bright areas (in the images) caused by salinization or sediment deposit
Woody	Forest, groves, shelterbelts
Settlements	Cities, villages, some major streets
Water	Lakes, rivers, flooding, ponds, pools, swamps

9.4.1 Preprocessing

The topographic maps from 1948 were scanned and geo-referenced by the Institute for Water and Environmental Problems (IWEP) in Barnaul, Russian Federation. A total of 727 aerial images from 1937 were scanned by IWEP. The grey value images were mosaicked using Autopano Pro software with automatic tie points' detection in overlapping areas of neighbouring images. The images were geo-referenced, with control points found in the topographic maps (1:200,000) from 1948 and in the aerial images. A relative radiometric balancing was performed without atmospheric correction or spectral calibration. The overall quality of the scanned aerial image data was problematic for automatic matching and geo-referencing. Seven aerial image mosaics were generated. The mosaics cover a total area of 2017 km^2, 1/38 of the KULUNDA study area. Visible agricultural areas on the mosaics were digitized manually. Satellite data were atmospherically corrected using ATCOR2 and mosaicked.

9.4.2 Classification

The absence of a direct signature for agricultural areas in topographic maps from 1948 leads to the development of an indirect indicator-based land-use probability map. The workflow of the multi-criteria approach can be summarized as in the following listing:

1. Deriving potentially agricultural areas starts with eliminating areas of other LULC classes. From the KULUNDA study site, the digitized polygons (i.e. settlements, lakes, salinization, swamps, clear-cuts, burned areas, light taiga, dark taiga and meadow/steppe) were removed first. As streets, rivers, and railways are generalized in the topographic maps, these lines were give a 2.5-m buffer on both sides and then removed from the KULUNDA study site, leaving blank areas in the topographic map. In these regions, agricultural activity is assumed.

2. The topographic maps from 1948 contain signatures of shelterbelts, which are artificially planted strips of trees and bushes to reduce wind erosion on agriculture areas. These shelterbelts were digitized as lines and assumed to be the most important indicator for the existence of agricultural areas.
3. Other signatures from the topographic maps that indicated agricultural activities were field camps, barns, farms, farmhouses and wells. The most evenly distributed indicators in the study site were shelterbelts and field camps. Wells, for example, are found mostly in the dry steppe (i.e. in the south-west). To extract areas with a high potential for agricultural activity, the signatures (i.e. lines and points) were buffered. With the help of the aerial image mosaics, the buffer sizes of shelterbelts and field camps were validated. (Other indicators were not present in the mosaics.)
4. Shelterbelts are buffered with five diameters: 1, 2, 3, 4, and 5 km. The validation conducted using three aerial image mosaics (i.e. Semenowka, Kurgan, Allak) for the three steppe types showed that the most accurate coverage of cropland is achieved by applying a buffer of 3 km.
5. The same analysis was done with the field camps. Buffer diameters ranging from 1 to 11 km (in 1 km steps) were computed, with the best results for cropland coverage achieved using an 8-km buffer diameter. For all other indicators—barns, farms, farmhouses and wells—a general buffer diameter of 5 km was applied.
6. To derive the agricultural areas, all buffers were intersected, and the overlaps were counted and normalized for each indicator. All indicators were then added and divided by the number of indicators used. Four different tests were performed: Shelterbelts with Ø 3 km buffer; field camps with Ø 8 km buffer; barns, farms, farmhouses, and wells with Ø 5 km buffer; without weighting of indicators; shelterbelts with Ø 3 km buffer; field camps with Ø 8 km buffer; barns, farms, farmhouses, and wells with Ø 5 km buffer, with double weighting of shelterbelts and field camps.
7. Ø 5 km buffer for all → six indicators, without weighting of indicators.
8. Ø 3 km buffer of shelterbelts as a single indicator.

A validation using the seven aerial image mosaics identified Test 2 as the best predictor of agricultural areas for dry and typical steppe regions, and Test 4 as most suitable for forest steppe. In the final map, a combination of Test 2—for dry and typical steppe areas—and Test 4—for forest steppe—was therefore applied. Areas with no buffer occurrence were assigned as steppe.

The same workflow was used to derive the LULC from the satellite image mosaics for the years 1975/1976, 1989, and 2000/2001. An object-based approach was developed and implemented within Trimble eCognition software. In this approach, a multiresolution segmentation fragments the image into image segments, which join similar adjacent pixels using a homogeneity criterion. For each LULC class training, samples were manually selected (i.e. supervised classification). Settlements were classified using the settlement polygon layer of a topographic map published in the mid-1980s. Using thresholds for band values, spectral ratios and indices, and form-based properties, the LULC classes were assigned to the image segments. To reduce misclassifications, some segments were reclassified using neighbourhood criteria (e.g. relative border to surrounding classes, enclosed by a certain class) or area limitations. After each automatic classification, the LULC map was validated using a manual classification of stratified random sampling points. Since it is very important to achieve very high classification accuracies for post-classification change detection, due to error propagation, a manual reclassification was carried out. A final validation using stratified random sampling confirmed overall accuracies of over 90% for each LULC map.

A total of 213 features of the training samples were used to train a random forest classifier, a machine learning algorithm and nonparametric method developed by Breiman (2001), which generates an entity of bagged decision trees. The features were evaluated based on importance, with the 70 most important features used to train the random forest model. The model was applied to the segments to retrieve the classification, and a manual visual pre-classification of 1000 stratified random sampling points was used to validate the classification. Missing information from either data set due to clouds or no-data values was filled in with the other data sets. Manual reclassification using visual inspection was necessary to increase accuracy and to fill gaps caused by haze and cirrostratus clouds. A final validation with stratified random sampling points reached an overall accuracy of 95%.

9.4.3 Post-Classification Change Analysis

The post-classification method compares two independent classifications. The accuracy of change detection maps therefore depends on the quality of the previously classified satellite image mosaics

Six different change detection pairings were defined:

- 1947 (topographic maps)—1975/1976 (Landsat 1/2),
- 1975/1976 (Landsat 1/2)—1989 (Landsat 4/5),
- 1989 (Landsat 4/5)—2000/2001 (Landsat 7),
- 2000/2001 (Landsat 7)—2013/2014 (Landsat 8/RapidEye),
- 1947 (topographic maps)—2013/2014 (Landsat 8/RapidEye),
- 1975/1976 (Landsat 1/2)—2013/2014 (Landsat 8/RapidEye).

The relatively uncertain classification of cropland from the historical topographic maps from 1947 leads to a combined approach with change analysis based also on satellite mosaics from 1975/1976.

The two classification data sets contained different objects, making an intersection of both data sets necessary. Since clouds and gaps in the data sets also had to be excluded from the change detection, different maps were therefore generated for each change analysis:

- A change–no-change map,
- A map concerning change between cropland and herbaceous areas, and

- A map concerning change between forest and herbaceous areas.

The transformation matrices for each change analysis were also provided in both hectare and per cent.

For the selection of five Rayons—Mamontovskij, Pavlovskij, Romanovskij, Shelabolixinskij and Rebrixinskij—a comparison of satellite image mosaics, LULC classification, change detection maps, and area summaries for each LULC class was also performed (Fig. 9.2).

9.5 Results

9.5.1 Land-Cover/Land-Use Classification Maps

Figure 9.3 shows the LULC classification maps for the total KULUNDA study site. Between 1948 and 1975/1976, wide areas were brought under cultivation, changing the land-cover/land-use type from herbaceous land into cropland. This reflects the previously discussed Zelina political action of the 1950s, which convinced many farmers to settle in the Kulunda region and to plough wide areas of the former steppe. Second, salinization (classified as yellow colour within the map products) is more visible in 1948 than in any other years, as classified from satellite images. The reason for this is that salinized areas were digitized in 1948 using the topographic map signature. The transition zone between salt and steppe or salt and cropland is undefined, meaning that in the satellite images salty soils may also appear as steppe, meadow or cropland, resulting in an underestimation of salinized areas in the satellite image classification. Focusing on Barnaul—the capital of the Altai Krai, which lies along the river Ob in the east of the KULUNDA study site—ongoing urbanization is visible over the years. Between 1989 and 2000/2001, wide areas of forest in the south of the KULUNDA study site were deforested for unknown reasons and in May 2000/2001 the Ob flooded huge areas, which are normally classified as herbaceous (e.g. steppe/meadow).

9.5.2 Land-Cover/Land-Use Statistics

In Fig. 9.4, information regarding total areas (in hectare) for all six LULC classes of the KULUNDA study site is provided. Important changes of the political situation are indicated by vertical lines: After the Zelina action in the 1950s, herbaceous area decreased and cropland increased; after the breakdown of the USSR in 1991, the opposite trend can be observed. Water areas peaked in 2000 due to the flooding of alluvial meadows of the Ob. Overall settlement area did not change much as the increase in urbanization was compensated for by the decline in smaller settlement structures, due to migration into larger cities.

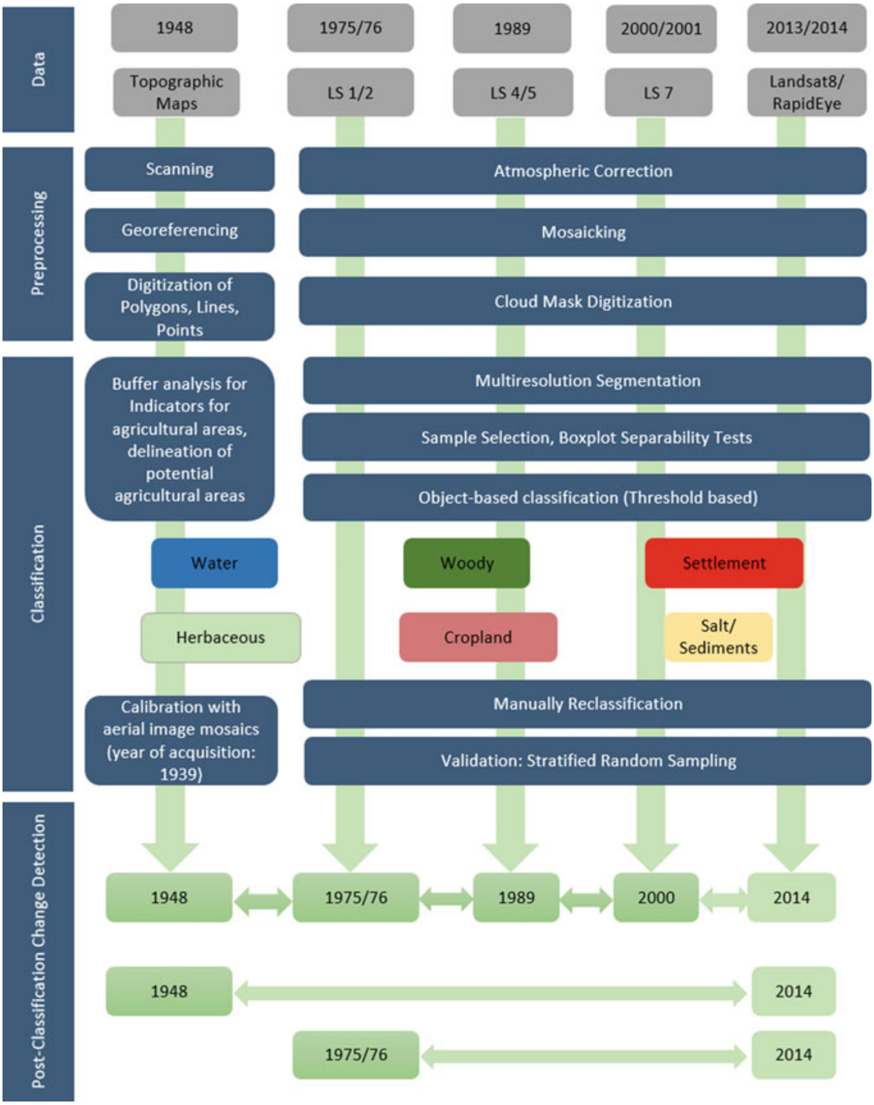


Fig. 9.2 Workflow of the LULC classification, starting with the used data and their preprocessing. The used classes are water, woody, settlement, herbaceous, cropland and salt/sediments

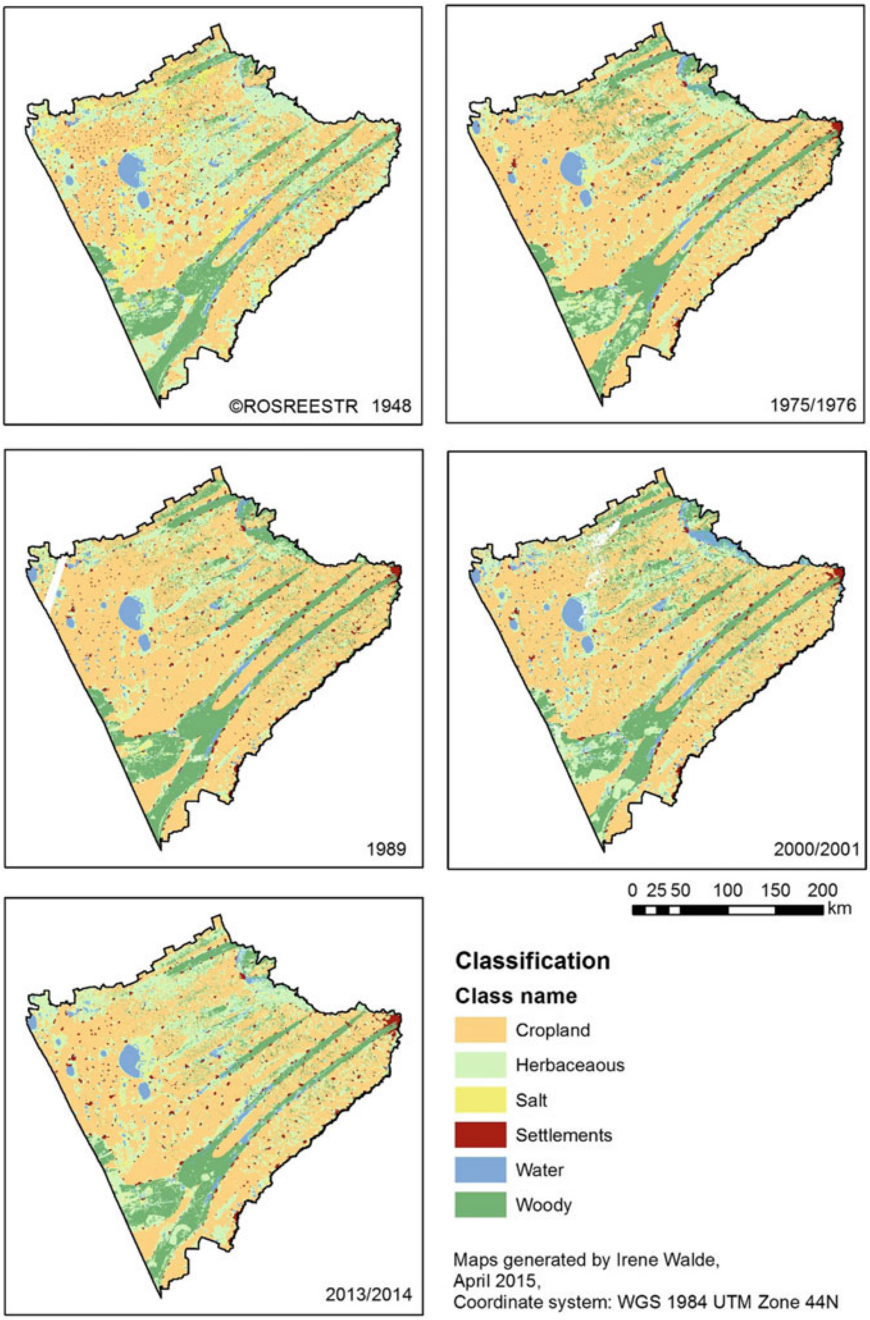


Fig. 9.3 LULC maps of the KULUNDA study area for 1948, 1975/1976, 1989, 2000/2001, and 2013/2014

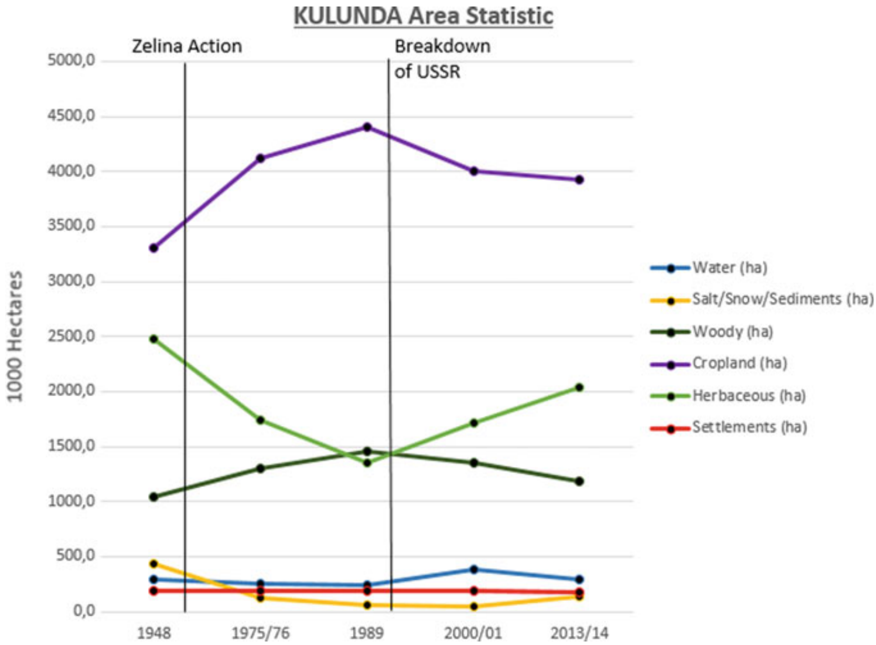


Fig. 9.4 LULC statistic of the KULUNDA study area in 1000 ha for 5 points in time from 1948 to 2014 together with two important political impacts Zelina action and breakdown of the USSR indicated by vertical lines

Figure 9.4 shows the total area for all six LULC classes for each Rayon for each year of the classification. It should be noted that the Rayons on the southern border are not completely within the KULUNDA study site and are clipped at the river Alej. This could have introduced errors into the comparison of the statistical values. Several of the Rayons were also created within the years of analysis; other Rayon borders were shaped differently. These changes in Rayon border shape were not taken into account. The present borders for the Rayons were used for all classifications.

In general, cropland appeared to peak in 1989 and to decline after the breakdown of the USSR in 1991.

A steppe-type analysis for the classes of cropland and herbaceous areas was also performed. Analysing the amount of cropland area per steppe type (Fig. 9.5) revealed the steepest slope for the increase in agricultural areas for the dry steppe. For all three steppe types, there is a visible gain in cropland areas until 1989, along with a loss in cropland until the present day. The opposite is true for herbaceous areas, as shown in Fig. 9.6. Herbaceous areas in the three steppe types decreased until 1989, with larger decreases in dry and forest steppe than in typical steppe. The time frame from 1989 onwards shows the strongest increase in herbaceous areas for the dry steppe. From 2000/2001 to 2013/2014, a strong increase in herbaceous areas in the forest steppe is shown; this is likely due to the flooding of the Ob and its floodplains in May 2000

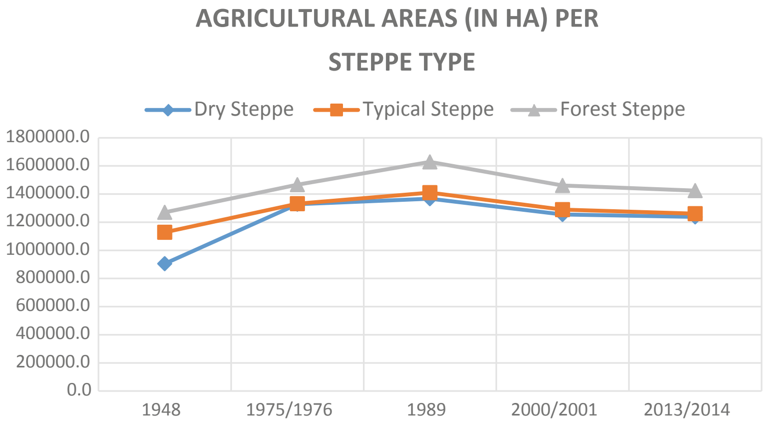


Fig. 9.5 Agricultural areas by steppe type in hectare from 1948 to 2014

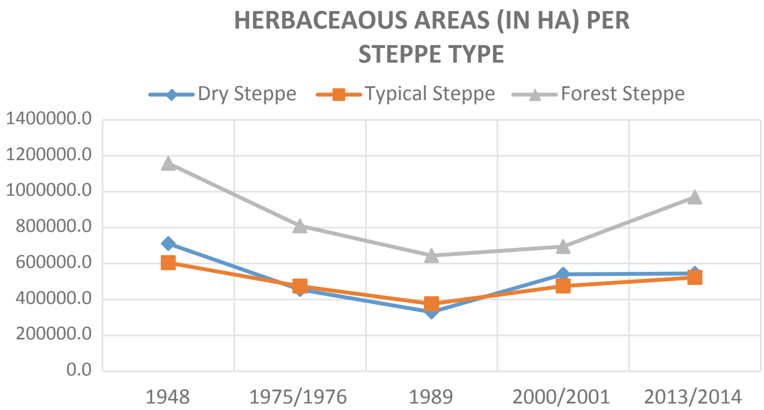


Fig. 9.6 Herbaceous areas by steppe type in hectare from 1948 to 2014

(as indicated in satellite data). Broad areas that were classified as water in 2000/2001 were classified as herbaceous areas in 2013/2014.

9.5.3 Land-Cover/Land-Use Change Statistics

In Fig. 9.7, the relative changes are given. The bars represent 100% of each LULC class in the succeeding year, while the colours within each bar express the percentage of each LULC class for the preceding year. The settlements, for example, gained a relatively large amount of area between 1948 and 1975/1976 (upper-left bar chart), with mostly herbaceous and cropland areas being converted into settlements.

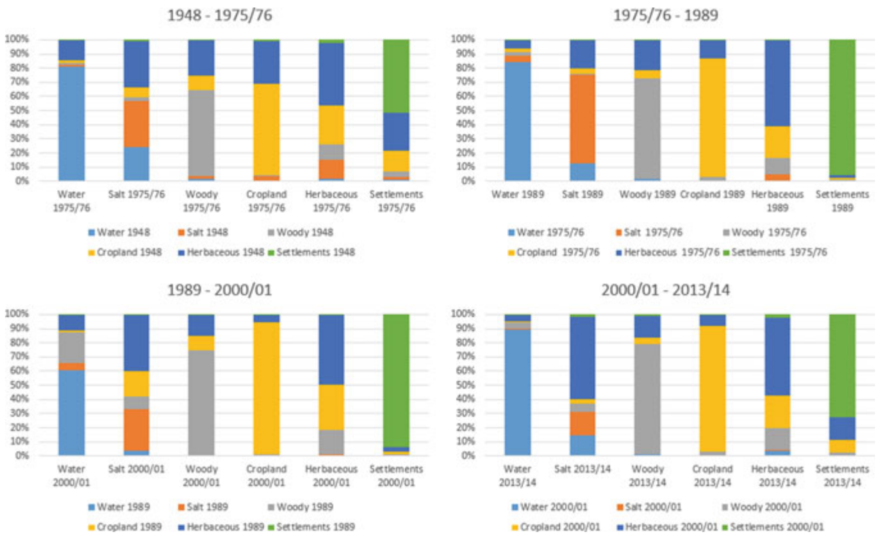


Fig. 9.7 Relative changes of LULC classes in 1948 to 1975/1976, 1975/1976 to 1989, 1989 to 2000/2001 and 2000/2001 to 2013/2014. The bars represent 100% of each LULC class in the succeeding year, while the colours within each bar express the percentage of each LULC class for the preceding year

The salt class was very variable throughout the change analysis, and changes often co-occurred with herbaceous areas and water. Cropland was relatively stable for 1975/1976–1989, 1989–2000/2001, and 2000/2001–2013/2014. The area of herbaceous land also varied throughout the years of the study period. Because of the high potential for the misclassification of herbaceous land as cropland, the highest error propagation potential is within those two classes.

9.6 Validation

Table 9.3 summarizes the overall accuracies of the classification results before and after manual reclassification. It shows that it was necessary to perform a manual reclassification due to the error combination within the change analysis concept. The overall accuracy is clearly improved after a manual reclassification and achieved the values of 94–95%, while the results without reclassification show an accuracy of 77–87%.

Accuracy information for the derivation of the historical agricultural map from topographic maps is not possible due to missing reference data sets. Table 9.3 gives error values from best spatial error correlation (overlap) and worst spatial full de-correlated error combination. Following Stow et al.'s (1980) method, the overall accuracies from the single classifications were also multiplied. Minimum and max-

Table 9.3 Overall accuracies before and after manual reclassification

Classification data	Before manual reclassification	After manual reclassification
	Overall accuracy (%)	Overall accuracy (%)
1975/1976—Landsat 1/2	77	95
1989—Landsat 4/5	87	94
2000/2001—Landsat 7	79	95
2013/2014—Landsat 8/RapidEye	77	95

Table 9.4 LULC change map accuracies after Stow et al. (1980) in combination with minimum and maximum error values

Change map	Accuracy after Stow et al. (1980) (%)	Min–Max error range (%)
1975/1976–1989	89	89–94
1989–2000/2001	89	89–94
2000/2001–2013/2014	90	90–95
1975/1976–2013/2014	90	90–95

imum error values are given in Table 9.4. The results show a good accuracy of 89–90%, improved with the newer change maps.

9.7 Water Surface Change and Settlement Change (Performed by IWEP)

To study the dynamics of desertification in the Kulunda steppe, a retrospective analysis of topographic maps and space images for different years was made on two regional test areas, i.e. Kulundinsky and Mikhailovsky municipal units (Fig. 9.8) (Kurepina et al. 2016).

Topographic maps (scale 1:200,000; years of survey: 1933–1937, 1939–1947 and 1983–1986, ©Roskartografiya) and satellite images with a 30-m spatial resolution from Landsat archives (Google Earth, https://www.google.com/earth/) (http://earthexplorer.usgs.gov/) were used.

Topographic maps as an information source comprise remote-sensing data, statistical indices and some data on natural and socio-economic objects, including their change in time. The retrospective analysis involves the material for an 80-year period. Natural (i.e. lakes, which represent the majority of hydrographic information, and forests) and anthropogenic (forest shelterbelts, settlements) objects were chosen as indicators of desertification.

Hydrographic objects are responsive to both the amount of precipitation and anthropogenic impact that eventually affects the water level and the coastline of the reservoirs.

Fig. 9.8 Layout of model municipal units in physiographic steppe provinces of Altai Krai. Physico-geographical zoning of the territory was performed by IWEP SB RAS (Vinokurov et al. 1988, 2016)

Settlements served as one of key anthropogenic indicators in our investigation. Though it plays an indirect role in assessing the desertification dynamics of the Kulunda steppe, nevertheless, the change in the number of settlements, their areal characteristics and spatial arrangement clearly demonstrates the change in population concentration, its economic activity, and ultimately the impact on the environment that in turn leads to the increased desertification of the territory.

Topographic maps and space images converted into a digital format were used for further analysis. The retrospective analysis of lake states was made via comparison of water surface areas, whereas of forest shelterbelts by their extension that was automatically generated by GIS approach. We used ArcGIS to process analytical data, to integrate them into a single coordinate system followed by further simulation as well as to display the results.

The characteristics of the selected test areas are specified below.

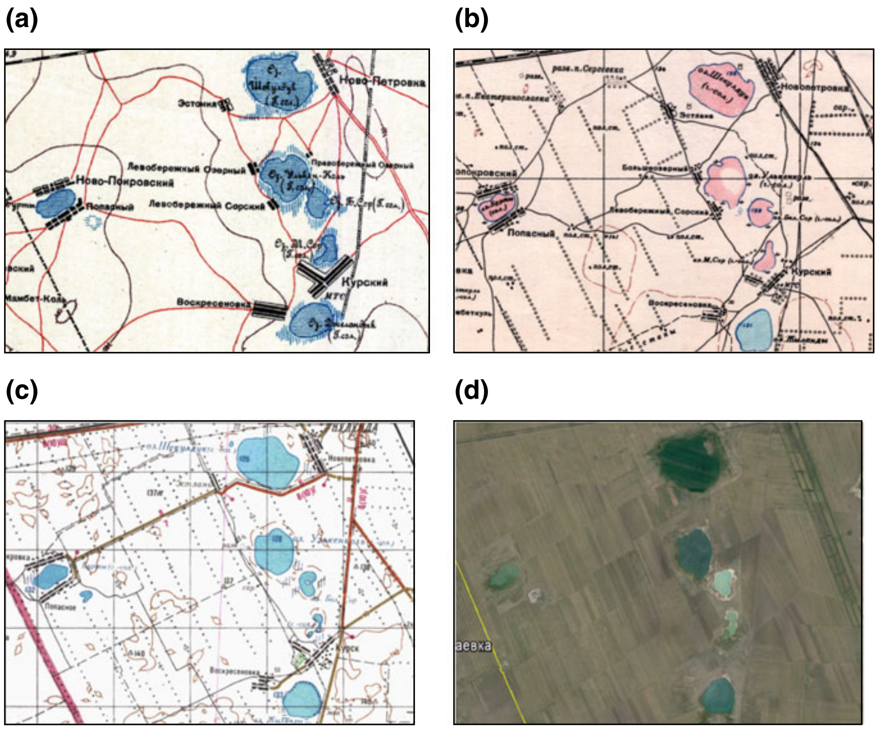


Fig. 9.9 An example of source materials for south-western part of KMR. Fragments of topographic maps: **a** Years of survey 1937, **b** 1946, **c** 1980; **d** Landsat space image of 2013

Kulundinsky municipal unit (KMU) was founded in 1938; its area is 1980 km^2, population 22,223 people. Administrative centre is v. Kulunda (founded in 1918) (http://www.altairegion22.ru/territory/regions/culrain). A total of 32 settlements were registered in KMU. A graded relief with numerous residual depressions is partially occupied by 25 brackish and salt lakes: Shekulduk, Zhira, Gor'kiye Kil'ty, Ulkenkol' and B.Shklo are the largest ones.

Mikhailovsky municipal unit (MMU) was founded in 1941; it borders with the Republic of Kazakhstan; its area is 3114 km^2, with a population of 19,844 people. Administrative centre is v. Mikhailovskoye (founded in 1878) (http://mhlaltay.ru/about/historical_note). As of 27 June 2016, MMU numbered 11 settlements. The northern part of the unit is similar to that in KMU; it is distinguished by a graded relief with numerous lake depressions.

Topographic maps (years of survey: 1933–1937, 1939–1947 and 1980–1986) served as the source material for the analysis of KMU (Fig. 9.9), the current state of which was defined with the use of synthesized images (from Landsat archival data 2003–2004, 2007, 2013, 2016).

We used topographic maps of the years: 1941–1945 and 1983–1985 (©Roskartografiya) as the source data for MMU study within its present boundaries. The current state of MMU was identified based on the synthesized images (from Landsat archival data 2003–2004, 2007, 2013, 2016).

When analysing the reduction in the lake area induced by desertification, we realized that the coastline position and the surface area are quite dynamic and depend on many factors. On the one hand, it is natural ageing and degradation (shallowing) of a water body due to the inflow of minerals (erosion products from the catchment) and biogenic (overgrowing) material. To some extent, such a phenomenon can be considered as desertification naturally deteriorating the water-resource potential of the territory.

It should be noted that some factors hinder the identification of coastline behaviour regularities. In particular, these are changes in average annual precipitation (from year to year) and intra-annual irregularity of precipitation in different parts of the study area, especially noticeable for small shallow water bodies.

The comparison shows the reduction in the water area in most lakes (Table 9.5; Fig. 9.10a, b) from 1933–1937 to 1984–1986 with its insignificant increase in 1939–1947 due to uneven precipitation distribution throughout the region during this period.

The study of the last analysed period (2003–2016) was backed solely by space images; there was an increase in the area of seven reservoirs (compared to 1933–1937) that correlates with a general increase in the precipitation amount in the area for the studied period.

In MMU, there are two groups of named lakes, 27 of which are represented on topographic maps (scale 1:200,000) (Fig. 9.10). The northern group of lakes (1/3) is located close to the plain, while the rest (2/3) are situated in dune slacks and broad flat lowlands of deltas of ancient flow gullies. Lakes Malinovoye, Gornostalevo, Ushivka, Danai and Iodnoye have the largest water surface area.

The results of the analysis of water area change in MMU reservoirs are even more revealing. The area change of 16 lakes is consistently regressive. In 2003–2016, the water area in 10 lakes increases a bit, not reaching, however, the initial level; only two water bodies with the area less than 1.0 km^2 show a slight increase that is evidence of continued desertification of the steppe territories. Natural woody vegetation in KMU is scarce; there are only artificial plantations—forest shelterbelts.

Though shelterbelts planting in the Kulunda steppe started in the late 1920s (Ishutin 2005), they are not represented on maps of the 1930s (see Fig. 9.10a). In succeeding years, there occurred ups and downs in forest management depended on socio-economic situations and desertification development. According to maps of the 1940s, the total amount of forests is 212 with a total length of over 452.8 km (see Fig. 9.9b); by the year 1960—247; in 1961–1980, it makes up 3691. In 1981–1990, only 134 forests were planted which along with poor forest management brought about the degradation of existing trees. Topographic maps of the 1980s (scale 1:200,000) demonstrate only 373 forest belts of 1162.3 km long (Fig. 9.9). In 1999–2000, a total of 405 forest belts were planted in KMU (Ishutin 2005).

Table 9.5 Changes in water surface area (km^2) of lakes in KMU

Name[a]	Mineralization	Time series			
		1933, 1937	1939, 1941–1947	1984–1986	2003–2004, 2007, 2013, 2016
1. Zhira (Dzhira, Dzhiry)		7.2	7.7	6.9	6.6
2. Shekulduk	br.l.	6.9	6.7	6.3	7.7
3. Karakul’	br.l.	4.6	3.3	2.9	3.4
4. Gor’kiye Kil’ty (Kelyty)	br.l.	4.2	4.4	3.8	4.7
5. Ul’kenkol’ (Ul’ken-Kol’, Ul’ken-Kul’, Ul’kenkul’)	br.l.	4.0	3.8	3.6	4.3
6. Bol’shoye Shklo (Bol’shoye Shklo-Ushkaly)[b]	s.l.	3.2	2.9	2.6	3.4
7. Zhylandy (Dzhelandy, Dzhelandyk, Zhilandy)		2.9	3.0	2.8	3.1
8. Belen’koye	br.l.	2.0	1.6	1.0	1.4
9. Sintas (Sintaz)	s.l.	2.0	1.5	2.2	1.1
10. Maloye Shklo (Shklo)	s.l.	1.9	1.8	1.9	2.1
11. Burty	br.l.	1.8	1.8	1.4	1.8
12. Bol’shoi Sor (B. Sor)	br.l.	1.3	1.4	0.8	1.2
13. Maly Sor	br.l.	1.0	0.9	0.3	0.7
14. Mezgil’	br.l.	0.9	0.7	1.6	0.4
15. Presnye Kil’ty (Kel’ty)		0.8	0.6	0.6	1.3
16. Malye Tabuny		0.5	Solonchaks	0.2	0.2
17. Gor’koye (Kaki)	br.l.	0.3	0.3	0.6	0.3
18. Tazakul’ (Tushtykul’; (Taza-Kul’)		0.3	0.3	0.3	0.3

[a]The table list contains only named lakes from topographic maps of scale 1:200,000
[b]Outdated names of lakes from multi-temporal topographic maps are given in brackets

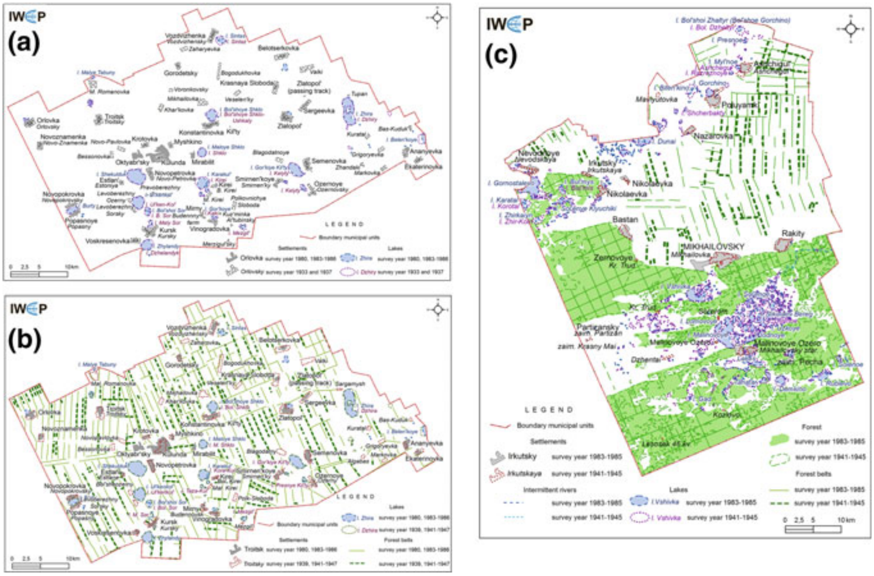


Fig. 9.10 Time history of desertification indicators by multi-temporal data: for KMU—boundaries of lakes and settlements (**a**), forest belts (**b**); for MMU—boundaries of lakes, settlements and forest belts (**c**)

The situation with the forest management in KMU and MMU is similar. The forest degradation caused by lack of human maintenance and poor management, trampling down of forests by livestock and unauthorized felling dramatically accelerate the process of desertification.

In the southern part of MMU, a relict pine forest grows on sands of deltas of ancient flow gullies. The retrospective analysis was conducted based on the quantitative characterization of the area occupied by forest. Within the present boundaries of the region, this indicator amounted to 765.8 km^2 in 1945; by 1983, it increased up to 1006.5 km^2 due to recovery of extensive burnt woods (see maps of 1945) to the state of light or even full-pine forests. Meanwhile, it was impossible to reveal desertification effects.

Considering next the results of the analysis of changes in residential structure:

The greatest number of settlements in KMU (52) is displayed on the maps of the 1930s. Settlements appeared due to peasant and internal migration (1901–1917), adoption of the settled way of life by Altaians and Kazakhs, and railway construction (1913). Their number varied with time: on the maps of 1940s there are 48 settlements, in 1980s—31, in 2000—30 (Fig. 9.11a). The largest regional centres are Kulunda (11.72 km^2), Zlatopol (2.40 km^2) and Kursk (2.26 km^2). The area of the remaining settlements makes up less than 2 km^2.

In MMU, the largest number of settlements (21) is present on maps of the 1940s (see Fig. 9.10). Currently, there are 11 settlements in the region (Fig. 9.11b). The

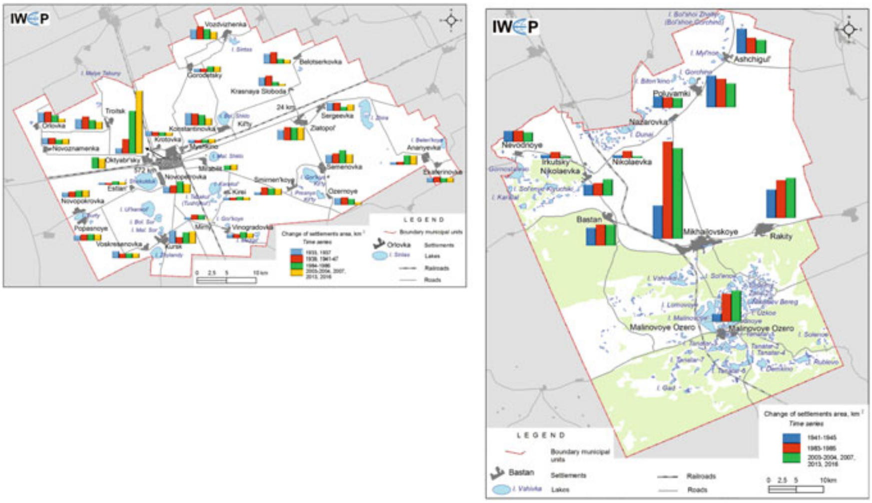


Fig. 9.11 Current placement and change of the settlement area according to synthesized Landsat images for the 2000 s

largest regional centres are Mikhailovskoye (12.6 km^2), Rakity (5.7 km^2), Lake Malinovoye (4.3 km^2), v. Poluyamki (3.4 km^2) and v. Bastan (2.9 km^2).

The analysis of topographic maps and images for different years of survey, fixing the situation at a certain time, can be used for the assessment of the desertification intensity.

The conducted research allows us to draw the following conclusions:

– the studied indicators (water, forests, residential areas) derived from multi-temporal cartographic maps and space images can be used for the assessment of desertification dynamics;
– as direct indicators, natural water objects that are area reduced because of desertification, are the most informative ones;
– the analysis of reservoirs with an area of more than 2.0 km^2 gives the best results. The area of small (<2.0 km^2) water bodies strongly depends on numerous factors; the analysis of their dynamics can be used as an auxiliary material, emphasizing, for example, the precipitation field heterogeneity as an indicator of the areal non-uniformity of desertification process.

The dynamics of artificial afforestation makes it possible to evaluate two different, but interrelated processes, i.e. natural degradation of forest (desertification) and efforts of the society to combat desertification and to create more favourable ecological conditions for its existence.

The history of structure and size of settlements is closely related to the changes in both of living conditions due to the desertification (e.g. falling groundwater levels and wells drying caused by water body shrinkage) and socio-economic conditions and priorities, including planned merges of farms and settlements.

Acknowledgements This project was financed by the German Federal Ministry of Research and Education (funding No: 01LL0905K). This work is based on the results of research work carried out in the scope of the German–Russian project KULUNDA. We want to thank the IWEP in Barnaul, supporting our research and for their assistance with both organizing and conducting our field campaigns. Their always cooperative communication is very much appreciated. We are deeply grateful for the RapidEye data provided by DLR as part of RESA RapidEye Science Archive initiative (RESA Project 501). The authors would also like to acknowledge the NASA Goddard Space Flight Centre and the US Geological Survey for their open data policy, which made this work possible.

References

Breiman L (2001) Random forests. Mach Learn 45(1):5–32

Di Gregorio A (2005) Land cover classification system software version 2: based on the orig. software version 1. Environment and natural resources series Geo-spatial data and information, vol 8, rev edn, Rome

Fleischer E, Khashimov I, Hölzel N, Klemm O (2016) Carbon exchange fluxes over peatlands in Western Siberia: possible feedback between land-use change and climate change. Sci Total Environ 545–546:424–433

Foley JA, Defries R, Asner GP, Barford C, Bonan G, Carpenter SR et al (2005) Global consequences of land use. Science 309:570–574

Fuchs R, Herold M, Verburg PH, Clevers JGPW (2013) A high-resolution and harmonized model approach for reconstructing and analysing historic land changes in Europe. Biogeosciences 10(3):1543–1559

Fuchs R, Verburg PH, Clevers JGPW, Herold M (2015) The potential of old maps and encyclopedias for reconstructing historic European land cover/use change. Appl Geogr 59:43–55

Godet L, Thomas A (2013) Three centuries of land cover changes in the largest French Atlantic wetland provide new insights for wetland conservation. Appl Geogr 42:133–139

Gonzalez-Puente M, Campos M, McCall MK, Munoz-Rojas J (2014) Places beyond maps; integrating spatial map analysis and perception studies to unravel landscape change in a mediterranean mountain area (NE Spain). Appl Geogr 52:182–190

He C, Zhang Q, Li Y, Li X, Shi P (2005) Zoning grassland protection area using remote sensing and cellular automata modelling—a case study in Xilingol steppe grassland in northern China. J Arid Environ 63:814–826

Houghton RA, House JI, Pongratz J, van der Werf GR, DeFries RS, Hansen MC, Le Quéré C, Ramankutty N (2012) Carbon emissions from land use and land-cover change. Biogeosciences 9:5125–5142

Ishutin YN (2005) Lesopolosy v Kulundinskoy stepi (Shelterbelts in the Kulunda steppe). Publ Altai State University, Barnaul (in Russian)

Jawarneh RN, Julian JP (2012) Development of an accurate fine-resolution land cover timeline: Little Rock, Arkansas, USA (1857–2006). Appl Geogr 35(1–2): 104–113

Kühling I, Broll G, Trautz D (2016) Spatio-temporal analysis of agricultural land-use intensity across the Western Siberian grain belt. Sci Total Environ 544: 271–280

Kuemmerle T, Radeloff VC, Perzanowski K, Hostert P (2006) Cross-border comparison of land cover and landscape pattern in Eastern Europe using a hybrid classification technique. Remote Sens Environ 103:449–464

Kurepina NY, Tsimbalei YM, Plutalova TG, Tsilikina SV (2016) Otsenka dinamiki opustynivaniia territorii na osnove retrospektivnogo analiza topo- i kosmokartmaterialov (na primere ob"ektov kulundinskoi stepi) [Evaluation of desertification dynamics based on retrospective analysis

of maps and space images (Kulunda objects as a case study)]. In: Izvestiya of Altai Regional Department of the Russian Geographical Society, vol 4, issue 43, pp 30–43 (in Russian)
Marull J, Tello E, Wilcox PT, Coll F, Pons M, Warde P et al (2014) Recovering the landscape history behind a Mediterranean edge environment (The Congost Valley, Catalonia, 1854–2005): the importance of agroforestry systems in biological conservation. Appl Geogr 54:1–17
Meyer BC, Schreiner V, Smolentseva EN, Smolentsev BA (2008) Indicators of desertification in the Kulunda Steppe in the south of Western Siberia. Arch Agron Soil Sci 54(6):585–603
Meinel HT (2002) Die geoökologischen Folgewirkungen der Steppenumbrüche in den 50er Jahren in Westsibirien. Ein Beitrag für zukünftige Nutzungskonzepte unter besonderer Berücksichtigung der Winderosion (The geoecological consequences of the steppe breaches in the 1950s in Western Siberia. A contribution to future usage concepts with special consideration of wind erosion). Dissertation. Martin Luther University of Halle-Wittenberg. Available at: http://sundoc.bibliothek.uni-halle.de/diss-online/02/03H082/t1.pdf (in German)
Official site of Altai Krai (YEAR) Kulundinsky region. http://www.altairegion22.ru/territory/regions/culrain/. Accessed
Official site of Administration of Mikhailovsky region (YEAR). Istoricheskaia spravka (historical note). http://mhlaltay.ru/about/historical_note/. Accessed
Orczewska A (2009) Age and origin of forests in South-western Poland and their importance for ecological studies in man-dominated landscapes. Landscape Res 34:599–617. https://doi.org/10.1080/01426390903184579
Skaloš J, Weber M, Lipský Z, Trpaková I, Santráěková M, Uhlírová L et al (2011) Using old military survey maps and orthophotograph maps to analyse long-term land cover changes e case study (Czech Republic). Appl Geogr 31:426–438
Skokanová H, Havlíček M, Borovec R, Demek J, Eremiášová R, Chrudina Z et al (2012) Development of land use and main land use change processes in the period 1836–2006: case study in the Czech Republic. J Maps 8:88–96
Stow DA, Tinney LR, Estes JE (1980) Deriving land use/land cover change statistics from Landsat: a study of prime agricultural land. In: Proceedings of the 14th international symposium on remote sensing of environment held in Ann Arbor in 1980 (Ann Arbor, Michigan: Environmental Research Institute of Michigan), pp 1227–1237
Stadelbauer J (1987) Neuland und Getreideversorgung. Möglichkeiten und Grenzen agrarpolitisch motivierter Raumerschließung in den Steppen der Sowjetunion, der VR China und der Mongolischen VR (New land and grain supply. Possibilities and limits of agricultural policy-driven spatial development in the steppes of the Soviet Union, the People's Republic of China and the Mongolian People's Republic). In: Albert-Ludwigs-Universität Freiburg (ed) Hungersnöte. Freiburger Universitätsblätter 96. Rombach, Freiburg, pp 129–145. Available at: http://www.freidok.uni-freiburg.de/volltexte/4262/pdf/Stadelbauer_Neuland_und_Getreideversorgung.pdf (in German)
Tucci M, Giodano A (2011) Positional accuracy, positional uncertainty, and feature change detection in historical maps. Results of an experiment. Comput Environ Urban Syst 35:452–463
Van Eetvelde V, Antrop M (2009) Indicators for assessing changing landscape character of cultural landscapes in Flanders (Belgium). Land Use Policy 26:901–910
Vinokurov YI, Agafonova NA, Pudovkina TA, Tsimbalei YM et al (1988) Prirodno-meliorativnaia otsenka zemel' v Altaiskom krae (Natural and reclamation evaluation of lands in Altai Krai). IG SB RAS, Irkutsk (in Russian)
Vinokurov YI, Tsimbalei YM, Vinokurov YI, Lubenets LF, Tsilikina SV, Kurepina NY (eds) (2016) A landscape map of Altai Krai (map). (1:500,000). IWEP SB RAS, Barnaul
WWU Münster (2011) SASCHA Project-Institute of Landscape Ecology. http://www.uni-muenster.de/SASCHA/en/project/index.html. Accessed 9 May 2015
Yang X, Zheng X-Q, Chen R (2014) A land use change model: integrating landscape patter indexes and Markov-CA. Ecol Model 283:1–7
Zanoni L, Gurnell A, Drake N, Surian N (2008) Island dynamics in a braided river from analysis of historical maps and air photographs. River Res Appl 24:1141–1159

Chapter 10
Influence of Agricultural Reclamation on Vegetation Cover and Biodiversity in the Forests and Steppes of Kulunda

M. M. Silantyeva, N. V. Elesova, I. Hensen, T. A. Terekhina, A. Yu Grebennikova and N. V. Ovcharova

Abstract Throughout Eurasia, steppes are preserved in forms of small fragmented areas within the landscapes of tilled fields, fallow lands, pastures, and infrastructural complexes. In Kulunda, steppes are preserved owing to the areas of alkaline steppe with saline soil complexes as well as secondary steppes formed in uncultivated lands. Intensive agriculture in the steppe and forest-steppe areas of Kulunda exerts the most significant impact such as total plowing of fertile lands, overgrazing by excessively numerous livestock, and inadequate agricultural technologies for certain agroclimatic and landscape-ecological conditions. This led to a whole range of consequences: destruction, fragmentation, and ecotonization of steppe communities, direct extermination of key plant species, forest and birch kolki clearance, biota unification and introduction of alien species, reduction of species and cenotic diversity in steppes as well as destruction of their structure and loss of self-regeneration and self-regulation ability. The start of human influence dates back to the Neolithic age (the cattle-raising stage of the territory development). However, the most devastating impact began in the twentieth century with the arable farming stage. Almost all tillable lands were plowed at the time of Stolypin's agrarian reform in the beginning of the twentieth century and during the years of Khrushchev's land reclamation campaign 1954–1955. Nowadays, agroecosystems have been formed in the places of former natural steppe ecosystems. The influence of agricultural reclamation on the vegetation cover and biodiversity distribution in the steppe and forest-steppe areas of Kulunda is to a large extent studied and documented.

Keywords Agriculture · Agroecosystem · Reclamation · Invasive species · Steppe · Forest · Kulunda · Siberia

M. M. Silantyeva (✉) · N. V. Elesova · T. A. Terekhina · A. Y. Grebennikova · N. V. Ovcharova
Faculty of Biology, Altai State University, Prospect Lenina 61, 65049 Barnaul, Russian Federation
e-mail: msilan@mail.ru

I. Hensen
Institute of Biology/Geobotany and Botanical Garden, Martin-Luther-Universität Halle-Wittenberg, Am Kirchtor 1, 06108 Halle, Germany

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_10

10.1 Introduction

Worldwide, forests and steppes are transformed or destroyed to a large extent by humans. Nowadays in Russia, steppes are preserved in forms of small fragmented areas within the landscapes of tilled fields, fallow lands, and pastures. In southern Siberia, particularly in the Kulunda region, steppes are additionally preserved within areas of saline soils. Another part of steppes is transformed by high-grazing intensity to such an extent that they cannot be restored without active management measures.

For thousands of years, extensive cattle-breeding was predominant in the Kulunda region. During that time, landscape and microclimate were different as soils were covered by dead remains of steppe plants and did not dry out so strongly. Thus, the air was cooler and moister than today, naturally mitigating the consequences of anticyclonic climate effects such as soil aridization (Gnatovskiy 2010).

Agriculture is the most significant factor for the transformation of steppes that strongly influences both vegetation cover and biodiversity. The consequences of, i.e., total plowing of fertile lands, overgrazing by excessively numerous livestock and/or inadequacy of agricultural technologies for certain agroclimatic and landscape-ecological conditions can be various (Fig. 10.1).

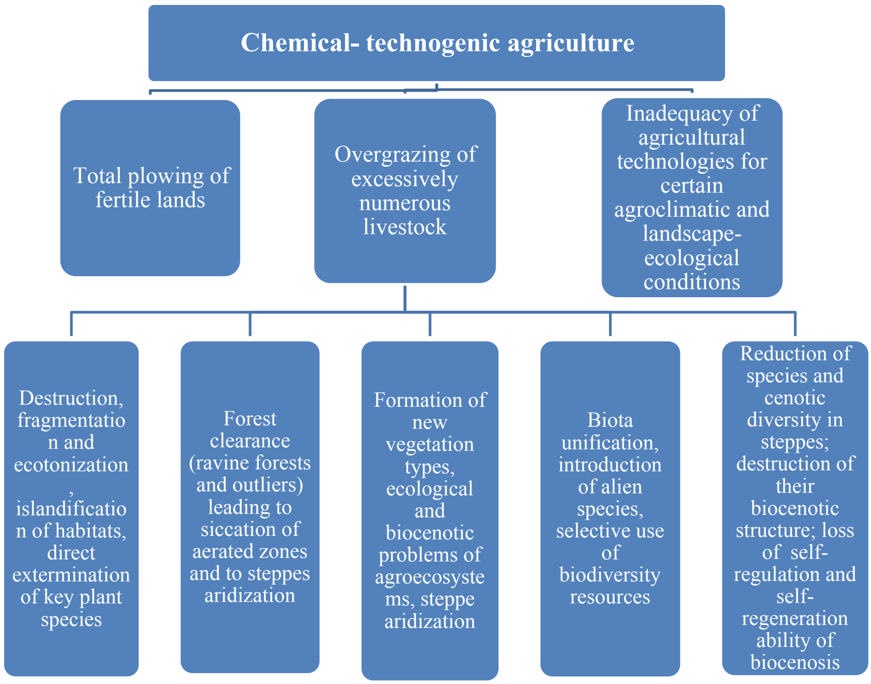


Fig. 10.1 Influence of agricultural reclamation on vegetation cover and biodiversity in the Kulunda region. *Source* Silantyeva, M

10.2 Changes of the Vegetation Cover in Kulunda Due to Agricultural Development

Pasture farming is characterized by local pasture degradation and by uncontrollable autumn burnings for the purpose of preparing spring pastures. However, before the colonization of the Kulunda region by Russian farmers, these impacts were of a local character. Before the sixteenth century, the land was inhabited by rare groups of nomad stock raising Teleut tribes who only bred cattle. Uncontrolled peasant migration started not earlier than in the first 30 years of the eighteenth century, following dowsers and designated peasants to the Kulunda territory. This gave rise to the process of a wildland reclamation. From the middle of the eighteenth century onwards, agriculture became permanent and the cultivated territories expanded consistently. From the 60s and 70s of the nineteenth century, the region witnessed an increase in the entry of migrants that cut down much of the forest for construction purposes.

Practically, all tillable land was already plowed in the first decade of the Stolypin agrarian reform in the twentieth century. Along with the disappearance of virgin Kulunda steppes, forests were disappearing as well. The first scientific consideration of Kulunda vegetation cover, performed in 1910 (the expedition of the Migratory Administration) showed that extensive areas were already tilled, and even small areas of wildland were very difficult to find (Krylov 1913a, b, 1915; Kuznetsov 1914). The disappearance of forests composed by large birches (mixed with aspen) and low ridge birch forests in the northern part of the Kulunda steppe were particularly highlighted by the authors. In the central part of Kulunda, the woody vegetation was represented by small fragments (hereafter forest outliers) of bushy birches developing as coppice shoots and by outliers consisting of small bushes of birch and aspen scattered at some distance from each other (Baranov 1927). Secondary steppes developed at the sites of the disappearing forest outliers.

The second turning point in the transformation of the vegetation cover in Kulunda took place in the 50s of the previous century and was connected to the reclamation of wildlands and fallow lands by thousands of Russian immigrants. Most of the remaining steppes were converted to farming land. A total of 2.3 million ha of the true steppes on the southern black soils and the dry steppes on the dark chestnut and chestnut soils were plowed (Frühauf et al. 2004). In 1960, the area of croplands accounted for 7.5 million ha, while at present it accounts for 6.5 million ha (61.3%) out of 10.6 million ha of agricultural lands. This is the largest tillage area among all the regions of the Russian Federation.

In the 60s of the previous century, the geobotanist E.I. Lapshina stated the fact that the elimination of birch forest outliers in Kulunda created the conditions preventing reforestation and promoting the further steppification of the whole deforested territory (Lapshina 1963). Meadow steppes appeared at the sites of the former birch forest outliers, while secondary steppes with halophytes appeared on the unplowed salinized areas. The recent existence of these forest outliers could be traced only by lignified leftovers within forb meadow vegetation, scattered among tilled fields and areas of fescue-feather grass steppes. Under the arid conditions of the southern forest-steppes, forest outliers were indicated by saucer-like hollows ranging from 10 to 100–200 m in diameter and of different depths situated on the elevated relief elements where the drainage was better and without salinification ("kolki vegetation"; Lapshina 1963).

In 2012, we tried to find remains of natural vegetation, described during the field work of the Migratory Administration by P.N. Krylov in cooperation with L.A. Utkin and Reverdatto. Krylov (1915) distinguished 11 areas of steppe vegetation in the Kulunda region (within the modern boundaries of Altai Krai). We have chosen typical wildland spots and—for lack of the latter—fallow lands. With high certainty, we found three remaining areas of those described 100 years ago by Krylov (1916) but did not rediscover the complete species composition. The correspondence between the descriptions of 1913 and 2012 (Silantyeva et al. 2012a, b) varied from 30 to 83%. Species we did not rediscover were: *Aster alpinus* L., *Allium nutans* L., *A. clathratum* Ledeb., *A. globosum* M. Bieb. ex Redoute, *Adonis villosa* Ledeb. and others. At the same time, several steppe grasses were still preserved, such as *Stipa pennata* L., *S. capillata* L., *Festuca valesiaca* Gaudin, *F. pseudovina* Hack. ex Wiesb., *Poa angustifolia* L., and *Helictotrichon desertorum* (Less.) Nevski. Thus, grasses now dominate in the remaining steppe fragments which confirm their high competitive strength (Silantyeva et al. 2011, 2012a, b).

Another part of the agricultural reclamation in Kulunda was the degradation of the vegetation cover as a result of stock-breeding development. Long-term pasture operation led to the fact that most of the rangelands in central Kulunda transited to the third–fourth stages of the pasture degradation scale in the 80s–90s of the twentieth century (see Silantyeva et al. 2012a, b for more details of this classification). This resulted in a strong reduction of pasture yield, as cover of the herbaceous layer decreased from 70% to 40%, and of the amount of litter. Consequently, soil temperatures increased, which led to xerophytization and halophytization of the vegetation cover as a result of the alteration in the topsoil hydrological regime, to the decrease of plants non-resistant to grazing, and to the expansion of resistant, unpalatable weed species. Number of plant species decreased strongly, while coverage of dwarf semishrubs (*Artemisa frigida* Willd., *A. nitrosa* Weber *ex* Stechm., *Atriplex canescens* (Pursh) Nutt.) increased sharply from the second to the forth pasture degradation stages. Repeated studies between 2009 and 2011–2012 showed that under dry steppe conditions, processes of pasture rehabilitation were very slow, even taking into consideration the fact that livestock stocking rates were reduced in the beginning of the twenty-first century (Elesova 1990; Silantyeva et al. 2012a, b).

Observations of recovery processes at several monitoring sites and ecological profiles (Fig. 10.2), situated on the banks of Lake Kulundinskoye (the villages of Znamenskoye and Uspenka, former villages of Demyan Bedniy and Priozernoye, Tabunskiy District), reflect the fact that nowadays the anthropogenic influence is reduced (Elesova 2009; Silantyeva and Elesova 2013). Grazing and haying take place close to the villages, the number of cattle stocks reduced tenfold in comparison with the 80s of the twentieth century, cows and horses breeding prevails, and the number of sheep is low. Impelled recovery influenced the species composition of the

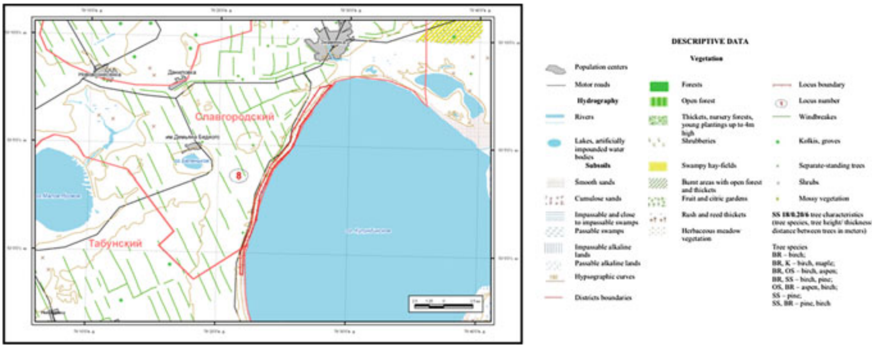


Fig. 10.2 Location of the monitoring sites on the banks of Lake Kulundinskoye. *Source* Kurepina, N. Yu

steppe and meadow communities in a positive way. The number of plants species increased by 1.2–1.5 times owing to the appearance of feather grasses, legumes, and forbs. Coverage of the dominant grass species (*Stipa pennata*, *S. capillata*, *Festuca valesiaca*, *F. pseudovina*, *Puccinellia tenuissima* Litv. ex V.I. Krecz.) improved and so did their average height and bunch diameter. The vertical profile of the fescue steppes lengthened by 15–30 cm (from 25 to 40–60 cm) due to the increase of steppe grass species (mainly fescue and wheat grass), and legumes and forbs reappeared. The main part of the aboveground phytomass concentrated in the 0–30 cm layer (previously 0–15 cm). The general projective cover extended by about 10% in the fescue steppes and by 20–30% in the alkaligrass salt meadows. Thus, the reduction in pasture load positively influenced community productivity. The overall stock of the phytomass increased twice in the fescue pastures and by half in the alkaligrass salt ones (Elesova 2009; Silantyeva and Elesova 2013). However, in the case of *Stipa pennata*, isolation was shown to negatively affect genetic diversity, highlighting that fragmentation can have potentially strong impacts on genetic structure even in natural grasslands (Heinicke et al. 2016).

In summary, the facts mentioned above regarding the changes in the vegetation cover of Kulunda are indicative of the destruction, fragmentation, and ecotonization of plant communities, the reduction of species numbers and cenotic diversity in the steppes, the destruction of their biocenotic structure, and the loss of phytocenoses' self-regulation and self-regeneration ability. Moreover, the elimination of the previously existing forest types (ravine forests and forest outliers) had a significant impact on the development of the steppe vegetation, which led to desiccation and to further aridization of the steppes.

10.3 Current Species Diversity of Agrophytocenoses

More than 200 years of agricultural development gave rise to ecosystems of a new type—agroecosystems—in the place of the former natural ecosystems. Agrophytocenoses appeared, accompanied by a new type of vegetation—agrophyton. However, the prevalence of the chemical-technogenic approach in agriculture in the second half of the twentieth century led to a great reduction in their biodiversity.

The agrophytocenoses in Kulunda as well as all over the world are mostly monocultural. A small number of high-yielding species and breeds are used; mainly cereal crops occupy vast uniform agricultural areas. Beside wheat and corn, people grow sunflower and forage grasses; in the forest-steppe regions of Kulunda, additionally, buckwheat, rye, sugar beet, flax, rapeseed, and soya bean are cultivated. Herbicides are widely used to fight weeds, and fertilizers are used to increase crop yield. The existing traditional technologies of the farming steadily led to soil erosion and dehumification, loss of soil fertility and soil ecosystems biodiversity (Frühauf et al. 2004).

One of the peculiarities of the agrophytocenoses biodiversity in Kulunda is the low species diversity of segetal plants in comparison with European agrophytocenoses, which is due to particular climatic characteristics (Terekhina 2000). In the crops of Kulunda, segetal species comprise not more than 2–3 weed species. Approximately, 150 species are noted in all types of agrophytocenoses, with about 30 species being abundant, i.e., *Chenopodium album* L., *Ch. polyspermum* L., *Salsola collina* Pallas, *Amaranthus retroflexus* L., *A. albus* L, *A. blitoides* S.Wats, *Fallopia convolvulus* (L.) A. Love, and *Corispermum declinatum* Stephan ex Iljin. A distinctive feature of these annual and biennial species is their ability to form long-term persistent seedbanks. In Kulunda, the number of viable seeds in the 0–20 cm layer was found to range from 2000 to 220,000 m^{-2} (Terekhina 2000). During arid years, many species are able to produce seeds already at the stage of the first 2–3 leaves. One individual of a segetal plant might produce up to 15,000 seeds. In addition, the spherical form of the seeds of some weed plants, and their production in the postharvest period, contribute to long-distance seed dispersal, if the wind speed is high enough (Terekhina 2000). In addition, there are perennial weeds, with, e.g., *Convolvulus arvensis* L., *Euphorbia virgata* Waldst. et Kit., *Sonchus arvensis* L., *Mulgedium tataricum* L., and *Vincetoxicum sibiricum* (L.) Decne. being the most widespread. All of them successfully reproduce both by seeds and root suckers, and demonstrate a significant resistance to different groups of pesticides (Terekhina 2000).

10.4 Invasive Species

Immigration of invasive plant species to the Kulunda region was favored by the frequent disturbances characteristic for agrophytocenoses and degraded rangelands. As invasive species are known to transform natural communities, they are considered to be the second significant threat to biodiversity (after habitat destruction). One

(a) (b)

Fig. 10.3 **a** Oleaster (*Elaeagnus angustifolia* L.); **b** The communities formed by the oleaster in the lakeside hollow. *Source* Silantyeva, M. M

example of an invasive tree species is the oleaster (*Elaeagnus angustifolia* L.). Its planting started from 1926 onwards due to specialized agroforestal nursery areas created in Rubtsovsk and Slavgorod, and from 1931 onwards in Kluchi, Rodino, Volchikha, and Blagoveshenka (Paramonov et al. 1997). Being an undemanding and quickly growing species, *Elaeagnus angustifolia* spread rapidly within the steppes of the region. In 10–20 years, it was established even under driest soil conditions and in the salinized areas (Fig. 10.3a, b). Oleaster was the only species surviving within windbreaks where the formerly dominant species such as birch and poplar—and in some places, even the associated species such as green ash, sugar maple, or elm tree—died due to desiccation and salinization.

In the territory of Altai Krai, *Elaeagnus angustifolia* is a "transformer" species that intrudes actively into natural and seminatural communities, changes the ecosystems character, acts as an ecosystem engineer, and becomes highly dominant. References to the "natural oleaster communities" were infrequent just 20 years ago. Nowadays, such communities are validated as a new vegetation type in Kulunda (Silantyeva 2006, 2008).

Among the transformer species, we can also add sumpweed (*Cyclachaena xanthiifolia* (Nutt.) Fresen). It was first registered on the territory of Altai Krai in 1993 in Mikhaylovskiy district (Terekhina 1995a, b) as a ruderal plant. Most probably, it got there with different freights from the direction of Kazakhstan. Within 10 years, the sumpweed spread quickly over the territory of the region. At present, it grows in all anthropogenically transformed phytocenoses of Kulunda (Krasnoborov 2000; Silantyeva et al. 2013a, b).

10.5 Role of Windbreaks in the Vegetation Cover of Kulunda

As steppes and forests in Kulunda were destroyed within a short period of time, people started to create windbreaks, in order to mitigate climatic conditions. Windbreaks were established from 1926 onwards, as a result of the severe drought of 1925, when people were exposed to heavy dust storms for the first time. In 1942, the total tree plantation area in the Kulunda steppe accounted for 32,000 ha, but as the windbreaks were not maintained, they often died due to the lack of attention. The range of the species used at that time was very wide. It included *Populus balsamifera* L., *Populus laurifolia* Ledeb., *Betula pendula* Roth, *Ulmus parvifolia* Jacq., *Ulmus minor* Mill., *Acer saccharum* Marshall, *Fraxinus americana* L., *Larix sibirica* Ledeb., *Pinus sylvestris* L., *Malus baccata* (L.) Borkh., *Caragana arborescens* Lam., *Ribes aureum* Pursh, *Sambucus racemosa* L., *Elaeagnus angustifolia* L., *Hippophae rhamnoides* L., and *Lonicera tatarica* L. (Dyachenko and Zemlyanitskiy 1947). Some of these species have naturalized later and constitute an adventitious component of the Kulunda flora. The problem aggravated after the big land reclamation in the 50s of the twentieth century when dust storms started to blow millions of tons of the soil fertile layer into the air. Therefore, from 1928 to 2002, 200,000 ha of windbreaks were established. In recent years, however, a significant part of the windbreaks has been lost as many of the composing tree species have reached their maximum age and died due to natural reasons. Another reason for their disappearance is anthropogenic factors (burnings, grazing, wood-felling; own observations).

The windbreaks in Kulunda did not only play a significant ecological and landscape role but also became a habitat for a great number of steppe plants. From these “stepping stones,” species spread to the fallows and other degraded communities. Within the windbreaks, such conspicuous and colorful species as the steppe peony (*Paeonia hybrida* L.) were protected (Fig. 10.4). The presence of these windbreaks may contribute to explaining why genetic effects of recent fragmentation were found to be still limited for three long-living steppe species of the Kulunda area (*Adonis villosa* Ledeb., *Jurinea multiflora* (L.) B. Fedtsch. and *Paeonia hybrida*; Rosche et al. 2018).

Fig. 10.4 Steppe peony (*Paeonia hybrida* L.) in front of a windbreak (Mikhaylovskiy district). *Source* Silantyeva, M. M

10.6 Peculiarities of the Species and Cenotic Diversity in Kulunda

Nowadays, the natural vegetation cover of Kulunda is represented by pine forests stretching from the north-east to the south-west; salt steppes; birch forests (mostly outliers); complexes of aquatic and semi-aquatic vegetation, shrub and meadow vegetation used as pastures leading to degradation; and small areas of meadow and true steppes used for haying or grazing. Agrocenoses as a special type of vegetation occupies about 60–90% of the area in Kulunda depending on the district.

Unfortunately, we cannot estimate diversity of the Kulunda flora in the preagricultural period as there are no historical records. At present, the remaining steppes of Kulunda host about 700 plant species, out of which 88 species (about 13%) are adventitious (alien) in this territory. About 50 plant species of the Altai region flora are endemics. Rigid endemics (neoendemics) of the district are *Lotus krylovii* Schischk. ex Serg., and *Puccinella kulundensis* Serg. Most important genera are *Artemisia*, *Carex*, *Potentilla*, *Astragalus*, *Atriplex*, *Allium*, *Juncus*, *Ranunculus*, *Salix,* and others (Silantyeva et al. 2013a, b, c). However, the influence of the agricultural reclamation in connection with the formation of agroecosystems and inadequacy of the agricultural technologies for certain agroclimatic and landscape conditions led to a sharp deterioration and unification of the phytodiversity, intrusion of alien species, and loss of several steppe species.

In the twenty-first century, we have a significantly transformed vegetation cover on the territory of Kulunda. At the same time, the small-area elements of the natural ecosystems are preserved. The transition to green land-use management and agricultural production and the introduction of an adaptive landscape specific agriculture are the key to the resolution of the existing conflict between the further depletion of the natural ecosystems and the decrease in the agricultural efficiency. In the first place, one needs to differentiate between the land-use modes in the steppe area and to expand the natural ecosystems.

References

Baranov VI (1927) Rastitel'nost' chernozemnoy polosi Zapadnoy Sibiri (Opit botaniko-geograficheskoy svodki i rayonirovanie) [Vegetation of the chernozem strip of Western Siberia (experience of botanical-geographical summary and zoning)]. RGO, Western Siberian Branch, Omsk [in Russian]

Dyachenko AE, Zemlyanitskiy LG (1947) Zadachi obleseniya Kulundinskoy i dr. stepey Altayskogo kraya [Afforestation tasks of the Kulunda and other steppes, Altai Krai]. Tr. VNII agrolesomelioratsii. Itogi rabot za 1943–1944 gg. Goslestekhizdat, pp. 15–24. (in Russian)

Elesova NV (1990) Sovremennoe sostoyanie tipchakovikh pastbishh Tsentral'noy Kulundi: Biotsenozi Altayskogo kraya i vliyanie na nikh antropogennykh vozdeystviy [Current state of the fescue pastures in the central Kulunda: Biocenoses of Altai Krai, their exposure to the anthropogenic impact]. Conference Abstracts. Altai State University, pp. 18–21. (in Russian)

Elesova NV (2009) Sovremennoe sostoyanie rastitel'nogo pokrova okrestnostey Kulundinskogo ozera [Current state of vegetation cover in the vicinity of the Kulunda Lake]. In: Shmakov AI, Kamelin RV, Terekhina TA, Silantjeva MM, Dyachenko SA, Smirnov SV, German DA, Kutsev MG (eds) Problemi botaniki Yuzhnoy Sibiri i Mongolii. Altai State University, Barnaul, pp 171–177 (in Russian)

Elesova NV, Silantyeva MM (2013) Geobotanicheskiy monitoring lesnikh soobshhestv raznogo genezisa na territorii Kulundi [Geobotanical monitoring of forest communities of different genesis in the Kulunda territory]. Izvestiya of Altai State University, pp 71–75. (in Russian)

Frühauf M, Meinel T, Belaev V (2004) Ecological consequences of the conversion of steppe to arable land in Western Siberia. Europa Regional 12:13–21

Gnatovskiy VM (2010) Proshloe, nastoyashhee i budushhee Kulundinskoy stepi: Materiali Mezhdun. nauchn.-prakt. konferentsii «Rol' agrarnikh reform P.A. Stolipina v osvoenii Sibiri i Dal'nego Vostoka» [Past, present and future of the Kulunda steppe: materials of the international scientific-practical conference "The role of P.A. Stolypin's agrarian reforms for the development of Siberia and the Far East]. Ltd. TL «Krasnyy ugol», pp 225–235. (in Russian)

Heinicke S, Hensen I, Rosche C, Hanselmann D, Gudkova PD, Silantyeva MM, Wesche K (2016) Fragmentation and environmental constraints influence genetic diversity and germination of Stipa pennata in natural steppes. Flora 224:42–49

Krasnoborov IM (2000) Po povodu nekotorikh vidov vo flore Altayskogo kraya [On the subject of some flora species in Altai Krai]. Turczaninowia, pp 56–57. (in Russian)

Krylov PN (1913a) Rastitel'nost' Barabinskoy stepi i smezhnikh s ney mest Predvaritel'niy otchet o botanicheskikh issledovaniyakh v Sibiri i Turkestane v 1912 g. [Vegetation of the Barabinskaya steppe and the adjoining areas. Preliminary report on the botanical research in Siberia and Turkestan]. St. Petersburg, pp 41–84. (in Russian)

Krylov PN (1913b) Stepi zapadnoy chasti Tomskoy gubernii: Botaniko-geograficheskiy obzor [Steppes of the western part of Tomskaya guberniya: Phytogeographical review]. Tr. pochv.-botan. ekspeditsiy po issled. r-nov Aziatskoy Rossii. Ch. 2: Botan. issledovaniya 1913 g. Petrograd, T 42, Vip 1, pp 1–139. (in Russian)

Krylov PN (1915). K voprosu o kolebanii granitsi mezhdu lesnoy i stepnoy oblastyami (Na materialakh Ob. Irtishskogo vodorazdela (Baraba, Kulunda i dr. sib. mest) [On the subject of the borders fluctuations between the forest and steppe areas (As exemplified in Ob-Irtishskiy water-shed (Baraba, Kulunda and other Sib. areas)] Tr. Botan. muzeya imp. AN. Petrograd, pp. 82–130. (in Russian)

Kuznetsov NI (1914) Ocherk rastitel'nosti Barnaul'skogo uezda. Predvaritel'nyy otchet o botanicheskikh issledovaniyakh v Sibiri i Turkestane v 1913 godu [Vegetation outline of the Barnaulskiy uezd. Preliminary report on the botanical research in Siberia and Turkestan in 1913]. Petrograd, pp. 1–33. (in Russian)

Lapshina EI (1963) Berezovie lesa yugo-vostoka Zapadnoy Sibiri. Rastitel'nost' stepnoy i Парамонов Лесное хозяйство Алтая lesostepnoy zon Zapadnoy Sibiri. [Birch forests of the southeastern region of West Siberia. Vegetation of the steppe and forest-steppe areas in West Siberia.] Novosibirsk: Sibirian branch of the Academy of Sciences of the USSR, pp. 103–130. (in Russian)

Paramonov EG, Menzhulin ID, Ishutin Ya N (1997) Lesnoe khozyaystvo Altaya [Forestry in Altai]. GIPP Altay, Barnaul. (in Russian)

Rosche C, Heinicke S, Hensen I, Silantyeva MM, Stolz J, Gröning S, Wesche K (2018) Spatio-environmental determinants of the genetic structure of three steppe species in a highly fragmented landscape. Basic Appl Ecol 28:48–59

Silantyeva MM (2006) Etapy antropogennoy transformatsii rastitel'nogo pokrova, ispol'zovaniya rastitel'nykh resursov i dinamika formirovaniya adventivnogo elementa flori na territorii Altayskogo kraya [Stages of the anthropogenic transformation of the vegetation cover, plant resources use and dynamics of the flora adventitious element formation in the territory of Altai Krai]. Problemi botaniki Yuzhnoy Sibiri i Mongolii, pp 218–252. (in Russian)

Silantyeva MM (2008) Osnovnie tendentsii i rol' antropogennogo faktora v razvitii rastitel'nogo pokrova v golotsene na territorii Altayskogo kraya [Main tendencies and the role of the anthropogenic factor in the development of vegetation cover in the Holocene on the territory of Altai Krai]. Problemy regional'noy ekologii, pp 143–151. (in Russian)

Silantyeva MM, Elesova NV (2013) Geobotanicheskiy monitoring lesnikh soobshhestv raznogo genezisa na territorii Kulundi [Geobotanical monitoring of the forest communities of different origin on the territory of Kulunda]. Izvestiya Altayskogo gosudarstvennogo universiteta, pp 71–75. (in Russian)

Silantyeva MM, Elesova NV, Shibanova AA, Bondarovich AA, Grebennikova AY (2011) Stepnie soobshhestva Kulundi nachala proshlogo veka i v nastoyashchee vremya (po marshrutam ekspeditsii P.N. Krylova 1913 g.). [Steppe communities in Kulunda in the beginning of the 20th century and nowadays (along the expedition route of P.N. Krylov, 1913)]. *Problemy botaniki Yuzhnoy Sibiri i Mongolii*, pp. 160–163. (in Russian)

Silantyeva MM, Elesova NV, Shibanova AA, Grebennikova AY (2012a) O sovremennom sostoyanii stepnoy rastitel'nosti stepnoy i lesostepnoy zon Altayskogo kraya [On the subject of the current state of steppe vegetation in the steppe and forest-steppe areas of Altai Krai]. Izvestiya Altayskogo gosudarstvennogo universiteta, pp 78–84. (in Russian)

Silantyeva MM, Kharlamova NF, Mironenko ON, Elesova NV (2012b) Sostoyanie rastitel'nogo pokrova Kulundy v usloviyakh izmeneniy klimata i sistem zemlepol'zovaniya [Vegetation cover condition in Kulundy in the context of the climate change and the change in land management systems]. Vestnik Altayskoy nauki, pp 114–118. (in Russian)

Silantyeva MM, Grebennikova AY, Kirina AO, Kosachev PA, Elesova NV, Ovcharova NV, Grebennikova AE (2013a) Novie svedeniya o rasprostranenii redkikh i ischezayushhikh vidov rasteniy, vklyuchennie v «Krasnie knigi» federal'nogo i regional'nogo urovnya na territorii Altayskogo kraya. [New data on the spread of rare and endangered plant species enlisted in the federal and regional Red Books on the territory of Altai Krai] Problemi botaniki Yuzhnoy Sibiri i Mongolii, pp 175–182. (in Russian)

Silantyeva MM, Kharlamova NF, Mironenko ON, Elesova NV, Shibanova AA (2013b) Ekologo-ekonomicheskie problemi stepnogo prirodopol'zovaniya v Kulunde [Eco-economic problems of the steppe nature management in Kulunda]. Vestnik Altayskoy nauki, pp 129–139. (in Russian)

Silantyeva MM, Kosachev PA, Elesova NV, Grebennikova AY, Kirina AO (2013c) Dopolnenie k flore Altayskogo kraya [Addition to the flora of Altai Krai]. Turczaninovia, pp 64–68. (in Russian)

Terekhina TA (1995a) Adventivnie rasteniya vo flore Altayskogo kraya [Adventitious plants in the flora of Altai Krai]. Botanicheskie issledovaniya Sibiri i Kazakhstana, pp 229. (in Russian)
Terekhina TA (1995b) Konspekt flory Kamnya-na-Obi [Flora summary of Kamen-na-Obi]. Botanicheskie issledovaniya Sibiri i Kazakhstana, pp 150–166. (in Russian)
Terekhina TA (2000) Antropogennie fitosistemi [Anthropogenic phytosystems]. Altai State University Press, Barnaul (in Russian)
Titlyanova AA, Kosikh NP (1999) Izmenenie biologicheskogo krugovorota ugleroda v landshaftakh Zapadnoy Sibiri v svyazi s razlichnim ispol'zovaniem zemel'. [Changes in the biological carbon cycle in West Siberian landscapes due to diverse land use]. Geografiya i prirodnye resursi, pp 66–76. (in Russian)

Chapter 11
Physical Soil Properties and Erosion

G. Schmidt, P. Illiger, A. E. Kudryavtsev, N. Bischoff, A. A. Bondarovich, N. A. Koshanov and N. V. Rudev

Abstract Chernozems and Kastanozems are widespread and used for agricultural production in the Altai Krai. The physical properties of these soils are favourable for agriculture because the parent material is mainly composed of silt and fine sand. Humus accumulation is another important factor for the development of stable soil aggregates in the course of soil development. Resulting soils are characterized by a favourable water balance and a good air capacity and are resistant against erosion. Due to the conversion of natural steppe into agricultural land, the natural physical soil properties are damaged with lasting effects. Other soil properties (soil organic matter) are degraded too, and the soil productivity is affected. Mechanical stress can be reduced by using methods of adapted soil management, which in turn improves beside physical also chemical soil properties and, therefore, the soil fertility.

Keywords Soil erosion · Aggregate stability · Soil compaction

---

G. Schmidt (✉) · P. Illiger
Institute of Geosciences and Geography, Martin-Luther-Universität Halle-Wittenberg,
Von-Seckendorff-Platz 4, 06120 Halle, Germany
e-mail: gerd.schmidt@geo.uni-halle.de

A. E. Kudryavtsev
Faculty of Agronomy, Altai State Agrarian University, Prospect Krasnoarmeiski 98,
656049 Barnaul, Russian Federation

N. Bischoff
Institute of Soil Science, Leibniz Universität Hannover, Herrenhäuser Str. 2,
30419 Hannover, Germany

Landesamt für Bergbau, Energie und Geologie (LBEG), Referat L3.2 Landwirtschaft,
Bodenmonitoring Stilleweg 2, 30655 Hannover, Germany

A. A. Bondarovich
Faculty of Geography, Altai State University, Prospect Lenina 61, 656049 Barnaul,
Russian Federation

N. A. Koshanov · N. V. Rudev
OOO Partner, 656056 Poluyamki, Altai Krai, Russian Federation

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations
in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_11

11.1 Introduction

The development of a soil results in its distinct physical properties which determine soil fertility, influence degradation processes, and determine a soil's suitability for agricultural production. As described in Chap. 4, Chernozems and dark and light Kastanozems are the dominant soil types within the research area (Fig. 11.1). Locally different morphological and hydrological characteristics resulted in a multitude of soil-type modifications (Basilevich and Shavrigin 1959; Kovda and Rozanov 1988). The agricultural soil usage is concentrated on areas dominated by Chernozems and Kastanozems (Meinel 2002; Frühauf and Meinel 2014). Furthermore, Podzoluvisols are widespread and developed especially in the forest areas, which are typical for the region. Solonetz developed locally in areas with special morphological (depressions) and groundwater preconditions (Rosanov andKarmanov 1959; FAO 2007). Areas with these soils are usually not used for tillage but occasionally for grazing.

The area-wide parent material consists of aeolian sediments with high contents of silt (45–70%) and fine sand (10–40%). These sediments are highly susceptible to erosion. Due to grassland vegetation and regional climate, large amounts of organic matter are mixed with the sediment and humified in the course of the pedogenesis. The mineralization of organic matter is very slow because of the dry and cold climate which leads to an accumulation of humus which in turn promotes the formation of stable soil aggregates (Illiger et al. 2014). The resulting Chernozems and Kastanozems

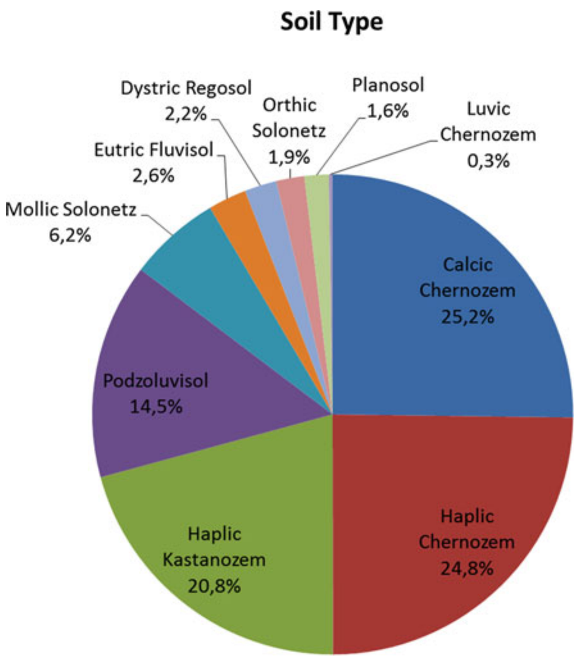


Fig. 11.1 Soil distribution in the research area. *Source* FAO (2007)

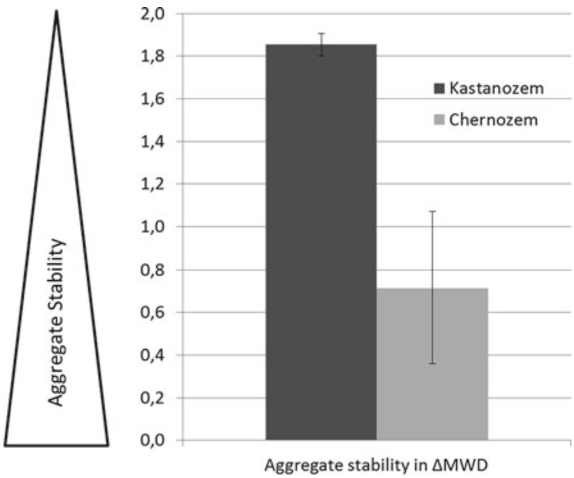


Fig. 11.2 Aggregate stability of quasi-natural Chernozems and Kastanozems

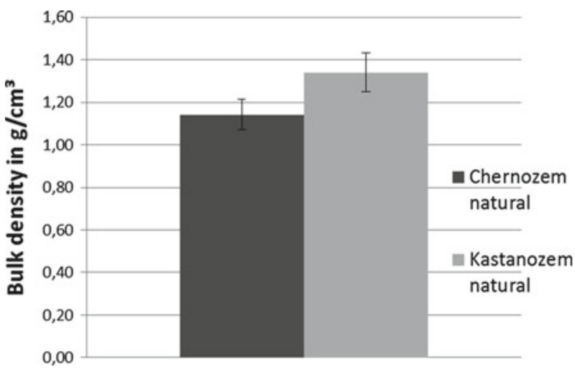


Fig. 11.3 Bulk density of Chernozems and Kastanozems in the Altai Krai

are very resistant to erosion by wind and water. Differences in the erosion resistance between Kastanozems and Chernozems are due to different humus contents, which is the determining factor of the formation of stable soil aggregates (Sect 1.3). The stability of soil aggregates from the forest steppe to the dry steppe decreases, and therefore, the susceptibility to erosion increases at the same time (Basilevich and Shavrigin 1959; Basilevich 1959; Shavrigin 1959; Bischoff et al. 2016; Illiger et al. 2014) (Fig. 11.2).

Despite the same parent material of soil genesis, the Chernozems show a lower bulk density than the Kastanozems (Fig. 11.3). This is caused by the higher content of soil organic matter of the Chernozems (Chap. 13). Bulk density is mainly affected by tillage operations, where minimum and no-till operations lead to higher bulk density at the surface than under conventional tillage (Hill and Cruse 1985; Grant and Lafond 1993; Unger and Jones 1998).

Erosion processes are very slow under natural conditions in Siberia's steppe and only locally very dynamic. The vegetation consisting of grassland and wild herbs

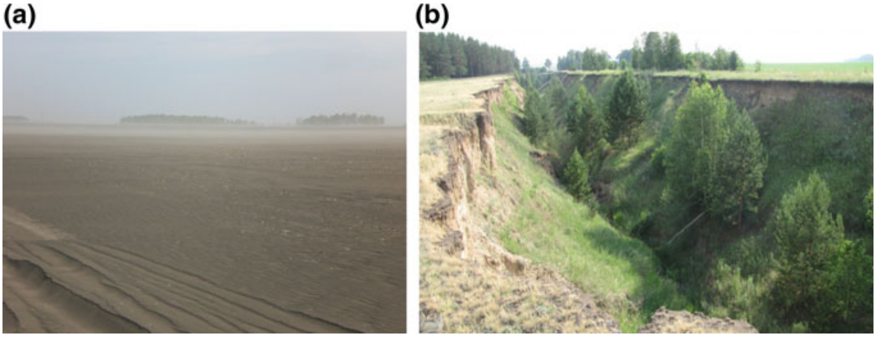


Fig. 11.4 **a** Wind erosion in dry steppe. *Picture source* Meinel (2002). **b** Gully formed by water erosion (ovrag) in forest steppe. *Picture source* Illiger et al. 2014)

offers a natural protection against erosion. Erosion type and intensity depend also on the climate which shows an north-eastern to south-western gradient in the Altai Krai. The precipitation decreases from 500–600 mm in the north-east to only 250–300 mm in the south-west (Schmidt et al. 2016). The temperature amplitude follows an opposite trend. The annual temperature variation increases from the north-east to the south-west. Due to the regional climatic differences, water erosion dominates in the forest steppe and wind erosion in the dry steppe (Fig. 11.4a, b).

11.2 Effects of Agricultural Land Management on Physical Soil Properties

The steppe conversion into arable land was the beginning of grave changes gradually, resulting in a significant soil transformation due to a steady intensification of soil usage (Meinel 2002; Frühauf and Meinel 2014). The physical soil properties are especially affected. The beginning of tillage causes mechanical stress changing the soil structure and subsequently other important physical soil properties like bulk density and aggregate stability, which results in negative transformations of further soil properties. The end of this chain reaction is the extreme soil degradation processes of wind and water erosion.

The soil degradation processes (among them erosion is the most extreme) accelerated with the beginning of the cultivation of the steppe soils in the eighteenth century (Chap. 7) caused by the conversion of the natural steppe soils and regular mechanical stress due to tillage. First, the protective vegetation cover and the stable soil aggregates are destroyed (Fig. 11.4). The removal of biomass during crop yield causes a reduced accumulation of organic matter in the soils. The recurring destruction of the soil aggregates results in a higher susceptibility of the soils to erosion. Furthermore, they are unprotected against the exogenous forces without a protective vegetation

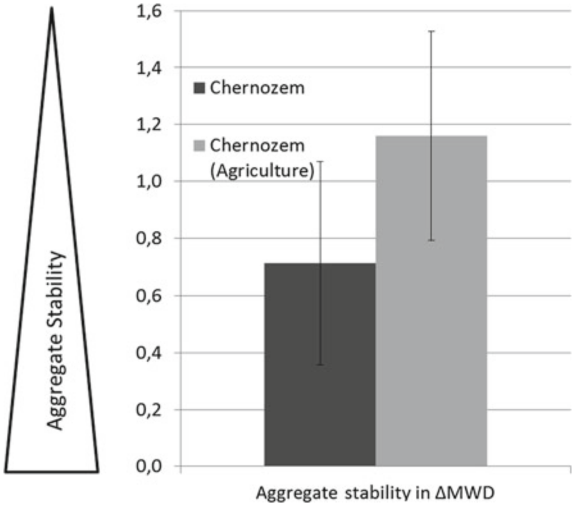


Fig. 11.5 Aggregate stability of quasi-natural Chernozems and Chernozems used for tillage

cover over a prolonged time during a year. Mechanical stress of the soils causes also a changed density and loss of humus. The breakdown of humus leads to a further decreased aggregate stability because humus is an important factor for the formation of stable soil aggregates (Chap. 14). The soil's water retention potential decreases (Chap. 13) and its susceptibility to erosion increases further (Fig. 11.5).

Soil density changes in two ways when conventional, turning tillage is applied (Dammann et al. 2011; Grunwald et al. 2016). The density decreases in the upper part of the ploughed horizon due to a loosening of the soil material. Beneath the plough horizon, the density increases which is caused by the load of the agricultural machinery and tractors. The mechanism can be described quite well based on the results of long-term tests regarding the effects of different tillage intensities on physical soil properties (Kahlon et al. 2013). Figure 11.6a, b displays the vertical change of penetration resistance of no-till and tillage soil. The penetration resistance indicates density differences within a soil profile, which allows conclusions regarding the effects of soil usage on physical soil properties. The results of locations with no-till soils (so-called Salesch) and locations used for tillage were analysed and compared. Salesch are soils which were converted during the Virgin Lands Campaign but were not used for agriculture later. Because of natural succession, these locations are again grasslands.

The data displayed in Fig. 11.6a, b are typical for Chernozems of the dry and typical steppe regions of the Altai Krai. The so-called Salesch, only one time during the Virgin Lands Campaign tilled soil, shows a high stability in the first 10 cm. The soil used with conventional tillage has a low penetration resistance to a depth of approximately 25 cm. The regular tillage disturbs the soil structure in this depth and inhibits the formation of stable soil aggregates. Below follows a compaction zone where the soil density sharply increases. The compaction zone is a limiting zone which is difficult to penetrate for plant roots and soil organisms.

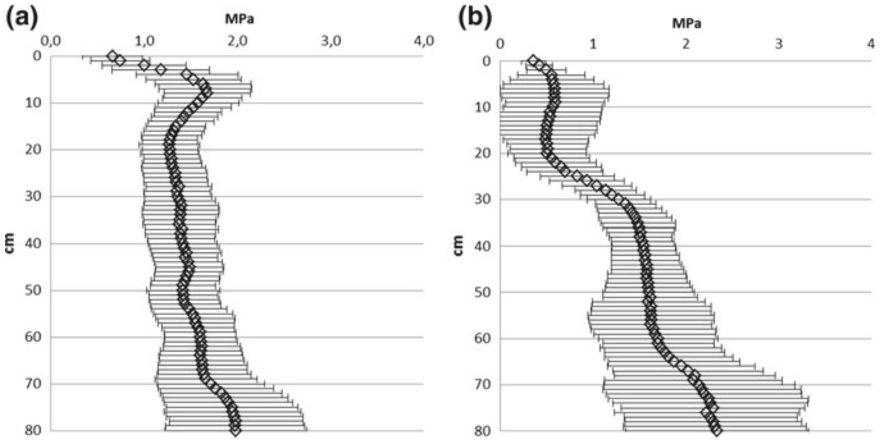
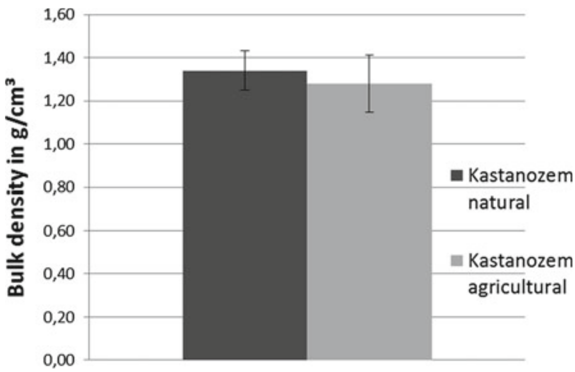


Fig. 11.6 **a** and **b**: Penetration resistance of Chernozems under no-till (left) and under conventional tillage operation (right)

Fig. 11.7 Bulk density of Kastanozems under different land uses in the Altai Krai



The soil changes caused by cultivation are also reflected in the bulk density. Here, the same effects are visible. Due to the lack of mechanical stress, permanent vegetation cover, and higher amounts of organic matter, the Kastanozems under grassland show slightly higher bulk densities (Fig. 11.7) and therefor the soils are more resistant to erosion.

The destruction of stable aggregates and decrease in bulk density result in an increased surface exposed to exogenous forces with a multitude of consequences for physical, chemical, and biological processes within a soil. The oxygen supply increases, the humus breakdown accelerates, and surfaces are enlarged and susceptible to chemical weathering (Carter 1990; Lal 1993; Kandeler et al. 1999; Dexter 2004; McVay et al. 2005). From a soil-physical point of view, the destruction of aggregates and resulting enlargement of surface caused by mechanical stress are the most significant changes. The resulting weak adhesion of the soil components causes a further susceptibility to erosion. Thus, soil components are easily removed from the soil structure and dislocated by erosion.

11.3 Extent of Erosion Disposition and Effects of Soil Erosion

Depending on climatic conditions, water and wind act regionally different as erosion triggering forces. The Altai Krai is divided into different agro-ecological zones. The designation of such zones has a long tradition in Russian agrarian research, and its target is the establishment of a base for an optimized regional differentiation of agrarian production (Bulgakov et al. 2016). Here, the climatic conditions for agrarian production are described for the respective region. The system is based on the respective requirements of agricultural crops. Table 11.1 displays erosion disposition data of agricultural land of different agro-ecological zones in the Altai Krai.

The data in Table 11.1 illustrate the dependence of erosion disposition on climatic conditions and soil inventory. Kastanozems are more susceptible to erosion than Chernozems because of a lower organic matter amount and, therefore, a lower aggregate stability. Shelterbelts are in use to protect Kastanozems from erosion, but they are ineffective in the dry steppe because of larger fields with areas between 50 and 200 ha (Meinel 2002; Meyer et al. 2008; Theisel 2013). The tree height of the shelterbelts is too low in relation to the large distances between the windbreaks to be effective. Therefore, large field areas are exposed to wind despite shelterbelts. According to Theisel's research (2013), maximal 22% of the area at risk is protected by shelterbelts from wind erosion. In comparison, less area is at risk of water erosion which affects more the forest steppe zone with its higher precipitation (Belyaev 2015; Theisel 2013). Here, 15–35% of the agricultural land is susceptible to erosion.

Table 11.1 Agricultural land affected by erosion in different agro-ecological zones of the Altai Krai

Zone	Steppe type	Land affected by erosion [%]					
		Erosion by wind			Erosion by water		
		Mean	min	max	Mean	min	max
Kulunda—West	Dry	97.1	92.1	99.2	0.7	0	2.6
Kulunda—East	Dry	87.5	81.2	93.2	3.6	0	10.9
Alejsk	Forest	22.2	0	69.8	35.5	0	95.8
Priobsk	Typical	61.3	4.3	89.2	15.4	0.4	39.0
Central	Forest	11.7	0	58.6	35.3	19.8	53.0

Source Belyaev (2015)

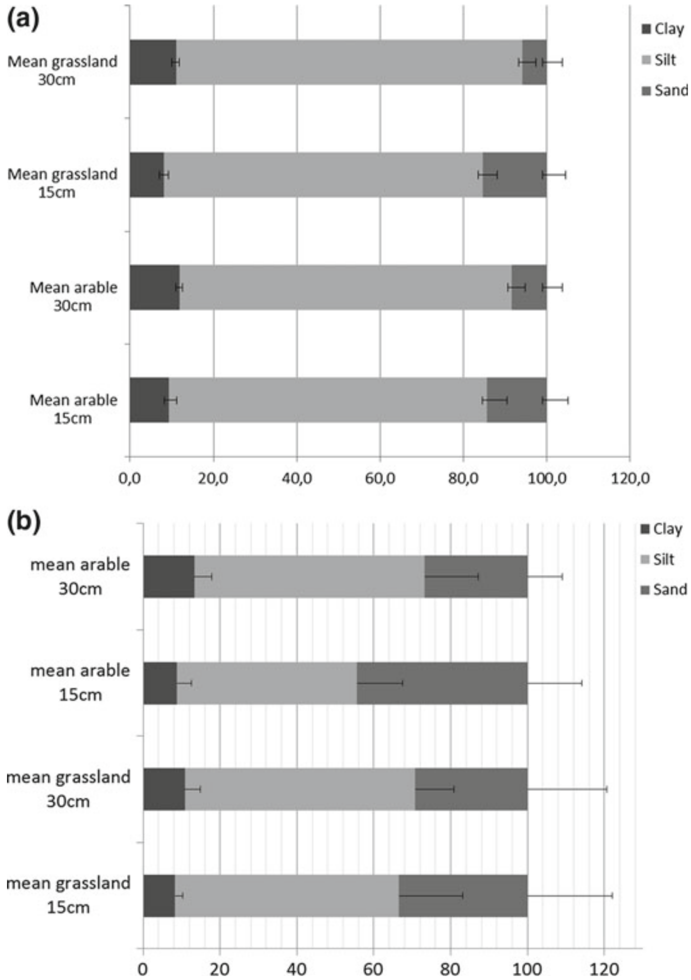


Fig. 11.8 **a** Grain size distribution of Salesh and conventionally cultivated Chernozems. **b** Grain size distribution of Salesh and conventionally cultivated Kastanozems

But only 2–4% of the areas at risk have ovrags (Theisel 2013). Water erosion occurs in the dry steppe only in spring during a rapid snowmelt over still frozen ground.

The erosion processes result in different landforms in a landscape. While the outcome of water erosion is obvious in the form of gullies and gulches, the effect of wind erosion is less visible. The shelterbelts and their lee side are accumulation areas for wind-blown soil material. Furthermore, the blow-off results in a grain size separation in the top soils of the affected locations (Fig. 11.8a, b).

Figure 11.8a, b displays clearly the result of the soil destabilization caused by the permanent mechanical stress. The upper 15 cm of arable soils has a higher amount of sand than the top of the grassland soils. This difference does not exist in the depth of 30 cm. This sand accumulation in the upper top soil is caused by the blow-out or wash-out of predominant mineral silt and organic matter. This process affects Kastanozems more than Chernozems. The sand accumulation has negative effects on water retention capacity and nutrient availability for plants which is a problem regarding (Mikheeva 2010) soil protection, agricultural production, and aspects of climate change mitigation.

11.4 Options of Sustainable Land Management Practices to Reduce Erosion Disposition

However, erosion and its negative effects can be countered by using adapted soil management methods. In particular, the reduction in tillage intensity and frequency is expected to minimize the mechanical stress on the soils. The examples of penetration resistance and grain size distribution show that applying adapted soil management methods like minimal tillage or direct seeding significantly improves physical soil properties.

Different intensive methods were tested within the scope of extensive and multi-year field experiments to analyse and compare effects of soil cultivation on physical soil properties. After only three years of no-till, the top soils stabilized slowly and the penetration resistance values were comparable to these of Saleshi (Fig. 11.9).

Results show also positive effects on aggregate stability, bulk density, and grain size distribution, but the changes were less distinct than the penetration resistance changes which might be explained by the short time the experiments were running. Because of the short observation time of 4 years, the current data do not allow any

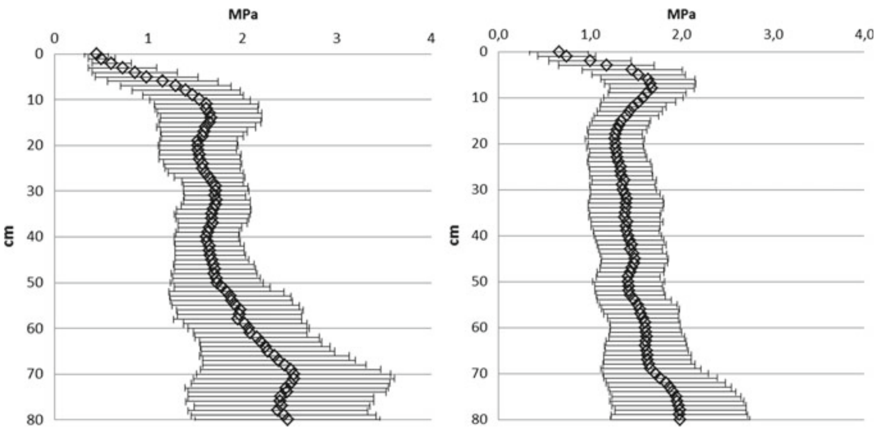


Fig. 11.9 Penetration resistance of Chernozems under grassland (left) and under no-till (right)

conclusions regarding an improvement of physical soil properties by the adapted soil management methods in the region.

11.5 Conclusions

The soils in the Altai Krai steppe were disturbed by the steppe conversion and, especially, by the intensive mechanical stress. Soil structure destruction resulted in negative changes of physical soil properties. The negative outcomes are lower aggregate stabilities and increasing sand content in top soils. That effects on other soil properties like decreasing water capacity, air capacity and saturated water conductivity. This results in negative effects of soil fertility. From the physical point of view, the gravest consequence of mechanical stress is the destruction of stable soil aggregates and resulting increased soil erosion disposition. Findings of the project's long-term field tests show that the soil structure can be stabilized by reducing the intensity of cultivation, which in turn positively affects other soil properties like erosion resistance and water capacity.

Acknowledgements The chapter is based on the research work carried out in the German–Russian cooperation project KULUNDA under finance of the German Federal Ministry of Education and Research (BMBF; FKZ 01LL0905D). We appreciate the collaboration with all the German and Russian partner institutions. Special thanks we would like to express to all the farmers of Altai Krai that gave us their support and for their hospitality.

References

Basilevich II, Shavrigin NI (1959) Pochvy chernozemnoy zony zasushlivoy, umerenno-zasushlivoy i kolochnoy stepi [Soils of the chernozem zone of the, arid, moderately arid and stony steppes]. In: Akademii Nauk SSSR (ed) Pochvy Altaiskogo Kraia. USSR Academy of Sciences Publishing, Moscow, pp 46–65 [in Russian]

Basilevich NI (1959) Pochvy kashtanovyi sukhoi stepi [Chestnut soils of the dry steppe]. In: Akademii Nauk SSSR (ed) Pochvy Altaiskogo Kraia. USSR Academy of Sciences Publishing, Moscow, pp 31–45 [in Russian]

Belyaev VI (2015) Ratsional'nye parametry tekhnologii "notill"i priamogo poseva pri vozdelyvanii sel'skokhoziaisvennykh kul'tur v Altaiskom krae [Rational technology parameters of "no-till" and direct seeding in the cultivation of agricultural crops in the Altai region]. Vestnik Altaiskoi Nauki 23:7–12 [in Russian]

Bischoff N, Mikutta R, Shibistova O, Puzanov AV, Reichert E, Silanteva MM, Grebennikova A, Schaarschmidt F, Heinicke S, Guggenberger G (2016) Land-use change under different climatic conditions: consequences for organic matter and microbial communities in Siberian steppe soils. Agr Ecosyst Environ 235:253–264

Bulgakov DS, Rukhovich DI, Shishkonakova EA, Vil'chevskaya EV (2016) Separation of agroclimatic areas for optimal crop growing within the framework of the natural–Agricultural Zoning of Russia. Eurasian Soil Sci 49(9):1049–1060

Carter MR (1990) Relative measures of soil bulk density to characterize compaction in tillage studies on fine sandy loams. Can J Soil Sci 70(3):425–433

Dammann S, Meinel T, Beljaev VI, Frühauf M (2011) Einfluss verschiedener Bodenbearbeitungsmethoden auf Bodenwasserhaushalt und Pflanzenproduktion in Trockengebieten [Influence of different tillage methods on soil water balance and crop production in drylands]. Hallesches Jahrbuch für Geowissenschaften 32(33):33–48 [in German]

Dexter AR (2004) Soil physical quality: Part I. Theory, effects of soil texture, density, and organic matter, and effects on root growth. Geoderma 120(3–4):201–214

FAO—Food and Agriculture Organization of the United Nations (2007) Digital soil map of the world. Version: 3.6. 1:5.000.000. ESRI-shp-Format. http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116. Accessed 14 March 2018

Frühauf M, Meinel T (2014) Ökosystemkonversion in den temperierten Grasländern Südwestsibiriens: Steuerfaktoren, Etappen und Geoökologische Konsequenzen [Ecosystem conversion in the temperate grasslands of southwestern Siberia: key factors, stages and geoecological consequences]. Geoöko 35(1–2):5–38 [in German]

Grant CA, Lafond GP (1993) The effects of tillage systems and crop sequences on soil bulk density and penetration resistance on a clay soil in southern Saskatchewan. Can J Soil Sci 73(2):223–232

Grunwald LC, Belyaev VI, Hamann M, Illiger P, Stephan E, Bischoff N, Rudev NV, Kozhanov NA, Schmidt G, Frühauf M, Meinel T (2016) Modern cropping systems and technologies for soil conservation in siberian agriculture. In: Mueller L, Sheudshen AK, Eulenstein F (eds) Novel methods for monitoring and managing land and water resources in Siberia. Springer, Cham, pp 681–715

Hill RL, Cruse RM (1985) Tillage effects on bulk density and soil strength of two Mollisols. Soil Sci Soc Am J 49(5):1270–1273

Illiger P, Frühauf M, Schmidt G, Meinel T, Belyaev VI, Silanteva MM, Kasarjyan M (2014) Ökosystemkonversion und ihre Folgen Bezüglich der Kohlenstoffsenken-Funktion in der westsibirischen Kulundasteppe [Ecosystem Conversion and its Consequences Concerning the carbon sink function in the West Siberian Kulunda steppe]. BfN-Skripten 373:300–319 [in German]

Kandeler E, Tscherko D, Spiegel H (1999) Long-term monitoring of microbial biomass, N mineralization and enzyme activities of a Chernozem under different tillage management. Biol Fertil Soils 28(4):343–351

Kahlon MS, Lal R, Ann-Varughese M (2013) Twenty two years of tillage and mulching impacts on soil physical characteristics and carbon sequestration in Central Ohio. Soil Tillage Res 126:151–158

Kovda VA, Rozanov M (eds) (1988) Pochvovedenie—Tipy pochv, ikh geografiia i ispol'zovanie [Soil Science—Soil types, their geography and use]. Vysshaia shkola, Moscow

Lal R (1993) Tillage effects on soil degradation, soil resilience, soil quality, and sustainability. Soil and Tillage Research 28(1–4):1–8

McVay KA, Budde JA, Fabrizzi K, Mikha MM, Rice CW, Schlegel AJ, Peterson DE, Sweeney DW, Thompson C (2005) Management effects on soil physical properties in long-term tillage studies in Kansas. Soil Sci Soc Am J 70(2):434–438

Meinel, H.T. (2002). Die geoökologischen Folgewirkungen der Steppenumbrüche in den 50er Jahren in Westsibirien. Ein Beitrag für zukünftige Nutzungskonzepte unter besonderer Berücksichtigung der Winderosion [The geoecological consequences of the steppe breaches in the 1950s in Western Siberia. A contribution to future usage concepts with special consideration of wind erosion]. Dissertation. Halle-Wittenberg: Martin Luther University. [in German]

Meyer BC, Schreiner V, Smolentseva EN, Smolentsev BA (2008) Indicators of desertification in the Kulunda Steppe in the south of Western Siberia. Arch Agron Soil Sci 54:585–603

Mikheeva IV (2010) Changes in the probability distributions of particle size fractions in chestnut soils of the Kulunda Steppe under the effect of natural and anthropogenic factors. Eurasian Soil Sci 43(12):1351–1361

Rosanov AN, Karmanov II (1959) Sistematika Potchv Altaiskogo Kraia [Systematics of Soils of the Altai Krai]. In: Akademii Nauk SSSR (ed) Pochvy Altaiskogo Kraia. USSR Academy of Sciences Publishing, Moscow, pp 27–31 [in Russian]

Schmidt G, Bondarovich AA, Scherbinin VV, Ponkina EV, Harlamova NF, Matsyura AV, Stephan E, Illiger P, Rudev NV, Kozhanov NA (2016) Rezul'taty funktsionirovaniiamezhdunarodnoi agrometeorologicheskoi i pochvenno-gidrologicheskoi monitoringovoi seti v predelakh Kulundinskou ravniny na iuge Zapadnoi Sibiriza 2013–2015 [Results of operation of the international agricultural–meteorological and soil–hydrological monitoring network in the Kulunda plain (south of Western Siberia, 2013–2015)]. Acta Biologica Sibirica 2:89–102 (in Russian)

Shavrigin NI (1959) Pochvy zony lesostepi [Soils of the forest-steppe zone]. In: Akademii Nauk SSSR (ed) Pochvy Altaiskogo Kraia. USSR Academy of Sciences Publishing, Moscow, pp 66–74 [in Russian]

Theisel T (2013) Entwicklung übertragbarer Kartierungsverfahren zur automatisierten Ableitung von Bodendegrada-tionsprozessen in einem semi-ariden Steppen-Ökosystem [Development of transferable mapping methods for the automated derivation of soil degradation processes in a semi-arid steppe ecosystem]. Master's Thesis, Friedrich Schiller University Jena, unpublished. [in German]

Unger PW, Jones OR (1998) Long-term tillage and cropping systems affect bulk density and penetration resistance of soil cropped to dryland wheat and grain sorghum. Soil Tillage Res 45(1–2):39–57

Chapter 12
Soil Moisture and Evapotranspiration

A. A. Bondarovich, V. Scherbinin, E. V. Ponkina, A. Matsyur, A. Puzanov, E. Stephan, D. Balykin, H. Rupp and R. Meissner

Abstract The assessment of land management practices according to their impact on soil water and solute balance is of great importance for crop yield potentials and sustainable development of the territory of Altai Krai (Russia). This contribution presents the results obtained from automatic weather stations, soil-hydrological measuring stations and a weighable gravitation lysimeter station established in the framework of the German—Russian KULUNDA project (2012–2016). It was shown that No-Till technology gradually formed soil conditions close to the natural background (steppe). For the first time, data regarding the amount of actual evapotranspiration (Eta) for the environmental conditions of the Kulunda dry steppe have been produced based on sophisticated lysimeter measurements.

Keywords Evaporation · Gravitation lysimeter · Hydrological station · Precipitation · Soil moisture · Temperature · Weather station

12.1 Introduction

The complexity of economic activity in the Kulunda plain is mainly caused by the specific climatic and soil conditions (Mosienko 1972; Frühauf 2014; Belyaev 2015; Belyaev et al. 2016). In the continental climate of the Kulunda steppe occur long, cold and little-snowy winters and short, but hot and dry summers (more details are given in Chaps. 2, 3). The annual precipitation is about 250–450 mm; the precipitation

A. A. Bondarovich (✉) · V. Scherbinin · E. V. Ponkina · A. Matsyur
Altai State University, Lenin St., 61, 656049 Barnaul, Russia
e-mail: andrei.bondarovich@yandex.ru

A. Puzanov · D. Balykin
Institute of Water and Environmental Problems, Siberian Branch of the Russian Academy of Sciences, Molodezhna St. 1, 656038 Barnaul, Russia

E. Stephan · H. Rupp · R. Meissner (✉)
Helmholtz-Centre for Environmental Research GmbH–UFZ, Department of Soil System Science, Lysimeter Facility Falkenberg, Falkenberg 55, 39615 Altmärkische Wische, Germany
e-mail: ralph.meissner@ufz.de

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_12

from April to October is about 200 mm. In the last few years, the rainfall decreased to 170 mm (Sljadnev 1965; Harlamova et al. 2014; Schmidt et al. 2016).

The soils in the study area developed from Mesozoic to Cenozoic sediment according to the respective climate conditions. The lowland is covered by a 50–60 m thick layer which was formed during the period from the Pleistocene to the Holocene and covered by a 0.5–10 m layer of aeolian sediments. The soil cover of the dry steppes of Kulunda consists of chestnut soils, meadow-chestnut soils, meadow soils, solonetz and solonchaks with different degrees of hydro-morphism (compare Chaps. 4 and 11).

The chestnut soils significantly vary in texture as a result of the ancient limnic and aeolian genesis of the territory. Sandy loams (15–19% clay, 11–20% silt, 65–70% sand) are predominant; their contents of humus (2–4%) and carbon (5–8%) are comparatively high (Bazilevich 1959; Rudaya et al. 2012). This granulometric texture led to low hydrophilic conditions with a reduced water-holding capacity and high infiltration rates.

The precipitation in the region is a limiting factor. Therefore, the assessment and management of water and solute balance of soils are of great importance for crop yield potentials and sustainable development. Also in former Soviet Union research activities were started to minimize the water deficit in the region. Already since 1970 the Kulunda plain was included in the national Russian economic plan of reclamation to increase the area of irrigated land (Mosienko 1972). But the economic conditions have changed and present land management activities in the region showed that irrigation does not play an essential role in agriculture. Alternative methods to improve the soil water efficiency have been developed and tested (Dmitrieva & Naprasnikov 2008). The main agricultural methods to retain soil moisture were to apply minimum tillage or no-till technologies including stubble conservation and chopped crop residues (Belyaev et al. 2016).

An essential topic of the interdisciplinary KULUNDA project was to evaluate land management practices according to their impact on the soil water and solute balance in the Kulunda steppe of Altai Krai (BMBF 2011–2016). For this reason, a pedo-hydrological measuring network was installed. The objectives of this contribution are:

i. to study the regional climate features using weather stations (WS);
ii. to compare the soil moisture regime between the deep autumn tillage technology (DATT) and the modern soil tillage (No-Till) technology based on in situ measurements with soil-hydrological measuring stations (SHMS);
iii. to investigate the actual evapotranspiration (*Eta*) under arable land and natural steppe conditions based on lysimeter measurements (Lys).

The outcome will focus on measurements by monitoring stations which were installed in the dry steppe region of Kulunda in the vicinity of the farm ‘Partner’, village Poluyamki, Mikhailovsky district of the Altai Krai (station ‘Poluyamki’).

12.2 Materials and Methods

In September 2012, one WS and two SHMS (manufacturer 'Eco-Tech', Germany) were installed. WS was equipped with a pyranometer (at a height of 2 m) to measure the solar radiation as well as with the multisensor 'Vaisala' (at a height of 2 m), measuring wind speed and direction, air temperature and humidity, barometric pressure and rainfall. Additionally, the liquid and solid precipitation was measured by a pluviometer, which is mounted in 'Hellmann' rain gauges on the standard height of 1 m (Table 12.1). SHMS are equipped with sensors which measured soil water content, soil temperature, soil matrix potential and electric conductivity fitted at depths of 30, 60 and 120 cm in automatic mode (cf. Table 12.1).

During June–August 2013, a containerized weighable lysimeter station (Polyethylene PE-HD; manufacturer 'UGT Muencheberg', Germany and Helmholtz Centre for Environmental Research—UFZ, Germany) was installed at the test farm 'Partner' of the KULUNDA project in Poluyamki (Fig. 12.1).

The soil monoliths (surface area of 1 m^2, 2 m depth) extracted from both an arable land site (lysimeter 1) and a fallow site which was ploughed once in the 1950s, but

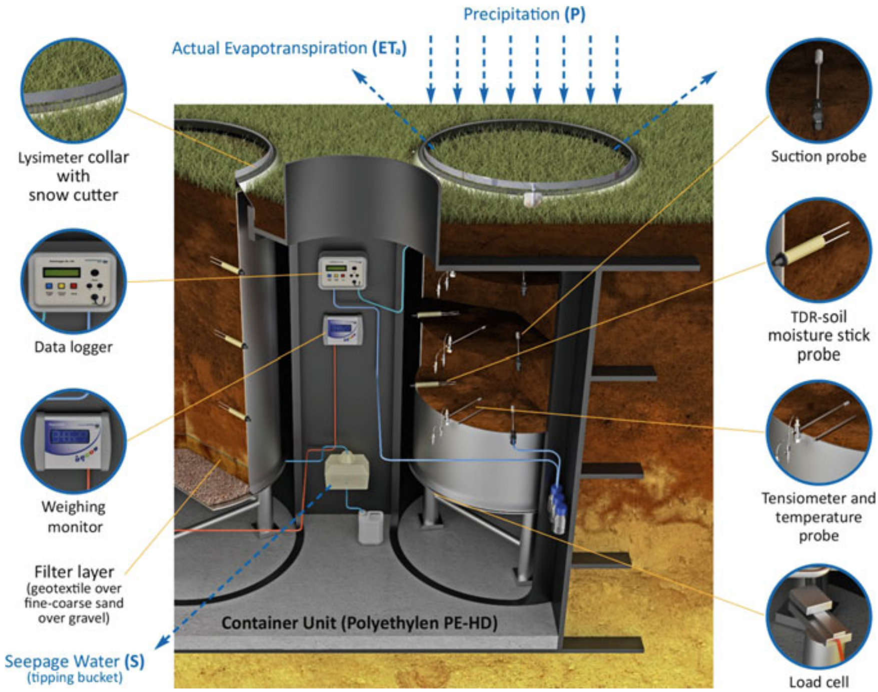


Fig. 12.1 Scheme of a weighable gravitation lysimeter installed at site Poluyamki, Siberia (Balykin et al. 2016)

Table 12.1 Compartments of the pedo-hydological measuring network

Name and coordinates	Lysimeter	Soil-hydrological measuring station		Weather station
	N 52°03.959’ E 79° 42.786’	DATT[a] (SHMS 1) N52 04.180 E79 54.014	No-Till (SHMS 2) N52 04.128 E79 54.006	N 52° 03.959’ E 79° 42.786’
Parameters	Soil monoliths mass for registration of various atmospheric precipitation, amount and contamination of seepage, soil water content and soil temperature, matrix potential	Soil water content and soil temperature, matrix potential, electrical conductivity		Amount of liquid precipitation (multisensor), equivalent of frozen precipitation (pluviometer in Hellmann rain gauge), wind speed and direction, air temperature, humidity, and pressure, solar radiation
Sensor types	1. TDR sensor: soil water content in volume per cent (coupled with thermometer) 2. Tensiometer: matrix potential (coupled with thermometer) 3. Suction cups: gather soil solution in different depths 4. Tipping bucket: seepage registration at the bottom of the lysimeter vessel	1. TDR sensor: soil water contamination in volume per cent (with thermometer) 2. pF metre: matrix potential (with thermometer and electrical conductivity measuring function)		1. Multisensor «Vaisala» : amount of precipitation, air temperature and humidity, atmospheric pressure, wind speed and direction 2. Radiometer: solar radiation 3. Pluviometer in Hellmann rain gauge: measurement of frozen precipitation
Height and depth of sensor location (cm)	−30; −50; −120	−30, −60, −120		+100 (Rain gauge) +200 (Radiometer) +230 (Multisensor)

[a]Deep autumn tillage technology on 22–24 cm depth

Fig. 12.2 Excavated soil monolith in stainless steel vessel: the natural steppe vegetation (*Stípa pennáta*). *Picture Source* Bondarovich, A. (June 2013)

since then covered with natural steppe vegetation (lysimeter 2; Fig. 12.2) (Balykin et al. 2016).

The monoliths are identified as Calcic Chernozems according to the FAO Soil Guidelines. 'The first monolith (Lys 1) consists of a 25 cm thick humic horizon including a plough layer at its top. It is followed by a crossing AC-horizon until a depth of 50 cm below ground level. Beneath there is a subsoil C-horizon from parent material including calcareous deposits. The grain size distribution in the upper part of the profile (0–50 cm) indicates sandy loamy silt, beneath silt loam and below 70 cm loamy sand occurs. The site has been under intensive agricultural use for 60 years.

The second monolith (Lys 2) consists of a 30 cm thick humus Ah-horizon, followed by a 15 cm thick crossing AC-horizon and by the subsoil from parent material which is interjected by calcareous deposits. The upper 30 cm consists of sandy loamy silt, below silty loam, occurs, which is underlain by loamy sand beneath 70 cm' (Balykin et al. 2016, p. 392). Both lysimeter vessels are equipped at different depths (0.30, 0.50 and 1.20 m) with time-domain reflectometry (TDR) stick probes to measure the soil moisture content, with combined tensiometer and temperature probes to measure the matrix potential as well as the temperature changes in the soil, and with suction cups to extract soil solution (cf. Table 12.1). This type of lysimeter is specifically adapted to the cold winter conditions in Siberia by adding a ring in order to cut the snow on the lysimeter surface from the adjacent snow in the surrounding (Fig. 12.3). It should be mentioned that the two SHMS were installed on same site where lysimeter monolith 1 (Lys 1) was extracted.

The lysimeter station installed in the Kulunda steppe consists of two vessels, which allows comparative analyses between arable lands (converted from grassland)

Fig. 12.3 Mechanical cutter to remove snow from the edge of the lysimeter vessel. *Picture source* Bondarovich, A. (January 2016)

and unconverted (nearly pristine) grassland. The vessels are weighable to ensure a continuously monitoring of mass changes at the study site for any time periods. Thus, it is possible to calculate water fluxes between pedosphere and atmosphere, in particular precipitation (measured also with WS) and *Eta*. 'Based on the measured parameters, *ETa* (in mm) can be derived using the following equation:

$$Eta(t) = P(t) - S(t) - \Delta W(t), \quad (1)$$

where $P(t)$—precipitation (mm); $S(t)$—amount of seepage water, (mm); $\Delta W(t)$—change in the quantity of stored water (mm) as determined from the mass change of the lysimeter over time ($1\,kg \approx 1\,L/m^2 = 1\,mm$); t—time of measurement parameters' (Balykin et al. 2016, p. 391).

12.3 Results

12.3.1 Temperature and Precipitation

The measurement of temperature and precipitation by WS 'Poluyamki' results in a significant correlation with the meteorological data from the Russian weather service (Roshydromet) in the Altai territory (Stephan et al. 2014; Meissner et al. 2016; Schmidt et al. 2016). A permanent exceedance of average daily air temperature of +5 °C was fixed at the beginning/end of the vegetation season (Friedrich et al. 2009; Kasam et al. 2009; Crabtree 2010). The longest growing season was recorded in 2014 and consisted of 202 days (29 March–10 October). In 2015, the duration of the growing season was 184 days (April 11–October 12), in 2016—187 days (first of April–October 04). Data analysis of vegetation season for May–September

Table 12.2 Monthly averaged temperatures, humidity, wind speed, solar radiation and the amount of precipitation during the vegetation season in 2015 and 2016, WS 'Poluyamki'

Period	Average air temperature (°C)	Average air humidity (%)	Average solar radiation (W/m^2)	Average wind speed (m/s)	Total rainfall (mm)
2015					
May	15.7	50.5	279.6	3.1	22.4
June	20.9	54.5	299.3	3.2	59.0
July	21.4	55.1	246.1	2.8	89.8
August	19.2	51.9	216.1	2.5	55.4
September	11.6	56.9	133.4	2.6	18.0
Average (Sum)	17.8	53.8	234.9	2.8	(244.5)
2016					
May	13.1	46.2	260.8	2.9	45.7
June	20.3	53.5	271.2	2.5	62.8
July	21.6	68.3	227.0	2.1	141.7
August	18.1	62.1	234.6	2.4	30.2
September	15.6	42.9	157.7	2.3	7.5
Average (Sum)	17.7	54.6	230.3	2.4	(287.9)

2013–2016 showed that the warmest period was in 2015, and the most humid periods were 2014 and 2016 (Belyaev et al. 2016; Schmidt et al. 2016). These values for 2015–2016 are presented in Table 12.2. The total amount of precipitation by rain gauge 'Vaisala' was used in calculations.

12.3.2 Soil Moisture

As already mentioned SHMS were firstly established in September 2012 on arable land and because of trial changes (field test design and survey of various crop cultivation technologies in the crop rotation) reinstalled in May 2013. The following technologies were tested:

(a) 'DATT' technology with deep loosener (PG-3-5—'ploskorez glubokorykhlitel'') on 22–24 cm depth (SHMS 1). Crop rotation: wheat (2013)—fallow (2014)—wheat (2015)—wheat (2016);
(b) 'No-Till' technology, without autumn tillage (SHMS 2). Crop rotation: wheat (2013)—rape (2014)—wheat (2015)—peas (2016).

Additional measurements of soil moisture content were performed by Lys 1 and Lys 2 at depths 30–50–120 cm for different crop rotations Lys 1: wheat (2013)—peas (2014)—wheat (2015)—fallow (2016). Lys 2: natural feather grass *(Stípa pennáta)* dominated dry steppe (2013–2016).

From our point of view, the measuring results gathered by SHMS 1, 2 and Lys 1, 2 for the period May–September 2015–2016 are of outstanding interest. This period is characterized by the most complete data set for all monitoring devices and by the end of the 'transition phase' for No-Till system.

The year 2015 is especially interesting when the spring wheat was seeded in all variants of arable land (SHMS 1 and Lys 1; Fig. 12.4). The measuring results of soil moisture in a depth of 30 cm for SHMS 1 and Lys 1 were different in 2015. In June–July–August of 2015, the soil moisture by Lys 1 was at 22.4–23.4–21.3 vol%, respectively. At the same period, soil moisture by SHMS 1 was measured at 11.7–10.2–11.3 vol%. The difference between soil moisture content by Lys 1 and SHMS 1 was approximately 50%. Most probably, the wall of the lysimeter vessel could prevent a run-off and thus lead to an increased infiltration. Furthermore, we assumed that the conditions under SHMS 2 should approximate to Lys 2. This was confirmed by measurements: soil moisture content at 30 cm by Lys 2 (19.3–18.3–18.2 vol%) was also higher than on SHMS 2 (18.0–14.8–12.6 vol%). The reason for the soil moisture differences between Lys 1 and 2 at 30 cm depth is the higher water consumption of the natural steppe vegetation. But at the following depths, the relations are vice versa—Lys 2 has more available water than Lys 1 and this means that additional water is stored under the natural steppe conditions which make this land use type more resistant to droughts (Fig. 12.4).

The results of soil moisture content measurements by Lys 1 in 2016 are quite interesting because a 'mechanical fallow' was tested here (Fig. 12.5). In general, we registered a smooth decrease of soil moisture content at all depths. This finding confirms the feasibility of fallow for water conservation. However, the economic efficiency of this management strategy is not solved until now and needs further investigations.

An analysis of the soil moisture regime of SHMS 1 and 2 for 2013–2016 showed that advantages of No-Till arose only in the third year, so since 2015 (cf. Table 12.3). The results from SHMS 2 demonstrated the advantages of No-Till at a depth of 30 and 60 cm in June–July 2015, when the site was seeded with spring wheat. Also in 2016, we observed the same effects, when it was seeded with peas, which had higher soil moisture consumption than spring wheat. In general, the measurements under the No-Till system demonstrate the similar dynamics of soil moisture in different depths for the vegetation season 2015–2016.

12.3.3 Evapotranspiration

The first results on testing the methodology for calculating the water balance in the Kulunda steppe using weighable gravitational lysimeter were published by Stephan

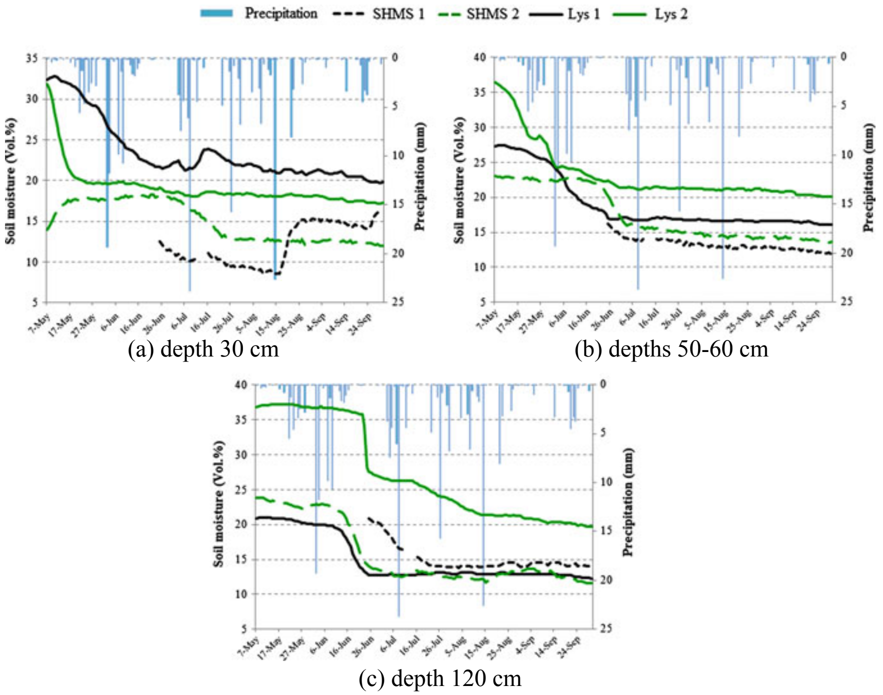


Fig. 12.4 Soil moisture (vol%) at the depths of 30–50 and 60–120 cm and precipitation (mm) measured at SHMS 1, 2 and Lys 1, 2 during the investigation period 07 May–30 September 2015

et al. (2014), Balykin et al. (2016) and Meissner et al. (2016). Due to technical reasons, there was the problem of continuity of measurements and there are some gaps in the data. In winter months, the system that allows separating the mass of snow layer on the lysimeter monoliths from the adjacent snow works irregularly, so the measured mass of the monoliths during snow cover was not always correct.

The most complete data series were registered for vegetation seasons in 2015 and 2016. Thus, there was a problem with the displacement of Lys 1 vessel, which was solved on 24 June 2015. In this context, data from May to June 2015 obtained on the Lys 1 were not valid. In general, the monthly available data set for the measuring period 2015–2016 is presented in Table 12.4 (and specified in the footnotes a–e).

There are differences regarding the amount of *Eta* between Lys 1 and 2. The tightly closeness steppe vegetation at Lys 2 increases the moisture loss due to higher interception and transpiration. A significant difference (28%) between *Eta* of Lys 1 and 2 was obtained in July and August 2015 and during the whole vegetation period in 2016.

It is interesting to compare presently calculated *Eta* values, based on sophisticated lysimeter measurements, with previous data for the period 1965–1970. The data from Kulundinskaia (1972) are based on simple evaporimeter measure-

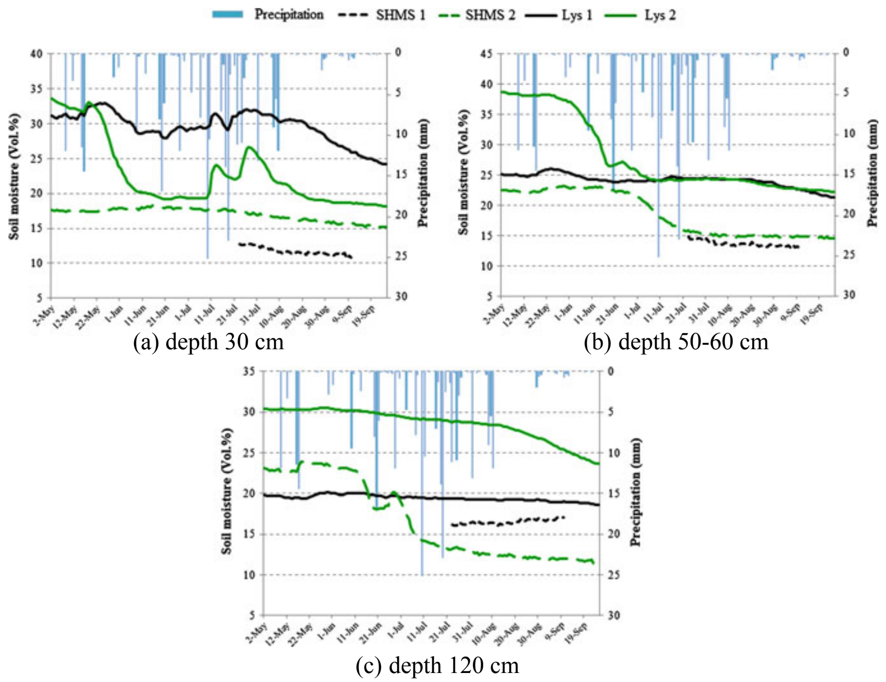


Fig. 12.5 Soil moisture (vol%) at the depths 30–50 and 60–120 cm and amount of precipitation (mm) measured at SHMS 1, 2 and Lys 1, 2 during the investigation period 01 May–25 September 2016

ments which were used to calculate maximum possible evaporation during this time period. The total value of evaporation during the vegetation season near the Mikhailovskiy Soda Plant (approximately 25 km away from the present lysimeter station 'Poluyamki') was 372.6 mm (in detail May–June–July–August–September—71.3–75.0–77.5–74.4–74.4 mm; further details are explained in Meissner et al. 2016). We know that this comparison is scientifically incorrect, but we will demonstrate the development of the measuring technique and show that the problem of exact estimation of evapotranspiration is still relevant. These findings confirm the trend that especially for natural steppe conditions an increasing evaporation (compare Lys 2) is visible. This result agrees with other investigations (Harlamova et al. 2014). They found a significant positive linear trend in annual temperature and a significant negative trend in annual precipitation in the steppe zone of the Altai Krai in 1966–2011.

Table 12.3 Monthly average soil moisture in depths 30, 60, 120 cm during the vegetation season in 2015 and 2016, SHMS 1 and 2 'Poluyamki'

Period	Soil moisture in the depth 30 cm (vol%)		Soil moisture in the depth 60 cm (vol%)		Soil moisture in the depth 120 cm (vol%)	
	DATT	No-Till	DATT	No-Till	DATT	No-Till
2015						
May	–	16.1	–	22.7	–	23.1
June[a]	11.8	18.0	15.4	21.6	15.4	19.0
July[b]	10.2	15.0	13.8	15.5	13.8	12.9
August	11.3	12.6	13.0	14.5	13.0	12.5
September	14.9	12.4	12.5	14.1	12.5	12.7
Average	12.0	14.8	13.7	17.7	13.7	16.0
2016						
May[c]	21.4	17.5	21.6	22.6	20.7	23.2
June	–	17.9	–	22.6	–	20.8
July[d]	12.7	17.5	14.5	17.4	16.2	14.3
August	11.6	16.4	13.6	15.0	16.5	12.4
September[e]	11.2	15.5	13.3	14.8	16.9	11.8
Average	15.6	17.0	16.8	18.5	18.2	16.5

[a]Data for 25–30 June 2015
[b]No data from 11–15 July 2015
[c]Data by DAAT only for 05 May 2016
[d]Data by DAAT for 23–31 July 2016
[e]Data for 01–25 September 2016

12.4 Discussion

The most important controversial issues in modern meteorology are a) the representativeness of the data and b) sources of possible measurement errors (Hoffmann et al. 2016). The general problem of representativeness is particularly acute when measuring precipitation. There are plenty of errors typical for total rain gauges, which sometimes only encompass 30% of the actual rainfall amount reaching the earth's surface. Furthermore, we found differences in soil moisture measurements between Lys 1 and Lys 2 as well as between SHMS 1 and SHMS 2. These differences were caused by: (a) a weak link between monoliths and the surrounding landscape and (b) differences in the technical characteristics of the used sensor types.

We also consider the second group of errors caused by the technical features of the sensors. SHMS 1 and 2 are equipped with the sensor type 'Hydra-Sonde' that was capable to measure the soil moisture (precision ±3% of the measured value), soil temperature (accuracy ±0.1 °C), electrical conductivity (accuracy ±5 mS/m). Lys 1 and Lys 2 are equipped with 'UMP1' sensors. They have the following measuring accuracies: soil moisture content (±2%), soil temperature (±0.2 °C) and electrical

Table 12.4 Results of measuring amount of precipitation and Eta with weighable lysimeters

	Days of observation (n)	Total rainfall by lysimeter (mm)		Soil temperature at depth of 30 cm (°C)		Soil moisture at depth of 30 cm (vol%)		Actual evapotranspiration by lysimeter (mm per month)		Actual evapotranspiration by lysimeter (mm per day)	
		Arable land (Lys 1)	Steppe (Lys 2)	Arable land (Lys 1)	Steppe (Lys 2)	Arable land (Lys 1)	Steppe (Lys 2)	Arable land (Lys 1)	Steppe (Lys 2)	Arable land (Lys 1)	Steppe (Lys 2)
2015											
May	24[a]	–	28.8	15.2	13.4	30.9	22.6	–	105.2	–	4.4
June	30	–	47.4	19.5	18.0	23.4	19.3	–	130.3	–	4.3
July	31	73.3	86.7	22.1	19.8	22.5	18.4	78.5	117.6	2.5	3.8
August	31	50.1	64.3	19.9	18.2	21.3	18.2	66.8	87.2	2.2	2.8
September	30	36.6	71.6	14.5	13.1	20.5	17.6	38.2	72.0	1.3	2.4
Average (Sum)	(146)	160.1	298.8	18.2	16.5	23.7	19.2	(183.4)	(512.3)	1.3	3.5
2016											
May	9[b]	10.2	10.4	13.6	11.2	31.7	31.1	6.6	21.7	0.7	2.4
June	22[c]	49.4	61.8	20.5	17.7	29.2	20.2	36.4	120.1	1.7	5.5
July	31	109.4	129.9	21.8	20.3	30.6	22.5	93.1	135.9	3.0	4.4
August	31	24.7	37.9	20.1	18.2	30.1	20.8	58.7	116.2	1.9	3.7
September	25[d]	5.4	18.2	18.4	16.1	25.7	18.5	24.1	54.5	1.0	2.2
Average (Sum)	(118)	199.1	258.2	18.9	16.7	29.4	22.6	(219.0)	(448.4)	1.9	3.8

conductivity (±1%). A special feature of UMP1 sensor is the possibility to integrate the measuring principles of TDR and FDR (frequency domain reflectometry) technique. This property allows the use for different soil conditions. In general, we suppose that technical differences between the sensors are rather small and can be neglected.

In general, we demonstrated the functionality of the established pedo-hydrological measuring network and discussed possible measuring errors. In principle, there was sufficient agreement between the different measuring systems. During the vegetation period, the lysimeter reflects the natural field conditions with good accuracy. Problems arose during winter time because snow and ice impede the measuring regime of the weighable lysimeter. Furthermore, the differences in soil moisture between the lysimeter and the SHMS at different depths should be investigated more intensively in future.

12.5 Conclusions

There are certain advantages of No-Till management compared to technology with deep autumn tillage due to more available soil moisture at depths of 30–60–120 cm. Moreover, the rise of moisture from the deeper soil horizons probably occurs at topsoil aridization. We suggest that No-Till technology gradually forms soil conditions close to the natural background (steppe) with respect to possible errors caused by technical measurements.

At the first time, reliable data regarding the amount of *Eta* for the environmental conditions of the Kulunda dry steppe have been produced based on sophisticated lysimeter measurements.

Further studies are necessary to extend the monitoring network on comparable sites in the neighbourhood and to get sufficient reliable datasets to model water and solute balance for the dry steppe regions in Siberia, Kazakhstan, Mongolia and China.

Acknowledgements The paper is based on the results of the research work carried out in the scope of the German–Russian cooperation project KULUNDA. The project is financed by the German Federal Ministry of Education and Research (BMBF; FKZ 01LL0905D). We would like to thank all colleagues from the German and Russian partner institutions for their cooperation and support during the investigations. Especially, we thank the farmer family Koshanov in Poluyamki for the support during the installation of the lysimeter station.

References

Balykin D, Puzanov A, Stephan E, Meissner R (2016) Using the innovative Lysimeter technology in the German-Russian research project «KULUNDA». In: Mueller L, Sheudshen AK, Eulenstein F (eds) Novel methods for monitoring and managing land and water resources Siberia. Springer International Publishing, Cham, pp 387–399

Bazilevich NI (1959) Pochvy kaschtanovoi sonoi stepi—Poochvy Altaiskogo kpaja. Soils of the Kastanozem Zone in the dry steppe. In: Soils of the Altai Krai. Academy of Sciences of the USSR, Moscow, pp 31–46 (in Russian)

Belyaev VI (2015) Ratsional'nye parametry tekhnologii «no–till» i priamogo poseva pri vozdelyvanii sel'skokhoziaistvennykh kul'tur v Altaiskom krae [Rational Technology Parameters of «no–till» and direct seeding in the cultivation of agricultural crops in the Altai region]. Vestnik Altaiskoi nauki 1(23):7–12 (in Russian)

Belyaev V, Grunwald L, Meinel T, Schmidt G, Bondarovich AA, Scherbinin VV, Ponkina EV, Matsyura AV, Stephan E, Illiger P, Kozhanov NA, Rudev NV (2016) Vodnyi rezhim pochvy i urozhaynost' sel'skokhoziaistvennykh kul'tur pri razlichnykh tekhnologiiakh vozdelyvaniia v Kulundinskoi stepi Altaiskogo kraia [Soil water regime and crop yields in relation to various technologies of cultivation in the Kulunda Steppe (Altai Krai)]. Visnyk of Dnipropetrovsk University. Biol Ecol 24(2):531–539 (in Russian)

Crabtree B (2010) Search for sustainability in dryland agriculture. Crabtree Agricultural Consulting, Beckenham, WA

Dmitrieva VT, Naprasnikov AT (2008) Vektor meliorativnogo prirodopol'zovaniia: Ot drevnego do sovremennogo mira [The vector of reclamative nature management: From the ancient to the modern world]. Vestnik MGPU. Seriia Estestvennye nauki 2(24) (in Russian)

Friedrich T, Kasam AH, Shaxon FT (2009) Conservation agriculture. Final Report Agriculture for Developing Countries, Science and Technology Options Assessment (STOA) Project. Karlsruhe: European Technology Assessment Group

Frühauf M (2014) Opyt i posledstviia severoamerikanskogo sindroma "dust bowl—pyl'nykh bur'" dlia proekta "Kulunda" [Experience and Consequences of the North American Dust Bowl Syndrome for the Kulunda Project]. Vestnik Altaiskoi nauki 4:226–233 (in Russian)

Harlamova NF, Bondarovich AA, Kozlova DS, Plehova AV (2014) Izmenchivost' uvlazhnennosti territorii lesostepnoi i stepnoi zon Altaiskogo kraia v techenie 1982–2013 [Variability of humidification of the territory of the forest-steppe and steppe zones of the Altai Krai during 1982–2013]. Geografiia i prirodopol'zovanie Sibiri: sbornik nauchnykh statei, pp 206–215. (in Russian)

Hoffmann M, Schwartengräber R, Wessolek G, Peters A (2016) Comparison of simple rain gauge measurements with precision lysimeter data. Atmos Res 174–175:120–123

Kassam AH, Friedrich T, Shaxson F, Pretty J (2009) The spread of conservation agriculture: justification, sustainability and uptake. Int J Agri Sustain 7(4):1–29

Meissner R, Bondarovich AA, Scherbinin VV, Ponkina EV, Matsyura AV, Puzanov AV, Rupp H, Schmidt G, Stephan E, Illiger P, Frühauf M, Harlamova NF, Galahov VP, Balykin DV, Rudev NV (2016) Metodika rascheta vodnogo balansa dlya sukhoy stepi yuga Zapadnoy Sibiri po dannym mezhdunarodnoy monitoringovoy seti [Calculation of water balance for the south desert area of western Siberia by international monitoring network data]. Biol Bull Bogdan Chmelnitskiy Melitopol State Pedagogical Univ 6(2):223–238 (in Russian)

Mosienko NA (1972) Agrogidrologicheskie osnovy orosheniia v stepnoi zone (na primere Zapadnoi Sibiri i Severnogo Kazakhstana) [Agrohydrological basics of irrigation in the steppe zone (using the example of Western Siberia and Northern Kazakhstan)]. Idrometeoizdat, Leningrad (in Russian)

Polubarinov-Kochin PJ (1972) Kulundinskaia step' i voprosy ee melioratsii [Kulunda steppe and its melioration issues]. Nauka, Moscow (in Russian)

Rudaya N, Nazarova L, Nourgaliev D, Palagushkina O, Papin D, Frolova L (2012) Mid–late Holocene environmental history of Kulunda, southern West Siberia: vegetation, climate and humans. Quatern Sci Rev 48:32–42

Schmidt G, Bondarovich AA, Scherbinin VV, Ponkina EV, Harlamova NF, Matsyura AV, Stephan E, Illiger P, Rudev NV, Kozhanov NA (2016) Rezul'taty funktsionirovaniia mezhdunarodnoi agrometeorologicheskoi i pochvenno-gidrologicheskoi monitoringovoi seti v predelakh Kulundinskou ravniny na iuge Zapadnoi Sibiri za 2013–2015 gg [Results of operation of the international agricultural–meteorological and soil–hydrological monitoring network in the Kulunda plain (south of Western Siberia, 2013–2015)]. Acta Biologica Sibirica 2:89–102 (in Russian)

Sljadnev AP (1965) Geograficheskie osnovy klimaticheskogo raionirovaniia i opyt ikh primeneniia na iugo–vostoke Zapadno-Sibirskoi ravniny [Geographical foundations of climatic zoning and their application in the southeast of the West Siberian Plain]. Geografija Zapadnoj Sibiri 53:3–122 (in Russian)

Stephan E, Meissner R, Rupp H, Frühauf M, Schmidt G, Illiger P, Bondarovitsch A, Balykin D, Scherbinin V, Puzanov A (2014) Aufbau eines bodenhydrologischen Messnetzes in der sibirischen Kulundasteppe [Construction of a soil hydrological monitoring network in the Siberian Kulundasteppe]. Wasserwirtschaft 10:15–22 (in German)

Chapter 13
Interactive Effects of Land Use and Climate on Soil Organic Carbon Storage in Western Siberian Steppe Soils

G. Guggenberger, N. Bischoff, O. Shibistova, C. Müller, S. Rolinski, A. Puzanov, A. V. Prishchepov, F. Schierhorn and R. Mikutta

Abstract Soils store much more carbon (C) than all terrestrial plants and the Earth's atmosphere together, and the C exchange between soils and atmosphere largely influences the CO_2 contents in the atmosphere. While converting native ecosystems into agricultural land in the past caused a huge historical release of C into the atmosphere, an optimization of the management of agricultural soils offers the possibility of restoring parts of the previously lost C in the soil. However, in this respect, interrelationships of land use and soil management with climate change must be considered. In this chapter, land use and climatic effects on soil organic carbon (SOC) stocks in the large western Siberian grasslands will be evaluated and scenarios of future development of SOC storage will be given. A combination of soil analysis along a climatic gradient from the forest steppe to the dry steppe and a modelling approach

G. Guggenberger (✉) · N. Bischoff · O. Shibistova · R. Mikutta
Institute of Soil Science, Leibniz Universität Hannover, Herrenhäuser Str. 2, 30419 Hannover, Germany
e-mail: guggenberger@ifbk.uni-hannover.de

G. Guggenberger · O. Shibistova
VN Sukachev Institute of Forest, Siberian Branch of the Russian Academy of Sciences, Akademgorodok, Krasnoyarsk 660036, Russian Federation

N. Bischoff
Landesamt für Bergbau, Energie und Geologie (LBEG), Referat L3.2 Landwirtschaft, Bodenmonitoring Stilleweg 2, 30655 Hannover, Germany

C. Müller · S. Rolinski
Institut für Klimafolgenforschung (PIK), Telegraphenberg A56, 14412 Potsdam, Germany

A. Puzanov
Institute for Water and Environmental Problems, Siberian Branch of the Russian Academy of Sciences, Molodezhnaya Street 1, 656038 Barnaul, Russian Federation

A. V. Prishchepov · F. Schierhorn
Department of Geosciences and Natural Resource Management, University of Kopenhagen, Øster Voldgade 10, 1350 København K, Denmark

R. Mikutta
Soil Science and Soil Protection, Martin-Luther-Universität Halle-Wittenberg, Von-Seckendorff-Platz 3, 06120 Halle/Salle, Germany

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_13

with the Lund–Potsdam–Jena managed Land (LPJmL) model revealed, that since their cultivation soils of the Kulunda steppe lost about 20–35% of their organic C. Surprisingly, not only particulate organic C was affected but likewise also organic C located within mineral-organic associations was lost, and the proportion of the lost C is independent from the climatic conditions. Parts of this lost organic C can be restored by abandoning arable land. However, due to political and economic constraints, this does not seem to be likely. Minimum or zero tillage may provide an option to increase the organic C storage in western Siberian steppe soils, but the potential effect may be limited. The LPJmL model simulates a continuing climate-change driven C loss from soil, which corroborates results of soil analysis along the climatic gradient. The management of SOC stock has to be evaluated also for its effect on soil erosion, water deficiency and nutrient shortage.

Keywords Arable land · Climate change · Land use · LPJ model · No till · Soil cultivation · Soil fractions · Soil management · Soil organic matter

13.1 Introduction

Soils store about three times as much C in the form of organic matter (about 2.200 Pg or 10^{15} g C) than does the atmosphere in the form of CO_2 (about 750 Pg C) (Batjes 2014). Its effect on the atmospheric CO_2 concentration is considered most relevant, as the soil organic carbon (SOC) pool is potentially much more labile than the larger reservoir of marine C (IPCC 2014). In equilibrium, each soil can store a certain amount of organic matter depending on abiotic conditions such as texture, mineralogical composition, and climate, but also on biotic conditions such as vegetation and soil biota (Gupta and Rao 1994). Any change of these variables results in a change of the C input with plant litter and/or in a change of the C output as CO_2 or CH_4. Cultivation of soil typically results in a significant C flow from the soil to the atmosphere (Foley et al. 2005). Lal (2004) estimated that land-use change caused a historical release of 136 Pg C into the atmosphere, which is about half of the amount of C emitted into the atmosphere by burning fossil fuels. The most important contribution to C emissions is the conversion of native ecosystems to arable land. In temperate regions, the depletion of soil C due to land-use change occurred already in the past. As a consequence, a new equilibrium of C inflow to and C outflow from the soil was established at a lower level than in native soils. This offers the possibility to restore parts of the SOC stocks by either changing land use to a more C sustainable system or by optimizing the soil management (Lal 2004; Kurganova et al. 2014). However, interrelationships of land use and soil management with climate change must be considered in the estimation of the C sequestration potential through sustainable agriculture.

In this chapter, land-use effects on SOC stocks in the large grasslands of western Siberia will be evaluated. Consequences of farming collapse for C stocks at the end of the Soviet Union and possibilities of improved land and soil management systems will be emphasized, the impact of different climatic conditions on the effects of land-use change on SOC will be discussed, and scenarios of the future development of SOC storage in these soils will be given.

13.2 Land-Use Effects on Soil Organic Carbon Stocks

General effects of land use on SOC stocks can be most certainly determined by meta-analyses, where the relative impact of a treatment (i.e. land-use change) on different variables (i.e. the SOC stock) is investigated. To date, one of the most prominent meta-analysis on the effects of land-use change on SOC stocks is the one by Guo and Clifford (2002), who included 537 observations from 74 publications in their study. According to Fig. 13.1, the transition from pasture to crop has the most drastic impact on SOC among all types of land-use change, as this change reduces the SOC stock by about 50%. Similar losses were reported by Paul et al. (1996) in a compilation of data from 34 long-term field experiments in the USA, most of them on prairie soils. A newer analysis by Poeplau et al. (2011), considering 176 worldwide observations of a change from grassland to cropland, came up with a predicted SOC loss of 36%. Surprisingly, a new steady state equilibrium was already reached within 17 years after conversion. Two processes are relevant for the much smaller SOC stocks in agricultural soils as compared to grassland soils. First, the organic matter input to grassland soils is much higher, despite some usually very productive arable cultures such as maize (Schulze et al. 2010). In grasslands, 30–50% of the total assimilated C is allocated to the soil, whereas in arable lands, it is just 20–30% (Kuzyakov and Domanski 2000), and it is particularly the rhizodeposition, which is relevant for soil organic matter formation (Schmidt et al. 2011). Second, the mineralization rate of soil organic matter is much higher in arable soils, primarily due to disruption of soil aggregates, which are considered to protect organic matter by physical occlusion within the aggregates (Elliott 1986).

So far, research on land-use effects on steppe soils predominantly focused on American prairie soils. Within Russia, most studies have been carried out in the European part, where a decrease of SOC of 27 to >40% was reported (Mikhailova et al. 2000; Rodionov et al. 1998). For the Kulunda steppe in western Siberia, Bischoff et al. (2016) assessed the impact of grassland conversion to arable soil on SOC at 21 plots of nine sites in the forest steppe, the typical steppe and the dry steppe (Fig. 13.2). Soils in the forest steppe and in the typical steppe were mostly Chernozems, while in the dry steppe Kastonzems dominated. Also, sodic and saline soils (Solonetz, Solochaks) were identified within the study area.

The measured SOC stocks down to 60 cm soil depth ranged from about 10–250 Mg ha^{-1} (10–25 kg m^{-2}) and generally decreased from forest steppe to typical steppe to dry steppe (Bischoff et al. 2016). Conversion of grassland to arable land use decreased the SOC stocks by about 20–35%. Chrono sequence data from the forest steppe showed that by far most of the organic C was lost within the first five years after ploughing the grassland, thus corroborating the results of Poeplau

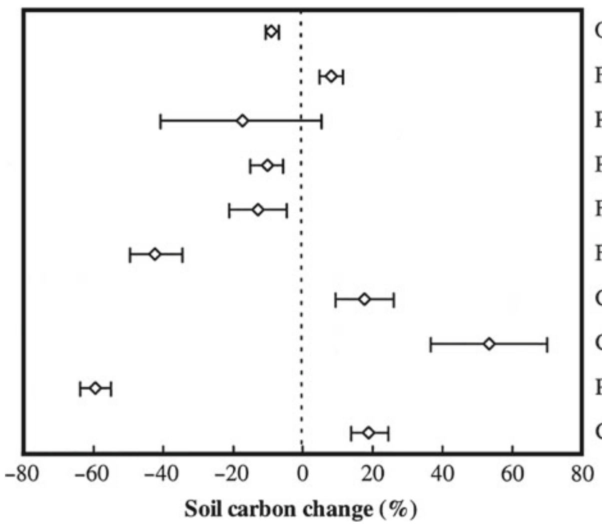


Fig. 13.1 Soil carbon response to various land-use changes; 95% confidence intervals are shown and numbers of observations are in parentheses. *Source* Guo and Gifford (2002)

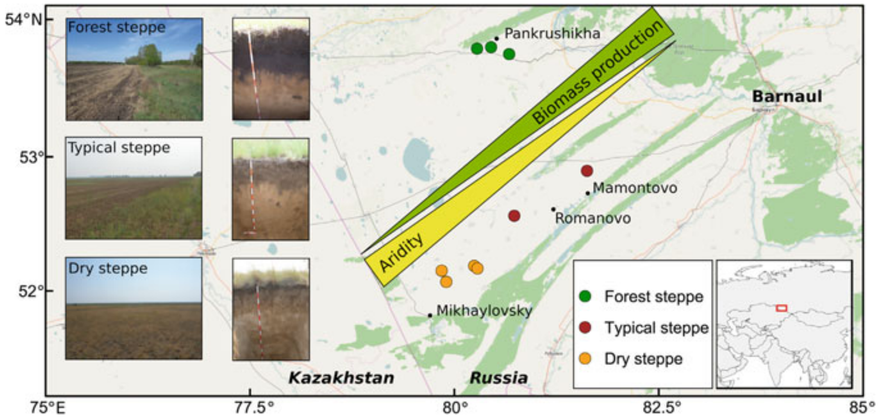


Fig. 13.2 Map of the Kulunda steppe with sampling sites at forest steppe, typical steppe and dry steppe, along with a representative landscape picture and soil profile. Biomass and aridity gradients are shown schematically. *Source* Bischoff et al. (2016)

et al. (2011), and emphasizing the fast response of soil organic matter on land-use change in a degrading system. Müller, Rolinski, Prishchepov and Schierhorn (unpublished) applied the Lund–Potsdam–Jena managed Land (LPJmL) model to simulate the SOC stocks in the Kulunda steppe, which is based on process formulations for photosynthetic plant growth depending on climatic variables, atmospheric CO_2 concentrations and soil parameters with a resolution of 30 × 30 angle minutes (Bondeau et al. 2007; Rolinski et al. 2018). The simulated data fit quite well to the measured

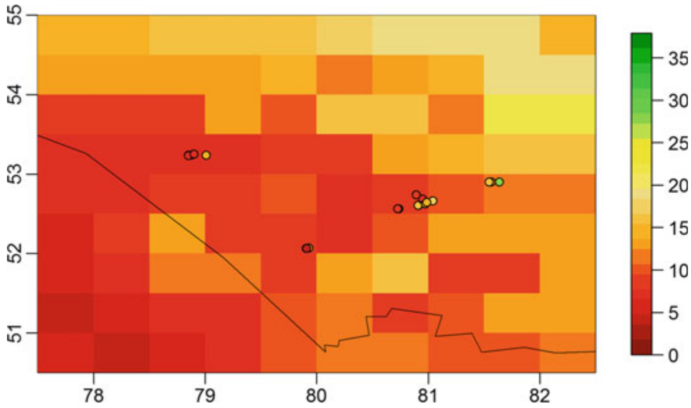


Fig. 13.3 Soil organic carbon (SOC) stocks (kg m^{-2}) in the Kulunda region as mean of 1985 to 1995 as obtained by the Lund–Potsdam–Jena managed Land (LPJmL) model (Bondeau et al. 2007). Simulations were run with standard input data at a spatial resolution of 30 × 30 angle minutes and compared with measured data (dots). The black line shows the border to Kazakhstan

ones (Fig. 13.3), in spite of some uncertainties concerning land-use history and soil type. Generally, the decreasing SOC stocks from north-east to south-west reflect very well the aridity gradient shown in Fig. 13.2. The cumulative analysis of the simulation data for the whole Kulunda region reveals that about 3.3 Pg organic C accumulated in the soils during the pre-agriculture time and stayed relatively constant until the advent of the large-scale conversion of grassland to arable land, colloquially called Virgin Lands Campaign (Tselina, hereinafter Campaign), which lasted from 1954 to 1963 (more details on the Campaign can be found in Chap. 6 by Prishchepov et al. and Chap. 8 by Frühauf and Borisenko). Since then the LPJmL model revealed a constant decrease in SOC stocks, independent of scenarios used in the model.

Interestingly, in soils of the Kulunda steppe, the organic C losses driven by conversion of grassland to arable soil occurred not only in the ploughed topsoil but also at soil depths down to 60 cm (Bischoff et al. 2016). Guo and Gifford (2002) reported similar SOC changes at <30 cm and 30–60 cm soil depth after land use change from forest to cropland. Only at >60 cm soil depth, SOC stocks were not affected. This observation rather contradicts the view that ploughing is primarily responsible for the depletion of SOC in agricultural soils, as that would mean that the organic C losses are much more pronounced in the ploughed soil layer.

In fact, the aggregate stability was smaller in cropland soils than in grassland soils, and decreased with increasing tillage intensity (Fig. 13.4). Further, the organic C contents were well related to aggregate stability. This statistical relationship led to the tentative conclusion that SOC is better protected from microbial decomposition by the more stable soil aggregates of grassland soils than by the less stable aggregates in arable soils (see also e.g. Six et al. 2002). However, a comparison of mineralization rates of intact soil macro-aggregates (250–2000 μm) with crushed soil macro-aggregates (<250 μm), simulating the result of ploughing on soil organic

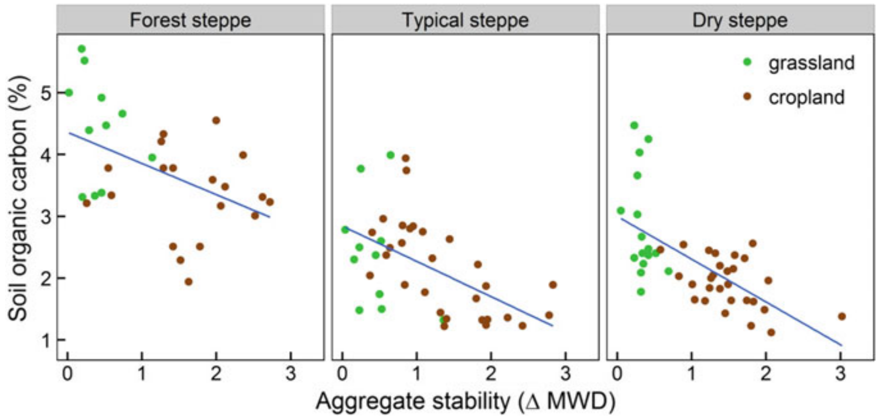


Fig. 13.4 Relation between aggregate stability (ΔMWD) and soil organic carbon (SOC) (%) for topsoils in the three different steppe types. The solid line corresponds to the trend line over all plots within one steppe type. *Source* Bischoff et al. (2016)

matter decomposition, revealed no differences (Fig. 13.5). Macro-aggregate protected organic C that was almost absent in the soils of the Kulunda steppe, and it contributed only marginally to the organic C mineralization during the 401 days of incubation (Bischoff et al. 2017). These results suggest that the tillage-induced breakdown of macro-aggregates and the subsequent release of organic matter are not the key factor driving organic C losses due to the conversion of grassland soils into arable soils. This observation is in contrast to observations made in prairie soils in the North American Great Plains, where Cambardella and Elliott (1993, 1994) reported a pronounced protective capacity of macro-aggregates for SOC, which is largely lost due to arable land use. Bischoff et al. (2017) explained this discrepancy by very small proportions of particulate organic C (<10%) in the Siberian soils which can result from small organic matter inputs with crop residues and rhizodeposits (Gulde et al. 2008; Brown et al. 2014) or a wetter climate than in the North American Great Plains, which favours the formation of mineral–organic associations.

The small contribution of particulate organic C to the whole SOC pool has the additional effect that about 80–90% of the lost organic C due to land-use change has been associated with minerals. In turn, this means that in the Kulunda soils, a considerable part of organic matter bound to minerals is quite vulnerable to soil management and possibly part of a labile soil organic matter pool (Bischoff et al. 2016, 2017). This observation challenges the view of a pronounced organic C stabilization by the formation of mineral–organic associations (Kleber et al. 2015). Mineral-associated organic matter thus represents a continuum in biodegradability, driven by the action of rather weak (e.g. hydrogen bondings or cation bridges) to strong (e.g. innersphere complexation) mineral–organic bondings, which depends on the reactivity of abundant organic matter and minerals (Kaiser and Guggenberger 2003; Mikutta et al. 2007).

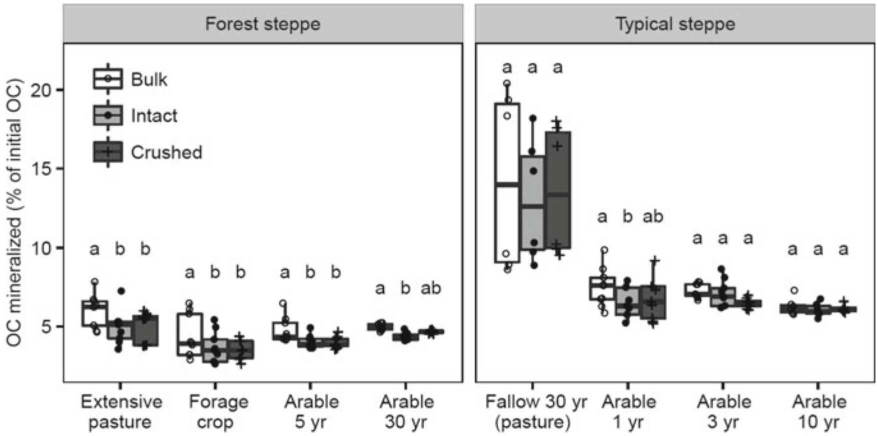


Fig. 13.5 Whisker plots with the percentage of soil organic carbon (SOC) mineralized during 401 days of incubation for eight plots within two steppe types and for the three fractions bulk soil, intact macro-aggregates, and crushed macro-aggregates. Different lowercase letters indicate significant differences ($p < 0.05$) between fractions within plots. *Source* Bischoff et al. (2017)

13.3 Soil Organic Carbon Restoration after Farming Collapse and by Improved Soil Management

As mentioned above, long-term agricultural management leads to depletion in SOC. This provides the chance to restore the SOC stocks (Paustian et al. 2016), either by conversion of arable land to grassland or forest (Laganière et al. 2010) or by practices that increase organic C inputs (Burney et al. 2010) and/or decrease organic matter mineralization by conservational tillage practices (Ogle et al. 2005). For instance, Schulze et al. (2010) reported that improved agricultural management contributes to European ecosystems having a net C sink of 114 Tg or 10^{12} g yr^{-1}. However, considering the emission of all greenhouse gases, soils are a source of about 26 Tg CO_2-C-equivalent.

After the collapse of the Soviet collective farming system in the early 1990s, about 25 million ha of arable land were abandoned in western Siberian and Kazakh steppes (Kamp et al. 2015). In a meta-analysis, Kurganova et al. (2014) calculated an average C accumulation rate of 0.96 Mg or 10^6 g C ha^{-1} yr^{-1} in 0–20 cm depth of abandoned Russian soils, though data vary widely between −0.23 and 3.70 Mg C ha^{-1} yr^{-1}. Parts of this variation are due to different soil types. The smallest C accumulation rates were found for Albeluvisols that prevail in European Russia, while the largest rates are reported for Chernozems (Fig. 13.6), which comprise almost 70% of the abandoned land in western Siberia (Kurganova et al. 2014). This result is mirrored by another meta-analysis of Kämpf et al. (2016), who reported a mean annual organic C accumulation rate of 0.72 Mg C ha^{-1} yr^{-1} in temperate agricultural soils after the termination of arable land use, leading to 18% higher organic C storage in soils

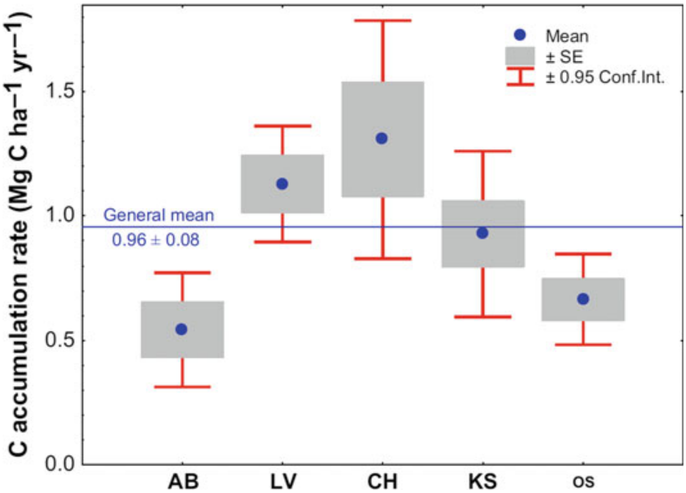


Fig. 13.6 Average carbon accumulation rates (±standard error) in five main soil groups for the first 20 years after the abandonment of cultivation (1990–2009). The confidence interval reflects significant differences ($P < 0.05$) between the soil groups. The five main soil groups according to Targulyan and Gerasimova (2007) are: AB, Albeluvisols; LV, Luvisols; CH, Chernozems; KS, Kastanozems; os,'other soils'. *Source* Kurganova et al. (2014)

of ex-arable land than of arable land. The proportional gain of SOC was highest in sub-humid and semi-arid climate (Fig. 13.7), which coincides with the climate of the western Siberian steppe.

Taking the results of Kurganova et al. (2014) and Kämpf et al. (2016) together, the potential of agricultural soils of western Siberia is particularly high. According to Kurganova et al. (2014), the extra C currently accumulating in former arable soil is equal to about 10% of the fossil fuel emissions of Russia on a yearly basis. However, Poeplau et al. (2011) emphasized that such C accumulating land-use types reach their equilibrium only after many decades, indicating that a current C saturation in the soils cannot be expected. Moreover and most importantly, land-use conversions conflict with agricultural production and food security objectives worldwide and particularly in Russia after 2014 (Wegren 2013). Furthermore, the region's currently not fully used agricultural potential is increasingly coming into the focus of national governments and investors (Swinnen et al. 2017; Saraykin et al. 2017). Kraemer et al. (2015) and Meyfroidt et al. (2016) reported that land that has been set aside after the collapse of the Soviet Union was increasingly recultivated, particularly in southern European Russia, Russia's western Siberia and northern Kazakhstan. This possibly leads to a re-emission of C into the atmosphere that has been recently fixed as soil organic matter. Therefore, we consider the abandonment of arable land in the western Siberian steppe not as an appropriate option to increase SOC storage.

An alternative to increasing the organic C storage in the soil is the establishment of more sustainable and C-gaining land management. In order to increase the organic C

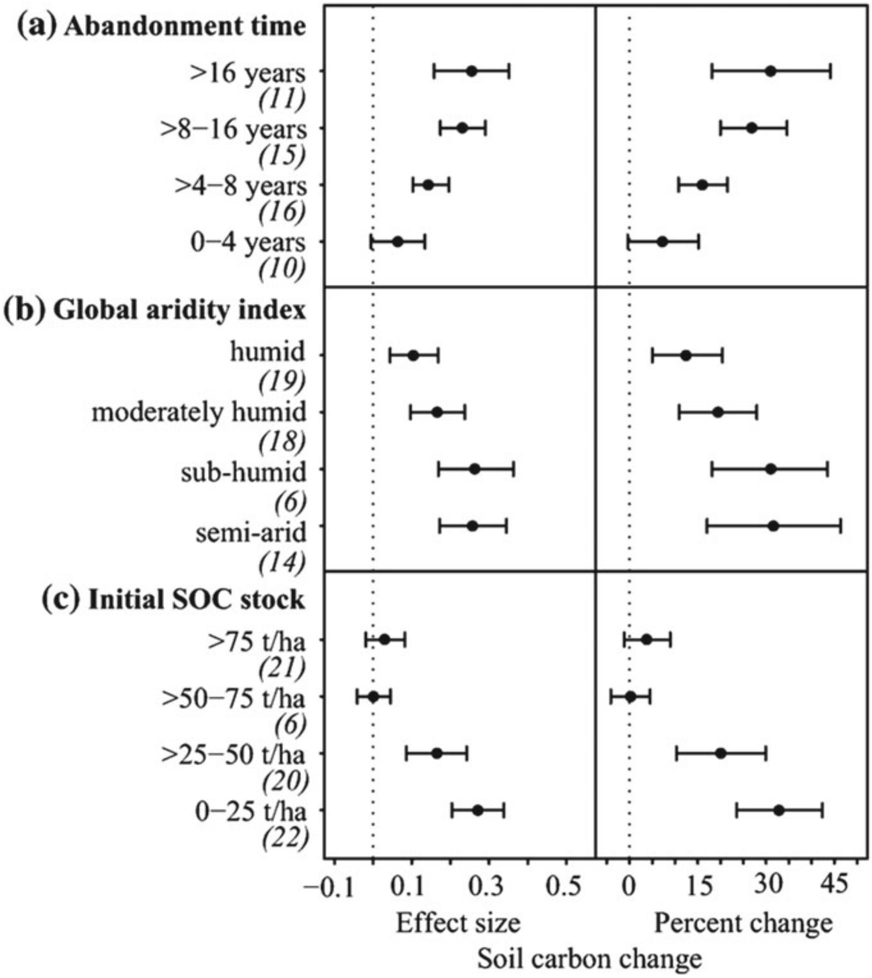


Fig. 13.7 Effects of **a** age, **b** climate and **c** initial SOC stock on carbon sequestration in ex-arable land of the temperate eco-zone compared to former arable land use. Means and 95% confidence intervals for effect size (response ratio) (left) and percentage change (right), sample size in parentheses. *Source* Kämpf et al. (2016)

input, a number of options exist (summarized in Paustian et al. 2016). However, most of them are not suitable in the steppe climate of western Siberia. Cover crops have been shown to sequester organic C by their large production of residues (Poeplau and Don 2015). But in western Siberia, this is not possible due to a lack of soil moisture and due to the short vegetation time. Also, strategies to increase the root mass to deposit C into deeper soil layers (Kell 2012) do not work in this dry climate, as this would be at the cost of production of above-ground biomass, including grain formation. For many northern American soils, it has been shown that less intensive tillage, particularly zero tillage, leads to an increasing SOC storage (Paul et al. 1996). However, this perception has been recently challenged by Powlson et al. (2014), emphasizing that an increased organic C content/stock in the surface soil is offset by C losses in deeper soil horizons. In contrast, Kämpf et al. (2016) identified 3 and 14% larger SOC stocks in temperate soils under reduced and zero tillage management, respectively, as compared to their conventionally tilled counterparts. In the soils of the Kulunda steppe, Bischoff et al. (2016) revealed slightly larger organic C stocks along with higher aggregate stability with decreasing tillage intensity (Fig. 13.4). However, the results are not significantly different. In summary, it appears that minimum or zero tillage may provide an option to increase the organic C storage in western Siberian steppe soils. But the quantity may be limited. This calls for running long-term experiments in the west Siberian steppe belt to study the effects of different tillage systems on SOC storage along with other soil parameters.

13.4 Interaction of Land-Use Change and Different Climatic Conditions and Its Impact on Soil Organic Carbon

Land use and land-use change are still considered the most important driver for the loss of biodiversity and ecosystem services such as C sequestration in the soil (Sala et al. 2000). However, climate change is projected to be the second most important driver (Elmhagen et al. 2015). As climate change has a direct impact on the type of land use, the interplay between both drivers on ecosystem services, including SOC storage, has to be better understood (Foley et al. 2011). However, not much is known about the effects of land-use change in different climate conditions. At a global level, Guo and Gifford (2002) reported that after the conversion from grassland to cropland, most of SOC was lost at mean annual precipitation of 400–500 mm (about 75%). At mean annual precipitation >500 mm, the SOC losses were about 50% and at mean annual precipitation of 300–400 mm, the soils lost about 54% of their organic C. In contrast, Poeplau et al. (2011) identified temperature as being positively correlated to the relative SOC loss due to land-use change, but not mean annual precipitation. However, for none of the statistical observations, an explanation is given.

Comparative investigations on the effects of land-use change on SOC storage under different climatic conditions in the Kulunda steppe revealed that the proportional organic C stock change was similar for forest steppe and dry steppe, while the typical steppe tended to have larger proportional organic C losses, though not statistically different (Bischoff et al. 2016; Fig. 13.8). This indicates that the proportional decline of the organic C stock is independent of climate. However, the decreasing SOC stocks from forest steppe to typical steppe to dry steppe must be considered when investigating land-use change—climate change interactions. Hence, the predicted drier climate in the semi-arid steppes of western Siberia will likely lead to a

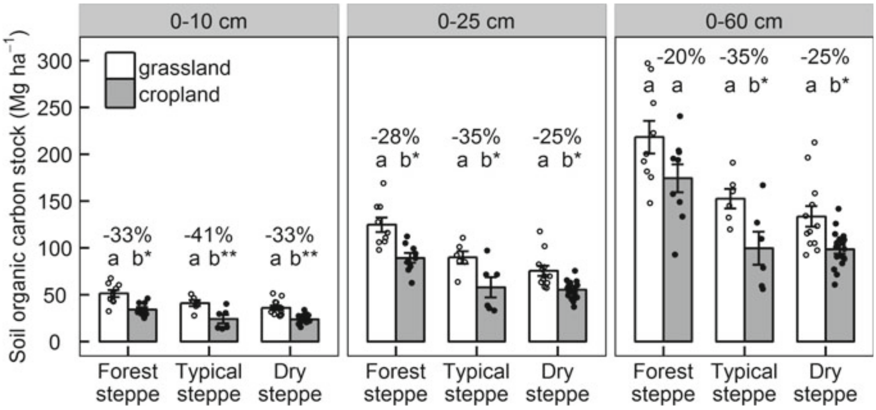


Fig. 13.8 Soil organic carbon (SOC) stocks (Mg ha^{-1}) depending on land-use type for 0–10, 0–25 and 0–60 cm in different steppe types. Values are given as arithmetic mean ± standard error of the mean. Points show individual measurements and lowercase letters indicate significant differences between land-use types, tested within steppe type and depth increment (p-value, $0 < *** < 0.001 < ** < 0.01 < * < 0.05$). Numbers above bars indicate the relative SOC stock decline due to grassland to cropland conversion. *Source* Bischoff et al. (2016)

pronounced loss of organic C in both grasslands and arable soils due to decreasing biomass input under drier conditions (Bischoff et al. 2016).

There are also many salt-affected soils, such as Solonchaks and Solonetz, in the Kulunda steppe, mostly in locations that are close to the groundwater. Surprisingly, a toposequence study revealed higher organic C stocks in the non-sodic and sodic Solonchaks than in neighbouring Kastanozems (Bischoff et al. 2018). Plant growth, as measured by above-ground biomass, obviously was not reduced under high salinity levels due to concomitant higher soil water contents, leading presumably to an organic matter input into the salt-affected soils similar to the Kastanozems. Further, the high salt contents led to the flocculation of soil constituents and thus to the formation of stable mineral–organic associations. Thus, salt-affected soils contribute significantly to the SOC storage in the semi-arid soils of the Kulunda steppe (Bischoff et al. 2018), but more data on salt-affected soils are required.

13.5 Future Perspectives

For the analysis of the future development of the C storage in the vegetation and soil of the Kulunda steppe and associated C fluxes, Müller, Rolinski, Prishchepov and Schierhorn (unpublished) employed the LPJmL hydrological and vegetation model on reconstructed land use with local official statistics on agricultural productivity, inputs and sown crops and remote sensing estimates of recent land-use changes. The calculation of the net ecosystem exchange (NEE) of the Kulunda steppe revealed

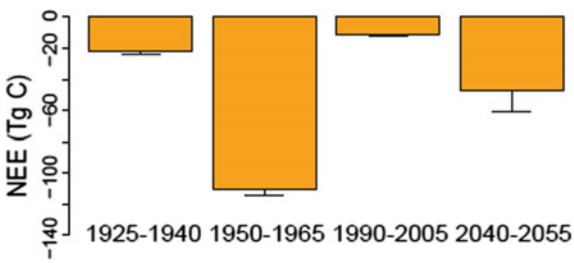


Fig. 13.9 Accumulated carbon fluxes as net ecosystem exchange (NEE; in Tg C per period) in the Kulunda steppe during four periods: (1) 1925–1940; (2) 1950–1965; (3) 1990–2005; (4) 2040–2055

organic C losses throughout the whole study period from 1925 to 2055 (Fig. 13.9). The negative NEE prior to the Virgin Lands Campaign activities was due to the conversion of grassland into arable land at a smaller scale that started already in the nineteenth century (see Chaps. 6–8). Total organic C losses from the biosphere to the atmosphere during the Campaign from 1954 to 1963 were estimated at 110 Tg or 10^{12} g C. During the period from 1990 to 2005, the NEE was almost balanced, which reflects the organic C gains in abandoned soils, thereby outbalancing the continuing losses from soils under arable land use. However, this situation will change in future until the middle of the twenty-first century. Projected increasing recultivation of currently abandoned land together with climate-change driven reduction of organic matter input will most likely lead to negative NEE values and SOC mineralization and release. For instance, within the period from 2040 to 2055, simulated organic C losses from the Kulunda steppe are estimated at about 48 Tg.

These simulated changes in NEE are also reflected in the calculated storage of organic C in vegetation and soil in the Kulunda region from 1900 to 2100 (Fig. 13.10). According to the simulations under different meteorological drivers, the vegetation of the Kulunda region contained 140 Tg C at the beginning of the twentieth century, whereas the soils contained more than 10 times as much (about 2.1 Pg or 10^{15} g C). All model runs showed a drastic decrease in the organic C bound in vegetation during the Campaign period due to the ploughing large areas of grasslands and the clearing of forests. This land-use change also affected negatively the SOC storage from ca. 1950 onwards. The current slight increase in the organic C of the vegetation can be explained by increasing productivity due to improved management systems and increasing CO_2 concentrations in the atmosphere. However, in the second half of the twenty-first century, a dramatic decline in the organic C in vegetation is simulated, which is highest for the A2 scenario with the strongest temperature increase. Also, the SOC will decline at increasing rates for all scenarios tested, which corroborates the results of the space-for-time approach by Bischoff et al. (2016).

As shown before, the simulated spatial distribution of SOC stocks shows a quite heterogeneous pattern, with decreasing stocks from the north-east to the south-west, following the climatic gradient (Fig. 13.11). The south-eastern corner does not belong to the steppe biome anymore but to the Altai Mountains with its moister and cooler climate and forest soils. In soils of the forest steppe and the typical steppe, the largest loss rates occurred in the past and are simulated to occur in the future. This

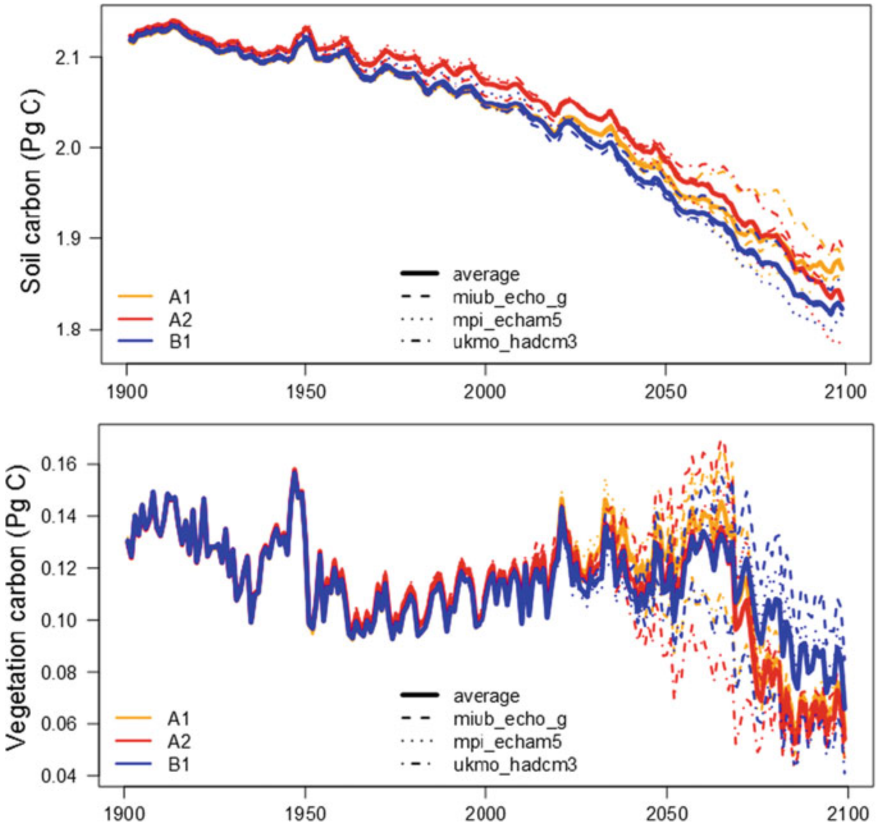


Fig. 13.10 Simulation results of organic carbon in vegetation (top) and soil carbon (bottom) (in Pg C) in the Kulunda region from 1900 to 2100 for the GLUES scenarios A1, A2 and B1 for different climatic models

is due to a combined effect of continuation of arable land use and recultivation of abandoned lands and the changing climate. In the south-western part, representing the dry steppe, the possible abandonment of arable fields due to drier climate leads to the accumulation of organic C also during the next decade.

13.6 Conclusions (Soil Organic Matter and Beyond)

Experimental data as well as modelling exercises show that the potential of organic C sequestration in soils of the western Siberian steppe, namely the Kulunda steppe, is limited. There is no clear proof that minimum or zero tillage leads to an increase in the SOC storage. However, the associated database is still weak. Yet even when a small potential gain of organic C due to a more conservative tillage system is taken

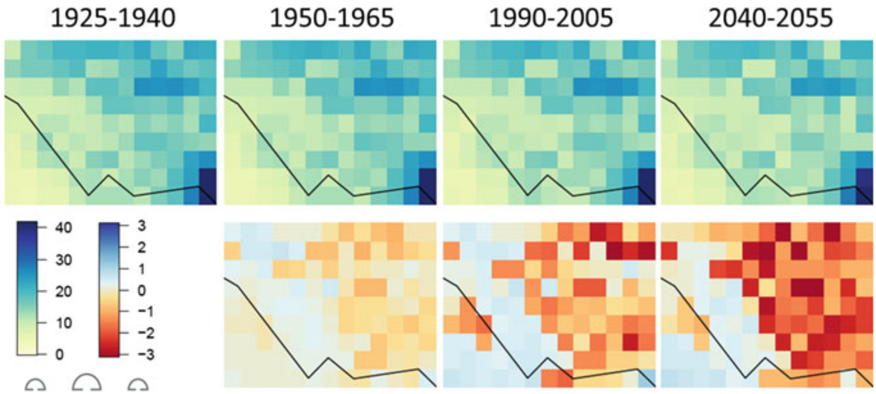


Fig. 13.11 Simulation results of mean soil organic carbon (SOC) stocks (in kg C m^{-2}) for four periods (upper maps) as well as differences as compared to the period 1925–1940 (lower maps). The black line shows the border to Kazakhstan

into account, the overriding effect of a changing climate with higher temperature and increasing water deficiency will likely decrease the soils' organic C storage in large areas of the Kulunda steppe. This should not lead to the conclusion that investment in the development and implementation of soil conserving agricultural techniques is not necessary. However, we should not constrain the climate change and land-use change debate in agricultural utilization of these steppe soils purely to the management of organic C stock changes. Other factors are likely more important and deserve more attention.

There are possibly three major obstacles of efficient arable land use in the western Siberian steppe soils, namely are soil erosion, water deficiency and nutrient depletion.

1. **Soil erosion**: We could not identify a significant stabilization of SOC in macroaggregates, but we were able to show a linear relationship between the SOC content and the aggregate stability of the surface soil, which follows the order grassland soil > minimum/zero tillage > conventional tillage. Hence, even if there is no significant increase in the whole SOC stock at minimum or zero tillage, the likely higher organic C stock at the first few cm of the soil leads to larger mean weight diameters of soil aggregates and a higher aggregate stability, thus reducing soil erosion and providing an advantageous pore size distribution for root growth.
2. **Water deficiency**: As water supply to plants is of utmost importance for plant growth at the steppe, particularly in the dry steppe, climate-optimized land management must focus on increasing the relative water uptake by the crops (i.e. increasing transpiration water losses at the cost of evaporation water losses). As is shown in Chap. 12, soil moisture conditions are more favourable for plant growth under minimum and zero tillage than under conventional tillage.
3. **Nutrient depletion**: Due to financial constraints, large areas of arable soil in the Kulunda steppe did not receive any or much too less fertilizer since the collapse of

the Soviet Union. This leads to nutrient limitations of plant growth, which might be particularly serious for nitrogen and potassium. While nitrogen is of utmost importance for biomass formation, a good potassium supply helps to increase the water use efficiency by plants. Nitrogen is likely depleted in the soils due to organic matter mining, while potassium deficiency may be particularly relevant in soils of neutral pH with low silicate weathering rates. In addition, in soils of high pH also micronutrients may become limited.

To overcome these three obstacles, the establishment of innovative agricultural machinery to realize climate-adapted tillage concepts and the development of an optimized fertilization regime is necessary. As in recent years, agriculture is getting increasingly into the focus of decision-makers in the Russian Federation, the chances to realize such concepts are higher than in the past. Investment into new technologies enabling minimum or no-tillage agriculture along with optimized fertilization will increase biomass production and with that organic matter input to the soil. Likewise, the aggregate stability will increase as a result of less soil disturbance and higher organic matter stocks, while the soil water balance is improved at the same time. Agricultural intensification, not to be confounded with tillage intensification, will thus lead to lower soil erosion, higher soil resilience, and with that to a higher likelihood of stable and high yields.

Acknowledgements The paper is based on the results of the research work carried out in the scope of the German–Russian cooperation project KULUNDA. The project is financed by the German Federal Ministry of Education and Research (BMBF; FKZ 01LL0905I). We would like to thank all colleagues from the Russian and German partner institutions for their cooperation and support during the investigations.

References

Batjes NH (2014) Total carbon and nitrogen in the soils of the world. Eur J Soil Sci 65:4–21

Bischoff N, Mikutta R, Shibistova O, Puzanov A, Reichert E, Silanteva M, Grebennikova A, Schaarschmidt F, Heinicke S, Guggenberger G (2016) Land-use change under different climatic conditions: Consequences for organic matter and microbial communities in Siberian steppe soils. Agric Ecosyst Environ 235:253–264

Bischoff N, Mikutta R, Shibistova O, Puzanov A, Silanteva M, Grebennikova A, Fuss R, Guggenberger G (2017) Limited protection of macro-aggregate-occluded organic carbon in Siberian steppe soils. Biogeosciences 14:2627–2640

Bischoff N, Mikutta R, Shibistova O, Dohrmann R, Herdtle D, Gerhard L, Fritzsche F, Puzanov A, Silanteva M, Grebennikova A, Guggenberger G (2018) Organic matter dynamics along a salinity gradient in Siberian steppe soils. Biogeosciences 15:13–29

Bondeau A, Smith PC, Zaehle S, Schaphoff S, Lucht W, Cramer W, Gerten D, Lotze-Campen H, Müller C, Reichstein M, Smith B (2007) Modelling the role of agriculture for the 20th century global terrestrial carbon balance. Glob Change Biol 13:679–706

Brown KH, Bach EM, Drijber RA, Hofmockel KS, Jeske ES, Sawyer JE, Castellano MJ (2014) A long-term nitrogen fertilizer gradient has little effect on soil organic matter in a high-intensity maize production system. Glob Change Biol 20:1339–1350

Burney JA, Davis SJ, Lobell DB (2010) Greenhouse gas mitigation by agricultural intensification. Proc Natl Acad Sci USA 107:12052–12057
Cambardella CA, Elliott ET (1993) Carbon and nitrogen distribution in aggregates from cultivated and native grassland soils. Soil Sci Soc Am J 57:1071–1076
Cambardella CA, Elliott ET (1994) Carbon and nitrogen dynamics of soil organic matter fractions from cultivated grassland soils. Soil Sci Soc Am J 58:123–130
Elliott ET (1986) Aggregate structure and carbon, nitrogen, phosphorus in native and cultivated soils. Soil Sci Soc Am J 50:627–633
Elmhagen B, Eriksson O, Lindborg R (2015) Implications for climate and land-use change for landscape processes, biodiversity, ecosystem services, and governance. Ambio 44(Suppl 1):1–5
Foley JA, DeFries R, Asner GP, Barford C, Bonan G, Carpenter SR, Chapin FS, Coe MT, Daily GC, Gibbs HK, Helkowski JH, Holloway T, Howard EA, Kucharik CJ, Monfreda C, Patz JA, Prentice IC, Ramankutty N, Snyder PK (2005) Global consequences of land use. Science 309:570–574
Foley JA, Ramankutty N, Brauman KA, Cassidy ES, Gerber JS, Johnston M, Mueller ND, O'Connell C, Ray DK, West PC, Balzer C, Bennett EM, Carpenter SR, Hill J, Monfreda C, Polasky S, Rockström J, Sheehan J, Siebert S, Tilman D, Zaks DPM (2011) Solutions for a cultivated planet. Nature 478:337–342
Guo LB, Gifford RM (2002) Soil carbon stocks and land use change: a meta analysis. Glob Change Biol 8:345–360
Gulde S, Chung H, Amelung W, Chang C, Six J (2008) Soil carbon saturation controls labile and stable carbon pool dynamics. Soil Sci Soc Am J 72:605–612
Gupta RK, Rao DLN (1994) Potential of wastelands for sequestration carbon by reforestation. Curr Sci 66:378–380
IPCC (2014) Climate change 2014: synthesis report. Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change [Core Writing Team, RK Pachauri and LA Meyer (eds.)]. IPCC, Geneva
Kaiser K, Guggenberger G (2003) Mineral surfaces and soil organic matter. Eur J Soil Sci 54(2): 219–236
Kamp J, Urazaliev R, Balmford A, Donald PF, Green RE, Lamb A, Phalan B (2015) Agricultural development and the conservation of avian biodiversity on the Eurasian steppes: a comparison of land-sparing and land-sharing approaches. J Appl Ecol 52:1578–1587
Kämpf I, Hölzel N, Stöffle M, Broll G, Kiehl K (2016) Potential of temperate agricultural soils for carbon sequestration: a meta-analysis of land-use effects. Sci Total Environ 566–567:428–435
Kell D (2012) Large-scale sequestration of atmospheric carbon via plant roots in natural and agricultural ecosystems: why and how. Philos Trans Roy Soc B 367:1589–1597
Kleber M, Eusterhues K, Keiluweit M, Mikutta C, Mikutta R, Nico PS (2015) Mineral-organic associations: formation, properties and relevance in soil environments. Adv Agron 130:1–140
Kraemer R, Prishchepov AV, Müller D, Kuemmerle T, Radeloff VC, Dara A, Terekhov A, Frühauf M (2015) Long-term agricultural land-cover change and potential for cropland expansion in the former Virgin Lands area of Kazakhstan. Environ Res Lett 10:054012
Kurganova I, De Gerenyu VL, Six J, Kuzyakov Y (2014) Carbon cost of collective farming collapse in Russia. Glob Change Biol 20:938–947
Kuzyakov Y, Domanski G (2000) Carbon input by plants into the soil. Review. J Plant Nutr Soil Sci 163:421–431
Laganière J, Angers D, Paré D (2010) Carbon accumulation in agricultural soils after afforestation: a meta-analysis. Glob Change Biol 16:439–453
Lal R (2004) Soil carbon sequestration impacts on global climate change and food security. Science 304:1623–1627
Meyfroidt P, Schierhorn F, Prishchepov AV, Müller D, Kuemmerle T (2016) Drivers, constraints and trade-offs associated with recultivating abandoned cropland in Russia, Ukraine and Kazakhstan. Glob Environ Change 37:1–15
Mikhailova EA, Bryant RB, Vassenev II, Schwager SJ, Post CJ (2000) Cultivation effects on soil carbon and nitrogen contents at depth in the Russian Chernozem. Soil Sci Soc Am J 64:738–745

Mikutta R, Mikutta C, Kalbitz K, Scheel T, Kaiser K, Jahn J (2007) Biodegradation of forest floor organic matter bound to minerals via different binding mechanisms. Geochim Cosmochim Acta 71:2569–2590

Ogle SM, Breidt FJ, Paustian K (2005) Agricultural management impacts on SOCarbon storage under moist and dry climatic conditions of temperate and tropical regions. Biogeochemistry 72:87–121

Paul EA, Paustian KH, Elliott ET, Cole CV (eds) (1996) Soil organic matter in temperate agroecosystems—long-term experiments in North America. CRC Press, Boca Raton, USA

Paustian K, Lehmann J, Ogle S, Reay D, Robertson GP, Smitz P (2016) Climate—smart soils. Nature 532:49–57

Poeplau C, Don A (2015) Carbon sequestration in agricultural soils via cultivation of cover crops—A meta-analysis. Agric Ecosys Environ 200:33-41

Poeplau C, Don A, Vesterdal L, Leifeld J, VanWesemael B, Schumacher J, Gensior A (2011) Temporal dynamics of SOCarbon after land-use change in the temperate zone—carbon response functions as a model approach. Glob Change Biol 17:2415–2427

Powlson DS, Stirling CM, Jat ML, Gerard BG, Palm CA, Sanchez PA, Cassman KG (2014) Limited potential of no-till agriculture for climate change mitigation. Nat Clim Change 4:678–683

Rodionov A, Amelung W, Urusevskaja I, Zech W (1998) Beziehungen zwischen Klimafaktoren und C-, N-Pools in Partikelgrößen-Fraktionen zonaler Steppenböden Russlands [Relationships between climate factors and C, N pools in particle size fractions of zonal steppe soils of Russia]. Zeitschrift für Pflanzenernährung und Bodenkunde 161:563–569 (in German)

Rolinski S, Müller C, Heinke J, Weindl I, Biewald A, Bodirsky BL, Bondeau A, Boons-Prins ER, Bouwman AF, Leffelaar PA, te Roller JA, Schaphoff S, Thonicke K (2018) Modeling vegetation and carbon dynamics of managed grasslands at the global scale with LPJmL 3.6. Geoscientific Model Dev 11:429–451

Sala OE, Chapin FS, Armesto JJ, Berlow E, Bloomfield J, Dirzo R, Huber-Sanwald E, Huenneke LF, Jackson RB, Kinzig A, Leemans R, Lodge DM, Mooney HA, Oesterheld M, Poff NL, Sykes MT, Walker BH, Walker M, Wall DH (2000) Global biodiversity scenarios for the year 2100. Science 287:1770–1774

Saraykin V, Yanbykh R, Uzun V (2017) Assessing the potential for Russian grain exports: a special focus on the prospective cultivation of abandoned land. In: Paloma SG, Mary S, Langrell S, Ciaian P (eds) The Eurasian wheat belt and food security change. Springer International Publishing, Cham, pp 155–175

Schmidt MWI, Torn MS, Abiven S, Dittmar T, Guggenberger G, Janssens IA, Kleber M, Kögel-Knabner I, Lehmann J, Manning DAC, Nannipieri P, Rasse DP, Weiner S, Trumbore SE (2011) Persistence of soil organic matter as an ecosystem property. Nature 478:49–56

Schulze ED, Ciais P, Luyssaert S, Schrumpf M, Janssens IA, Thiruchittampalam B, Theloke J, Saurat M, Bringezu S, Lelieveld J, Lohila A, Rebmann C, Jung M, Bastviken D, Abril G, Grassi G, Leip A, Freibauer A, Kutsch W, Don A, Nieschulze J, Börner A, Gash JH, Dolman AJ (2010) The European carbon balance. Part 4: integration of carbon and other trace-gas fluxes. Glob Change Biol 16:1451–1469

Six J, Feller C, Denef K, Ogle SM, Moraes JC, Albrecht A (2002) Soil organic matter, biota and aggregation in temperate and tropical soils—effects of no-tillage. Agronomie 22:755–775

Swinnen J, Burkitbayeva S, Schierhorn F, Prishchepov AV, Müller D (2017) Production potential in the "bread baskets" of eastern Europe and Central Asia. Glob Food Secur 14:38–53

Targulyan VO, Gerasimova MI (eds) (2007) Mirovaia korreliativnaia baza pochvennykh resursov: osnova dlia mezhdunarodnoi klassifikatsii i korreliatsii pochv (World correlative base of soil resources: basis for international classification and correlation of soils). KMK Scientific Press Ltd, Moscow (in Russian)

Wegren SK (2013) Food security in the Russian Federation. Eurasian Geogr Econ 54:22–41

Chapter 14
Types, Occurrence and Tendencies of Soil Degradation in the Altai Krai and the KULUNDA Research Region

M. Frühauf, G. Schmidt, P. Illiger and T. Meinel

Abstract The Kulunda Steppe in southwestern Siberia is nowadays an agrarian region characterized by an intensive land use unsuited for the natural environmental conditions. The KULUNDA project's research region is part of the agricultural regions ploughed and cultivated during the so-called Virgin Lands Campaign of the Soviet era. Here, cause and effect relationships between physical and chemical soil properties under different land use managements are analysed regarding climate change adaptation, reduction of greenhouse gases and a sustainable regional development. This chapter focuses on the spatial differentiation as well as intensity- and process-related assessment of selected forms of soil degradation in the research region. The region's soil degradation is characterized by changed physical and chemical soil properties besides the occurrence of water and especially wind erosion. Type and intensity of the different degradation processes vary with local environmental conditions. In this connection, we could show that type, intensity and period of land management practice resulted in various negative effects on local conditions which increase overall the vulnerability and erosion susceptibility of the locations. In areas with an annual precipitation of less than 250 mm, the degradation even leads partly to a desertification phenomenon.

Keywords Altai Krai · History of land use · Causativ factors and types of soil degradation · Desertification · Different types of degradation · Wind erosion

[1]BMBF—Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung).

M. Frühauf (✉) · G. Schmidt · P. Illiger
Institute of Geosciences and Geography, Martin-Luther-Universität Halle-Wittenberg,
Von-Seckendorff-Platz 4, 06120 Halle, Germany
e-mail: manfred.fruehauf@geo.uni-halle.de

T. Meinel
Amazonen-Werke, Rippachtalstraße 10, 04249 Leipzig, Germany

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_14

14.1 Introduction and Previous Knowledge

The KULUNDA project (www.kulunda.eu) was an interdisciplinary joint research project funded by the BMBF[1] with the goal to develop locally adapted, sustainable land use strategies. The project's research results are examined in the context of other studies on the agrarian regions of southwestern Siberia and the Altai Krai. Two-thirds of the 100,000 km^2 of the Kulunda Steppe belong to the administrative unit. A fundamental requirement to achieve the project's goal was to study the scientific basics of the cause and effect relationships of soil degradation phenomena. The knowledge about the soil resources of our research region is the foundation for a sustainable agricultural production.

While selected processes and phenomena were topic of previous chapters, this article focuses on the spatial synthesis and predictions of soil degradation trends.

The attribution of soil degradation phenomena to agro-ecological regions, each with specific climatic and pedologic characteristics, is an important foundation for the evaluation of the phenomena's spatial dimensions. The agro-ecological regions have been previously classified and named differently by researchers. Afonin et al. (2008) named them West Kulunda, East Kulunda, Pri-Aleisk, Central Area and Pri-Obsk, while Morkovkin et al. (2013) called them dry steppe, arid steppe, temperate-arid steppe, central steppe and meadow steppe. The regions are part of KULUNDA's research region and have been also classified as forest steppe, typical steppe and dry steppe according to Atlas Altaiskovo kraia (1978). Latter classification is used as spatial reference basis for the following statements regarding the spatial as well as intensity- and process-related differentiation of selected forms of soil degradation in the research region.

Almost 30% of the steppes in southern Siberia have been damaged by wind erosion and 16% by water erosion. The Altai Krai is of special importance regarding the erosion susceptibility and erosion types of its agricultural areas. 88.5% of the 6.1 million ha of arable land is rated as at risk for erosion (Gos Doklad 1998). In comparison with the agricultural regions around Novosibirsk and Omsk, the extent of the damage is much higher in the Altai Krai (Tanasienko et al. 1999). 47% of arable land in the Altai Krai show wind and water erosion damage, whereas only 40% around Omsk and 13% around Novosibirsk are affected by erosion.

As described in previous chapters, the occurrence of erosion and its type, intensity and spatial dimension is related to the different stages of ecosystem conversion and cultivation of steppe (Frühauf and Meinel 2014). To some extent, different soil degradation phenomena influence and interfere with each other. The following will first discuss the causes and forms of erosion in the research region of the KULUNDA project.

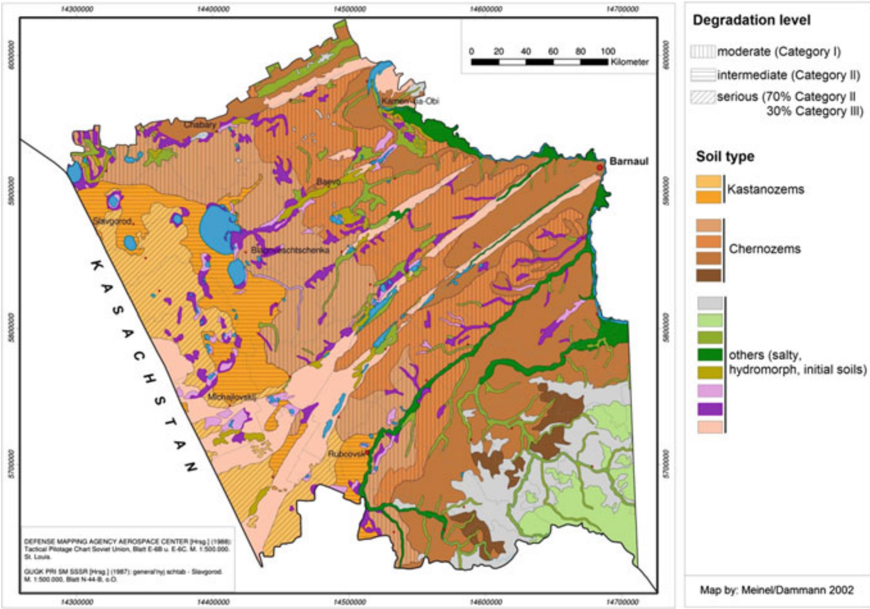


Fig. 14.1 Soil degradation by wind in the agricultural regions of the Altai Krai. *Source* Meinel (2002)

14.2 Wind Erosion as the Dominant Type of Soil Degradation in the Research Region

The research results of Meinel (2002), which confirm and extend Burlakova's (1999) findings, show that wind erosion is the dominant process of soil degradation in the Altai Krai and especially in the selected research region with its ecological and economic impacts. Meinel (2002) defined in this context three categories with a different annual soil loss.

As shown in the map in Fig. 14.1, the most severely damaged areas are in the southwestern dry steppe where Kastanozems are the dominant soil type. As mentioned in Chap. 8, interrelations between the different stages of agricultural steppe cultivation, type and intensity of land use practices and wind erosion phenomena are evident (Frühauf and Meinel 2014). The most severe wind erosion damage was observed in the central part of the Kulunda Steppe (Fig. 14.2).

The light Kastanozems of this area are predominantly composed of fine sand substrate (the same soil type consisting mainly of silt substrate is less affected with grade two damage). Schreiner and Meyer (2014) point out the strong wind erosion impact in the northern Kulunda Steppe (Baga district of the Novosibirsk Region). In addition to the forms of soil degradation, they specify indicators of desertification in this region. Such severe soil degradation phenomena caused by wind erosion affect

Fig. 14.2 Degraded top soil of a Kastanozem. *Picture source* Meinel (2002)

not only arable land but also pastures. Pastures in the Kulunda Steppe that are located near the border to Kazakhstan show to some extent severely damaged vegetation and topsoils (compaction and humus depletion). Often, drifts blur the boundaries between arable land and pastures. Figure 14.3 shows these phenomena can be found also in the dry steppe of the KULUNDA research region.

With an annual precipitation of less than 250 mm, forms of desertification can be found here which are also reflected in quantitative and qualitative changes of biomass and, respectively, its productivity. Wind erosion often affects land across different usage types and affected areas become hotspots of degradation and desertification from where damage can spread in neighbouring, still intact arable land or pastures.

These findings about the dominance of wind erosion are backed by the results of Paramonov et al. (2003). They are based on their spatial- and intensity-related differentiation of three soil degradation processes on agro-ecological zones (Table 14.1). Especially, the Kastanozems of the dry steppe but also the southern Chernozems zone in the semi-arid steppe are affected by wind erosion.

The data in Table 14.1 clearly display wind erosion as the main form of soil degradation in the Altai Krai. Soil salinization affects only one third and water erosion one fifth in comparison with the area damaged by wind erosion (spatial interference is not distinguishable by this data). The impact (and intensity) of wind erosion and (secondarily) soil salinization decreases with the climatic-pedological gradient

Fig. 14.3 Soil drifts caused by wind erosion from arable land into neighbouring pastures near Slavgorod. *Picture source* Meinel (2011)

Table 14.1 Soil degradation phenomena in the agro-ecological regions in the Altai Krai

No.	Zone	Area (1000 ha)	Area (1000 ha) affected by			
			Soil salinization	Water erosion	Wind erosion	T ha
1.	West Kulunda	1459.8	199.1	8.7	1246.9	1454.7
	%	100.0	13.6	0.6	85.4	99.6
2.	East Kulunda	1575.2	400.4	60.7	1081.5	1542.6
	%	100.0	25.4	3.8	68.7	97.9
3.	Pri-Alejskaja	1578.4	301.8	368.7	382.5	1053.0
	%	100.0	19.1	23.4	24.26	66.7
4.	Pri-Obskaja	1750.9	337.4	310.8	775.8	1424.1
	%	100.0	19.3	17.8	44.3	81.4
5.	Kulunda steppe total	6364.3	1238.8	749.0	3486	5774.5
	%	100.0	19.4	11.8	54.8	86.0

Based on Paramonov et al. (2003)

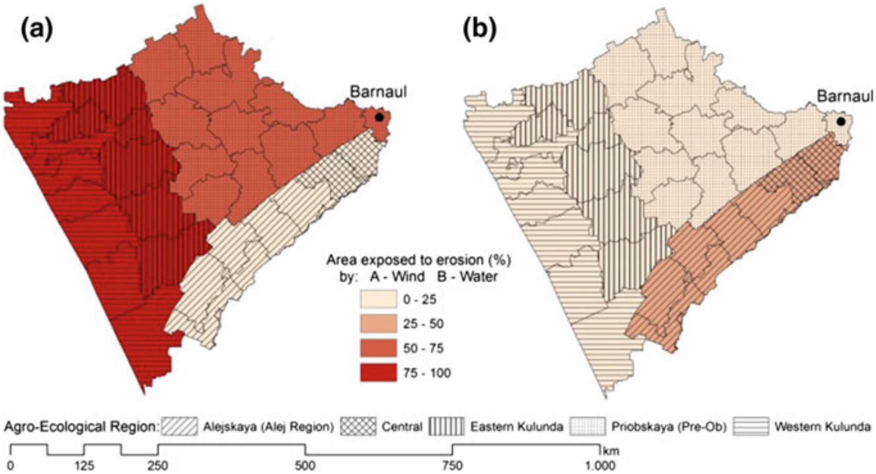


Fig. 14.4 Area exposed to erosion by wind and water in the research region

and increasing humidity towards the northeast (Table 14.1). Concurrently, the dominant soil type changes from Kastanozems to Chernozems of different developmental stages.

Besides the dominance of wind erosion processes in the flat landscapes of the dry steppe zone with Kastanozems, a combined action of wind and water erosion is observed in the subzones of arid, temperate-arid and forest-outlier steppe, and water erosion develops in the zones of central forest steppe and meadow steppe. With increasing humidity in the temperate-arid and arid steppes, water erosion also occurs beside wind erosion. Another reason besides the mostly low precipitation for the less widespread occurrence of water erosion is the very flat relief of the KULUNDA project's research region. Hence, the less widespread, different forms of water erosion are mostly localized to the hillier area of the Altai Mountains foreland with a higher precipitation (Fig. 14.4).

Reasons for the dominance of wind erosion in the dry areas of the Altai Krai and, therefore, in the semiarid landscapes are natural conditions combined with factors resulting from land use which will be described in the following.

14.3 Natural Factors Promoting Wind Erosion in the Southwestern Part of the Research Region

The widespread Kastanozems developed from substrates with a high silt and sand content, especially in the middle part of the southwestern dry steppe and thus, they are very susceptible to wind erosion (Paramonov et al. 2003; Illiger et al. 2014). In comparison with soils under quasi-natural conditions (pastures), dark Kastanozems showed an average reduction of the humus horizon by 15 cm to an average depth of 36 cm due to wind erosion (Meinel 2002). Not only the precipitation but also the silt and humus content in the soils increases from the southwest to the northeast. Soils are consequently less erodible due to the more frequent water availability. Also, the southern Chernozems with their higher humus content have a better aggregate stability and thus, are more resistant to drifts. According to the findings of Morkovkin et al. (2013), the ratio of water to wind erosion intensity is 1–22.4 in the arid steppe and 1–14.5 in the temperate-arid and forest-outlier steppe. Both results show not only the significance of wind erosion but also that with increasing precipitation the percentage of the areas exposed to water erosion increases, but it is not equal to wind erosion in this zone. Unlike the dry steppe, the wind protection plants are less damaged in this area and complemented by numerous natural wood enclaves. Here, the average soil horizon reductions were (only) 10 cm in comparison with adjacent natural steppe areas. Therefore, these values are in accordance with results determined for this region by Russian authors (Atlas Altaiskovo Kraia 1978).

Another factor resulting in a higher susceptibility to wind erosion of soil is that during the summer the precipitation occurs as convective rainfalls (Bergmann and Frühauf 2011). Higher summer temperatures and a low water retention ability due to type and intensity of land use result in an increased evaporation from topsoils with a smaller humus and higher sand content. Strong katabatic winds from the Altai Mountains during the summer (so-called Sukhowei's) have an even more desiccating effect on the arable soils and increase their wind erosion susceptibility. These winds as well as the so-called 'black' storms during winters with low snow coverage are more localized to the drier agrarian steppes (Meinel 2002).

14.4 Use-Related Causes of the Severe Wind Erosion Damage

Besides natural conditions, type and intensity of land use practices during and after the steppe cultivation (see Chap. 4) were important factors for the development of wind erosion. Mechanical stress (Meinel 2002; Frühauf and Meinel 2014) along with the subsequent reduction of organic matter (see below) resulted in the destruction of stable soil aggregates (see this chapter). The particle surface area exposed to wind increased while the density and bonding forces decreased. The parent material in the middle parts of the dry steppe with a higher fine sand content is even more susceptible to wind erosion (Illiger et al. 2014).

Grunwald et al. (2016) pointed out the role of black fallow for wind erosion, which is still widely practiced in the investigation area. Its purpose is the retention of precipitation in the soils for the next crop-growing cycle as well as an efficient pest control. But usually, a deep loosening is applied additionally to these soils in fall so that the soils are unprotected against wind for most of the year which strongly promotes wind erosion. In this context, Grunwald et al. (2016) pointed

Fig. 14.5 Often used practise of burning stubble in the field with various negative ecological effects. *Picture source* Meinel and Frühauf (2011)

out the widespread crop-growing cycle ‘summer wheat after summer wheat’, which usually involves a deep cultivation of the soils after the harvest in fall.

Incorporating stubbles in the soils by intensive cultivation is practiced already for a long time and still a common practice. But, as displayed in Fig. 14.5, stubbles are also burned on the field to some extent. On the stubble-free soil surface, the snow retention decreases during winter when winter storms occur often. A low snow depth or a snow-free soil surface (snow blown away by wind) result in a small soil water availability in spring (Meinel 2002). In spring, the soil is usually cultivated in two steps with weed control as the main target. Lack of funding for herbicides is compensated by a repeated flat soil cultivation before sowing. Considering the usual sowing date around the end of April/beginning of May in the Kulunda Steppe, the huge erosion potential created by this land management practice becomes obvious!

The snow melt in the region occurs on average between the end of March and mid-April. Therefore, the described soil cultivation practise during this spring period results often in intense and additional topsoil evaporation. As a result, the topsoil becomes unprotected, dry and very well loosened. According to Morgen and Hassenpflug, these are very favourable conditions for wind erosion. They are even more prevalent when noon temperatures reach above 30 °C as it often happens in May (GUGS 1977) and the evaporation increases even more. Additionally, the already mentioned dry katabatic winds (Sukhowei) occur more frequently in May

Fig. 14.6 Wind erosion destroys the just sowed crop in a field and causes ripple formation. *Picture source* Meinel (2008)

(Tanasienko et al. 1999) and cause extreme wind erosion. During the KULUNDDA project, such occurrences were observed especially at the end of May and beginning of June. They result occasionally in the total loss of the just sowed crop but also in the formation of dunes along the field borders (Fig. 14.6).

The topsoil (A) horizons of the local soils are affected in two ways by the wind erosion: The A horizon is either reduced up to the total loss or buried under accumulated soil material due to drifts (Fig. 14.7). This causes texture-selective changes with negative ecological impacts for the sites (Meinel 2002). The local environment becomes more heterogeneous due to vertically and laterally changing soil moisture, humus and nutrient contents which influence the yield. These wind erosion phenomena reach at times and locally the dimensions of dust storms with off-site effects beyond the deflation areas. Effects are not only the covering of natural soil horizons in and around shelterbelts or material deposition in natural lakes or water reservoirs but also a considerable dust pollution of more distant settlements affecting the people living there (see Fig. 14.8) The forms and effects of these wind erosion phenomena in the investigation area are often very like the 'Dust Bowl Syndrome' of the North-American agrarian region in the middle West in the 1930s and 1950s and the present (Frühauf and Meinel 2014).

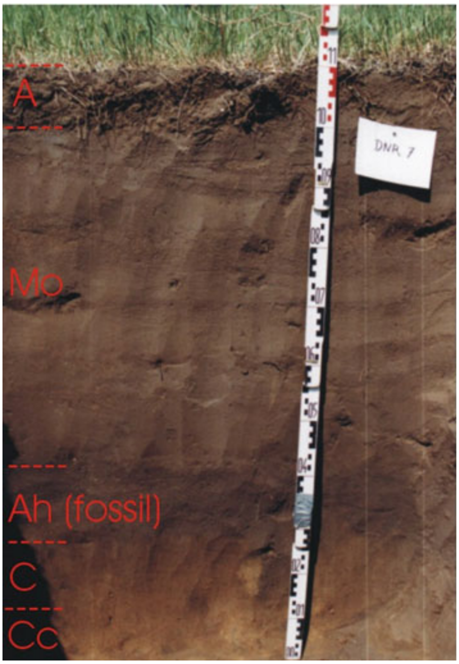


Fig. 14.7 Profile of a soil affected by drifts with accumulated material in the M horizon and a new initial A horizon. *Picture source* Meinel (2002)

Fig. 14.8 Dust storm in Barnaul. *Picture source* Silanteva (24.05.2012, 2.50 pm)

14.5 *Ovragi* (Gullies) as the Formative Type of Water Erosion

As already mentioned, water erosion is of less importance than wind erosion regarding soil degradation phenomena in the KULUNDA research region. Main types of water erosion are rill, gully and valley erosion (in Russian called ovragi), while soil degradation by sheet erosion occurs much less (Larionova et al. 2003; Van der Maarel and Titlyanova 1989; Zonn 1995). Occurrence, dynamic and geomorphologic preconditions of the water erosion types have been rarely researched and were not part of the KULUNDA project either. The development of ovragi or rather gullies result in an ongoing surface destruction of landscapes and massive soil loss. Its ecologic-economic consequences are specially widespread and not only limited to on-Site effects.

Depending on the relief, water erosion occurs largely in the hilly foreland of the Altai Mountains and the higher river banks along the southwestern border of the research region. Here—especially on the cut banks of larger rivers like the Ob or Aley—large gullies have been formed showing a very dynamic development (Dammann 2005) and cutting deeply in the flat surface of the plateaus (Fig. 14.9).

Fig. 14.9 Very dynamic gully formation along the river Aley causes soil loss on the bordering agricultural used plateaus. *Picture source* Meinel (2008)

Research findings regarding occurrence and dynamic of water erosion revealed the negative impact of the prolonged snow accumulation by shelterbelts and its effects on subterranean water and matter transport (De Jong and Kowalchuk 1995; Dammann 2005).

14.6 Loss of Organic Matter in Soils

The decrease of organic matter and the resulting loss of humus stock and depth are an important effect complex of soil degradation. Numerous findings (show also this chapter of this book) regarding cause-effect relations as well as on- and off-site consequences (such as influence on the greenhouse effect) from the world's different biomes and land use regions have been published (Ajami et al. 2016; Bruun et al. 2015; Guo and Gifford 2002; Hiederer and Köchy 2011; Kalinina et al. 2011; Poeplau et al. 2011).

That also applies to the agricultural region of southwestern Siberia. Titljanova (2000) and Rusalimova et al. (2006) calculated an average loss of organic matter of 44% for arable land, 32% for meadows and 23% for pasturages in this region over the last 100 years. Hence, the overall loss of soil organic carbon (SOC) in all agrarian ecosystems of the forest steppe in western Siberia amounts to 13.4×10^8 t just in the twentieth century. Optimistic studies show SOC losses of up to 20% (Rusalimova et al. 2006; Poeplau et al. 2011), while pessimistic approaches show losses up to 43% (Mikhailova et al. 2000), or even 64% (Mikhailova and Post 2006; Meinel 2002; Kalinina et al. 2011).

The most important factors are the type and intensity of soil cultivation, the inadequate additional supply of organic matter by (organic) fertilization but also other agricultural land management practices which are partially rooted in the previous political (soviet) system. In this context, Schreiner and Meyer (2014) refer to the following fact: Until the mid-1930s, fallow-black fallow-agricultural systems existed in already cultivated regions. Annual crop rotations were widely used in this landscape until then. This (new) agricultural practice entailed the cultivation of a field for six years followed by nine years of fallow, and two years of black fallow. After the collectivization under Stalin's leadership was completed at the beginning of 1930s, the soils were continuously cultivated without any fallow periods.

Research regarding this matter during the KULUNDA project incorporated previous findings of Burlakova (1999), Meinel (2002), Morkovkin et al. (2013) and Frühauf and Meinel (2014). They point out the interaction between type, intensity and duration of land use and the resulting loss of organic matter in the process structure of the soil. Findings regarding land-use-initiated losses of organic matter showed differences depending on soil type and type of landscape (Illiger et al. 2014). Based hereupon but also on findings from Meinel (2002; Fig. 14.10), the humus contents of soils in the typical steppe and dry steppe were reduced by approximately 50% since the Virgin Lands Campaign, and Illiger et al. (2014) estimated an overall loss of organic carbon in the soils of KULUNDA's research region of 143.8 million t

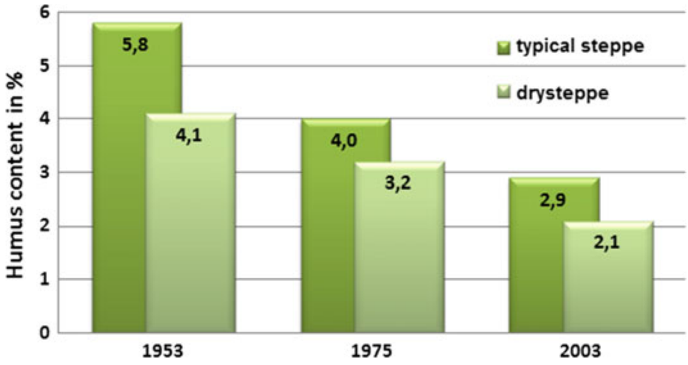


Fig. 14.10 Humus loss of approximately 50% in different steppe zones in 50 years (example of pessimistic approach). *Source* Meinel (2002)

since the start of the Virgin Lands Campaign (Fig. 14.11). But not only the (natural) humus contents differ between the typical and dry steppe regions. The statements of the National Report (Gos Doklad 1998) point out that the humus content of Chernozems in the Altai Krai (forest steppe) has been reduced from 6 to 8% before the start of Virgin Lands Campaign to 3.5 to 5.8% in 1997. Over the same period, the humus content of dark Kastanozems decreased from 3.5 to 4.5% to 2.0 to 2.4%. These values illustrate, similar to our own research results (see this chapter) that, besides wind erosion phenomena in the agrarian steppes, the humus loss as another form of soil degradation has reached a particular intensity. These findings back the results of Morkovkin et al. (2013). They reached the conclusion that the largest decrease of organic matter can be found in the soils of arid and temperate semiarid steppes. Thus, they signal a climate dependence of the reduction of humus, which could not be confirmed by their own investigations.

Furthermore, the research results of Morkovkin also pointed out that the thickness of the A horizon is reduced by the humus decomposition (We believe that wind erosion has a significant role to play here).

While it is of between 38 and 40 cm thick in unploughed Chernozems in the forest steppe, it is reduced by 12–22 cm in agricultural soils due to *deflation* and loss of organic matter (Morkovkin et al. 2013). The largest decrease of the A-horizon thickness was found by these authors in the Kastanozem region. It is already thinner in native soils and further reduced by wind erosion. Therefore, the agrarian locations with Kastanozems are even more susceptible to wind erosion.

The soil degradation also affects the water infiltration and retention and, therefore, soils are less able to buffer typical regional weather conditions like droughts or torrential rainfalls. Therefore, the soils dry out faster, more intensively and deeper, resulting in an even higher susceptibility for wind erosion. In this regard, Eisold (2016) pointed out partly a higher evaporation rate and an increased upwards capillary action. These conditions led partly to secondary soil carbonization and salinization, especially increased by the applied irrigation methods.

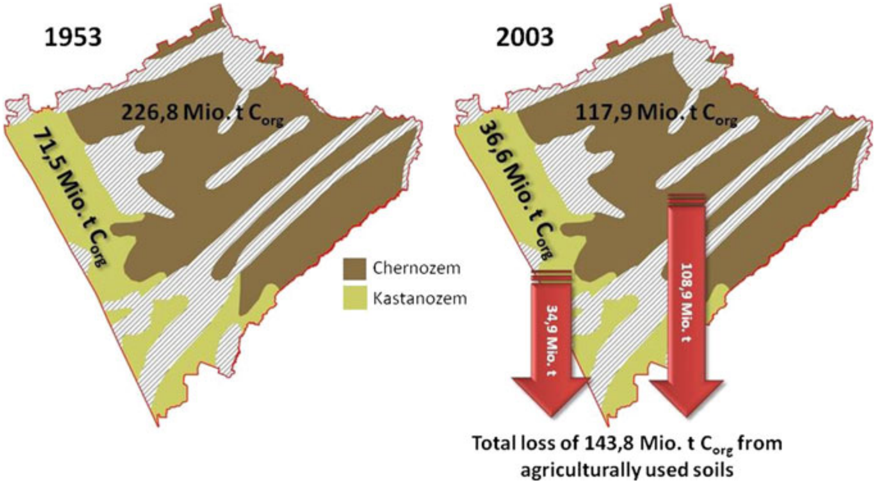


Fig. 14.11 Carbon loss in the upper 30 cm of agricultural soils in the Kulunda Steppe between 1953 and 2003. *Source* Illiger et al. (2014)

Further regional ecological consequences of humus loss have been previously described (compare Meinel 2002; Frühauf and Meinel 2007). But it should be mentioned here that the importance of these agricultural steppes as greenhouse gas sink (especially for carbon dioxide but also nitrous oxide) sharply decreased and their role as a source increased. These results confirm the statements by Houghton et al. (2001) that the agrarian steppes became a (diffuse) source of greenhouse gases with respective impacts on greenhouse effect and climate change (Lal 2010; IPCC 2014). Based on the estimated C losses from soils of the KULUNDA Steppe by Illiger et al. (2014), a CO_2 emission of more than 527 million t has occurred since the start of the Virgin Land Campaign. This number equates the annual CO_2 emission by the industrial nation France or a quarter of Russia's anthropogenic annual CO_2 emission (UNFCCC 2006) and illustrates the important role of these soils as greenhouse gas sources.

14.7 Attempt of a Synthesis of the Different Soil Degradation Phenomena

The different forms and processes of soil degradation interfere with each other in space and time often resulting in complex synergy effects which are difficult to recognize, evaluate and describe. Paramonov et al. (2003) attempted to compile them by creating a cumulative index of degradation phenomena for the arable land and grassland of the Altai Krai. The results show a degradation disposition with a northeast-southwest gradient corresponding to soil types and climatic conditions. Figure 14.12

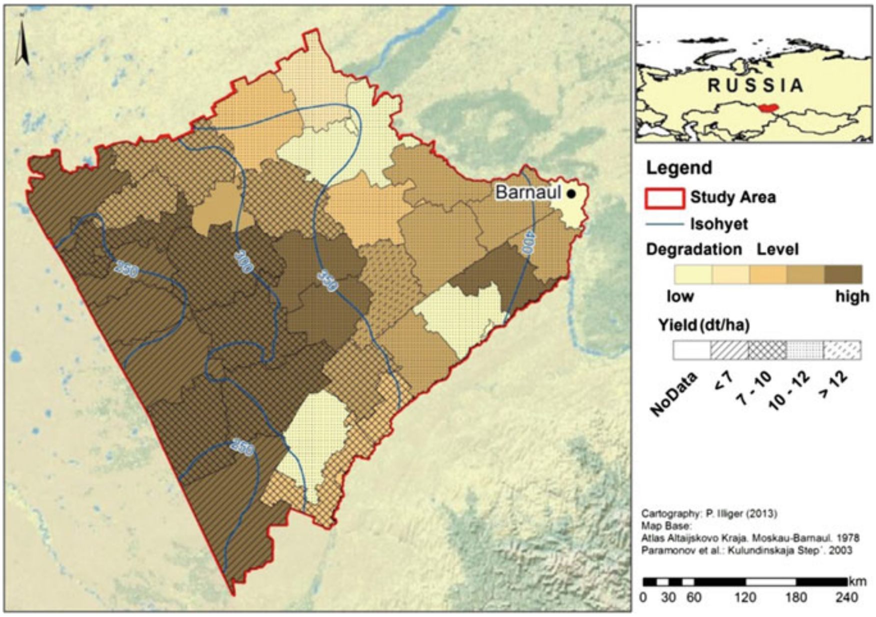


Fig. 14.12 Extent and regional spread of soil degradation in the research area. *Source* Illiger et al. (2014), based on Paramonov et al. (2003)

confirms the resulting statement of the previous description of the different soil degradation phenomena. Wind erosion is the most important soil degradation process in the investigation area which is reflected in the cumulative index. The dry steppe and in part areas of the typical steppe are the most affected by soil degradation. These results regarding regional soil degradation are supported by the displayed average yield data, which show also a strong dependency on precipitation (Fig. 14.12).

Further, these findings show that soil degradation phenomena are not limited to arable land but also occur on meadows and pasture. Especially, the pastures along the border to Kazakhstan have severely damaged vegetation and topsoils (compaction and humus loss) (see Fig. 14.13). Those observed degradation phenomena affect not only the soils. They match the characteristics of desertification as shown by Schreiner and Meyer (2014, Table 1, p. 538) for the northern Kulunda Steppe outside of the investigation area. This process was locally intensified due to the growing cattle number during the years of the KULUNDA project. The increased private life stock resulted also in giving up of desertified fields.

For the entire Altai Krai, Paramonov et al. (2003) developed a method for assessing the degradation level as a function of both field and pasture use. The analyses were conducted on district (rayon) level to gather soil degradation information on a smaller scale. The results revealed direct relations between natural and anthropogenic soil degradation effects due to type and intensity of land use. Those results revealed that the land use was correlated with soil information to localize degradation hot spots,

Fig. 14.13 Fine sand deflation on a field in black fallow. *Picture source* Meinel (1998)

identify potentially endangered areas and recognize patterns. We used this method in our research as well. Our study results for the Mamontovsky Rayon are displayed in Fig. 14.14 as an example. For our analyses, the land use categories derived from satellite data were evaluated regarding hemeroby status (Walz and Stein 2014) and afterwards normed. Soil values of the local soils (based on KGKRF 1992) were normed in the same way. The land-use-soil-mosaic was aggregated which evaluates land use type and soil with 50% each. As a result in the example displayed above, relatively nutrient-poor soils (like calcic Chernozems) used as arable land were identified to show the highest degradation potential. Areas covered with steppe vegetation or forests (defined as 'herbaceous' in the legend) have the lowest degradation potential and the soil type is the least important.

14.8 Development Tendencies of Degradation Processes and Outlook

Besides finding information regarding the spatial dimension (of different forms) of soil degradation in the context of its natural and land use factors, research also focused on finding possible temporal tendencies of degradation development. Possible changes in the factors had to be taken into consideration. Kukis and Gorin were first to point out the relationship between the large-scale steppe conversion during the Virgin Lands Campaign and the afterwards continuously increasing soil degradation.

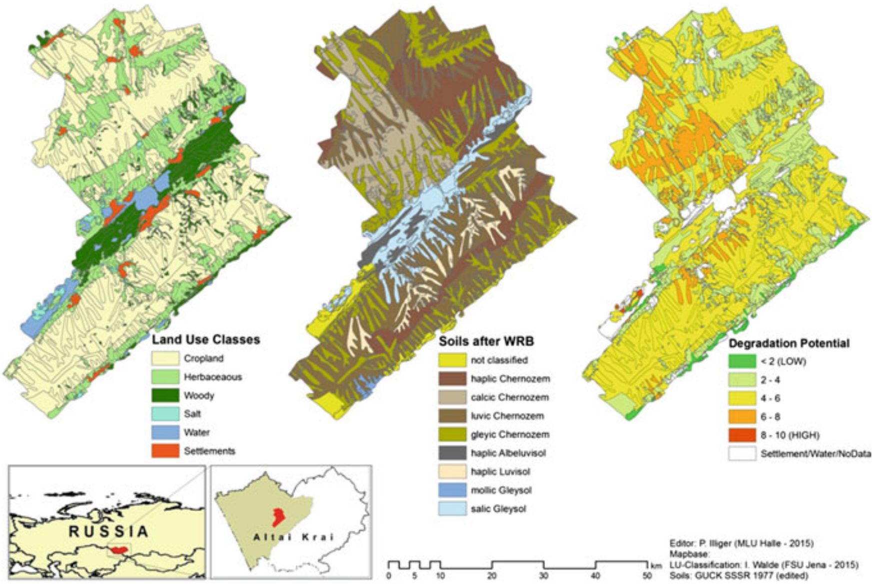


Fig. 14.14 Soil degradation potential at the example of the Mamontovsky Rayon, Altai Krai

They concluded that the degradation had intensified ten years after the beginning of the large-scale cultivation. In their opinion, the boundary to severely damaged soils was moved 50–60 km to the north or northeast, the boundary to moderately damaged soils was moved even a 100 km in the same direction. In this context, some authors have also used the term 'anthropogenic aridization' and reported a northward movement of the steppe-forest boundary (Williams 2003).

In this context, Burlakova (1999) researched the extent of the degraded areas and the spatial development of the degradation in the Altai Krai in different time stages (see Table 14.2). However, the numbers in the first line of Table 14.2 are questionable because it seems difficult to understand that, in 1980, a larger area (900,000 ha) was devastated by water erosion than by wind erosion. The results previously described in this chapter and our geomorphological observations showed that the Kulunda Steppe has hardly any elevation. Moreover, Burlakova (1999) points out the evident increase in soil devastation caused by wind erosion, leading to a five-time increase of degraded land between 1980 and 1995.

Furthermore, Morkovkin et al. (2013) also refer to indicators for an increase and even acceleration of soil degradation phenomena. Findings of Morkovkin et al. (2013), based on a comparative analysis of the results of two soil surveys (first survey period between 1960 and 1970; second survey period between 1980 and 1990), show the following interesting results:

Table 14.2 Soil area degraded by water and wind erosion in the Altai region

Year	Water	Wind
1980	900	600
1990	1300	1600
1995	1500	3000

Based on Burlakova (1999, p. 6)
Degradation by water and wind erosion of cultivated land in the Altai Krai (in 1000 ha)

Table 14.3 Annual changing rate (in %) of soil areas with different erosion degrees

State of soils in terms of erosion degree	Dry steppe	Arid steppe	Temperate-arid steppe	Central steppe	Meadow steppe
Not eroded	−3.42	−4.45	−3.72	−1.11	−0.19
Slightly washed-off	0.00	0.19	0.20	1.01	0.32
Moderately washed-off	0.00	0.00	0.03	0.10	−0.11
Severely washed-off	0.00	0.00	0.01	0.00	−0.01
Slightly wind-eroded	2.99	4.12	3.27	0.00	0.00
Moderately wind-eroded	0.43	0.13	0.21	0.00	0.00
Severely wind-eroded	0.03	0.00	0.00	0.00	0.00

Based on Morkovkin et al. (2013)

- During these two survey periods, the greatest change in eroded area was registered in the zone of southern Chernozems in the arid steppe with an increase of about 4.5% per year (Table 14.3)
- Chernozems of the temperate-arid steppes and Kastanozems of the dry steppe are subject to intense erosion as well. The eroded soil area increased annually by 3.7 and 3.4%, respectively, during the monitoring period.

The decomposition rate of organic matter accelerated during the last decades. According to Morkovkin et al. (2013), the annual loss of organic matter in cultivated Chernozems in the Kulunda Steppe increased from 0.7 to 0.9 t ha^{-1} between the first and the second soil survey to 1 t/ha since the collapse of the political system. The annual loss of organic matter in Kastanozems increased from 0.5 t/ha to 0.7 t ha^{-1} in the same period.

The authors showed that especially soils with small humus contents in the temperate-arid steppe were affected by this process.

The results are mainly based on the findings of two large-scale soil quality surveys in the late 1970s and 1980s and the status of soil degradation in the Altai Krai. The

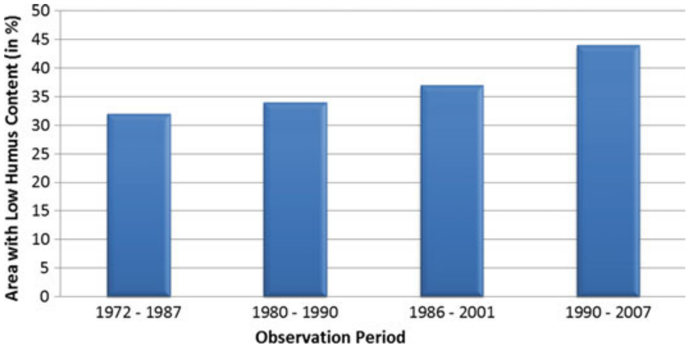


Fig. 14.15 Development of arable land with low humus content in Altai Krai

findings had revealed that the area of these soils had increased annually by 2.7%. At the same time, the depth of the humus horizon was reduced. The highest reduction was found in the Kastanozems in the dry steppe and the southern Chernozems in the arid steppe with an annual loss of 2.3 and 2.1% during the monitoring cycles.

Such results were echoed by Ponkina et al. (2014), who found that the area of soils with a small humus content (less than 4%) increased in the Altai Krai (Fig. 14.15) and, therefore, the quality of the location decreased generally and in relation to the area. The area of soils with small humus content increased particularly after the collapse of the Soviet system in 1990. This can be explained by the decline of the crop production infrastructure. Almost, no fertilizer and herbicides were available and land management had to shift to more intensive soil cultivation methods to perform necessary tasks like weed control and provision of nutrients. Organic matter decreased even more in the soils and the susceptibility to wind erosion increased.

It becomes clear that the land use practises during the Soviet era but also the changed conditions after the collapse of the Soviet Union resulted in a dramatic and catastrophic increase in soil degradation phenomena. Even now, these land cultivation methods, which are so conducive to wind erosion and humus loss are still widely in use. The topsoils become even more stressed and susceptible to wind erosion and humus loss. The nutrient supplementation is inadequate because of the insufficient fertilization with mineral but especially with organic fertilizers.

If and to what extend these processes are affected by regional climate change should be topic of future research. That applies also to the different climate scenarios for the near and further future provided for this region, which identify various challenges regarding sustainable land use and ecosystem development. For western Siberia, the national report of climate change impacts on Russia (NIC 2009) states major changes by: (a) An increase of the average temperature by 3–4 °C until 2050, and (b) a shift of this semiarid landscape zone to the north by 30–80 km in the next 20–25 years (up to 150–200 km by 2050) and a shift of the steppe boundary to the north. By that time, the steppe zone of southern Siberia will be extended by 30%

and the territories affected by land degradation and desertification will be up to 50% larger (Tchebakova et al. 2003).

These facts must be considered during today's planning and implementation of measurements for a future, resource-protecting agrarian land use.

References

Afonin AN, Greene SL, Dzyubenko NI, Frolov AN (eds) (2008) Interactive agricultural ecological Atlas of Russia and neighboring countries. Economic Plants and their Diseases, Pests and Weeds [Online]. Available at: http://www.agroatlas.ru

Ajami M, Heidari A, Khormali F, Gorji M, Ayoubi S (2016) Environmental factors controlling soil organic carbon storage in loess soils of a subhumid region, northern Iran. Geoderma 281:1–10

Bergmann & Frühauf (2011) Regionalklimatische Untersuchungen in der Südwestsibirischen Kulundasteppe. Geoöko 32:160–194

Bruun TB, Elberling B, Neergaard A, Magid J (2015) Organic carbon dynamics in different soil types after conversion of forest to agriculture. Land Degrad Dev 26(3):272–283

Burlakova LM (1999) Pochvenno-zemel'nye resursy [Soil-land resources]. In: Vinikurov UI (ed) Sostoianie okruzhaiushchei sredy v Altaiskom Kraie. OOO NEKSI, Barnaul (in Russian)

Dammann S (2005) Ursachen und Auswirkungen der Ovragbildung in der südsibirischen Kulundasteppe und ihre Wechselwirkungen zur Naturraumausstattung sowie der Landnutzung [Causes and effects of ovragi formation in the South Siberian Kulunda Steppe and its interaction with natural region layout and land use]. Diploma Thesis, Martin Luther University Halle-Wittenberg (unpublished, in German)

De Jong E, Kowalchuk TE (1995) The effect of shelterbelts on erosion and soil properties. Soil Sci 159(5):337–345

Eisold A (2016) Untersuchungen zur Bodenversalzung durch Bewässerung in der südwestsibirischen Kulundasteppe [Studies on soil salinization due to irrigation in the southwest Siberian Kulunda Steppe]. Master's Thesis, Martin Luther University Halle-Wittenberg (unpublished, in German)

Frühauf M, Meinel T (2007) Desertification in the agricultural used dry steppes in Central Asia. In: Proceedings of the international conference soil and desertification—integrated research for the sustainable management of soils in drylands 5–6 May 2006, Hamburg, Germany, Available at: http://www.desertnet.de/proceedings/content/Fruehauf_Meinel.pdf

Frühauf M, Meinel T (2014) Ökosystemkonversion in den temperierten Grasländern Südwestsibiriens: Steuerfaktoren, Etappen und Geoökologische Konsequenzen [Ecosystem conversion in the temperate grasslands of southwestern Siberia: key factors, stages and geoecological consequences]. Geoöko XXXV(1–2):05–38 (in German)

Gos Doklad - Gosudarstvennyi doklad (1998) O sostoianii okruzhaiushchei prirodnoi sredy Rossiiskoi Federatsii v 1997 godu [About the condition of the environment of the Russian Federation in the year 1997]. Moscow. p 606 (in Russian)

Grunwald LC, Belaev VI, Hamann M, Illiger P, Stephan E, Bischoff N, Rudev NV, Kozhanov NA, Schmidt G, Frühauf M, Meinel T (2016) Modern Cropping Systems and Technologies for soil conservation in Siberian agriculture. In: Müller L, Sheudshen AK, Eulenstein F (eds) Novel methods for monitoring and managing land and water resources in Siberia. Springer, London, pp 681–719

GUGS (Glawnoe Gidrometeopologitscheskoi Sluschba) (1977) Spravotschnik po Klimatu. Bd. 20, Nowosibirsk

Guo LB, Gifford RM (2002) Soil carbon stocks and land use change: a meta analysis. Glob Change Biol 8:345–360

Hiederer R, Köchy M (2011) Global soil organic carbon estimates and the harmonized world soil database. EUR 25225 EN. Publications Office of the European Union. Available at: https://publications.europa.eu/en/publication-detail/-/publication/bab16047-419a-4aab-81a0-1ddecc280827/language-en

Houghton RA, Hackler JL, Cushman RM (2001) Carbon flux to the atmosphere from land-use changes: 1850–1990. Carbon Dioxide Information Center, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge

Illiger P, Frühauf M, Schmidt G, Meinel T, Belyaew V, Silanteva M, Kasarjyan M (2014) Ökosystemkonversion und ihre Folgen bezüglich der Kohlenstoffsenken-Funktion in der westsibirischen Kulundasteppe [Ecosystem conversion and its consequences for the carbon sink function in the West Siberian Kulunda steppe]. In: Grunewald K, Bastian O, Drozdow A, Grabovsky V (eds) Erfassung und Bewertung von Ökosystemdienstleistungen (ÖSD) – Erfahrungen, insbesondere aus Deutschland und Russland. BfN-Skripten 373, Bonn, pp 300–319 (in German)

IPCC—Intergovernmental Panel on Climate Change (2014) Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge

Kalinina O, Krause SE, Goryachkin SV, Karavaeva NA, Lyuri DI, Giani L (2011) Self-restoration of post-agrogenic chernozems of Russia: soil development, carbon stocks, and dynamics of carbon pools. Geoderma 162(1):196–206

Komitet po geodezii i kartografii Rossiiskoi Federatsii (KGKRF) (1992) Pochvennaia karta Altaiskogo Kraia i Respubliki Altai 1986 g., M. 1:200.000 [Soil map of the Altai Territory and the Altai Republic 1986, scale 1:200.000] (in Russian)

Larionova AA, Rozanova LN, Yevdokimov IV, Yermolayev AM, Kurganova IN, Blagodatsky SA (2003) Land-use change and management effects on carbon sequestration in soils of Russia's South Taiga zone. Tellus B 55(2):331–337

Lal R (2010) Beyond Copenhagen: mitigating climate change and achieving food security through soil carbon sequestration. Food Secur 2(2):169–177

Meinel T (2002) Die geoökologischen Folgewirkungen der Steppenumbrüche in den 50er Jahren in Westsibirien. Ein Beitrag für zukünftige Nutzungskonzepte unter besonderer Berücksichtigung der Winderosion [The geoecological consequences of the steppe ploughing in the 1950s in Western Siberia. A contribution for future usage concepts with special consideration of the wind erosion]. Dissertation, Martin Luther University of Halle-Wittenberg (in German)

Mikhailova EA, Bryant RB, Vassenev II, Schwager SJ, Post CJ (2000) Cultivation effects on soil carbon and nitrogen contents at depth in a Russian chernozem. Soil Sci Soc Am J 64:738–745

Mikhailova EA, Post CJ (2006) Organic carbon stocks in the Russian Chernozem. Eur J Soil Sci 57(3):330–336

Morkovkin G, Litvinenko Y, Maksimova N (2013) Dynamics of soil cover state and degradation processes intensity in natural soil zones of the Altai Region. Eurasian J Soil Sci 2(2):97–101

NIC (National Intelligence Council) (2009) Russia: impact of climate change to 2030 a commissioned research report. Joint Global Change Research Institute & Batelle Memorial Institute. Pacific Northwest Division

NN (1978) Atlas Altaiskogo kraia [Atlas of Altai krai]. Moskva-Barnaul: (in Russian)

Paramonov EG, Ischutin JN, Simonenko AP (2003) Kulundinskaia Step': Problemy opustynivaniia [The Kulunda Steppe: problems of desertification]. Altaiskii Gosudarstvennyi Universitet, Barnaul (in Russian)

Poeplau C, Don A, Vesterdal L, Leifeld J, Van Wesemael BAS, Schumacher J, Gensior A (2011) Temporal dynamics of soil organic carbon after land-use change in the temperate zone–carbon response functions as a model approach. Glob Change Biol 17(7):2415–2427

Ponkina E, Balaev V, Bavorová M, Prischepov A, Meinel T, Buhay Y, Frühauf M (2014) Economical, ecological and technological factors influencing farming in the conditions of Kulunda steppe (Altaj region, Russia). Barnaul. Russia. 140p. (Понькина, Е., Беляев, В., Боварова, М., Прищепов, А., Майнель, Т., Бугай, Ю. & Фрюауф, М. (2014). Экономические, экологические, технологические факторы и результаты деятельности сельскохозяйственных предприятий в условиях Кулундинской степи)

Rusalimova O, Savenkov O, Smirnova N, Barshukov P (2006) Soil carbon losses from seasonally-frozen soils of agricultural ecosystems in West Siberia from the 20th century. In: Hatano R, Guggenberger G (eds) Symptom of environmental change in Siberian Permafrost Region. Hokkaido University Press, Sapporo

Schreiner V, Meyer B (2014) Indicators of land degradation in Steppe Regions: soil and morphodynamics in the Northern Kulunda. In: Müller L, Saparov A, Lischeid G (eds) Novel measurement and assessment tools for monitoring and management of land and water resources in agricultural landscapes of Central Asia. Springer, Cham, pp 535–548

Tanasienko AA, Putilin AF, Artamonova VS (1999) Ekologicheskie aspekty erozionnykh protsessov. Analiticheskii obzor [Ecological aspects of the erosion processes. An Analytical overview], Institute of Soil Science and Agrochemistry. Ekologiia, 55, Novosibirsk, p 98 (in Russian)

Tchebakova N, Rehfeldt D, Parfenova E (2003) Pereraspredelenie rastitel'nykh zony populiatsii listvennitsy sibirskoi I sosny obyknovennoi v Srednei Sibiri pri poteplenii klimata [The shift of vegetation zones of Siberian larch and common pine in Central Siberia through climate change]. Sibirskii ekologicheskii zhurnal 6:677–686 (in Russian)

Titljanova AA (2000) Osvoenie lesostepnoi i stepnoi zon Zapadnoi Sibiri uvelichilo emissiiu ugleroda [Land reclamation in the forest steppe zone and steppe zone in Western Siberia increased the carbon emission]. Stepnoi biulleten', 8, Novosibirsk. Available at: http://ecoclub.nsu.ru/books/Step-8/index.htm (in Russian)

UNFCCC (United Nationa Framework Convention on Climate Change) (2006) Handbook. Climate Change Secretariat, Bonn. ISBN 92-9219-031-8

van der Maarel E, Titlyanova A (1989) Above-ground and below-ground biomass relations in steppes under different grazing conditions. Oikos, pp 364–370

Walz U, Stein Ch (2014) Indicators of hemeroby for the monitoring of landscapes in Germany. J Nat Conserv 22(3):279–289

Williams M (2003) Deforesting the earth: from prehistory to global crisis. University of Chicago Press, Chicago

Zonn IS (1995) Desertification in Russia: problems and solutions (an example in the Republic of Kalmykia-KhalmgTangch). In: Mouat DA, Hutchinson CF (eds) Desertification in developed countries. Springer, Dordrecht, pp 347–363

Part II
Socio-economic, Institutional and Demographic Dynamics Impacting Land Use in Post-socialist South Siberia

Chapter 15
Socioeconomic, Institutional, and Demographic Dynamics Impacting Land Use in Post-socialist South Siberia

I. Theesfeld

Abstract This chapter deals with socioeconomic, institutional, and demographic drivers, as well as impacts of land use change. A thorough understanding of interrelationships between these and ecological and production characteristics is necessary to make sound recommendations for more sustainable land use practices in Altai Krai and thus to fight against land degradation.

Keywords Socio-economy · Institutions · Demography · Land Use · South Siberia

This chapter deals with socioeconomic, institutional, and demographic drivers, as well as impacts of land use change. A thorough understanding of interrelationships between these and ecological and production characteristics is necessary to make sound recommendations for more sustainable land use practices in Altai Krai and thus to fight against land degradation.

Bavarova et al. in Chap. 16 lay the background of various important socioeconomic and political aspects. The authors first give information on farm structure concerning cultivated agricultural land in the area, including the numbers and types of operating farms. This allows a subsequent analysis of the effect of farm types on the adoption of soil cultivation technologies. Of particular interest is the share of arable land cultivated by various tillage systems, including no-till and mulch tillage. No-till systems are regarded as one of the best methods to prevent soil erosion in South Siberia (see Chap. 24). The authors show that all farm types use a mix of tillage systems, while stating that around one-quarter of large farms have already shifted to no-till technology. Yet, the share of large farms who adopt no-till uses it only on about 20% of their fields. Further Bavarova et al. discuss factors that generally hinder the introduction of reduced tillage operation from a socioeconomic perspective. Based on an empirical survey among 92 farms between 2015 and 2016, they highlight that the most important reason for non-adoption of no-till farming is a necessity for large investments. The survey further reveals a lack of farm managers' knowledge and thus

I. Theesfeld (✉)
Institute of Agricultural and Nutritional Sciences, Martin-Luther-Universität Halle-Wittenberg, Von-Seckendorff-Platz 4, 06120 Halle (Saale), Germany
e-mail: insa.theesfeld@landw.uni-halle.de

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_15

casts doubts on whether this new technology is suitable for their production condition when combined with a general perception of expected difficulties in introduction of no-till technology on their farms. Whereas the first reason points to financial policy support, the others show the simultaneous need for education and extension. The study found indications that the small-scale farmers were those needing the most information on the suitability of this technology for their production system. Therefore, in the last part of Chap. 16, current policy instruments are presented that aim at supporting the adoption of innovative agricultural technologies in Altai Krai, among them a program for farmers to receive subsidies based on interest payments. Yet, a detailed look on spending these subsidized credits reveals a priority for fuel and fuel materials, plant protection products, and fertilizers. In general, the authors judge that regional policy objectives rather focus on a short-term increase in crop production creating obstacles for adopting long-term sustainable soil cultivation technologies.

Chapter 17 by Ponkina et al. takes up the analysis of the role of the legal forms of agricultural farms and their impact on plant production efficiency. The authors investigate if the assumed dependency of the performance of agricultural enterprises on the legal form can be found in the Altai context as well. A higher technical efficiency goes in line with better profitability of farms and thus the willingness for long-term investments, such as introducing soil protection measures. Based on a statistical dataset of 211 agricultural organizations (period 2008–2012), representing 9% of all agricultural enterprises in the Kulunda region, Ponkina et al. show the crucial role of agricultural production cooperatives. Although their total number is decreasing and their technical efficiency of plant production is lower compared to noncooperative management forms, they can play a key role when it comes to sustainable land management. Agricultural production cooperatives do still hold a large share of land and fulfill social functions in the rural area, both aspects not to be underestimated. Likewise, they can provide the function of providing public goods in the rural areas, including introducing soil cultivation techniques that in turn could mitigate climate change.

Questioning who holds the land in ownership or tenancy, which is cultivated in South Siberia, the next Chap. 18 gives the range of the current land tenure system. Based on property rights theory, Fadeeva and Soliev assume that establishing a secure and clear land tenure system is detrimental for long-term investment. Likewise, a functioning land market for tenancy could provide more security with more long-term contracts, in contrast to the current practices that encourages less than a year commitment, described by the authors. In general, the authors find that the land market is not well developed yet.

Chapter 18 presents the various steps of Russia's land reform and the current land reform implementation failures at various administrative levels. Complications in registering titles and lease agreements and the weakening of the state's role in controlling the proper use of land resources are outlined. If formal reforms are not implemented and administered well, Fadeeva and Soliev point out that informal (non-contractual lease relations) can be expected to fill the vacuum. Likewise, the struggle over officially unclaimed land shares has intensified. This insecurity in tenure rights, because of its unfavorable impact on long-term investment, hinders the adoption of technical innovations such as soil conservation tillage systems. Particularly, measures against soil degradation or in favor of humus accumulation in the soil will only be considered by farm managers who perceive either their use rights as secure in the long term or possess guaranteed ownership titles by the state.

Further, the land redistribution fund as a particular common tenure system in post-socialist Russia plays a particular role also in the Kulunda region. Land registered under this fund can be rented with favorable conditions from the district administration, yet without special requirements for preserving topsoil or protecting against erosion. This, however, indicates to leverage in possession of district administrations that could be deployed for introducing land conservation requirements as part of lease and sale agreements.

Another institutional perspective on land use is provided in Chap. 19. Theesfeld and Jelinek check current agricultural land protection policies for their implementation capacity. Besides insufficient monitoring and controlling mechanism, also particular forms of property rights such as open access (the traditional free accessibility of any plot) can lead to non-suitable institutional arrangements of command-and-control nature. The main point in considering the institutional factors of policy implementation jointly is, however, as presented by Theesfeld and Jelinek, that if a command-and-control policy cannot be administered and monitored, it has to rely on voluntary commitment. If, however, the aim of the policy is not known to the target group—that is, the farm manager—or does not fit to their value and belief system concerning, for instance, their perception on the aesthetics of cultivated land, they will not comply with the new regulation. Theesfeld and Jelinek exemplify this with the help of the procedure of institutional compatibility analysis for the ban on crop-residue burning. They show that voluntary and advisory measures might be more cost-efficient and effective policy measures in reaching the aim of sustainable land management. Yet, it might be difficult in the current tradition of Russia's environmental policy.

In Chap. 20, first Bykov et al. look at the general demographic and migration processes in the Kulunda region by contrasting the various districts. The declining population is a central driving factor in the area's socioeconomic development, particularly in relation to the availability of skilled labor for the modernization of agriculture. It is likewise linked to the attractiveness of a region, which again has implications on the willingness for long-term investments of the current farm managers. Bykov et al. do also provide information on the population's age structure across individual districts. The major share of the mobile population is leaving the Kulunda region in favor of other regions in Russia, many of them to Barnaul. International outmigration of ethnic Germans and at the same way incoming migrants from Central Asian states is outlined by the authors as well. In almost all districts in the area, there is a negative migration balance of young people, the most crucial group if we think of long-term sustainable development of farms with well-educated young people trained in more sustainable cultivation measures.

Nikulin et al. in Chap. 21 focus on the possibility of Kulunda to become a learning region, where the link between ecology and efficiency should be the leading idea for development. The authors discuss various possible mechanisms of knowledge transfers related to new technologies for agricultural production, first of all within the educational system in the region. Nikulin et al. suggest even concrete measures such as the promotion of most distinguished farmers, supporting business organizations, facilitating networking, and finally integration of ecologically oriented views into educational programs. As a background, the authors summarize key data on the agricultural and forestry sector and demonstrate shortage of qualified labor force as one of the most hampering factors for both sectors' development.

Nikulin et al. do likewise give information on indicators of residents' living standards, such as the condition of housing and infrastructure (heating and water supply, as well as school system and health care). A particular focus of this contribution lays on the cultural institutions, such as rural libraries or cultural centers facing a hard time to continue offering their public services. The cultural centers and clubs, facing severe financial challenges, would be particularly important in letting social capital and collective action evolve. All these are connected to the willingness of people to stay in the region. Particularly, the authors highlight that social infrastructure would be required to build human capital for agricultural development. Yet, there is one particular reason for why better educated young people usually leave the area—for other jobs, which are not agricultural.

Social capital is regarded as an engine behind innovation-driven development, discussed in Chap. 22 by Sergienko. She highlights three aspects: the attitude toward innovation, the readiness to adopt innovation, and the availability and accessibility of knowledge transfer channels in the Kulunda region. Empirical data (based on surveys conducted from 2000 to 2016) show that the opportunities for adopting new land use technologies are perceived by local people to depend on availability of credit mechanisms, but likewise of skilled labor force and the motivation of young people to work in agriculture. Sergienko highlights the potential of new channels for knowledge transfer to increase the adoption of land use innovation.

This chapter has shown socioeconomic, institutional, and demographic dynamics, that is configurations of the social and institutional environment that provide intermingled hampering and facilitating factors in the implementation of land use policies. In this environment, actors make their decisions for or against adopting new soil conservation measures that would not only reduce soil degradation but also mitigate climate effects.

On the one hand, there are hampering socioeconomic factors for long-term oriented investments such as regional policy objectives which focus on a short-term increase in crop production, or insecurity in tenure rights due to short-term lease contracts. Outmigration of young people and the demographic trends provide two additional problems: First, the labor force basis for agricultural farms is diminishing; and second, the declining population makes the region even less attractive for those who might be willing to stay and invest long term.

On the other hand, there are promising ideas and opportunities: easy to be developed once such as the need to explain the suitability of minor tillage operation to farmers or to make environmental friendly farming as a condition to rent land from the land redistribution funds. More demanding ones are eliminating inconsistencies in the land reform creating conflicting incentives and loopholes making less powerful smaller farmers vulnerable to inequitable outcomes, as well as strengthening agricultural production cooperatives in their role of providing public goods, including measures for more sustainable land use.

There are special conclusions which can be drawn from the studies collected under this chapter for political and administrative actors in South Siberia where monitoring and controlling turns out to be largely ineffective or includes prohibitive high administrative transaction costs. Either way, one has to rely on the voluntary commitment which needs a basis of well-educated and knowledgeable farmers, or there should be a direct shift toward more voluntary-based policy measures such as supporting education and advisory service in reaching the aim of sustainable land management.

Chapter 16
Transition of Agriculture in Altai Krai: The Role of Structural Change, Introduction of Modern Soil Cultivation Practices and Agricultural Policy

M. Bavorová, E. V. Ponkina, T. Herzfeld, N. Imamverdiyev, N. Baisakova, S. V. Ganzha and N. Hirschauer

Abstract The main aim of this chapter is to provide an overview of the current developments in agricultural production in Altai Krai. First, the structural change ongoing in the last decade is presented. In this part, the importance of farm types is presented. This part is based on statistical data from the region. Second, current plant production practices the farmers are using are described based on a survey from 2016. We provide insight into the tillage technologies and crop rotations used as well as into the use of fertilizers and herbicides. We present this information separately for different farm types to be able to analyze the effect of farm types on the plant production technology. Furthermore, we provide and discuss the factors that—according to farmers—hinder the introduction of reduced-till technologies. In the last, third part of this chapter, we present the policy goals on the federal and regional levels and the main instruments for supporting the adoption of innovation technologies in the Altai Krai agriculture.

Keywords Farm structure · Sustainable agricultural practices · Adoption barriers

---

M. Bavorová (✉)
Faculty of Tropical AgriScience, Czech University of Life Sciences, Kamýcká 129, Prague, Czechia
e-mail: bavorova@ftz.czu.cz

E. V. Ponkina
Faculty of Theoretical Cybernetics and Applied Mathematics, Altai State University, pr. Lenina 61, Barnaul, Russia

T. Herzfeld · N. Baisakova
Department Agricultural Policy, Leibniz Institute of Agricultural Development in Transition Economies (IAMO), Theodor-Lieser-Straße 2, Halle (Saale), Germany

N. Imamverdiyev · N. Hirschauer
Department Agribusiness Management, Martin-Luther-Universität Halle-Wittenberg, Karl-Freiherr-von-Fritsch-Str. 4, Halle (Saale), Germany

S. V. Ganzha
Altai State University, pr. Lenina 61, Barnaul, Russia

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_16

16.1 Farm Types and Farm Structure

The first subchapter is devoted to the description of farm types. Regarding their form, there are four main types of farms in Russia: (1) agricultural organizations (AO), (2) private (peasant) farms (PF), (3) individual entrepreneurs (IE), and (4) subsidiary household farms (SHF). PF and IE are considered as very similar type of enterprises and thus described together.

The status of a legal entity, provided according to the Civil Code of the Russian Federation, characterizes enterprises' requirements for accounting and tax policies. There are 781 registered AO in Altai Krai. The AO cultivate the largest share of arable land of Altai Krai (3309 thousand ha) (ROSSTAT 2016). A single AO cultivates in average 4237 ha arable land. For a more detailed analysis of agricultural organizations as a legal form of agribusinesses split up into agricultural production cooperatives (APC) and non-cooperative forms (LLC and JSC), see Chap. 17. A total number of 2031 registered PF and IE utilize 2016 ha arable land, and the average cultivated area of arable land is 993 ha per enterprise. The 454,500 SHF cultivate 68.7 thousand ha arable land. The average area a single SHF cultivates is 0.15 ha (Table 16.1).

The share of arable land cultivated by the AO has decreased from 74.6% in 2006 to 61.4% in 2015 (Table 16.2). Opposite to it, the land cultivated by PF&IE has increased from 24.0% to 37.4% in the same time period. The share of arable land of SHF has nearly not changed in the considered period and achieved 1.3% in 2015. The grain farming belongs to the largest sectors of the agro-industrial complex of the Altai region. 62.4% of the total grain was produced by AO and 37.6% by PF&IE in 2015. The SHF produced with 82.8% the major share of potatoes and vegetables in 2015.

16.2 Plant Cultivation Practices

In the second subchapter, we provide information on the plant production technologies—especially to the soil cultivation technologies—used in the Altai Krai (after Bavorova et al. 2018). Our dataset was gathered through face-to-face questionnaire

Table 16.1 Farm types and arable land cultivated in Altai Krai in 2015

	AO[a]	PF&IE	SHF
Number of agricultural enterprises	781[b]	2031[b]	454,500[d]
Arable land cultivated (thousand ha)	3309[c]	2016[c]	68.7[c]
Average arable land (ha/enterprise)	4237	993	0.15

[a]AO—agricultural organizations, PF—private (peasant) farms, IE—individual entrepreneurs, SHF—subsidiary household farms

Source [b]Central Agricultural Administration in Altai Krai (2015); [c]ROSSTAT (2016); [d]ROSREESTR (2015)

Table 16.2 Share of arable land (%) cultivated by different farm types between 2006 and 2015

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
AO[a] (%)	74.6	71.8	70.5	69.6	69.8	68.8	68.5	66.6	63.8	61.4
PF&IE (%)	24.0	26.9	28.2	29.1	28.8	29.9	30.1	32.1	34.9	37.4
SHF (%)	1.4	1.3	1.3	1.3	1.4	1.3	1.4	1.3	1.3	1.3

[a]AO—agricultural organizations, PF—private (peasant) farms, IE—individual entrepreneurs, SHF—subsidiary household farms
Source ROSSTAT (2016)

survey. A total of 107 farms were interviewed between February 2015 and July 2016. We divided the farms into three groups according to their arable land size: small (<2000 ha), medium (2000–8000 ha), and large (>8000 ha). The smallest farm in the sample is 400 ha, and the largest farm is 26,242 ha. The sample consisted of 40 small farms, 37 medium, and 30 large farms dispersed around the Altai Krai. When selecting the farms, our objective was to have at least one large and medium or small farm from each rayon (i.e., district) in our sample. We closely achieved this aim as we covered 52 out of the 59 rayons in Altai Krai (Bavorova et al. 2018).

16.2.1 Crop Rotation and Yields

Table 16.3 depicts the share of crops cultivated by the farms in 2015 (Bavorova et al. 2018). Across all farm sizes, the main crop produced was wheat. In addition to wheat, the small- and medium-sized farms produced mainly buckwheat (18.3 and 20.8%) and pulses (8.1 and 8.9%, respectively). The highest share of crops cultivated by large farms after wheat was sunflower (14.7%), buckwheat (10.1%), and pulses (5.1%) (Bavorova et al. 2018).

Table 16.4 provides information on the average yield of spring wheat for all farms and for the three groups of farms over the period 2011–2015. In general, the average yield of spring wheat was highly volatile, with the minimum average yield (11.1 ct/ha) in 2012 and the maximum average yield (15.2 ct/ha) in 2015. When we consider the difference between the farm sizes, we observe that the yield increased by 9.8% and 12.4% in the case of small- and medium-sized farms, respectively, from 2011 to 2015. Furthermore, the results from 2015 show that the highest yield occurred in the medium-sized farms (17.2 ct/ha), followed by small (14.5 ct/ha) and large farms (13.8 ct/ha).

Table 16.3 Average share of crops on arable land (2015)

Crop	Average share of crops (%)		
	Farms' size		
	Small <2000 ha (n = 40)	Medium 2000–8000 ha (n = 37)	Large >8000 ha (n = 30)
Wheat	56.8 *M*	43.9 *S, L*	56.7 *M*
Buckwheat	18.3 *L*	20.8 *L*	10.1 *S, M*
Sunflower	3.7 *L*	4.8 *L*	14.7 *S, M*
Vegetables	2.6	2.9	0.3
Pulse (beans, soybeans, etc.)	8.1	8.9 *L*	5.1 *M*
Fallow (chemical)	1.1	1.1	1.6
Fallow (mechanical)	6.8	7.4 *L*	4.5 *M*
Other	3.1 *M*	9.3 *S*	5.9

S, *M,* and *L* depict statistically significant difference in means between subsamples of enterprises (*S* different to small, *M* different to medium, and *L* different to large farms), (t-test; p value = 0.1)
Source Adopted from Bavorova et al. (2018)

Table 16.4 Average yield (ct/ha) of spring wheat (2011–2015)

Year	2011	2012	2013	2014	2015
Average yield, all farms (ct/ha)	14.0	11.1	14.4	13.4	15.2
Average yield, small farms(ct/ha)	13.2	10.9	12.9	12.5	14.5
Average yield, medium farms (ct/ha)	15.3	12.3	15.3	16.6	17.2
Average yield, large farms (ct/ha)	13.5	10.0	15.1	12.3	13.8

Source Own survey, 2016; small farms (<2000 ha) n = 40, medium (2000–8000 ha) n = 37, large (>8000 ha) n = 30

16.2.2 Soil Cultivation Practices

Table 16.5 presents the different soil cultivation practices as used by farms. In the survey, farm managers indicated the share of arable land on which they use following tillage systems: no-till (without tillage), mulch-tillage (8–10 cm cultivation depth), min-till (14–16 cm), and intensive tilling technology (20–22 cm and more). In Table 16.5, we present the share of farmers, who use the given technology. Most of the farms mix different tillage systems at their farms (Bavorova et al. 2018).

Regarding the share of farms that use the given cultivation practices, we may see that the highest share of small and large farms use mulch-tillage, followed by deep cultivation and min-till technologies. Although most medium-sized farms use mulch-tillage, the next most often applied technology is min-till and it is followed by deep cultivation and "until 8 cm" cultivation. Another interesting point is that compared to small (5.4%) and medium farms (10.8%), a larger share of large farms

Table 16.5 Soil cultivation practices of farms (2015)

Groups	Farm size	No-till	Until 8 cm	Mulch-tillage (8–10 cm)	Min-till (14–16 cm)	Intensive (20–22 cm and more)	Other
Share (%) of farms who use the technology	Small	5.4	32.4	67.8	32.4	35.1	2.7
	Medium	10.8	35.1	83.8	43.2	40.5	0.0
	Large	40.0	30.0	63.3	46.7	66.7	6.7

Source Adopted from Bavorová et al. (2018); small farms (<2000 ha) $n = 40$, medium (2000–8000 ha) $n = 37$, large (>8000 ha) $n = 30$

Table 16.6 Assessment of perspectives of no-till technology in the region by farmers (2016), %

Range	Very good (%)	Good (%)	Fair (%)	Poor (%)	Very poor (%)	Difficult to answer (%)
Total	1.0	8.7	38.5	16.3	7.7	27.9
Small	0	2.6	44.7	13.2	5.3	34.2
Medium	0	8.3	36.1	22.2	16.7	16.7
Large	3.3	16.7	33.3	13.3	0	33.3

Source Own survey, 2016; small farms (<2000 ha) $n = 40$, medium (2000–8000 ha) $n = 37$, large (>8000 ha) $n = 30$

use no-till technology (40.0%) on some share of their land. Among the most popular soil cultivation practice counts mulch-tillage, mostly medium-sized farms are active (83.8%), followed by small (67.8%)- and large-sized (63.3%) farms. It is also worth to mention that large farms are the most active users of intensive cultivation system (66.7%).

The results of the survey regarding to the question "How do you assess the perspectives of no-till technology in your region?" show that most of the farmers selected the answer "fair" (38.5%) and "difficult to answer" (27.9%) (Table 16.6). The assessment as "very good" and "good" is very low. The farmers who think that no-tillage system is "good" are mostly observed among large-size farms (16.7%), followed by medium (8.3%)- and small (2.6%)-sized farms. When we look at which farmers chose the answer "difficult to answer," we see that mostly small (34.2%) and large (33.3%) farm managers had difficulties in assessment of perspectives of no-tillage technology in their region.

16.2.3 Reasons for not Using No-Till Technology

As mentioned above, most farmers do not use the no-till soil cultivation practice (Table 16.5). Because agronomists recommend no-tillage system as one of the best methods to prevent soil erosion in the region (Dammann et al. 2011), we looked for the reasons preventing farm managers to use this soil cultivation system (Table 16.7) (Bavorova et al. 2018).

One of the most important reasons named is that to implement no-till, large investments are required. The high investments are perceived to be an adoption barrier especially by small farms' managers (83.8%). Difficulty to get a loan for no-till technology is important barrier especially for small farmers (33.3%). No subsidies and (lack of) special programs of state support are seen as (very) important reason of non-adoption of no-till reported especially by large (43.8%) and small farms (35.5%). More than 50% of all interviewed farm managers state that the fact that the positive effects of no-till technology takes too long to materialize, prevents them from adoption. Especially small farm managers (74.2%) see this fact as a significant no-till adoption barrier.

The majority of farm managers are not sure if the no-till technology is suitable for their production conditions. In particular, managers of small farms considered this reason of non-adoption as important or very important (97.2%), followed by the managers of large farms (80.0%) and managers of medium-sized farms (77.4%) (Bavorova et al. 2018). A number of farm managers agree that it is difficult to introduce the no-till technology at their farms. A total of 65.7% of small farm managers, 60.0% of large farm managers, and 36.7% of medium-sized farm managers considered this reason as important or very important for non-adoption (Bavorova et al. 2018). Farm managers evaluated the current soil cultivation systems as no worse than no-till. This reason was important or very important for non-adoption of no-till, especially for managers of small farms (91.7%) and medium-sized farms (73.3%) followed by large farms (60.0%) (Bavorova et al. 2018).

16.3 Framework of Agricultural Policy in Altai Krai's Agriculture

This subchapter presents the agricultural policy framework and describes the most recent implementation of the programs in the Altai Krai. The basic laws which regulate the agricultural policy framework of the Russian Federation include the Federal Law "On Development of Agriculture" (Федеральный закон "О развитии сельского хозяйства" N 264-Фз) from December 2006. It is regulating the principles of public support to the sector and the retaliation of special (initially) five-year state programs in agriculture. One major objective of the Russian agricultural policy aims at increasing the domestic production of a range of food products up to certain thresholds defined in the 2010 Doctrine on Food Security (Доктрины продовольственной безопасности) (OECD 2013). Most thresholds are close to the level of self-sufficiency. Further objectives relate to a sustainable development of rural areas, an improvement of rural population's living conditions, the enhancement of domestic agricultural products' competitiveness as well as a better environmental

Table 16.7 Selected reasons for not using the no-till technology (2016)

	Not important (%)			Slightly and moderately important (%)			Important and very important (%)		
	S[a]	*M*[b]	*L*[c]	*S*[a]	*M*[b]	*L*[c]	*S*[a]	*M*[b]	*L*[c]
Large investments are required	6.5	17.9	18.8	9.7	14.2	12.5	83.8	67.9	68.8
Difficult to get a loan for these purposes	19.4	29.6	43.8	48.4	48.1	37.5	32.3	22.2	18.8
No subsidies and special programs of state support for this technology	16.1	25.9	37.5	48.4	51.8	18.8	35.5	22.2	43.8
The outcome of this technology takes too long	9.7	18.5	37.5	16.1	25.9	6.3	74.2	55.5	56.3
Not sure that this technology is suitable for our conditions of production	0.0	3.2	20.0	2.8	19.4	0.0	97.2	77.4	80.0
Difficult to introduce the technology	17.1	26.7	26.7	17.1	36.7	13.3	65.7	36.7	60.0
The used technology in the company is not worse	8.3	10.0	26.7	0.0	16.7	13.3	91.7	73.3	60.0

Source Adopted from Bavorová et al. (2018); *S*—small farms (<2000 ha) $n = 40$, *M*—medium (2000–8000 ha) $n = 37$, L—large (>8000 ha) $n = 30$

performance of agriculture. The policy instruments directly affecting the formation of agricultural prices largely protect livestock products and sugar but tend to (temporarily) tax-exportable goods like grains and oilseeds. Direct payments have been mainly directed toward livestock products. Additionally, concessional credit forms the most important measure of agricultural support and represents one of the largest budgetary transfers. Farmers can receive subsidies on interest payments, which have to be co-financed from federal and regional budgets, as well as subsidies for variable inputs. Finally, area payments gained in importance with the new state program. In recent years, all agricultural policy-related support to producers can be classified as "coupled support" following the definition of the OECD. That is, in order to be eligible for direct payments farmers have to produce the products of interest.

The agricultural policy framework for Altai Krai's agricultural producers is developed at two different policy levels. Agricultural policy is formulated at the level of the federal government and at the level of the Altai Krai. Both governments publish medium-term programs which will be implemented by central and regional authorities. Regions in Russia adjust their requirements on federal programs, which have the power of laws. Accordingly, all budget regulations adopted in federal programs have to be realized, whereas border measures and market interventions fall under the exclusive responsibility of the federal government, and other measures have to be implemented by provincial governments, often involving co-financing commitments.

The most recent state program for development of agriculture ("Программа развития сельского хозяйства и регулирования рынков сельскохозяйственной продукции, сырья и продовольствия на 2013–2020 годы") was adopted by the central government for the period 2013–2020. The overall financial volume of the program is subject to annual revisions due to the formation of the federal and regional budgets for the next year. According to OECD (2016) calculations, support for agriculture from public sources amounts to 0.93% of the Russian Gross Domestic Product (GDP). Over the eight-year period 2013–2020, financial resources from all sources are estimated to be 2498 billion Rubles. The largest share of it, 61%, is provided from the federal budget, followed by the provincial budgets (31%) and private sources (8%) (OECD 2013). The federal program contains six subprograms such as crop and livestock sector development, meat cattle breeding, small-scale farming, technical and technological modernization, and outlays for the state program's implementation. Furthermore, two so-called federal target programs are part of the federal agricultural policy framework.

From the perspective of sustainable land use, the target program on land improvement («О Федеральной целевой программе ("Сохранение и восстановление плодородия почв земель сельхоз назначения и агроландшафтов как национального достояния России на 2006–2010 годы и на период до 2013 года") is of special interest. This previously separated program finished in 2013. Similar measures, mainly focusing on melioration, have been now integrated into the 2013–2020 state program.

The main recent agricultural program for Altai Krai is called "Development of Agriculture in Altai Krai in 2013–2020" (Долгосрочная целевая программа

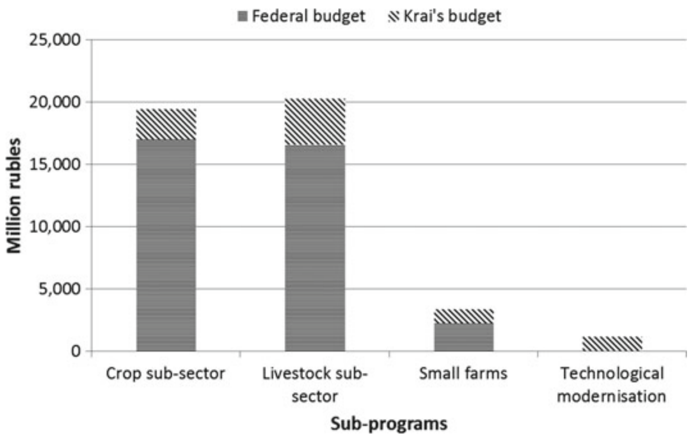


Fig. 16.1 Financing of Altai Krai's agricultural program 2013–2020. *Source* Administration of Altai Krai (2012), pp. 18–19

"Развитие сельского хозяйства Алтайского края" на 2013–2020 годы). In the regional program, there are four subprograms such as crop development, livestock development, support of small-scale farms as well as technological modernization and innovational development of the agro-industrial complex. The financial resources initially foreseen for the period 2013–2020 reach 44.3 billion Rubles. The overwhelming majority of the financial resources have been allocated to the first two subprograms. However, whereas the subprograms on crop and livestock development are largely covered by federal contributions (87 and 82%), the subprogram technological modernization relies heavily on regional finances (94%) (Administration of Altai Krai 2012). The distribution of funding from federal and regional budgets across the four subprograms is shown in Fig. 16.1.

At the level of the Altai Krai, the federal policy objectives translate into regional objectives to increase crop production by 25% until 2020. This goal is supported by precise production targets for grain, sunflower, sugar beet, potatoes, and flax as well as for livestock products. Within the subprogram "Development of crop subsector," the regional government provides funds to realize two different tasks. The first task comprises measures to increase crop production, credit subsidies, and subsidies for crop insurance. Out of the financial resources planned for the subprogram crop sector development, 90% have been allocated to this first task. The execution of the plan reported for 2015 reveals that per hectare subsidies (52.3%) and subsidies for compensation of interest rates on loans (41.4%) continue to represent the main areas of support in the subprogram crop production. On average, 2541 agricultural producers and enterprises received 298 Rubles per ha in 2015. However, the amount varies from district to district and ranges from a minimum of 159 Rubles/ha (Bystroistoksky raion) to a maximum of 581 Rubles/ha (Nemetsky national raion). A more detailed look at the spending behavior of Altai farmers benefiting from subsidized short-term loans reveals that fuel and fuel materials (43%), plant protection products (20%), and fertilizers (10%) represent the most prominent items (Central Agricultural Administration 2016).

The second task, for which the remaining 10% of finances are foreseen, includes rather diverse measures like support for elite seed development, the protection and restoration of soil fertility, and support for the horticultural sector. From the perspective of the Kulunda project, the support for the plantation of wind strips is of special relevance. The plan foresees the realization of plantations on 9900 ha and plans a total financial support of 495 mio Rubles (Administration of Altai Krai 2012). In the year 2014, 891 thousand Rubles and in the year 2015, 417 thousand Rubles have been spent on planting wind strips in Altai Krai. The funding in both years has been to a large extent provided by the Krai's budget (718 thousand Rubles) and so-called non-budgetary sources (417 thousand Rubles) (Central Agricultural Administration 2016).

From the perspective of a sustainable and location-specific land management, the current policy framework carries potential conflicts. Obviously, the dominating focus is on short-term production goals instead of the long-term preservation of soil resources. Coupled direct payments for grain production increase farmer's opportunity costs to convert arable land into grassland at places where such a measure would be preferable due to soil erosion. Furthermore and with the exception of support to wind strip plantation, no measures aim at providing direct incentives to diversify crop rotation or to monitor soil indicators such as humus content. The implementation of the framework by local authorities plays an important role in determining precise incentives faced by farmers.

References

Administration of Altai Krai (2012) Долгосрочная целевая программа “Развитие сельского хозяйства Алтайского края” на 2013–2020 годы, Barnaul: Администрация алтайского края

Bavorova M, Imamverdiyev N, Ponkina E (2018) Farm-level economics of innovative tillage technologies: the case of no-till in the Altai Krai in Russian Siberia. Environ Sci Pollut Res 25:1016–1032

Central Agricultural Administration (2015) Reester of agricultural enterprises in Altai Krai. www.altagro22.ru

Central Agricultural Administration (2016) Доклад о ходе и результатах реализации в 2015 году государственных и ведомственных целевых программ в сфере развития сельского хозяйства алтайского края, Barnaul: Главное управление сельского хозяйства алтайского края

Dammann S, Meinel T, Beljaev VI, Fruehauf M (2011) Effect of various soil cultivation technologies at the soil water balance and crop production in dry areas. Hallesches Jahrbuch für Geowissenschaften 32(33):33–48 (in German)

OECD (2013) Agricultural policy monitoring and evaluation 2013: OECD countries and emerging economies. OECD Publishing, Paris

OECD (2016) Producer and consumer support estimates database. www.oecd.org

ROSREESTR (2015) Department of Federal Agency of Cadastre in Altai Krai

ROSSTAT (2016) Russian statistical information system (ЕМИСС—EMISS). www.gks.ru

Chapter 17
Effect of Legal Form of Agricultural Organizations on Plant Production Efficiency in Russia: The Case of Kulunda Steppe

E. V. Ponkina, M. Bavorová and S. V. Lobova

Abstract During the transitional period since 1992 until today, many transformed and new legal forms of business were established in Russia. The main objective of this chapter is to analyse the effect of legal form of agricultural enterprises on efficiency of crop production in the Kulunda Steppe in Altai Krai in 2008–2012. We analyse statistical data collected through monitoring of agricultural enterprises by the Main Department of Agriculture in Altai Krai. Results of data envelopment analysis (DEA) show lower efficiency of plant production of agricultural organizations with cooperative legal forms (APC) compared to non-cooperative forms (LLC and JSC). The analysis identifies differences in use of human resources and in plant production intensification.

Keywords Legal form · Crop production · Efficiency · Data envelopment analysis · Agricultural productive cooperative

17.1 Introduction

In the planned economy, the main legal forms of agricultural enterprises in Russia were collective (*kolkhoz*) and state (*sovkhoz*) farms both in state ownership. In 1990, in the Altai region, there were 686 agricultural enterprises, 226 of them kolkhozes and 460 sovkhozes, using in total 12,653 thousand hectares of agricultural land (Tsarev

E. V. Ponkina (✉)
Faculty of Mathematics and Information Technology, Altai State University, Lenina 61, Altai Krai, 656049 Barnaul, Russian Federation
e-mail: ponkinaelena77@mail.ru

M. Bavorová
Institute of Agricultural and Nutritional Sciences, Martin-Luther-Universität Halle-Wittenberg, Karl-Freiherr-von-Fritsch-Str. 4, 06120 Halle (Saale), Germany

S. V. Lobova
International Institute of Economics, Management and Information Systems, Altai State University, Lenina 61, 656049 Barnaul, Russian Federation

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_17

et al. 1997). The average size of enterprises achieved up to 18.4 thousand hectares of agricultural land, with an average arable land of 5.8 thousand hectares.

During the reforms in 1991–1997, the legal forms of agricultural enterprises were transformed and new enterprises were established through restructuring of kolkhozes and sovkhozes. The state properties were partially privatized and transformed enterprises based on private, public, municipal and mixed forms of ownership.

The transformation of kolkhozes and sovkhozes resulted in the following main legal forms of agribusinesses: (a) "Aktsionernoe obshchestvo"—joint stock company (JSC); (b) "Tovarishchestvo s ogranichennoi otvetstvennost'iu"—limited liability partnership, which later became "Obshchestvo s ogranichennoi otvetstvennost'iu"—limited liability company (LLC); (c) "Selskokhozyaistvennyi proizvodstvennyi kooperativ"—agricultural production cooperative (APC); (d) "Krest'ianskoe (fermerskoe) khoziaistvo"—private (peasant) farm (PF); (e) "Individualnii predprinimatel"—individual entrepreneur (IE). Furthermore, "Lichnoe podsobnoe khosiaistvo"—subsidiary household farm (SHF) gained on importance (see also Chap. 16).

The development of family farms was limited particularly because of unwillingness of the population to run business independently. At the beginning of the reforms, only 10–15% of rural residents expressed a desire to own a farm (Chernyakov 1999; Serova 2016).

The agribusinesses of different legal forms in Russia differ in particular in ownership concentration, production management and decision-making, profit allocation and liability (Appendix 14.1). Based on the differences in legal forms, the effect of legal form on performance of agricultural enterprises may be expected (Jones 1998; Jones and Kalmi 2012; Kapelushnikov 2001; Chaddad 2014; Lerman et al. 2016). The comparison of technical efficiency for the corporate and cooperate farms was studied for example in Czech Republic for 1996–1998 (Curtiss 2002).

With a large number of proprietors in an enterprise for example, the management structure is more complicated and it is necessary to implement procedures to harmonize decisions and resolve conflicts of interests. This increases the transaction costs. The main differences in management are prevalent between the cooperatively owned agricultural organizations (APCs) and the other types of agricultural enterprises (JSCs, LLCs and PFs). The completion for leadership in APC leads to the need to create conditions that meet the needs of APC members but which often results in uneconomic decisions. In addition, APC is characterized by a high degree of socialization of the production results, which leads to the alienation of workers from the results of their work, although they may be co-owners. The main disadvantage of APC is that in practice it is difficult to attract direct investments, to sell the shares and to receive loans.

The effect of legal forms of agricultural enterprises on profitability and productivity was studied in Russia in the past in particular in the Nizhny Novgorod region (Altuhov and Rassadin 2015), Tambov region (Minakov 2015), Omsk region (Marakaeva and Scherba 2016), Belgorod region (Belchenko 2012) and Stavropolsky Krai (Didienko 2004). However, there is no recent research on the effect of legal form on technical efficiency of agricultural organizations in Altai Krai, the most important agricultural region in Siberia. A higher technical efficiency goes in line with better profitability of farms and thus the willingness for long-term investments, including soil protection measures. To close this gap, the main objective of this chapter is to analyse the effect of legal form of agricultural enterprises (APC, LLC and JSC) on technical efficiency of crop production in the Kulunda Steppe in Altai Krai.

Quantitative evaluation of business efficiency is based on the ratio of final results (*outputs*) and costs (*inputs*). One of the approaches to comparative analysis of production efficiency of different economic entities is frontier approach developed by Debreu (1951) and Farrell (1957), who identified the category of *overall efficiency* and its decomposition into *allocative* (AE) and *technical efficiency (TE)*. In line with this approach, efficient business provides the most productive generation of multiple outputs through the use of multiple inputs (Green 1993; Murillo-Zamorano 2004).

To assess *TE*, different nonparametric and parametric methods can be used, the most popular of which are *Data Envelopment Analysis* (DEA) (Charnes et al. 1978; Banker 1984; Deprins et al. 1984) and *Stochastic Frontier Analysis* (SFA) (Aigner et al. 1977; Battis and Coelli 1992; Green 1993). The DEA method used in this work is widely applied in studies of technical efficiency of agricultural enterprises (Abtania et al. 2012; Hassanov and Nomman 2011; Houshyar et al. 2010; Svetlov and Hockmann 2009; Murthy et al. 2009; Wadud and White 2000). We use DEA as it does not require finding a functional form depending on the production function and allows the use of multiple inputs and outputs.

The analysis of crop production efficiency in enterprises of cooperative form of management (APC) and the most common non-cooperative form (LLC and JSC) will identify the most efficient legal form of plant production under current conditions.

After the introduction, in the second part of the chapter, we describe the region of our interest. The third part of the study presents the used methodology and the data set. In the fourth part, we provide results of measuring technical efficiency. In the fifth part, we discuss the results, and in the last, sixth, part, we derive conclusions.

17.2 Description of the Region

Out of 2812 enterprises in the Altay Krai in 2015, 2031 (72%) had the legal form of private (peasant) farm (PF) or individual entrepreneur (IE), 543 (19%) of limited liability company (LLC), 150 (5%) of agricultural production cooperative (APC), 60 (2%) joint stock companies and 28 others (Table 17.1). The number of APCs decreased by 53 enterprises from 2012 to 2015. The comparison of different legal forms in Russia is provided in Appendix 14.1. On the territory of Kulunda Steppe, which is a part of Altai Krai, the structure of agricultural enterprises is similar to the one of the region (REESTR 2012).

Agricultural organizations (LLC, JSC and APC) play an important role in agricultural production in the Altai Krai. They cultivated 61.4% of the arable land in the region in 2015. PF and IE cultivated 37.4% of the arable land in 2015 (ROSSTAT

Table 17.1 Agricultural enterprises' structure, Altai Krai, Kulunda, 2012 and 2015

	2012				2015			
	Altai Krai		Kulunda		Altai Krai		Kulunda	
	Number	%	Number	%	Number	%	Number	%
Agricultural enterprises, total	2896	100	1914	100	2812	100	1802	100
of which:								
APC	203	7	121	6	150	5	80	4
LLC	661	23	388	20	543	19	293	16
JSC	90	3	48	3	60	2	30	2
PF&IE	1908	66	1350	71	2031	72	1381	77
Other	34	1	7	0	28	1	18	1

Agricultural production cooperative (APC); limited liability company (LLC); joint stock company (JSC); private (peasant) farm (PF); individual entrepreneur (IE)
Source Calculated by authors on the basis of data from REESTR of agricultural enterprises in Altai Krai (REESTR 2012–2015)

2016). The share of arable land cultivated by different farm types between 2006 and 2015 is presented in Chap. 16.

Climatic conditions of the crop production are instable in Kulunda Steppe. The past 15 years have seen two extreme periods that significantly affected the crop yield. In 2009, there were favourable climatic conditions that resulted in high yield of grain crops. The average yield of wheat achieved 1.5 t/ha. High yield in the region during that period led to grain price decrease. Price dropped from 5512 roubles per ton in August 2009 to 4309 roubles per ton in December 2009. Price falling continued until June 2010, when it reached 3398 roubles per ton (Grain-Online 2014). Otherwise, in 2012, the region suffered a drought that resulted in reduced crop yields. The average yield of spring wheat in Kulunda amounted to 0.7 t/ha. The fall in grain harvest resulted in a price increase on the market. The price of wheat in July 2012 was 5921 roubles per ton and in December 2012 increased up to 8499 roubles per ton (Grain-Online 2014).

17.3 Methodology

17.3.1 Data set

The statistical data collected by the Main Department of Agriculture of Altai Krai for the period of 2008–2012 were used for the analysis. From the total of 211 agricultural organizations (LLCs, JSCs and APCs) in the database, 150–174 farms (depending on the year) specialized in cultivation of spring wheat and sunflower were selected. The data obtained are independently generated samples for each year of study and cannot be treated as panel data. Enterprises cultivating sugar beets were excluded. The reason was that sugar beet cultivation has a significant impact on the crop rotation and on the structure of production costs. In order to improve the uniformity of the sample and form a “thick” efficiency frontier, we excluded abnormal objects that are significantly different by the indicators of yield, price and total costs per hectare of cultivated area. The proportion of PFs in the sample the statistical data are collected for is insignificant (3–4 enterprises); it is due to the fact that most PFs provide accounting information in very simplified form. Therefore, PFs were excluded from our analysis.

Businesses in the sample cover 9% of the total number of agricultural enterprises in the territory of Kulunda (59% of APCs, 18% of LLCs and 63% of JSCs) (2012 data) located in 21 districts (out of 32). In 2012, the area of agricultural lands covered by the enterprises amounted to 1750 thousand hectares of which 1345 thousand hectares are classified as arable land (Table 17.2) (39% of the total area of the arable land in Kulunda). According to the volume of crop output, the sample covers 33% of crop production and 34% of sunflower production in Kulunda.

Table 17.2 Sample description, Kulunda, Altai Krai, 2008–2012

	Units	2008	2009	2010	2011	2012
Number of enterprises, total	Number	150	168	172	169	174
of which:						
APCs	Number	62	67	71	62	71
LLCs	Number	60	73	69	75	69
JSCs	Number	24	25	28	28	30
Agricultural land	th. ha	1397	1530	1612	1529	1750
of which:						
APCs	th. ha	597	670	710	592	727
LLCs	th. ha	407	489	476	504	560
JSCs	th. ha	368	359	399	403	432
Arable land	th. ha	1092	1176	1240	1202	1345
of which:						
APCs	th. ha	470	508	543	450	540
LLCs	th. ha	318	393	368	422	454
JSCs	th. ha	279	264	304	300	324
Size of farm (by arable land)	th. ha/farm	7.3	7.0	7.2	7.1	7.7

(continued)

Table 17.2 (continued)

	Units	2008	2009	2010	2011	2012
of which:						
APC	th. ha/farm	7.6	7.6	7.7	7.3	7.6
LLC	th. ha/farm	5.3	5.4	5.3	5.6	6.6
JSC	th. ha/farm	11.6	10.6	10.9	10.7	10.8

Agricultural production cooperative (APC); limited liability company (LLC); joint stock company (JSC)
Source Authors' calculation

17.3.2 Sample Description

According to the land, JSCs are largest enterprises with an average area of 14 thousand hectares of agricultural land and 10 thousand hectares of arable land (Table 17.2). The average size of APC is 10 thousand hectares of agricultural land and 7.5 thousand hectares of arable land. The area of land cultivated by LLC is on average 7 thousand hectares and of arable land 5.6 thousand hectares for 2008–2012. Average yield per hectare of cereals and sunflower varies by the year. The highest yield of grain crops was achieved in 2009, when there was a record harvest in the region, and the lowest was due to drought in 2012.

Comparing to JSCs and APCs, LLCs are more oriented on crop production. The LLC average share in the revenue of plant production is 74%, while JSC and APC 46 and 48%, respectively (Table 17.3).

The share of fallow is about 8% in all organization types in average of the years 2008–2012.

Per 1000 hectares of cultivated arable land, in average 8 employees are employed in APC, 7 employees in JSC and 5 employees in LLC. The average age of the heads of APC and JSC is 53–54 years; slightly younger are LLC heads that are in average 51 years old.

The yield of cereals is in average highest in LLC and the yield of sunflower in APC in average of 2008–2012 (Fig. 17.1).

The comparison of main inputs in the crop production, such as costs for seeds, fertilizers and herbicides and fuel costs, shows that APCs use more extensive form of production (Fig. 17.2 and Appendix 14.2). The proportion of the total number of enterprises using fertilizers in the farm sample ranges from 25 to 48% for JSCs, from 23 to 34% for LLCs and from 13 to 32% for APCs. The cost of fertilizers per ha are in average 4 times lower in APCs than in LLCs, and 1.8 times lower than in JSCs. Average costs of herbicides per ha in LLCs are 1.8 times higher than in APCs. JSCs spend on herbicides in average 16% less than APCs. The costs of seeds (thousand roubles per ha) are on average 18 and 4% higher in LLCs and JSCs comparing with

Table 17.3 Sample description, Kulunda, Altai Krai, 2008–2012

		2008	2009	2010	2011	2012	Average
Share of revenue from plant production	%	63	61	61	58	54	**59**
of which:							
APC	%	52	50	51	46	41	**48**
LLC	%	77	76	74	71	72	**74**
JSC	%	55	45	46	43	38	**46**
Share of cereals area in total sown area	%	64.4	64.8	60.2	60.8	58.7	**61.8**
of which:							
APC	%	61.6	60.9	57.7	58.9	56.1	**59.0**
LLC	%	67.2	68.7	63.4	64.0	62.3	**65.1**
JSC	%	62.2	61.9	57.6	55.4	55.8	**58.6**
Share of sunflower area in total sown area	%	7.4	7.8	9.1	9.6	10.3	**8.8**
of which:							
APC	%	6.6	6.8	7.5	7.6	8.1	**7.3**
LLC	%	7.8	9.7	10.6	11.9	12.9	**10.6**
JSC	%	7.7	4.9	8.0	7.1	8.6	**7.2**
Share of fallow in total sown area	%	7.4	7.2	9.1	7.8	8.3	**8.0**
of which:							
APC	%	8.1	7.8	9.4	7.4	8.0	**8.1**
LLC	%	7.3	7.3	9.2	7.7	8.2	**7.9**
JSC	%	6.4	6.1	8.1	9.3	9.3	**7.9**
Employees	Persons/th. ha	7.5	7.1	6.8	6.1	5.9	**6.7**
of which:							
APC	Persons/th. ha	9.1	8.7	8.1	7.9	7.6	**8.3**
LLC	Persons/th. ha	6.1	5.2	5.4	4.7	4.1	**5.1**
JSC	Persons/th. ha	7.9	8.8	7.4	6.6	6.5	**7.4**
Age of manager	Years	53	53	53	52	53	**53**
of which:							
APC	Years	54	54	54	53	53	**53**
LLC	Years	51	52	52	52	51	**51**
JSC	Years	55	54	54	53	54	**54**

Agricultural production cooperative (APC); limited liability company (LLC); joint stock company (JSC)
Source Authors

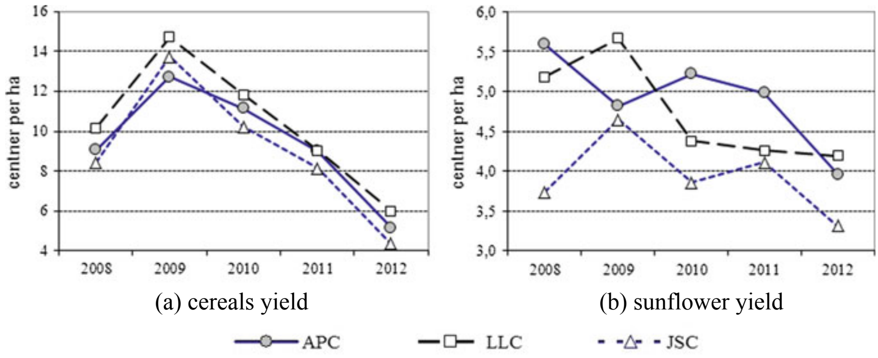
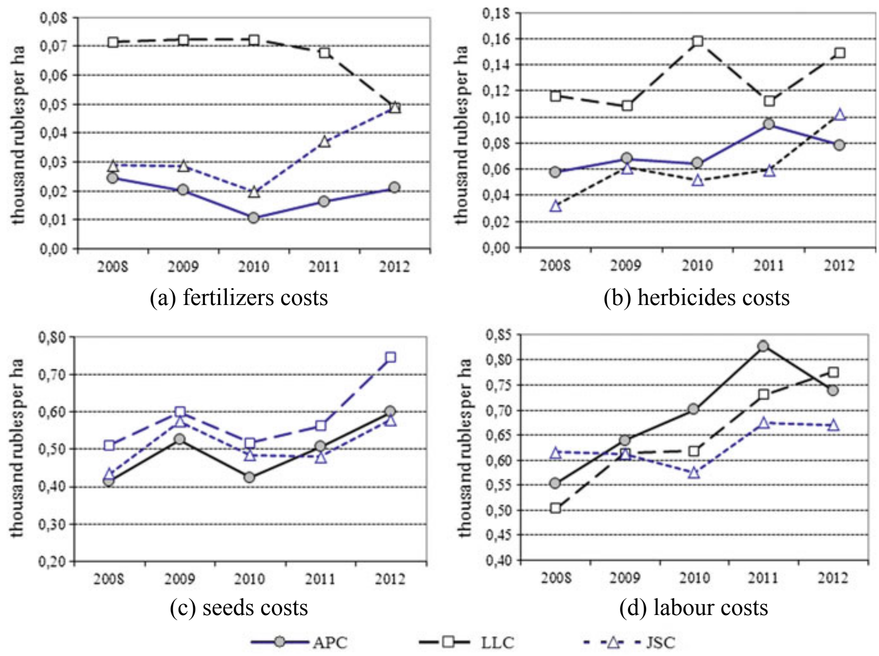


Fig. 17.1 Wheat yield and sunflower yield, centner per ha, 2008–2012. (agricultural production cooperative (APC); limited liability company (LLC); joint stock company (JSC). *Source* Authors.)



Agricultural Production Cooperative (APC); Limited Liability Company (LLC); Joint Stock Company (JSC).

Fig. 17.2 Costs of plant production, thousand roubles per ha. (agricultural production cooperative (APC); limited liability company (LLC); joint stock company (JSC). *Source* Authors.)

the average costs for APCs (Appendix 14.2). Fuel costs per ha by LLCs and JSCs are lower than in cooperative farms.

17.3.3 Data Envelopment Analysis

We use the data envelopment analysis (DEA) to assess technical efficiency of plant production in agricultural enterprises of three legal entities (APC, LLC and JSC) engaged in crop production in the Kulunda Steppe located in the Altai Krai. As inputs, we use the following variable costs of plant production (including fallow): seeds, fertilizers, herbicides, fuel, spare parts, labour costs (Curtiss 2002; Wadud and White 2000).

We assess technical efficiency of plant production for two output options:

Option 1—output is measured by gross production value of agricultural enterprise, calculated in average annual sale prices of the agricultural enterprise and gross yield of crops (thousand roubles).
Option 2—outputs are measured by gross yield (cereals and sunflower, centner).

As the basic model, a CCR-output model is used with constant return to scale (CRS) (Charnes et al. 1978) and BCC-output model with variable return to scale (VRS) (Banker et al. 1984). As a result of the decision of linear programming task for each evaluated object, we obtained evaluation of technical efficiency (*TE*). Assessment of technical efficiency can be expressed in quantitative form by a *TE* index ranging from 0 to 1.

Efficient enterprise has *TE* index that equals to 1 and lies on the efficiency frontier. It means that the evaluated object cannot increase the output at lower input; i.e., in the group of evaluated objects, it is the most effective. The average value of *TE* of the sample reflects the overall situation in the sector and can be an indicator of the general level of technical efficiency of the industry.

Comparative analysis of efficiency of plant production for those options makes it possible to assess the effect of sales prices of enterprises of different legal forms in achieving efficiency. We will refer to the role of being efficient in crop production and the willingness to produce more sustainable and adopt soil conservation measures in the discussion part of this chapter.

17.4 Results

As a result of application of the DEA model method *CCR-output* and *BCC-output* (CRS and VRS) for each year of the study, we received index estimates of technical efficiency (*TE*). Many agricultural enterprises are characterized by variable return to scale. Therefore, *TE* values for VRS variant are considered baseline assessments.

The results of the evaluation showed that minimum of *TE* in gross yield of cereals and sunflower (Option 2) was achieved in 2012 (dry conditions)

Table 17.4 Technical efficiency of plant production, average of farm sample, Kulunda, Altai Krai, 2008-2012

	2008	2009	2010	2011	2012
Option 1: *TE*	0.74	0.75	0.72	0.76	0.65
of which by legal entities:					
APC	**0.70**	**0.72**	**0.69**	**0.74**	**0.64**
LLC	0.76	0.77	0.76	0.74	0.64
JSC	0.80	0.75	0.68	0.80	0.69
Option 2: *TE*	0.81	0.84	0.83	0.75	0.73
of which by legal entities:					
APC	**0.78**	**0.81**	**0.83**	**0.74**	**0.70**
LLC	0.83	0.85	0.83	0.75	0.72
JSC	0.86	0.87	0.82	0.78	0.76

Agricultural production cooperative (APC); limited liability company (LLC); joint stock company (JSC)
Source Calculated by authors on the basis of DEA, BCC-output model

(Table 17.4). Similarly, dynamics of average *TE* in gross production value (Option 1) show that the lowest value was achieved in the same period; i.e., the rise of prices in August–December 2012 did not provide compensation for falling yields and production costs for most farms proved ineffective. The share of enterprises that did not receive outputs of more than 75% ($TE \leq 0.25$) in this period is the highest for all enterprises of all legal forms (Table 17.5).

The maximum of *TE* (0.84) in gross yield (Option 2) was achieved in 2009. In this period, despite a significant drop in prices during the sales period, *TE* (Option 1) was high (0.75). Delayed market reaction led to a decrease in the efficiency of plant production estimated by output value (Option 1) in 2010.

Comparison of *TE* for enterprises of different legal forms indicates that the APC is inferior in its efficiency of plant production to LLC and JSC. The average *TE* for 5 years of study (Option 1) for JSC was 6% and for LLC 5% higher than in the APC. Generation of gross yield (Option 2) due to the used inputs was by 6% more efficient in JSC than by APC and by 3% more efficient in LLC. The comparison of *TE* value of enterprises of various legal forms is presented in Table 17.4, which depicts that in all years under study, there were statistically significant differences of *TE* value in the researched sample. The average share of enterprises leading in technical efficiency of plant production with *TE* of more than 0.75 for LLC and JSC is higher than for enterprises of cooperative form APC (Table 17.5).

Table 17.5 Classification of enterprises by technical efficiency of plant production, Kulunda, Altai Krai, 2008–2012

TE index[a]	2008			2009			2010			2011			2012		
	APC	LLC	JSC	APC	LLC	JSC	APC	LLC	JSC	APC	LLC	JSC	APC	LLC	JSC
Option 1—Output is gross production value (% of businesses)															
0.75–1	**50**	**50**	**67**	**45**	**55**	**52**	**38**	**51**	**25**	**56**	**45**	**63**	**42**	**39**	**50**
0.5–0.75	26	43	25	34	32	32	44	31	57	19	39	19	21	30	17
0.25–0.5	19	5	8	18	12	16	14	18	18	23	13	19	25	21	23
0–0.25	5	2	0	3	1	0	4	0	0	2	3	0	11	10	10
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Option 2—Outputs are gross yield of wheat and sunflower (% of businesses)															
0.75–1	**63**	**73**	**79**	**63**	**70**	**84**	**69**	**67**	**68**	**52**	**56**	**59**	**41**	**54**	**50**
0.5–0.75	23	22	13	30	25	4	25	22	29	24	25	26	35	28	23
0.25–0.5	10	3	8	6	5	12	3	10	4	21	17	15	17	15	20
0–0.25	5	2	0	1	0	0	3	0	0	3	1	0	7	3	7
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Agricultural production cooperative (APC); limited liability company (LLC); joint stock company (JSC)
[a]Efficient enterprise has technical efficiency (TE) index that equals to 1 and lies on the efficiency frontier
Source Calculated by authors on the basis of DEA, BCC-output model

17.5 Discussion

Our results show that APC is in general inferior in the technical efficiency of plant production to non-cooperative forms of organization LLC and JSC. A similar result was obtained when comparing the main economic indicators of cooperative and non-cooperative agricultural organizations in other regions of the Russian Federation, in particular in the Nizhny Novgorod region (Altuhov and Rassadin 2015), Tambov region (Minakov 2015), Omsk region (Marakaeva and Scherba 2016), Belgorod region (Belchenko 2012) and Stavropolsky Krai (Didienko 2004). Analysis of profits for various legal forms in general in the Russian Federation in 2011–2013 showed that profitability of production in APCs is almost 2 times lower than in LLCs and 6 times lower than in JSCs (Minakov 2015).

Modern APCs are generally large, diversified organizations which inherited from Soviet sovkhozes and kolkhozes economic relations and management structure. In decision-making, each member of cooperative has only one vote at the general meeting regardless of the size of his share and it may lead to irresponsibility in decision-making (Altuhov and Rassadin 2015). A number of studies show (Altuhov and Rassadin 2015; Antsiferova 2010; Minakov 2015; Kolobova and Vorobev 2009) that development of APCs is hampered by the existing system of profit distribution and work motivation. Usually, the whole profit is invested into production development. The members of APC do not see any personal benefits of cooperation. The main income for members of cooperative is wage, which do not fully satisfy their economic interests.

The productivity of using land, labour and material resources in APCs is also low (Altuhov and Rassadin 2015; Minakov 2015; Marakaeva and Scherba 2016). The study shows that APCs applies extensive technology with low use of fertilizers and herbicides. Lower costs of seeds indicate that seed quality is lower than in non-cooperative farms. Labour resources are used less efficiently in the APCs. The gross production value of plant production per employee in APC is 16 and 50% lower than in JSC and LLC, respectively, in average of 2008–2012.

Lower technical efficiency may be explained by the lack of funds for intensification and development of production. As several studies show (Voronin et al. 2015; Minakov 2015; Rozhkova 2014; Myindrya 2010; Treskova 2008), cooperative enterprises such as APC have low investment attractiveness and have difficulty in getting loans. Investors are less interested in investing into the development of this legal-organizational form, as there are many owners and low responsibility. This has also implications on the manager's willingness to get engaged in long-term investment, such as into soil conservation and no-till farming. As data analysed by Bavarova et al. in Chap. 16 have shown that among those 25% of large farms who state using no-till farming at all, the adoption of this technology is only on 20% of their arable land. Although the APCs do only comprise 5% of all agricultural enterprises in Kulunda, and their share is decreasing (see Table 17.1), they still cultivate over the half of the arable land, thus representing an important actor, when considering the share of land they control. In Chap. 16 particularly the hampering factor of investment capital for implementing new cultivation measures has been mentioned. Referring to the APCs in Russia, the difficulty in receiving loans is connected with problematic collateral, because members of cooperative are not liable for cooperative obligations by their land shares (Kolobova and Vorobev 2009; Treskova 2008).

17.6 Conclusion

The lower profitability of the existing APCs has led to their replacement by more competitive forms of business such as JSC or LLC in the considered years. The number of APCs in the Altai Krai decreased from 203 to 150 from 2012 to 2015. A similar trend may be observed in the Russian Federation as a whole. This shows that the APC is less competitive organizational form of agricultural production in market conditions.

Even though our results show that APCs are less technically efficient in Kulunda Steppe in Altai Krai, we would like to stress that for the development of rural areas it is an important form of farming. APC is a social form of farming aimed at meeting the needs of its members. APCs inherited social responsibility of agricultural business from kolkhozes and sovkhozes (Minakov 2015; Kolobova and Vorobev 2009). The kolkhozes and sovkhozes in Soviet times developed social and engineering infrastructure of rural areas (schools, kindergartens, housing, water supply, etc.) (Serova 2016; Chernyakov 1999; Kalugina 2001). Many of APCs nowadays support social facilities in the rural areas. APCs aim to provide work for rural population. Weak market adaptability and orientation to economic results, however, makes them less competitive.

Some studies demonstrated the possibilities to increase profitability of APC activities through modification of the management system and profit distribution in the cooperative (Antsiferova 2010). APC is an organization form that provides and has even higher potential to provide public goods in Russian rural areas in the future including soil protection against degradation and more sustainable soil cultivation techniques such as no-till farming that help mitigate climate effects. It should be taken into account when building agricultural and rural policy. Still, policy measures that would support the development of APCs and support by that the assurance of public good provision in remote rural areas do not exist in Russia yet.

Appendix 14.1: Differences Between Legal Entities in Russia on Principles of Organizing Management System

APC	LLC	JSC	PF	SHF
Goals				
Making profit Social goals	Making profit	Making profit	Making profit	Satisfaction of family's demand for food
Owners				
Members of workforce, associate members	Founders	Shareholders	Members of farm	Members of farm (family)
Limitations on the number of owners and scale of production				
≥5 members Members of workforce must do ≥ 50% of all the production works.	≤50 founders	Public JSC—none, closed JSC—≤50 shareholders	Members of farm are relatives (≤3 families) and members who are not relatives ≤5	Members of farm are relatives. Area of land is limited
Personal labour participation				
Necessary Number of workforce who do not work in person must be ≤25% of total number of working cooperative members	Not necessary	Not necessary	Necessary	Necessary
Principles of appointing the head				
Election out of members of workforce	Appointment/election by founders	Appointment/election by shareholders	Appointment/election by members of farm	Appointment/election by members of farm
Weight of individual decision of owner in voting at the general meeting				
Equality of rights, each member has one vote	It depends on owner's share in the total funds	Depending on the proportion of shares	Equality of rights	Equality of rights
Principals of profit allocation				
By the decision of workforce, dividends are allocated according to participation in work and share size Up to 30% of profit can be used for bonus and dividend payment	By the decision of the meeting of founding members, dividends are allocated according to the number of shares	By the decision of the meeting of shareholders, dividends are allocated according to the number of shares	Independent use of profits	Independent use of profits

(continued)

(continued)

APC	LLC	JSC	PF	SHF
Responsibility for enterprise commitments				
Cooperative member is responsible by a share no less than 5% of its value	A participant is not liable in person and has limited liability	A shareholder is not liable in person and has limited liability	Unlimited liability, all property	Unlimited liability, all property
Conditions of participants exit				
Current share value is paid, or property of corresponding value is given	Property value corresponding to the share in the company's capital is paid, or property of corresponding value is given	In public JSC—sale of shares to the public, in ZAO (LLC) shares are offered to other shareholders	Only in case of ceased business	Only in case of ceased business

Agricultural production cooperative (APC); limited liability company (LLC); joint stock company (JSC); private (peasant) farm (PF); subsidiary household farm (SHF)
Source Authors

Appendix 14.2: Inputs and Outputs, Average by Farm Sample, Kulunda, Altai Krai, 2008–2012

	Unit	2008	2009	2010	2011	2012
Outputs:						
Variant 1—Gross production value of plant production	th. roubles/farm	24,676	24,682	21,173	20,618	19,508
of which:						
APC	th. roubles/farm	23,731	25,258	22,863	19,941	17,625
LLC	th. roubles/farm	21,290	21,308	18,384	19,311	21,218
JSC	th. roubles/farm	32,765	32,572	23,447	21,789	17,338
Variant 2—Gross yield						
Cereals	tonnes/farm	4166	6018	4626	3648	2307
of which:						
APC	tonnes/farm	4350	6108	5089	3942	2363
LLC	tonnes/farm	3342	4994	3685	3039	2249
JSC	tonnes/farm	5714	8851	5769	4383	2183
Sunflower	tonnes/farm	303	290	296	342	310
of which:						

(continued)

(continued)

	Unit	2008	2009	2010	2011	2012
APC	tonnes/farm	313	268	317	344	288
LLC	tonnes/farm	249	331	284	360	310
JSC	tonnes/farm	314	223	265	203	270
Inputs:						
Seeds	th. roubles/farm	2985	3699	3122	3787	5012
of which:						
APC	th. roubles/farm	2876	3823	3144	3495	4717
LLC	th. roubles/farm	2480	2890	2554	3620	5042
JSC	th. roubles/farm	4544	5626	4249	4524	5521
Fertilizers	th. roubles/farm	368	269	226	382	314
of which:						
APC	th. roubles/farm	206	173	100	174	241
LLC	th. roubles/farm	455	337	359	478	308
JSC	th. roubles/farm	416	346	249	436	470
Herbicides	th. roubles/farm	723	569	693	839	1048
of which:						
APC	th. roubles/farm	488	536	521	749	750
LLC	th. roubles/farm	913	585	928	952	1282
JSC	th. roubles/farm	459	617	557	514	995
Fuel	th. roubles/farm	5632	4623	4607	4849	5602
of which:						
APC	th. roubles/farm	6487	5443	5166	5470	6358
LLC	th. roubles/farm	3739	3261	3232	3749	4419
JSC	th. roubles/farm	8317	6614	6624	6236	6387
Spare parts	th. roubles/farm	3197	2874	2846	2796	3258
of which:						
APC	th. roubles/farm	3536	3141	3067	3037	3450
LLC	th. roubles/farm	2288	2305	2306	2253	2770
JSC	th. roubles/farm	4763	3866	3633	3472	3697
Salary and wages	th. roubles/farm	3877	4336	4644	5360	5801
of which:						
APC	th. roubles/farm	4261	4973	5359	6101	5846
LLC	th. roubles/farm	2563	3115	3309	3963	5077
JSC	th. roubles/farm	6118	6258	6086	7095	7300

Agricultural production cooperative (APC); limited liability company (LLC); joint stock company (JSC)
Source Authors

References

Abtania L, Hailu A, Mugera A (2012) Analysis of farm household technical efficiency in Northern Ghana using bootstrap DEA. In: Paper presented at 56th annual conference of Australian Agricultural and Resource Economics Society, Fremantle, 7-10 Feb 2012

Aigner DJ, Lovell CAK, Schmidt P (1977) Formulation and estimation of stochastic frontier production function models. J Econometrics 6:21–37

Altuhov I, Rassadin D (2015) Effektivnost organizatsionno-pravovyikh form v sel'skom khoziaistve [Efficiency of organizational legal forms in agriculture]. Ekonomika sel'skogo khoziaistva Rossii 1:34–37 (in Russian)

Antsiferova O (2010) Raspredelenie pribyili v sel'skokhoziaistvennom proizvodstvennom cooperative [Distribution of profits in the agricultural production cooperative]. Ekonomika sel'skogo khoziaistva Rossii 3:47–52 (in Russian)

Banker R (1984) Estimating most productive scale size using data envelopment analysis. Eur J Oper Res 17(1):35–54

Banker R, Charnes A, Cooper W (1984) Some models for estimating technical and scale inefficiencies in data envelopment analysis. Manage Sci 30(9):1078–1092

Battese G, Coelli T (1992) Frontier production functions, technical EFfiCIENCY and panel data: with application to paddy farmers in India. J Prod Anal 3:153–169

Belchenko OA (2012) Effektivnost' form sobstvennosti i organizatsii agrarnogo proizvodstva [Efficiency of forms of ownership and organization of agricultural production]. Sotsialno-ekonomicheskie yavleniya i protsessyi. 11(45). (in Russian)

Chaddad F (2014) BrasilAgro: organizational architecture for a high-performance farming corporation. Am J Agr Econ 96(2):578–588

Charnes A, Cooper W, Rhodes E (1978) Measuring the efficiency of decision making units. Eur J Oper Res 2:429–444

Chernyakov BA (1999) Uroki agrarnoy reformyi 1991–1998 gg. v Rossii. Analiticheskiy material. [Lessons from the agrarian reform of 1991–1998 in Russia. Analytical material]. Available on http://www.iskran.ru/russ/works99/chernyakov.html

Curtiss J (2002) Efficiency and structural change in transition—a stochastic frontier analysis of czech crop production. In: Beckann V, Hagedorn K (eds) Institutional change in agriculture and natural resources. Aachen, Shaker

Debreu G (1951) The Coefficient of resource utilization. Econometrica 19(3):273–292

Deprins D, Simar L, Tulkens H (1984) Measuring labor efficiency in post offices. In: Marchand M, Pestieau P, Tulkens H (eds) The performance of public enterprises: concepts and measurements. North Holland, pp 243–267

Didienko NN (2004) Otsenka effektivnosti deiatel'nosti sel'skokhoziaistvennyikh predpriiatii stavropol'skogo kraia razlichnyikh form sobstvennosti [Assessment of the effectiveness of agricultural enterprises of various forms of ownership in the Stavropol Krai]. Vestnik Severo Kavkaskogo Universiteta. Seriya Ekonomika. 1(12). (in Russian)

Farrell M (1957) The measurement of productive efficiency. J Stat Soc Ser A. 120(3):253–290

Grain-Online (2014) Informational Agency "Zerno-onlayn". Available on: http://www.zol.ru/

Greene W (1993) The econometric approach to efficiency analysis. In: Fried H, Lovell K, Schmidt S (eds) The measurement of productive efficiency. Oxford University Press, Oxford

Hassanov S, Nomman A (2011) Agricultural efficiency under resources scarcity in Uzbekistan: a data envelopment analysis. BEH—Bus Econ Horiz 4:81–87

Houshyar E, Davoodi MJ, Nassir SM (2010) Energy efficiency for wheat production using data envelopment analysis (DEA) technique. J Agri Technol 6(4):663–672

Jones DC (1998) The economic effects of privatization: evidence from a Russian panel. Comp Econ Stud 40(2):75–102

Jones DC, Kalmi P (2012) Economies of scale versus participation: a co-operative Dilemma? J Entrepreneurial Organ Diversity 1(1):37–64

Kalugina ZI (2001) Paradoksy agrarnoy reformy v Rossii: sotsiologicheskii analiz transformatsionnyikh protsessov [Paradoxes of Agrarian reform in Russia: a sociological analysis of transformation processes]. SO RAN, Novosibirsk. (in Russian)

Kapelushnikov RI (2001) Rossiiskii rynok truda. Adaptatsiia bez restrukturisatsii [The Russian labor market. Adaptation without restructuring]. Higher School of Economics, Moscow. (in Russian)

Kolobova AI, Vorobev SP (2009) Perspektivy razvitiia sel'skokhoziaistvennykh predpriiatii s obshchedolevoi formoi sobstvennosti. Vestnik Altayskogo gosudarstvennogo universiteta 1(51):62–67 (in Russian)

Lerman Z, Sedik D, Csaki C (2016) Agricultural cooperatives in transition countries. LAP LAMBERT Academic Publishing, Germany

Marakaeva TV, Scherba VN (2016) Analiz faktorov proizvodstva i puti povysheniia effektivnosti ispol'zovaniya zemel' sel'skokhoziaistvennymi organizatsiiami v Tiukalinskom raione Omskoy oblasti [Analysis of production factors and ways to increase the efficiency of land use by agricultural organizations in the Tyukalinsky District of the Omsk Region]. Vestnik Altayskogo gosudarstvennogo universiteta 5(139):175–179 (in Russian)

Minakov IA (2015) Sel'skokhoziaistvennye proizvodstvennye kooperativy: tendentsii i perspektivy razvitiia [Selskohozyaystvennyie proizvodstvennyie kooperativyi: tendentsii i perspektivyi razvitiya]. Vestnik Michurinskogo gosudarstvennogo agrarnogo universiteta 1:57–65 (in Russian)

Murillo-Zamorano L (2004) Economic efficiency and frontier techniques. J Econ Surv 18(1):33–77

Murthy S, Sudha M, Hedge M, Dakshinamoorthy V (2009) Technical efficiency and its determinants in tomato production Karnataka, India: data envelopment analysis (DEA) approach. Agric Econ Res Rev 22:215–224

Myindrya PN (2010) Organizatsionno-pravovye formy khoziaistvovaniia v agrarnom sektore ekonomiki: transformatsii, spetsifika ispolzovaniia i napravleniia razvitiia [Organizational and legal forms of management in the agrarian sector of the economy: the transformation, the specific use and direction of development]. Otraslevaya ekonomika, 3

REESTR (2012–2015) Reestr sel'skokhoziaistvennykh predpriiatii. 2012–2015. Upravlenie sel'skogo khoziaistva Altaiskogo kraia. (Register of Agricultural Enterprises in Altai Krai. The Main Department of Agriculture in Altai Krai). Available on: www.altay.agro.ru (in Russian)

ROSSTAT (2016) Federalnaya sluzhba gosudarstvennoy statistiki. Edinaya mezhvedomstvennaya informatsionno—statisticheskaya sistema (EMISS). (Federal State Statistics Service. United informational statistics system). Available on: http://www.gks.ru/wps/wcm/connect/rosstat_main/rosstat/ru/statistics/databases/emiss/. (in Russian)

Rozhkova DV (2014) Razvitie sel'skokhoziaistvennoi kooperatsii kak strategicheskogo elementa samoobespecheniia regiona prodovol'stviem (na materialakh Altaiskogo kraia) [Development of agricultural cooperation as a strategic element of the region's self-provision of food (on materials of the Altai Krai)]. Vestnik Altayskogo gosudarstvennogo universiteta. 9(119):170–174

Serova EV (2016) Agrarnaia reforma v Rossii perekhodnogo perioda [Agrarian reform in Russia in the transition period]. Istoriya novoy Rossii. Available on: http://www.ru-90.ru/node/1321. (in Russian)

Svetlov N, Hockmann H (2009) Optimal farm size in Russian agriculture. Contributed paper prepared for presentation at the international association of agricultural economists conference, Beijing, China, 16–22 Aug 2009

Treskova TV (2008) Finansirovanie sel'skokhoziaistvennykh proizvodstvennykh kooperativov i optimizatsiya struktury kapitala [Financing of agricultural production cooperatives and optimization of capital structure]. Avtoreferat na soisk. step. kand. ekon. nauk. Ulyanovsk. (in Russian)

Tsarev S, Davydova A, Prokopova A, Alexandrova A, Anton'eva M, Trotskovsky A at all. 60 year (1997) 60 let Altaiskomu kraiu [60 years Altai Krai]. Statistical book. Altay Publishing Housem, Barnaul. (in Russian)

Voronin BA, Voronina YV, Pogartseva EE, Dolgopolova AA (2015) Sel'skohoziaistvennaia kooperatsiia v sovremennoi Rossii [Agricultural cooperation in modern Russia]. Agrarnyiy vestnik Urala. 7(137):75–80 (in Russian)

Wadud A, White B (2000) Farm household efficiency in Bangladesh: a comparison of stochastic frontier and DEA methods. Appl Econ 32:1665–1673

Chapter 18
Institutional Analysis of Land Tenure System in Post-socialist Russia: Actors, Rules and Land Use

O. P. Fadeeva and I. S. Soliev

Abstract Governing land tenure and particularly ownership rights to land in post-socialist Russia is a long-term process that involves changes in norms, rules and administrative procedures. We analyse the land privatization reform in the context of evolving institutional limitations caused by the discontinuity and inconsistency of reform: domination of common (shared and joint) ownership, complications related to registering titles and lease agreements, and weakening of the state's role in controlling sustainability of land use. The agricultural districts of the Kulunda region of Altai Krai serve as a case study to show that, because of the development of informal local practices, the institutionalization of land relations is increasing as the investment appeal of the agricultural sector grows. Materials from in-depth interviews, participant observation, informal conversations and interactions, stakeholder workshops and statistical reports, are used to analyse existing practices in the interaction of the key actors in processes that are shaping up the current land tenure system. We discuss implications of the identified inconsistencies for long-term stability of the land tenure system and sustainability of land use. We will show that insecure formal land rights and the partly not functioning governance system pose high risks for innovation in agriculture. We observe that informal practices emerge to fill the flaws in the formal institutional arrangements, thereby increasing the relative stability of the resulting land use model. However, the overall prevalence of informal practices hinders the ability of actors to make long-term plans based on reliable expectations, raising equitability concerns and undermining efforts to shift to new technologies.

Keywords Privatization · Land reform · Ownership rights · Land tenure · Land use practices · Informal institutions · Kulunda region · Altai Krai

O. P. Fadeeva (✉)
Institute of Economics and Industrial Engineering, Siberian Branch of the Russian Academy of Sciences, 17 Avenue of Academic Lavrenitiev, 630090 Novosibirsk, Russian Federation
e-mail: Fadeeva_ol@mail.ru

Novosibirsk State University, 1 Pirogova street, 630090 Novosibirsk, Russian Federation

I. S. Soliev
Department of Agricultural, Environmental and Food Policy, Martin-Luther-Universität Halle-Wittenberg, 06099 Halle (Saale), Germany

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_18

18.1 Introduction

Russian land reform, with its first and most radical steps taken in the early 1990s, represents an attempt of transition to a new model of institutional regulation of land tenure system in agriculture (Buzdalov 2012; Uzun 2008). The reform aimed at bringing about a complete replacement of collective and state farms with a multitude of private farms and independent peasant landholders (Kalugina 2016). The privatization of farmlands and their redistribution based on needs and capacities were at the core of the reform. At the same time, the reform required that certain institutional adjustments be made, at least: to establish a new regulatory framework for privatization and trade of farmland; to regulate processes and records in relation to accounting, monitoring and control of land use; to develop standards and measures to ensure environmental sustainability of land use, as well as more fundamental norms for development and implementation of land use projects (Barsukova and Zvyagintsev 2015; Uzun and Shagayda 2015).

According to new economic institutional theory, clear and secure tenure system plays a major role in sustainable and equitable allocation and use of key resources such as land (Demsetz 1967; Barzel 1989; Feder and Noronha 1987). The establishment and protection of property rights, which define ownership and access to land, help cope with market fluctuations and shocks, as well as create conditions for increased investment activity and adoption of new technologies (such as those described in Chap. 16, for example, no-till systems to prevent soil erosion). These processes, in turn, are expected to contribute to the improvement of the quality of land use in the long run (Ault and Rutman 1979; Featherstone and Barry 1993).

At the same time, new institutional theory puts a strong emphasis on the necessity of taking a holistic approach in analysing and implementing policy interventions. Increasingly influential scholarship on institutions, transaction costs and larger-scale societal transformations (e.g. Ostrom 1986; North 1990; Williamson 1998; Meadows 1999) stresses that, particularly in cases of reforms with multitude of actors and priorities, changes are often needed on more than any single institutional level to bring about the targeted outcomes; and while the land reform discussed here represents a formal institutional change, it is often existing institutional arrangements that are formed over decades to centuries and millennia (e.g. norms, beliefs, perceptions, see also, next Chap. 19 on importance of institutional compatibility) and accompanying informal institutional practices (e.g. rules not defined in formal documents such as oral agreements), which reinforce or resist the change, determine the success of the reform. This is also in line with path dependency theory that views a change as an outcome of clash between drivers pushing towards a change and sources of path dependency resisting a change (for a summary of theoretical debate see Soliev et al. 2017).

The post-Soviet land reform in the Russian Federation, due to its discontinuity and inconsistency, provides an opportunity to analyse why formal institutions did not function efficiently or help to achieve the main goal of the introduced regulation—the creation of secure land tenure system and support for stable land markets. The liberalization of markets, if not reinforced by the appropriate formal and informal institutions, can lead to outcomes contrary to desired expectations. One risk associated with market liberalization is that a price mechanism that balances demand and supply in a market may destabilize the positions of producers (in our case previous state employees) during the transition. From a broader sustainability perspective, with the lack of knowledge, skills, technologies and initial capital, which would allow a competitive participation in a more open market, local producers might have to lower prices, which jeopardizes their financial stability potentially leading to collapse of the internal market (Fligstein 2001; North 1990). From an equitability perspective, in a transition where knowledge and skills of a vast majority of population suddenly becomes largely irrelevant in light of privatization, market liberalization might as well create an environment leading to a concentration of wealth in the hands of few individuals who might take advantage of those more vulnerable (Theesfeld 2018). This goes as well for markets for localized resources, primarily land and labour. In this instance, however, it is reasonable to expect high costs for skilled labour due to lack of sufficient supply, which produces the same results as in the commodity markets—a rise in (agricultural) producers' costs and a decline in profit. In the meantime, discontinuity and inconsistency in formal institutions (e.g. new official regulation) might increase transaction costs (e.g. administrative costs of implementation of a new reform that does not clearly define roles and responsibilities) further jeopardizing the establishment of a secure land tenure system.

In the remainder of this chapter, we concentrate on disentangling the formal and informal elements of the complex land reform in post-socialist Russia and the implications from their interaction. First, we describe the materials and methods applied in the research and establish key developments at the outset of land privatization processes relevant to our study. Then, we discuss the curious case of collective land ownership formed as a result of reform and particular limitations associated with the current land tenure system such as procedures undertaken to allocate and register ownership rights. It is followed by a discussion of findings documenting the emergence of informal practices accompanying the reform, their implications for establishing a secure land tenure system, equitability among actors participating in the emerging land market, and sustainability of land use.

18.2 Research Materials and Methods

Institutional arrangements affecting the land reform in Mamontovskiy district, one of the agricultural districts of Altai Krai in Russia, as well as the combined effect from these arrangements on the implementation of the land reform and on introducing technological innovation in the agricultural sector, were investigated as a case study. Specific attention was paid to causes leading to the emergence of informal practices, and their effects on the overall land tenure system. Data collection included archival research to identify official government documents introducing land reforms, participant observation during the research period from 2013 to 2016, a number of informal conversations and interactions, semi-structured interviews with key informants on specific topics, and a number of workshops with the participation of local stakeholders within the framework of the Kulunda project. Further, official statistics for Mamontovksiy district on agricultural activities of employees of the agricultural enterprises and farms within the territory of the district, as well as broader statistics for Altai Krai on land tenure were used to verify some of the findings from the field research. The semi-structured interviews were conducted with a total of 24 decision-makers, which included heads of district and federal authorities ($n = 3$), heads of agricultural enterprises ($n = 3$), heads of farms ($n = 15$) and heads of local municipalities ($n = 3$). Further data were obtained from seven interviews with farmers from four other districts of Altai Krai to understand broader validity of the findings within the same administrative division of Russia. Application of a variety of research methods allowed for triangulation to ensure that complexities of the local reality were correctly understood.

18.3 The Post-Soviet Land Reform of Russia in the 1990s

During the reform, state farmlands were divided into four groups. First, about 60% of lands of former collective and state farms were transferred to a common (joint or shared, discussed in the next section) ownership of their current and former employees, and to those employed in the social sector; while occasionally some of these lands were transferred directly to individuals without having to share with others (National Report 2015). Second, some lands of former collective and state farms were transferred to the so-called district redistribution funds to be managed by district administrations who became responsible for their further transfer. Third, rural (village) administrations received a certain share of lands of the former collective and state farms for development purposes not directly related to agriculture. Fourth, some of the lands remained the property of the state at the federal level.

The lands transferred to individuals included croplands, pasture lands, and hay fields. They were distributed according to norms that were defined by decision of the heads of district administrations. The size of the land share for each new owner was calculated based on two indicators—the total areas of farmland to be transferred to common ownership and the total number of applicants for those lands. A district norm in hectares of average-quality land was therefore determined. Differences in soil fertility were factored into even out variation in the quality of croplands to be privatized. The shares allocated as part of the common property were measured not in hectares, but in point/hectares, with the idea to allow for a fairer evaluation of the land parcels' quality. Land belonging to private citizens could be used to expand private household farm plots or establish private farms. It could be sold, given away, exchanged, or inherited. Land ownership was not tied to the requirement to personally use the land. Shareowners could lease their land to an enterprise or to local farmers.

The farmlands that left after the land was transferred to the employees of agricultural organizations and equivalent groups of rural residents were consolidated into district redistribution funds. The lands in these funds were leased to existing business entities. These funds were formed under the responsibility of district administration heads. Interview information indicated that according to a tacit understanding, the least valuable lands were transferred to the fund. In the early days, up to 10% of the farmlands of former collective and state farms were concentrated in funds, and early in the reform, they could be used by their former users without a lease until legal claimants for these lands showed up. Later, lands confiscated with court order due to legal violations or of out-of-business farmers were added to the fund, if they had the right to use the land for life (or if the right was inheritable). Lands with unidentified owners were also included in these funds.

Land under the management of rural administrations was intended for the development of settlements and for individual housing construction. Some of the lands became the property of owners of private farmsteads within the boundaries of the parcels they were actually using. In addition, lands were set aside for the needs of orchard and gardening associations, summer cottage construction, and the development of animal husbandry according to norms established by administrative divisions of the Russian Federation.

Finally, non-farm lands used for infrastructure, roads and other facilities within the boundaries of former collective and state farms remained state property on the federal level. They were transferred for perpetual use to the enterprises that were the successors to the former collective and state farms (business partnerships, associations, production cooperatives).

18.4 The Curious Case of Collective Land Ownership

An important feature of land reform was the collective nature of the allocated property rights to land. Instead of individual parcels with clear boundaries, rural residents received the right to land within the limits of common—either joint or shared—property. In the first case, the title to the land (land parcel) was indivisible. In the second case, each participant received the right to a land share, whereby any individual shareholder could enter into transactions (lease, sell or divide into individual parcels) provided that the other shareholders agreed with the intentions of this individual shareholder. Operationally, the process of privatization comprised several steps. First, a list of applicants for common tenure had to be approved at a meeting. Second, the head of district administration had to accept the request of the applicants on transferring the state land to their ownership (whether joint or shared). Each applicant could apply for an individual parcel before the parcel was transferred to common ownership. This required the filing of a separate application to the head of the administration. Farm enterprise employees could also submit a request for individual parcels. They could increase the sizes of their holdings by combining their land shares with the shares of their relatives and friends.

The collective nature of land ownership assumes a consensus among and the obligatory participation of each of the right holders in the registration of the title.

Not all shareholders were able to conform to established rules, which increased the transaction costs in the creation of the new tenure system. This approach to privatization was an impediment to the intended rapid redistribution of land. In 1996, a moratorium on the sale of farmland was introduced, which led to the development of a market for leasing land shares. In 2002, this moratorium was lifted. Early in the reform, it was assumed that land (as well as other state property associated with agricultural land) would be privatized in several phases. In the first phase, the former collective and state farms were appointed as intermediaries in the transfer of land titles to individuals. The land and the private titles were transferred to the operational management of the heads of entities that were supposed to facilitate the next phase of privatization. However, this process largely lacked transparency, and there were no mechanisms for overseeing the procedures of transfer, which in many cases prevented potential shareholders from registering their rightful claims. As Fadeeva (2013) and Shagayda (2013) document, a significant proportion of them did not come into possession of their rights, partly because their land was registered as the authorized capital of private companies (joints stock or other form) and was later seized or sold to third parties as a result of bankruptcy or resale of those enterprises.

18.5 Procedures for Allocating Land Parcels

During the early waves of reform in 1992–1993, the privatization of land administered by a separate enterprise led to the appearance of indivisible vast parcels that included tens and hundreds of individual fields, hay lands, and pastures. The total area of a parcel could reach thousands of hectares, and it could have hundreds of owners, who were supposed to meet to discuss all the issues related to land use and reach unanimous decisions. This made management of the common land very difficult and hindered the attempts to carve out individual smaller parcels from it, including for establishing smaller private farms. Procedures for sharing common ownership were therefore developed further. The new procedures introduced in 1994 (see also Chap. 17 by Ponkina et al.) enabled a shareholder or a group of shareholders to set aside parcels within their shares for private farms or for leasing, sale, or contribution to authorized capital. On the level of Russian regions, restrictions against over-fragmentation of lands were introduced. The federal-level administrative divisions of the Russian Federation were given the right to set dates for the beginning and ending of farmland privatization, and to develop regional land allocation rules, set the lengths of land leases, etc. The legislative bodies of Russian regions set their own standards for the minimum size of parcels that could be formed (surveyed) towards consolidated land shares. This decision reflected the regional authorities' preference regarding the size of business entities engaging in farm production in their area. The enlargement of land parcels gave the advantage to medium and large land users.

The physical allocation of new land parcels for farming took place after shareholders' collectives formed. Those who organized themselves in collectives were primarily shareholders who agreed to lease their lands to private or other farms.

Potential land users (tenants) took the minutes of shareholder (owners) meetings to land authorities, requesting the allocation of parcels from the land on which the Soviet farm organizations located there once worked. The allocation of parcels for newly formed private farms was not always accompanied by the provision of public land planning services or even with works to identify boundaries. This prompted the growth in cases of land grabbing and other violations of the law (Shagayda 2013).

18.6 Problems Registering Land Titles

Registration of land titles began only five years after privatization was launched. In 1998, Russia established a unified electronic public register of real-estate titles and transactions. The register keeps record of changes in relation to property rights and includes acts of registration of the property rights to land, lease agreements, purchase-sale transactions, and inheritance acts. Rights are registered only when parcels are registered in the cadastre, which assumes the existence of surveys of specific parcels, including those newly formed from land shares. The cadastre work is done at the expense of parcel owners. When the register was created, with the rush to get it into operation, a part of the paper-based information on parcel boundaries and rights to land shares was not included. As a result, many existing titles had to be re-registered (Uzun and Shagayda 2015).

To confirm their land rights, all owners had to have a land survey at their expense. In the case of common shared ownership, the shareholders were responsible for handling registration and cadastre matters. This involved serious outlays in terms of money, as well as time, since they had to conduct the physical survey to clarify the boundaries of the land shares they want to register, visit various departments and organizations at district centres as well as go through the lengthy processing of documents.

On the one hand, because cadastral registration and registration of land titles and transactions were based on applications, this procedure was largely voluntary for shareholders. On the other hand, the state lost important levers to influence and monitor the status of land resources, and large amounts of land went unregistered. In addition, according to the law, a lease agreement with a term less than a year does not have to be registered. This makes it possible to put into circulation parcels that have not undergone cadastral registration and do not have definite legal status. As a result, this loophole combined with the high transaction costs of registration procedures led to an expansion of the practice of informal (non-contractual) short-term lease relations. This practice, however, seriously weakens the position of the parties in such an informal transaction. Tenants (land users) have no guarantees that the lease term is sufficient to pay back the investment. Property owners (landowners), in this instance, likewise, cannot be certain that their rights will be protected. At the same time, this creates a situation making it hard to consider long-term oriented investments, for example, in soil quality.

18.7 Consequences and Institutional Limitations of Land Reform

Summarizing the results of 25 years of land reform, one should acknowledge that its results do not entirely match the expectations of reformers or of society as a whole. Privatization did not create a class of full-fledged landowners interested in preserving the land and in increasing its fertility and market value. The allocation of land shares on the basis of place of employment and place of residence rather resembled the distribution of free gifts, not the transfer of rights and obligations to responsible owners. Today, many shareholders cannot control the actions of the actual land users or influence the selection of agricultural technologies that will be used. They are not always able to influence the lease rates or the terms of the agreements, they conclude. In general, the strengths of actors on local markets are not equal, so the weaker ones have to accept the terms of the more powerful (larger) actors, especially as local authorities often promote the interests of the latter.

One might state that in post-socialist Russia opportunities for efficient trading in farmlands and for the dissemination of new land use technologies are facing a number of institutional limitations, which include but are not necessarily limited to the following:

– the land tenure system, as well as specification and registration of titles, is not fully formed;
– transaction costs associated with bringing unclaimed and unworked land into circulation are sufficiently high to hinder the process;
– the rights of landowners, especially in relation to common shared ownership, and land users are insufficiently protected;
– the role of local authorities in monitoring the terms of and quality of land use was lost or significantly weakened.

18.8 Structure of Land Tenure in Altai Krai

In 2013, farmland in Altai Krai occupied an area of 11,537.2 million ha, which was about 70% of the region's area. Agricultural lands (arable land, pastures, hayfields, perennial plantings and fallows) occupied an area of 10,597,000 ha (Report on the Status and Use of Land in Altai Krai for 2013 2014).

In Russia as a whole and in Siberia, in particular, large areas of land have been taken out of production. According to a report from the Ministry of Agriculture, as of 1 January 2014, some 26% of agricultural land in the Russian Federation was not in use (Report on the Status and Use of Agricultural Land for 2013 2014). Most of the unused land was in the Siberia Federal District (57%), followed by the share of Altai Krai of 5.04 million ha (44%). These data, however, are estimates only. They were obtained based on information from land users, who had an interest in distorting data on the areas in use (at least due to the expanding informal contractual relations), and from space images, methods for the analysis and interpretation of which are highly contested (Barsukova and Zvyagintsev 2015).

The structure of agricultural land ownership in Altai Krai differs from the national. In Russia as of 1 January 2014, roughly two-thirds of land belonged to national and municipal entities, but in Altai Krai, the dominant stratum of landowners was private citizens, who possessed more than half of the land (53.4% or 6161.2 million ha). The dominant form of land ownership by individuals was common shared ownership (89.1%). Formally, common shared ownership meant that former members of Soviet collective and state farms inherited an equal share in newly organized agricultural production cooperatives. The number of participants in this form of ownership totalled 313,008 people (Report in Altai Krai, 2014). At the time of privatization, applying the allocation criterion discussed earlier, each member of agricultural production cooperatives in Altai Krai was entitled to a land share of 10–12 ha depending on its location. The location of each share was, however, only approximate, largely based on districts, without specified boundaries.

Among the major players on Altai Krai's local markets are business partnerships and companies (e.g. in the form of Limited Liability Companies, Joint Stock Companies), agricultural production cooperatives, and individual private farms. In 2013, a major portion of agricultural land was assigned to agricultural organizations: partnerships and companies accounted for 29% of land (3175.2 million ha) and production cooperatives for 21% (2346.2 million ha). Private farms occupied an area of 2003.1 million ha, which represented 18% of the land of Altai Krai. The average size of one private farm considering the land in use was 447 ha (see further details on the legal forms of actors and statistics of their structure in Chap. 17 by Ponkina et al.).

The Krai's land users mostly cultivate the land they have on the basis of a leasing agreement. By and large, they conclude lease agreements for land parcels formed from the land shares that villages received during privatization (58% of all land in use), as well as for land in district redistribution funds that are managed by district administrations (from 27 to 37%). Out of all the farm entities in Altai Krai, only individual private farms worked on their own land, that is, not on the basis of a lease agreement, and this land represented 15% of the total used by farmers. The proportion of cultivated land owned by business partnerships and companies was far lower—around 5%; that of agricultural production cooperatives was only 1% (Report in Altai Krai, 2014). To accelerate the turnover of land parcels formed from shared land, the Krai rescinded the minimum term for leasing land, that is, this land can change tenants almost every year. The minimum threshold for leasing land from district redistribution funds is seven years.

The local land markets have certain specific features. A number of the rural districts that were studied had a shortage of available land and intense competition among land users. This is despite the apparent abundance of unused land in Altai Krai (44%). However, unused lands are not spread out evenly across districts often making land consolidation and access to infrastructure very difficult. At the same time, as was discussed above, high transaction costs associated with registering land titles and more generally related to procedures of bringing new lands into 'production' reinforce the artificial shortage of land, which will be discussed in more detail in the subsequent section. In some instances, a few large agricultural enterprises and numerous private farms ensured a high demand for land. In other instances, the demand for land increased after outside actors—the owners of processing enterprises planning to integrate agricultural production into their business or even development companies focusing on housing development in rural areas—came to the district. An entirely different competitive environment developed in districts with an especially arid climate and poor soil quality, where large quantities of cropland were abandoned and the authorities did not know how to attract new producers or restore these lands' quality.

18.9 Secure Land Tenure: A Combination of Formal and Informal Practices

Our field research showed that, in addition to formal rules, there were specific informal rules for interaction among the various actors on local land markets—different groups of agricultural producers, landowners and representatives of local authorities. Informal practices, which compensate for flaws in legislation, help to create conditions for the formation of a relatively secure local land tenure system, the introduction of technological innovations, and the alignment of the interests of landowners and tenants.

Agricultural producers turn out to have the most interest in the legal registration of land titles and suffer most from the flaws in the existing land tenure system. It is land users, not owners of land shares, who often organize and cover the monetary costs associated with title registration. They also organize surveys of parcel boundaries, put parcels on the cadastral register and prepare documents for registration. They, thereby, help to create conditions for extending the time for beneficial use of land parcels and ensuring the return on their investments. The drivers for the formalization of a secure land tenure system are, as a rule, the heads of private farms and enterprise owners, who have a stake in the long-term development of their businesses.

The interviewed farmers have explained that they undertook the registration of the land of their shareholders around ten years ago. Some of them did not manage to register land according to the old rules with the initial wave of land reform in 1992–1993 (see also the chronology of reforms discussed in Chap. 17 by Ponkina et al.). They had to start from scratch after the legislation on privatization changed numerously till 1997. Some farmers had problems identifying shareholders or their heirs in order to obtain powers of attorney to complete registration. Another obstacle on this path was that the majority of land users lacked the necessary legal knowledge and money to complete the procedures.

Problems related to establishing boundaries of land parcels pertain not only to shared land but also to lands in district redistribution funds. In a number of instances, the authorities requested land users, who won the right to lease at auction, to bear the costs of the cadastral registration, promising to compensate these costs by a reduction in future rent. The fact that municipal land is not registered is an obstacle to attracting investments and implementing major projects. As a result of difficulties and costs related to registration, in many cases instead of concluding a long-term lease, municipalities and land users agree on an 11-month lease term, for which cadastral registration is not required. However, the land remains outside the register with dubious legal status and the legal grounds for land use can be easily challenged (Alakoz and Nikonov 2013).

Nevertheless, once registration is completed, as agricultural producers noted in the interviews, leasing land from redistribution funds is the most appealing to them, since this land comes with lower lease rates and a minimum (more reliable seven years) lease term. In this instance, there is no need to enter into negotiations and contractual interactions with numerous parties, as happens when one attempts to lease shared property. At the same time, for local authorities, redistribution fund land is one of many tools for influencing the behaviour of agricultural producers. For example, administration of Altai Krai sets a priority for livestock farms in leasing land from redistribution funds. Another environmental policy option would be to set conditions on particular modes of allowed tillage operation.

Shared land requires that land users take shareholders' demands seriously and seek compromises. In rural settlements where different business entities—large farm enterprises and private farms—engage in production, a fight over shareholders' land is foreseeable. Elements of the fight over shared land are competing for proposals for lease rates and additional services that the land users will provide. Competitors agree on the 'rules of the game' and find compromises in land disputes, thereby guaranteeing long-term land use. The arrangements of the land lease allow rural families to receive rents, monetary or in-kind (feed, land tilling services, freight transport, etc.), which in turn allows these households to preserve their private farms, raise livestock and poultry, and produce meat and milk for sale. Land users occasionally also take over the responsibility to pay the land tax for shareholders.

In the farm milieu, it is also common to encounter 'gentlemen's agreements', prohibiting the enticement of shareholders and employees from some farms to others with more generous offers. In addition, subleases are arranged and arable fields are exchanged often by oral agreement. As a result, these informal arrangements slow the transfer of croplands from inefficient land users to those who managed to increase the land productivity through, e.g. modernization or introduction of new technologies and crop rotation. Likewise, they slow down the consolidation and expansion of lands that might have been more productive and more sustainable.

Moreover, to counter the expansion of large companies, representatives of farm communities agree to act unanimously at land auctions held by district administrations. To prevent the total buy-up of adjacent fields by stronger competitors, they buy some of the parcels they cultivate to create 'overlapping field strips' which does not allow the consolidation of the land.

In districts with a high demand for land, land with unidentified owners has tremendous financial potential. According to the current law, the administrations of rural districts have the right to register the so-called unclaimed shares of villagers. The administration's task is to find out about the nominal owners, collect documents about their loss of land rights (in case of death and if there are no heirs, or if a notarized abandonment of the land is presented), and then declare these lands ‘unclaimed’ in court. Then, the administrations can transfer ownership of these lands to district redistribution funds with the right to sell or lease them. On the one hand, the procedure is alarming as it seems to provide room for expropriation of less powerful, given the well-documented events of extortion and other threats to property in Russia’s post-Soviet history (see, e.g. Gans-Morse 2013). Although we have not come across such cases in our study, this clearly shows the necessity for a stronger protection of more vulnerable property right holders, on the level that could eliminate loopholes such as the above. On the other hand, this procedure provides a platform to bring new or abandoned lands into production, which appears crucial in Altai Krai for attracting investments and transferring technologies, and generally for moving towards more sustainable land use. There are numerous obstacles on this path, to which one may add that administrations lack personnel and financial capacities necessary to register titles and put land in the cadastral register. If, however, there are actors interested in obtaining access to these resources, the ‘no man’s land’ can quickly gain a legal status.

Powerful Altai farm producers do not hide their plans to expand their land holdings. Some of the private farmers that were interviewed stated that they increased their land by about 10% annually. This growth is delayed by the fact that some shareholders do not want to part with their land rights. Yet, Altai farmers believe that the low cost of land (about 500–700 Euros per share—10–12 ha) and low lease rates (about 70–100 Euros per share or 1–2 tons of grain) are their important competitive advantages which help to keep the cost of production relatively low.

18.10 Land Use Quality Control and Sustainability

Regional offices of Rosselkhoznadzor (the Russian Federation Federal Service for Veterinary and Phytosanitary Surveillance) are responsible for the quality control of land use. Performing this function competently requires efficient, mobile units on the ground staffed with specialists in land issues. However, the agency does not have these human or administrative resources (see this chapter).

By law, regulatory authorities audit agricultural producers once every three years. Audits are largely perfunctory. The main function of audits is to confirm the proper use of agricultural lands and compliance with certain technological requirements. Inspectors by looking at documents confirm that plant protectants and mineral fertilizers are on hand and correctly applied, that seeds are certified, and that wastes are disposed of, etc. The audit objectives do not include environmental assessment of technologies, crop rotation or the change in soil fertility. The perfunctory nature of audit procedures and regulatory authorities’ non-interference in production processes would allow land users to easily pay off claims against them (they pay fines, give small bribes) and keep inspectors out of areas where they might do real harm to the business.

In the land users' opinion, nominal landowners (shareholders) have little interest in preserving the quality of their land. They are interested only in the amount of the lease fee—and there have been more than a few instances when they were ready to lease their land quickly to another user, if that potential user orally promised a higher payment. They are usually indifferent to the fact that their lands are not planted or cultivated or that weeds and shrubs are overgrowing them. As a rule, lease agreements with owners of land shares, as well as with district administrations when it comes to land in the redistribution fund, contain no special environmental requirements or conditions ensuring long-term sustainability of land resources, for example, on preserving topsoil or protecting against wind and water erosion. There seems to be a naïve expectation that agricultural producers, most of who are on a lease agreement with little long-term security, will assume the responsibility for ensuring sustainability of land resources. In the absence of any serious consequences envisioned in legislation or in lease agreements, this tenure system does not prevent short-term destructive uses of land either. With the lack of interest from the owners to maintain the quality of land and establish tenure systems that are secure in the long-term, it remains a challenge to incentivize producers to invest in preservation and improvement of land quality.

18.11 Conclusions

The institutionalization of the land tenure system through development of informal local practices is increasing as the investment appeal of the agricultural sector grows. The inconsistency and lengthiness of the land reform pose high risks for innovation in agriculture, but low land lease and purchase prices are strengthening the competitive positions of Altai's producers. A combination of formal and informal practices ensures the relative stability of the resulting land use model, but does not always contribute to a growth in the efficiency in agricultural production or to sustainability of land resources. As a rule, farmers do not see investments in land in the context of improving or maintaining the quality of their land resources or increasing the market value of their farms. Evidence shows that most share motives of current profitability and preservation of the business to pass it onto their heirs.

One of the adverse consequences of land reform was the government's loss of control over and management of land resources, on all—federal, regional and local—levels. Local public authorities lost tools and resources for routine monitoring of land use by different groups of agricultural producers, for land planning and cadastral work, and for legal registration of land parcels and lease agreements. Public authorities became unable to obtain accurate, real-time data about the structure and quality of lands or information on the actual land users.

Existing government support measures do not directly encourage the introduction of new technologies. New support mechanisms are needed to encourage (i) an increase in the quality of land use and introduction of technologies aimed at more sustainable land use; (ii) less burdensome procedures for legalizing titles (with compensation of costs to survey and register land, especially in areas with challenging natural conditions and climate) and putting unclaimed, abandoned lands into circulation; and (iii) better—clear and long-term—protection of the rights of landowners, particularly in the case of common shared ownership, as well as land users, especially those who might not be in the position to bear high transaction costs of the current land tenure system.

References

Alakoz VV, Nikonov AV (2013) Land management—investment map of Russia in the agrarian sector. Land Manag, Cadastre Monit Lands 4:6–12 (in Russian)

Ault D, Rutman G (1979) The development of individual rights to property in Tribal Africa. J Law Econ 22(1):163–182

Barsukova SYu, Zvyagintsev VI (2015) Land reform in Russia in 1990–2000s, or how land reform was "reformed" during the departmental reorganization. J Inst Stud 7(2):84–98 (in Russian)

Barzel Y (1989) Economic analysis of property rights. Cambridge University Press, Cambridge

Buzdalov IN (2012) Land reform: looking through the prism of the plan. AIC: Econ Manag 7:3–17 (in Russian)

Demsetz H (1967) Toward a theory of property rights. Am Econ Rev 57(2):347–359

Fadeeva OP (2013) Siberian rural areas: land and labour in local contexts. EKO 5:29–47 (in Russian)

Featherstone A, Barry K (1993) Goodwin factors influencing a farmer's decision to invest in long-term conservation improvements. Land Econ 69(1):67–81

Feder G, Noronha R (1987) Land rights systems and agricultural development in Sub-Saharan Africa. Res Obs 2(2):143–169

Fligstein N (2001) The architecture of markets: an economic sociology of twenty-first-century capitalist societies. Princeton University Press, Princeton

Gans-Morse J (2013) Threats to property rights in Russia: from private coercion to state aggression. Post-Soviet Aff 28(3):263–295

Kalugina ZI (2016) Modernization of the Russian village: economic results and social consequences. Sci Europe 2(10):86–95

Meadows D (1999) Leverage points: places to intervene in a system. The Sustainability Institute, Hartland, VT, pp 1–19

National Report on the Status and Use of Land in the Russian Federation for 2014 (2015) Federal Service for State Registration, Cadastre and Cartography under the Ministry of Economic Development of the Russian Federation, Moscow (in Russian). URL: https://rosreestr.ru/upload/Doc/16-upr/%D0%B4%D0%BE%D0%BA%D0%BB%D0%B0%D0%B4%202014.rar. Accessed 19 May 2018

North D (1990) Institutions, institutional change and economic performance. Cambridge University Press, Cambridge

Ostrom E (1986) An agenda for the study of institutions. Public Choice 48:3–25

Report on the Status and Use of Agricultural Land for 2013 (2014) Federal State Funded Science Institute Rosgosinformagroteh under the Ministry of Agriculture of the Russian Federation, Moscow (in Russian). URL: https://www.rosinformagrotech.ru/sites/default/files/files/ispolzovanie_zemli_2014.pdf. Accessed 19 May 2018

Report on the Status and Use of Land in Altai Krai for 2013 (2014) Altai Krai Department of the Federal Service for State Registration, Cadastre and Cartography, Barnaul (in Russian)

Shagayda NI (2013) Agricultural land in Russia: 20 years after reform. EKO 5:5–22 [in Russian]

Soliev I, Theesfeld I, Wegerich K, Platonov A (2017) Dealing with "baggage" in riparian relationship on water allocation: a longitudinal comparative study from the Ferghana Valley. Ecol Econ 142:148–162

Theesfeld I (scheduled for 2018) The role of pseudo-commons in post-socialist countries. In: Hudson B, Rosenbloom J, Cole D (eds) Routledge handbook of the study of the commons. Routledge's Handbook Series. Routledge Publishing

Uzun VY (2008) Land reform in Russia: myths and reality. Voprosy Economiki 10:139–155 (in Russian)

Uzun VY Shagayda NI (2015) Agrarian reform in post-Soviet Russia: mechanisms and results. Russian Academy of National Economy and Public Service under the President of the Russian Federation, Moscow. http://dx.doi.org/10.2139/ssrn.2672054 (in Russian)

Williamson OE (1998) Transaction cost economics: how it works; where it is headed. De Econ 146(1):23–58

Chapter 19
The Role of Institutional Policy Congruity for Sustainable Land Use in the Kulunda Steppe

I. Theesfeld and L. Jelinek

Abstract In Russia and likewise in the Kulunda steppe, only recently, environmental-oriented policy measures have been introduced. Yet these are confronted with the prevailing post-socialist institutional environment, such as de facto property rights on land, administrative inertia, values and production habits of farmers. Revealing institutional factors with the help of the Procedure of Institutional Compatibility Assessment (PICA) that prevent effective and cost-efficient policy implementation can help to better support the prevention of soil erosion, nutrient loss and climate gas emission in the future and to work toward more sustainable land use. We investigate Russian agricultural land protection policies and specific regulatory instrument to explore and structure critical socioeconomic, administrative and institutional factors that diminish the effective execution of the instruments. Credible monitoring and sanctioning turned out to be almost impossible in the Kulunda region. Further, we argue that the servitude right, or farmers‘ perception on positive effects of inadequate soil practices, could not be addressed by short-term administrative solutions. We rather suggest information provision and subsidies for voluntary conservation measures to reach more sustainable agro-ecological practices.

Keywords Degraded black soils · Environmental policy measures · Crop residues burning · PICA method · Policy incongruity · Kulunda steppe

I. Theesfeld (✉)
Institute of Agricultural and Nutritional Sciences, Martin-Luther-Universität Halle-Wittenberg, Von-Seckendorff-Platz 4, 06120 Halle (Saale), Germany
e-mail: Insa.theesfeld@landw.uni-halle.de

L. Jelinek
Department of Agri-Environmental Policy, Research Institute of Agricultural Economics and Information (IAEI), Mánesova 75, 120 00 Prague 2, Czech Republic
e-mail: Jelinek.ladislav@uzei.cz

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_19

19.1 Introduction

Due to unsustainable agricultural production practices in the Kulunda Steppe, we face severe land degradation including a drop in humus content in Russia's black soil region. Agri-environmental policies could help to stop unsustainable land use. Yet if such policies are not in line with the prevailing institutional context and, particularly, if they mainly rely on command-and-control measures, they might be ineffective, meaning they do not reach their aim or only at prohibitive high transaction costs. We will exemplify this for the ban on crop residue burning, otherwise a common agricultural practice in the Kulunda region. In the following, we will shortly provide evidence for the loss in organic content of the soils and the need for an expansion of conservation tillage instead of residue burning. Thereafter, we will discuss the role of institutions to make policies effective. In Sect. 19.2, we will introduce the Procedure of Institutional Compatibility Assessment which guided the empirical analysis. After introducing the extent and effects of crop residue burning, we will present the actual monitoring mechanism of the responsible agencies. Section 19.4 gives results on crucial institutional aspects that hinder a more successful implementation of that regulation. At the same time, such institutional aspects are also relevant to be considered for other agri-environmental measures constructed in a similar way. We draw conclusions suggesting more measures that aim at long-term institutional change, addressing the perception of farmers and investing in information spreading and education campaigns, all with the aim to count more on voluntary compliance and less on monitoring and sanctioning to achieve the same aim: more sustainable land use.

19.1.1 The Agricultural Conversion of the Kulunda Steppe and Its Degraded Soils

The cultivation of the Kulunda region begun in the nineteenth century, but within the framework of the Virgin Land Campaign in the 1960s, 2.3 million ha natural steppes in the Altai Krai of South-Western Siberia were largely transformed into arable land (Frühauf et al. Chap. 8 this volume) (Durgin 1962). The Kulunda steppe in Altai Krai accounts currently for 6.7 million hectares utilized agricultural land, of which 75% are to some extent environmentally degraded (ROSREESTR 2013). The original humus content before cultivation has been estimated on average being 9.6% in the forest-steppe zone (Belajev 2009). Being aware that data show large variances between regions and plots, Meinel (2002), Charlamova and Revyakin (2006) and Guggenberger et al. (Chap. 14 this volume) point to a continuous reduction of soil organic content as well as to long-term nutrient loss (Bivalkjevich 2002).

19.1.2 Agri-Environmental Policies and the Role of Institutions to Make Them Effective

The question is how to politically facilitate agro-ecological practices on land that would lead to a more sustainable land use and which institutional factors led to the current ineffectiveness of policies, particularly those trying to fight the degradation of the soil. Environmental reforms in Russia in general are not regarded as accomplishing their intended effects (Mirovitskaya and Soroos 1995).

Studies with a comparable post-socialist legacy that focus on the institutional environment of soil protection policies are Prager et al. (2012) or Stupak (2016), showing that it is rather a mix of personal, sociocultural, economic, but also institutional and political factors that influence the behavior toward soil conservation efforts and that limit the effectiveness of existing laws that are being insufficiently put into practice (Prager et al. 2011, 2012).

Supporting land-use change toward a more environmental sustainable outcome is an agronomic and economic question, but to a large extent, it is also an institutional one. Institutions such as property rights on land and the corresponding governance structures play a central role in supporting policy measures that could be effectively implemented. The governance structures facilitate how the game is played or "the governance of contractual relations takes place," including issues of contract monitoring and enforcement, conflict resolution mechanisms, information sharing mechanisms, education systems, as well as market systems or voluntary self-organization.

In Russia, the corresponding governance structures were mostly rooted in a simple command-and-control measure. But also informal rules, norms and traditions are different to those of most Western European countries.

As a consequence resulting from the US dust bowl in the 1930s, we find early studies such as Uri (1999) who points out that it is difficult to quantify economic, demographic and policy factors' impact on the adoption of conservation technologies. Recently, Pereira et al. (2016) have shown that it depends on the perception of farmers on the environmental impact of their action, how they get engaged with conservation measures and follow legal regulations (see also Chap. 16). Prishchepov et al. (2012) highlight the importance of institutions for post-socialist countries, including Russia, relating mainly to differences in land privatization strategies and land markets on land-use decisions, particularly to abandon land.

Further, "command-and-control" agri-environmental measures can only be effective if applied to easily observable soil conservation problems (Prager et al. 2011). Just like the insufficient governance and administrative capacities to allow for a functioning land market in Russia, described by Lerman and Shagaida (2007), the capacities to govern environmental measures are comparably inadequate. The identification of the rule-breaker often suffers from the asymmetric information between controllers and land users.

The facilitating and hampering factors crucial to implement command-and-control measures can likewise be used to make predictions on the effectiveness and cost-efficiency of similar command-and-control policy types. It can further stimulate policy-makers and regional administrators to initiate ex-ante evaluation of future measures, a strategy that still is found rather seldom in a Russian context.

19.2 The Procedure of Institutional Compatibility Assessment (PICA) Method

The literature suggests that particular land policy implementation may fail because implemented rules are not compatible with the prevailing institutions (Theesfeld et al. 2010). If the individuals who are crafting and modifying rules do not understand how particular combinations of rules affect actions and outcomes in a particular ecological and cultural environment, rule changes may produce unexpected and, at times, disastrous outcomes (Ostrom 2005).

To shed light on different sources of policy incongruity, related to a regulatory policy, we follow the Procedure for Institutional Compatibility Assessment Method (PICA). PICA has been developed as a formalized methodology to assess the compatibility between policy options and various institutional contexts. Original PICA comprises four distinct working steps: 1. clustering policy options according to the type of intervention, the area of intervention, possible changes involving property rights, and the type of natural resources addressed by the policy options; 2. linking each policy cluster to specific sets of crucial institutional aspects (CIA); 3. using institutional indicators to evaluate the respective institutional aspects; and 4. deriving statements—arranged in thematic categories of institutional compatibility—about the probable effectiveness of the policy options from an institutional perspective depending on the combination and degree of the identified relevant institutional aspects (Schleyer et al. 2007). After the initial development of PICA (Theesfeld et al. 2010), additional studies have applied and further developed the method, as regards, e.g., the implementation of the Nitrate Directive in France (Amblard and Mann 2011) to the adaptive capacity to climate change in the Netherlands (Mandryk et al. 2015). Depending on the particular research interest, not all four steps in the PICA method need to be conducted.

We will exemplify a policy misfit for the Kulunda region on a recently introduced measure to fight against land degradation based on Theesfeld and Jelinek (2017). With the help of the PICA method, we could illustrate ex-post the aspects of institutional compatibility.

The initial library of CIA linked to the policy type command-and-control policy that intervenes on the market (Schleyer et al. 2007, p. 79) served as a basis. Some of the pre-determined CIA were not considered suitable for the policy option, or for the sociopolitical background in Western Siberia, and were therefore not considered.

The remaining CIA were presented and evaluated by 24 interviewees ranging from individual and corporate farms, environmental NGOs, locally based agronomic experts, administrative bodies (controlling and monitoring agency, fire patrol) and actors dealing with policy execution of the Altai Krai. They first assessed the three most determining aspects influencing the policy measure. During qualitative interviews, the respondents described and commented the intensity of an aspect and the direction of its influence. A Policy Discussion Forum conducted at the Altai State Agricultural University in Barnaul served to further discuss implementation obstacles in agri-environmental measures.

19.3 Case Study

19.3.1 Soil Protection Policies

Contrary to many European regions, the agricultural environment and soil quality in Kulunda are protected exclusively by regulatory instruments, predominantly implemented at federal level that implicitly aim at sustaining soil fertility and preventing degradation.

Such land-use policies have been implemented by a set of directives as outlined primarily in the Constitutional and Land Code. The Code states "only practices that ensure rational land use can be applied and each plot has to be kept in such a condition preventing weeds invasion, degradation and fertility reduction" (Land Code of Russian Federation, § 42). The potential damages are, among others, water and wind erosion, salinization, drying, chemical contamination and weeds spreading. The policy aims shall be achieved by regional-specific measures directed at local damage. We selected one measure—the ban on crop residue burning—and further characterized its instructional incongruity.

19.3.2 Counteracting Agricultural Soil Protection Policies—The Practice of Crop Residue Burning

Kulunda steppe, as indicated above, largely used for arable farming, shows a widespread production practice of crop residue burning (CRB) (Romanenkov et al. 2014). An analysis, conducted with the help of advanced satellite remote sensing methods, found that fire used in agricultural practices account for 8–11% of global fires from 2001 to 2003 (Korontzi et al. 2006). It was estimated that 31–36% of all agricultural fires worldwide occurred in Russia making the country globally to the largest contributor to crop residue burning (Korontzi et al. 2006), yet the missing data for exact estimation of the extent are frequently pointed out (Romanenkov et al. 2014, p. 349). Sukhinin et al. (2004) have calculated by using satellite pictures that in 2000, an area of 164.000 ha was burned in Altai Krai. Using the figures from the Federal Forest Agency, the agricultural land area under fire accounted for 76.000 ha in Altai

Krai in the first half of 2014, encompassing arable land as well as (dry) grasslands (Federal Forest Agency 2016),[1] but likewise with large regional differences.[2]

Crop residue burning, Altai Krai 2014. *Photo* Ladislav Jelinek

Pérez-Cabello et al. (2010) and Novara et al. (2011) regard such fires as the main contribution to land degradation. Despite these known side effects, the burning allows a relatively easy way of disposing the residues from arable land and preparing the land for subsequent agro-technological operations, suitable for standard Soviet-technology. Notably, off-field demand for crop residues (Smil 1999), such as for animal husbandry, is very limited in contemporary Russia (Romanenkov et al. 2014, p. 349).[3] Thus, there are not many alternatives to burning, except switching to conservation tillage practices, such as no-till or mulch tillage (see Bavarova et al., this volume). In the broadest sense, conservation tillage is defined as a tillage system that leaves enough crop residues (residue cover of at least 30%) to the field after harvest, to protect the soil from erosion (Laflen et al. 1985; Smil 1999; Uri 1999). Mirovitskaya and Soroos (1995) estimate that half of the cultivated farmland in Russia is affected by wind and water erosion, both are seen as continuous risks for the Kulunda region (ROSREESTR 2013). Conservation tillage would enhance carbon sequestration and humus accumulation in the soil (Chap. 14 this volume). An increase in the risk of drought is indicated by spatial patterns showing that the Kulunda area will

[1]Fire statistics usually refer to agricultural lands which includes forest belts and moorlands. We corrected the numbers accordingly.

[2]Expert opinion describes the outreach of that practice: "In the follow-up spring, after a high grain yield season, about 25% of the agricultural area under conventional cultivation is burned."

[3]Average density of the cattle is only around 7 heads/100 ha of agricultural land ROSSTAT 2016. Regional Statistics. Agriculture and Forestry Section. http://akstat.gks.ru/wps/wcm/connect/rosstat_ts/akstat/ru/statistics/enterprises/agriculture/. Accessed July 2016.

become drier and warmer (Degefie et al. 2014), which requires to follow agricultural production methods that stores moisture in the soil.

19.3.3 Land Protection Monitoring

Three authorities based at the federal level are responsible for land protection monitoring in the Altai Krai. This responsibility includes the identification of a potential non-compliance, damage rate quantification and, finally, sanctioning the offender. However, this monetarization of degradation only refers to the chemical contamination, illegal waste disposal or illegal plot development. No other land degradation parameter is quantified, in that sense.

Local oblast-level regulations were introduced in 2000 to regulate CRB (Romanenkov et al. 2014, p. 348). Since 2001, further regulations were passed: the *Federal Code on the Administrative Torts* in 2001 and in the frame of the regional *Administrative Act on the Violation of the Justice in Altai Krai* in 2002. The Federal Code did not explicitly refer to agricultural areas, but the regional law specifies "*burning of crop residues on agricultural land, natural protected areas, in traffic zones or around water basins*" will be penalized.[4] The regional law was amended at the end of 2013 as the court concluded there is no need for two separate legal acts. Since 2014, a new regulation specifies: "*burning of the crop residues on agricultural land is allowed under the following conditions: fire security of municipalities and infrastructure has to be ensured and it has to be proven that there is no other available mechanism how to dispose the crop residues.*"

The amendment requires strict pre-conditions for those who want to burn on the agricultural land. The unreasonable high costs to meet the pre-conditions[5] act as a de facto a prohibition to burn on agricultural land. The controlling and monitoring mechanisms remained unchanged and continued to be under the responsibility of the Regional Ministry of Natural Resources and Environmental Protection.

19.4 Institutional Compatibility Assessment

The policy and corresponding regulation aiming at reducing CRB that include the latest amendments are accompanied by the still large area under fire every year. Annual satellite pictures give hints that the regional appearance of agricultural fires has not been significantly reduced (Federal Forest Agency 2016). Following the PICA procedure also outlined in Theesfeld and Jelinek (2017), we will depict CIAs that counteract effective policy implementation at various institutional levels.

---

[4]The penalties varied between 1.500 RUB (30 EUR) up to 2.000 RUB (40 EUR) and 30.000 RUB to 40.000 RUB (600–800 EUR) for physical persons and legal entities, respectively.

[5]Authorization of the body carrying out the fires, proof of anti-fire equipment and training.

19.4.1 Governance

There is a lack of compensation payments schemes to enable farmers to refrain from the prevailing technology that entails burning of the harvested crop residues and tillage operations each season. In order to comply with the regulations enforced since 2000, farmers need to invest in new machinery to handle the straw and tackle the previous year's harvest. Direct seeding equipment must be designed to operate in heavy residue conditions and in soils that have much wetter surfaces when compared to conventional tillage systems. An agricultural technology dealer for Central Asia and Russia estimates the costs for a multifunctional sawing machine, which is capable to seed in the straw, to be at 150.000 Euro. Those machinery is partly missing in Russia or not compatible with the old Russian tractors used. The ability to chop and disperse residues uniformly across the cut is decisive, too, but most grain harvesters are not equipped with straw choppers. The cost of a straw chopper for the old Soviet harvesting machine is specified by the expert with approximately 2.000 Euro. Bavarova et al. (Chap. 16, this volume) do likewise point to the large investments obstacle believed by the farmers as a reason for non-adoption of no-till cropping.

Unlike nutrients from inorganic fertilizers, macronutrients in crop residues are not readily available. The straw to decay sufficiently requires microbiological processes in the soil. The short vegetative period in the Kulunda region could hardly provide such conditions. The decomposition of residues will actually withdraw nitrogen from the soil, and without additional nitrogen fertilizer to be spread on the field, the short-term productivity of the soil is even reduced (Smil 1999). Conservation tillage practices, ranging from zero tillage to minimum tillage, calls for more fertilizers and pesticides during the initial years but providing an estimated yield increase by 20–25% in future years. Figures from Kazakhstan clearly show this agronomic relationship (FAO 2012). Zentner et al. (2002) who could study longer time series in the Canadian Prairies, likewise support this relationship. Many farmers complained on a lack of information about this complexity of yield decrease and cost increase in the first years when shifting from traditional tilling technology (including residue burning) to conservation technology. This supports findings of Prager et al. (2012) and Sergienko (Chap. 22, this volume) on the importance of knowledge transfer, such as advisory systems as key requisites for the implementing environmental regulations or conservation practices.

The responsible agency which monitors the compliance in the Altai Krai and which organized the administrative procedure is the Administration of Natural Resources and Environmental Protection (CANREP). In fact, it governs the majority of policies that relate to the environmental protection on agricultural, forest and industrial areas, manages natural protected areas, executes the law on air protection, maintains the anti-erosion forest belts and executes hunting regulation. The CANREP uses publicly available satellite pictures with registered fires ("*kosmosnimky*") to detect the illegal fires and their extent. In addition, Rosleschoz—the organization responsible for the forest management—publishes data about identified field fires. The Gebler Ecological Society is actively involved in the patrolling of fires to help to put the fires down. Even, farmers confirmed that the staff capacities are not sufficient in relation to the area to be monitored and a number of 676.000 agricultural companies and (semi)subsistence household units. Additionally, CANREP's overlapping responsibilities do not allow for sufficient investigation. The agency admitted that the proportion of the violation that ended up with the offender prosecution is lower than 5%.[6]

The prosecution required to provide unique evidence, in order to find the accused person guilty. However, only in minor cases farmers admitted that they initiated the fire. In other cases, they claimed either that there were other causes of the fire or identified an unknown responsible person. Moreover, the relatively low level of fines, 30–40 Euro, has been stated to be not dissuasive.

The amendment that has been in force since 2014 has put even more administrative burdens on the controlling agency, such as investigating as to whether the potential offender had no alternative than to burn the residuals.

19.4.2 Property Rights

In the following, we draw the attention to the property rights arrangements, and how they impact on the regulatory measure. It has been argued that property rights, i.e., the rights and duties to the use of a natural resource, whether de facto or de jure, significantly affect the incentives individuals face to invest in long-term land improvements (Brasselle et al. 2002). The current proportion of land in private possession is estimated at about 55% for the region (ROSREESTR 2013). Although the relationship between the extent of private land ownership and the propensity to follow conservation soil management is complex (Brasselle et al. 2002), as outlined already in Theesfeld and Jelinek (2017) the interviewees in the Kulunda steppe often declared that with the increasing amount of privately owned land, they are more willing to apply the conservation land practices and are willing to invest in the soil fertility.

An important factor that impacted the investigation of the controlling agency was the existence of the public servitude right. Based on history, when land was commonly used in Russia, the court confirms that this free accessibility of any plot makes the prosecution to require evidence for the fire that was set or the waste that has been disposed illegally, more difficult by the alleged offender.

[6] *Personal communication with the staff at the Administration of Natural Resources and Environmental Protection.*

19.4.3 Beliefs, Norms and Trust

The crop residue burning is embedded in tradition, norms and social values. Such informal constraints are usually present in a society for a long period and take centuries or millennia to change. Given the fact that such embedded social institutions change only slowly and can hardly be directly addressed by a policy, it still has to be taken into account as a facilitating or hampering factor. The latter suggests that the policy procedure is not in line with the underlying social context and can thus not count on voluntary compliance.

Pereira et al. (2016) have shown for the post-socialist country Lithuania that particularly the perception of the impacts of fires determines the reaction of farmers to fire regulation. Analogously, in the Kulunda steppe, we could detect widespread believes (73% of respondents) about the positive effects of CRB on the soil, such as reducing weeds and pests. Not surprisingly, these farmers regard the regulation as an obstacle for farming. Bavarova et al. (this volume) provided evidence from the Kulunda region that particularly small-scale farmers doubt the suitability of no-till farming for their conditions. Further, as Schneider et al. (2010) stress for Switzerland, a switch to no-till farming has changed their perception of the aesthetics of cultivated land and thus their underlying values.

Similar to studies from Bulgaria and Czech Republic (Prager et al. 2012), we found low trust in officials as information providers, due to the communist legacy where government officials worked to conceal information. Yet this trust is detrimental for any policy that is based on voluntary measures.

19.5 Conclusion

Drawing on a case study of the Kulunda steppe in South-Western Siberia, we explored how far a command-driven policy, the ban on crop residue burning, is congruent with the prevailing institutional context. We have shown that the appearance of agricultural fires has not been significantly reduced, despite the formal regulation. With the help of the Procedure of Institutional Compatibility Assessment, we structured the reasons for the policy‘s ineffectiveness.

It turned out in line with the findings of Lutz et al. (1994) that missing of monetary compensation measures for the high adjustment costs, when switching to a different production method in order to reduce crop residue burning, is a core constraint of farmers to change to soil conservation practices. To keep the agronomic and technical requirements for law following behavior in mind and to support needed technological innovation is something likewise relevant with regard to other policies and measures dealing with sustainable land use.

High costs of monitoring and the almost impossibility to convict the offender are detrimental for the ineffectiveness, too. In line with the 2014 amendments, the updated law even puts new requirements on the monitoring agency as the newly introduced security pre-conditions that have to be administered and controlled. The controlling difficulties are similar to other soil protection measures, too. Farmers complain, for instance, about a non-transparent system of penalties referring to the required soil nutrient level. Additionally, there is a particular property right of free access of plots by anybody. The strength of embedded beliefs and traditions is signaled by farmers‘ attempts to cite such customary common access to land as a defense against prosecution for fire-setting, in court. Further, this argument makes it difficult to impose sanctions. In such situations where controlling and sanctioning impose prohibitive high transaction costs, policies need to count on measures that support rather voluntary commitment.

The ban of CRB is a typical example of the current model of land protection policy in Russia, namely a strictly regulatory administrative land measure. Following Hagedorn (2008) our analysis points out that this general and central way of administration omitted nature-related specificities of the sector, such as jointness of production and lack of separability, same as local agro-ecological conditions. Many actors, besides those being directly involved in the transaction (working on the soil), are affected, which calls for a broader participation in the planning of agricultural land protection measures. In line with that, we found a lack of knowledge on the broader policy objectives to fight land degradation and only few measures that advise and inform the farmers about agro-ecological relations of alternative production measures on their specific soil types.

Still, the adjustment costs of farmers and the governance of the controlling bodies can be addressed in short term. Yet the factors connected with the land tenure system and particularly personal attitudes of farmers toward soil conservation can persist over generations and can only be changed slowly, exceeding the time span of regular political programs. Yet the empirical case also proved for Russia that isolated measures addressing soil degradation at only one level of institutional analysis, e.g., introducing a targeted credit scheme, do not go far enough. Rather, an introduction of a public information campaign or strengthening the advisory system to supplement the investigated measure could shift farmers’ adherence to soil conservation policies. Yet the move toward novel forms of governance that count on voluntary participation and educating the addressed actors will encounter difficulties in a political and administrative environment with a command-and-control legacy, as in Russia. One of the difficulties with environmental measures is the time span of ecological processes: Humus accumulation in soil, for instance, is a process whose benefits can only be measured long term. The temptation in a political system however is to propose short-term policies, with arguably visible and measurable results.

References

Administrative Act on the Violation of the Justice in the Altai Krai (2002). Nr 182, § 40–1
Amblard L, Mann C (2011) Ex-ante institutional compatibility assessment of policy options: methodological insights from a case study on the Nitrate Directive in Auvergne, France J Environ Planning Manage 54(5):661–684
Belajev VI (2009) Modern cropping systems, tendencies and possibilities of development. In: Belajev, VI, Ustinov, VI, Plastinin, JJ (eds). Agricultural Science for Farming, Altai State Agricultural University, Barnaul, 145–147
Bivalkjevich V (2002) Racionalnoje zemljepolzovanie selskochozjajstveych zemelj: problemi i reschenija (Optimal agricultural land use: issues and solutions). APK, Ekonomika upravljenie, pp 89–95
Brasselle A-S, Gaspart F, Platteau J-P (2002) Land tenure security and investment incentives: puzzling evidence from Burkina Faso. J Dev Econ 67:373–418. https://doi.org/10.1016/S0304-3878(01)00190-0
Charlamova NF, Revyakin VS (2006) Regional climate and environmental chance in Central Asia. In: Vogtmann H, Dobretsov N (eds) Environmental security and sustainable land use—with special reference to Central Asia. Springer, Dordrecht, The Netherlands, pp 19–26
Degefie DT, Fleischer E, Klemm O, Soromotin AV, Soromotina OV, Tolstikov AV, Abramov NV (2014) Climate extremes in South Western Siberia: past and future. Stoch Env Res Risk Assess 28:2161–2173. https://doi.org/10.1007/s00477-014-0872-9
Durgin FA (1962) The virgin lands programme 1954–1960. Soviet Stud 13:255–280
FAO (2012) Advancement and impact of conservation agriculture/no-till technology adoption in Kazakhstan. Information Note, FAO Investment Centre
Federal Forest Agency. 2016. Информационная система дистанционного мониторинга Федерального агентства лесного хозяйства (Data on Remote Fire Monitoring). https://nffc.aviales.ru/main_pages/index.shtml, accessed July 2016
Hagedorn K (2008) Particular requirements for institutional analysis in nature-related sectors. Euro Rev Agric Econ 35:357–384. https://doi.org/10.1093/erae/jbn019
Korontzi S, McCarty J, Loboda T, Kumar S, Justice C (2006) Global distribution of agricultural fires in croplands from 3 years of Moderate Resolution Imaging Spectroradiometer (MODIS) data. Glob Biogeochem Cycles 20:1–15. https://doi.org/10.1029/2005GB002529
Laflen JM, Highfill EE, Amemiya M, Mutchler CK (1985) Structure and methods for controlling water erosion. In: Follett RF, Stewart BA (eds) Soil erosion and crop productivity. American Society of Agronomy, Madison
Lerman Z, Shagaida N (2007) Land policies and agricultural land markets in Russia. Land Use Policy 24:14–23. https://doi.org/10.1016/j.landusepol.2006.02.001
Lutz E, Pagiola S, Reiche C (1994) The costs and benefits of soil conservation: the farmers' viewpoint. World Bank Res Observer 9:273–295. https://doi.org/10.1093/wbro/9.2.273
Meinel T (2002) Die geoöekologische Folgewirkungen der Steppenumbrüche in den 50er Jahren in Westsibirien. Dissertation, University of Halle-Wittenberg, 122
Mirovitskaya N, Soroos M (1995) Socialism and the tragedy of the commons: reflections on environmental practice in the Soviet Union. J Environ Dev 4:77–110
Novara A, Gristina L, Bodì MB, Cerdà A (2011) The impact of fire on redistribution of soil organic matter on a mediterranean hillslope under maquia vegetation type. Land Degrad Dev 22:530–536. https://doi.org/10.1002/ldr.1027
Ostrom E (2005) Understanding institutional diversity. Princeton University Press
Pereira P, Mierauskas P, Novara A (2016) Stakeholders' perceptions about fire impacts on Lithuanian protected areas. Land Degrad Dev 27:871–883. https://doi.org/10.1002/ldr.2290
Pérez-Cabello F, Ibarra P, Echeverría MT, de la Riva J (2010) Post-fire land degradation of Pinus sylvestris L. woodlands after 14 years. Land Degrad Dev 21:145–160. https://doi.org/10.1002/ldr.925

Prager K, Helming K, Hagedorn K (2011) The challenge of developing effective soil conservation policies. Land Degrad Dev 22:1–4. https://doi.org/10.1002/ldr.1042

Prager K, Prazan J, Penov I (2012) Soil conservation in transition countries: the role of institutions. Environ Policy Gov 22:55–73. https://doi.org/10.1002/eet.592

Prishchepov AV, Radeloff VC, Baumann M, Kuemmerle T, Müller D (2012) Effects of institutional changes on land use: agricultural land abandonment during the transition from state-command to market-driven economies in post-Soviet Eastern Europe. Environ Res Lett 7:024021. https://doi.org/10.1088/1748-9326/7/2/024021

Romanenkov V, Rukhovich D, Koroleva P, McCarty JL (2014) Estimating black carbon emissions from agricultural burning. In: Müller L, Saparov A, Lischeid G (eds) Novel measurement and assessment tools for monitoring and management of land and water resources in agricultural landscapes of Central Asia. Springer, Switzerland, pp 347–364

ROSREESTR (2013) Svedenije o pravach, na kotorych ispolzovali zemlju grazhdane i organizacije. (Land ownership and tenancy rights). Federal Cadastral and Cartography Office: Barnaul, (in Russian)

ROSSTAT (2016) Regional statistics. Agriculture and forestry section. http://akstat.gks.ru/wps/wcm/connect/rosstat_ts/akstat/ru/statistics/enterprises/agriculture/. Accessed July 2016

Schleyer C, Theesfeld I, Aznar O (2007) Approach towards an operational tool to apply institutional analysis for the assessment of policy feasibility within SEAMLESS-IF. SEAMLESS Integrated Project, EU 6th Framework Programme, contract no. 010036–2

Schneider F, Ledermann T, Fry P, Rist S (2010) Soil conservation in Swiss agriculture—approaching abstract and symbolic meanings in farmers' life-worlds. Land Use Policy 27:332–339. https://doi.org/10.1016/j.landusepol.2009.04.007

Smil V (1999) Crop residues: agriculture's largest harvest: crop residues incorporate more than half of the world's agricultural phytomass. Bioscience 49:299–308. https://doi.org/10.2307/1313613

Stupak N (2016) Impact of agricultural transition on soil protection in Ukraine: the role of institutional change. Land Use Policy 55:86–97. https://doi.org/10.1016/j.landusepol.2016.03.022

Sukhinin AI, French NHF, Kasischke ES, Hewson JH, Soja AJ, Csiszar IA, Hyer EJ, Loboda T, Conrad SG, Romasko VI, Pavlichenko EA, Miskiv SI, Slinkina OA (2004) AVHRR-based mapping of fires in Russia: new products for fire management and carbon cycle studies. Remote Sens Environ 93:546–564. https://doi.org/10.1016/j.rse.2004.08.011

Theesfeld I, Aznar O, Schleyer C (2010) The procedure for institutional compatibility assessment: ex-ante policy assessment from an institutional perspective. J Inst Econ 6:377–399. https://doi.org/10.1017/s1744137410000056

Theesfeld I, Jelinek L (2017) A misfit in policy to protect Russia's black soil region. An institutional analytical lens applied to the ban on burning of crop residues. Land Use Policy 67:517–528. https://doi.org/10.1016/j.landusepol.2017.06.018

Uri ND (1999) Factors affecting the use of conservation tillage in the United States. Water Air Soil Pollut 116:621–638. https://doi.org/10.1023/a:1005168928627

Zentner RP, Lafond GP, Derksen DA, Campbell CA (2002) Tillage method and crop diversification: effect on economic returns and riskiness of cropping systems in a Thin Black Chernozem of the Canadian Prairies. Soil Tillage Res 67:9–21. https://doi.org/10.1016/S0167-1987(02)00028-4

Chapter 20
Spatial Patterns of Actual Demographic and Migration Processes in Kulunda

N. I. Bykov, M. A. Borisenko, S. Lentz and A. Wust

Abstract The Kulunda steppe is an important agricultural area in Russia and Kazakhstan. Yet, various socio-economic processes affect the options for its sustainable development. Actual demographics and migration have an important place among these processes and do particularly affect human capital and labour development for agricultural farm businesses. This chapter will outline various demographic and migration trends providing a detailed comparison among the districts of the Kulunda region.

Keywords Demographic situation · Migration · Kulunda · Altai Krai

20.1 Demographic Development in Altai Krai

The rapid growth in global population is increasing the importance of the agricultural lands, which are called on to solve the food problem. The Kulunda steppe is one of these areas with vast availability of agricultural lands. It has fertile black and brown soils and is a major farming area, whereas precipitation is a limiting factor. This area's sustainable development depends to a high degree on the success of farming, which requires the improvement of agricultural technologies, application of more economically efficient mechanisms, skilled human capital, as well as more effective public administration and regulations.

Demographic and migration processes are a consequence of and, at the same time, a central driving factor in the area's socio-economic development. One important process is the changes in the availability of skilled labour that is needed for

N. I. Bykov (✉) · M. A. Borisenko
Faculty of Geographie, Altai State University, Street Lenina 61,
Barnaul, Russian Federation
e-mail: nikolai_bykov@mail.ru

S. Lentz · A. Wust
Leibniz Institute for Regional Geography (IfL), Schongauerstraße 9,
04328 Leipzig, Germany

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_20

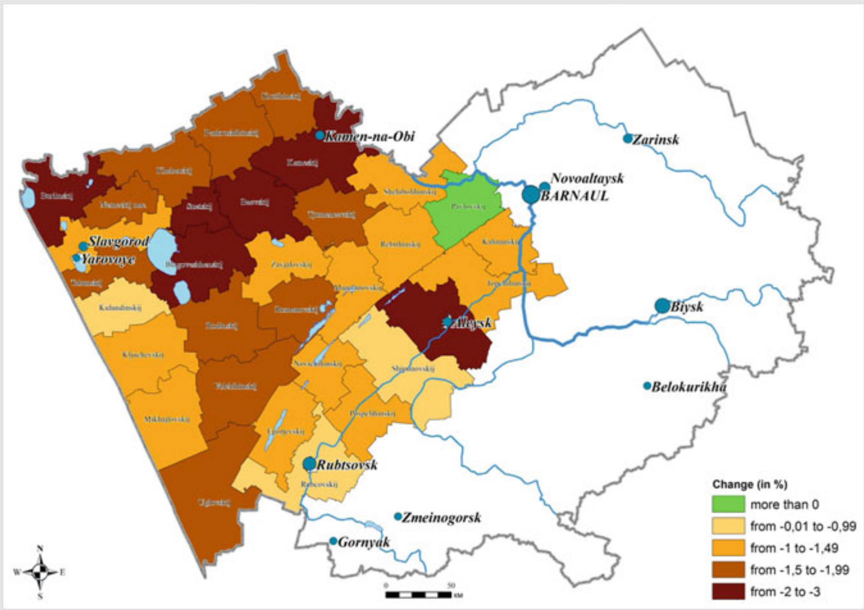


Fig. 20.1 Mean annual population change, 2010–2015. *Source* Bykov and Borisenko, own calculation (2015)

modernization of agriculture. This chapter describes the actual demographic situation in the region, which allows us to draw a more detailed picture of the region's socio-economic trends.

Overall, the region's population has been declining for a long period of time (Eremin and Bykov 2011). The period from 2010 through 2015 was no exception.

Among all districts of the Kulunda region, only Pavlovsk district saw a population increase in this period (Fig. 20.1), for all other districts the demographic balance was negative. Furthermore, the distribution of values for negative population balance indicates some correlation with the distance from the region's capital, Barnaul. Pavlovsk district is the closest and best-connected part to Barnaul compared to all other districts studied. Between 2010 and 2015, the population in all other districts has decreased by 1–3% annually (Fig. 20.1). For the majority of them, it is a result of both natural population decline and a negative migration balance.

Only three districts in the region were not affected by these two factors, but had a surplus of birth relative to the losses by deaths. These districts are part of the Barnaul conurbation or situated either within the main infrastructural 'artery' or the forest-steppe zone (Fig. 20.2; coded as types 3 and 4). The five districts coded as type 6 (Fig. 20.2) have higher natural losses than losses by migration. In the worst cases, a critical population structure causes such a situation: a long-term outgoing migration leads to ageing, so that at a certain point the potential for migration is exhausted and

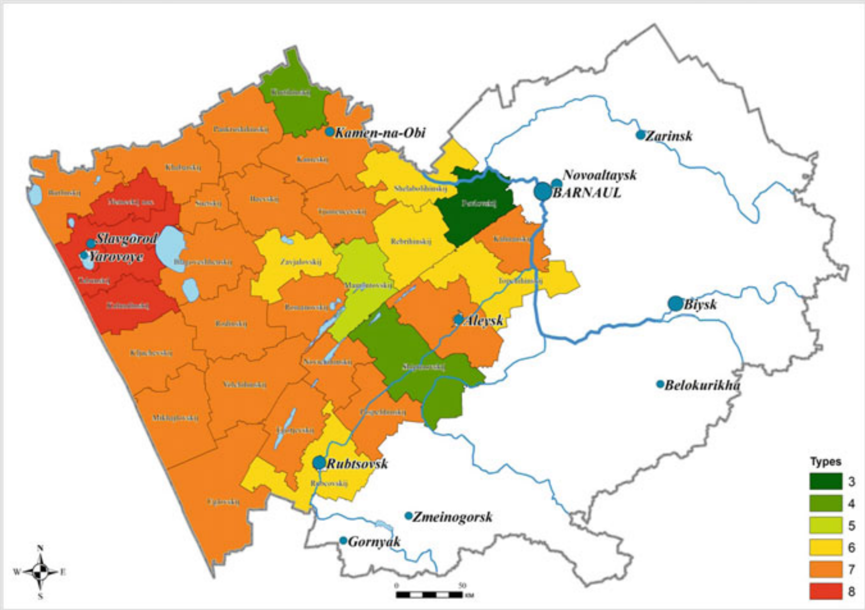


Fig. 20.2 Causation types for demographic dynamics. *Source* Bykov and Borisenko, own calculation (2015)

the cases of death become statistically more prominent. The demographics of the age structure in these districts deserves closer investigation.

Districts coded as type 7 show, contrary to the types discussed above, out-migration leading to net losses regardless of destination. Type 8 districts, all more remote from the regional capital Barnaul, are characterized by decreasing population because of migration, despite the demographic surplus of births over deaths.

In most districts, the numbers of in- and out-migration preponderate the cases of births and deaths. Therefore, the following sections will take a closer look at the migration statistics. Here, the unit of consideration is the district with the purpose to unveil spatial patterns of in- and out-migration across the entire Kulunda region.

In 2010–2014, Pavlovsk district was the only one with a positive migration balance (Fig. 20.3). All other districts experienced a negative migration balance, many of them from −15 to −25 per mill. and year. The major share of the mobile population leaves districts in the Kulunda region in favour of other regions of Russia, many of them, of course, for Barnaul, the region's capital; another larger share migrates to the European part of Russia.

Given this, it may be a surprise, that the statistics of international migration show a positive balance for the majority of municipal districts (Fig. 20.4). This is because Altai Krai is an attractive destination for migrants particularly from Kazakhstan and other Central Asian states, who seem to consider it a safe haven at the beginning of their migration paths. However, this does not necessarily lead to a sustainable inflow

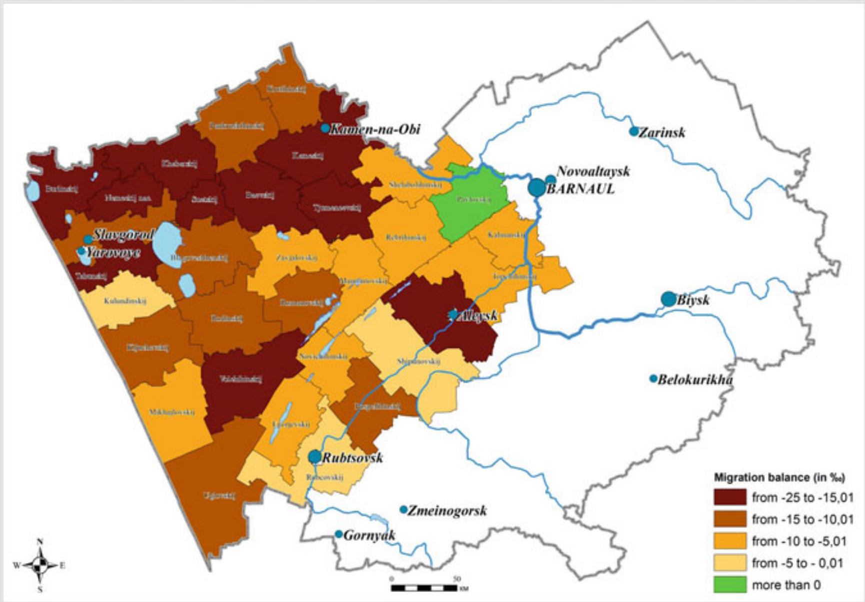


Fig. 20.3 Migration balance in the region 2010–2014, per mill. *Source* Bykov and Borisenko, own calculation (2015)

of population, since many migrants leave the region after a while, as it often cannot provide the desired socio-economic conditions to found a stable existence and make a living.

The special cases are the north-western districts Slavgorodskii, Khabarskii and Nemetskii. There, international migration balance is negative due to a still ongoing out-migration of ethnic Germans. Even after two decades of emigration, their share is still high in this area and the trend of emigrating to Germany persists. At the same time, similar to the other districts, these districts are also targets for quite a considerable number of migrants from Central Asia. However, this inflow does not fully compensate the out-migration (Fig. 20.4) so that the balance in international migration is still negative.

It is also important to consider the origins of migrants within Russia in order to design more effective and appropriate policy measures for regional development (e.g. further education).

The share of migrants arriving from other regions of Russia ranges from 12 to 41% of migration in the districts of arrival. The spatial distribution of values strongly correlates to the geographic proximity to other regions. The farther north and by that, the closer to other regions of Russia, the district is, the higher is the share of people arriving from other regions of Russia (Fig. 20.5). This gives rise to the hypothesis

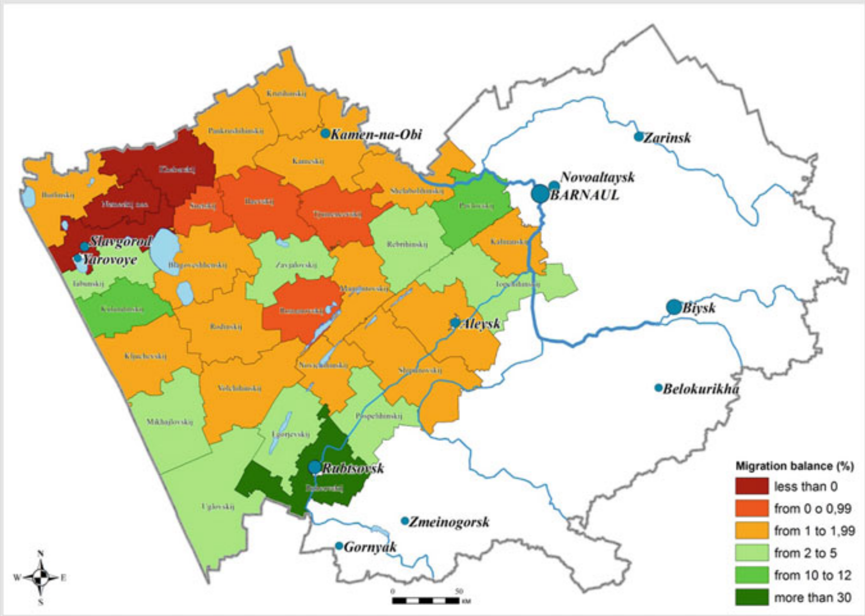


Fig. 20.4 Balance of international migration, 2012–2014. *Source* Bykov and Borisenko, own calculation (2015)

that this type of immigration is rather part of a regional migration system making the geographic convenience as a primary driver. On the national level, it appears that Kulunda region is not attractive enough for long-distance migration in a larger system.

The spatial pattern of inbound migration of the area is somewhat different. From a geographic and structural point of view, the proximity to urban areas and a good transportation infrastructure are crucial. The highest number of inbound migrants are heading to suburban districts—Pavlovskii, Rubtsovskii—and to district centres on major arteries, including transportation hubs. Secondary targets are district centres such as Aleiskii, Shipunovskii and Blagoveshchenkii (Fig. 20.6). In 2010–2015, some 6000–9500 people arrived in each of these districts. These districts are also the leaders in the absolute numbers of people coming from other regions of Russia.

Finally, migrants from other countries account for 1–20%. Here again, the spatial pattern is determined by proximity: the closer to the Kazakhstan border, the higher the relevance of international migrants (Fig. 20.7). Kulundinskii and Rubtsovskii districts are especially noteworthy. The first is adjacent to a major hub station, the second to the third-largest city in Altai Krai.

Additionally, there seems to be a structural pattern. The majority of international migrants first of all settle in districts close to Barnaul and Rubtsovsk—Pavlovskii, Topchikhinskii and Rubtsovskii; second in districts on major arteries—Kulundinskii and Blagoveshchenkii; third, in border districts—Uglovskii. Nemetskii district is a

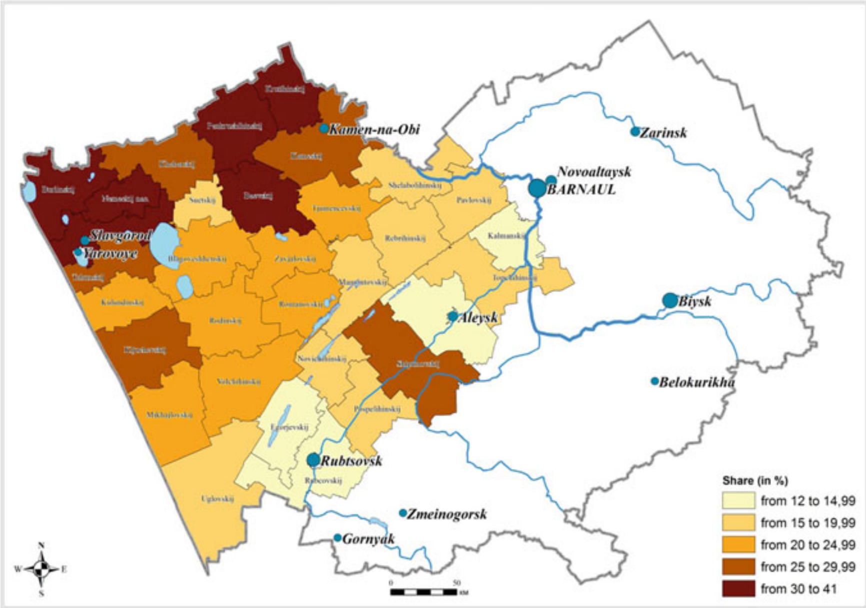


Fig. 20.5 Percentage of migrants from other regions of Russia of all immigrants 2012–2015. *Source* Bykov and Borisenko, own calculation (2015)

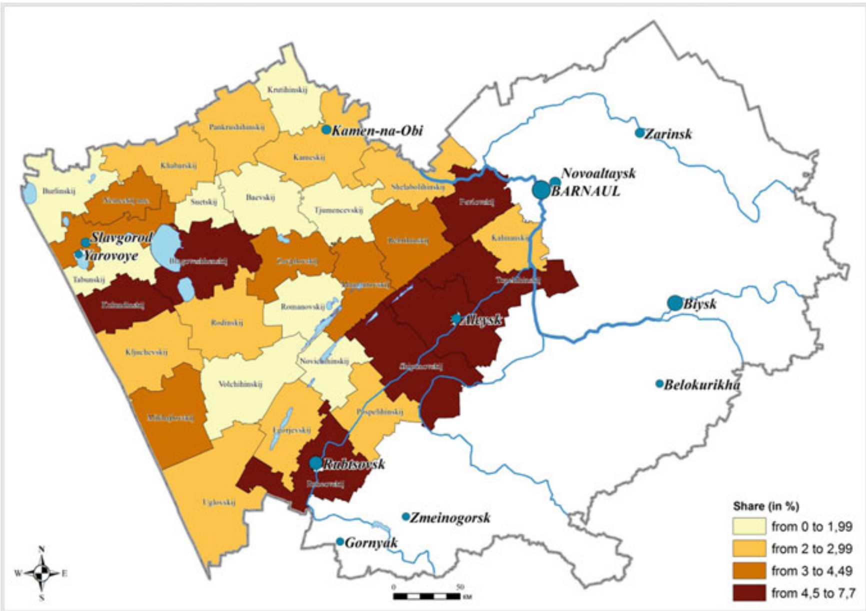


Fig. 20.6 Share of inbound migrants, 2010–2015. *Source* Bykov and Borisenko, own calculation (2015)

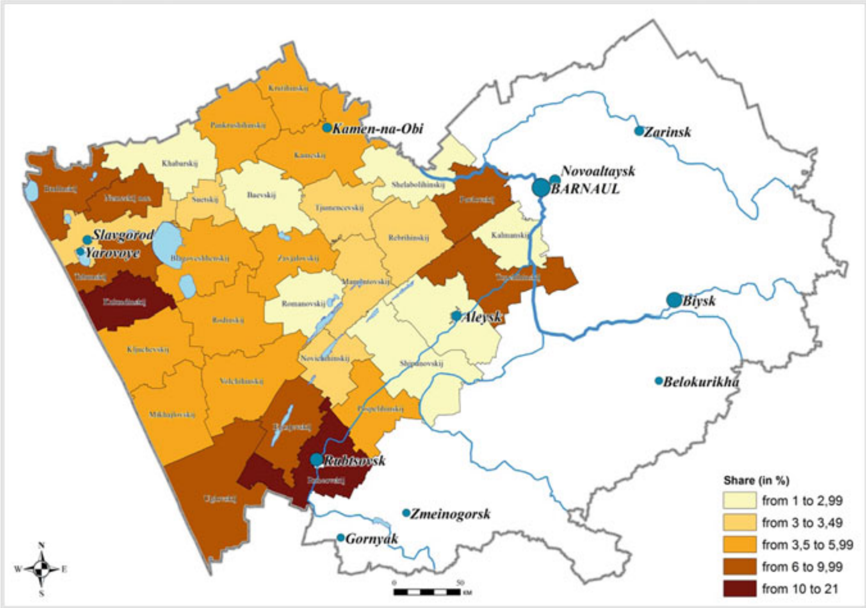


Fig. 20.7 Percentage of migrants from other countries 2010–2015. *Source* Bykov and Borisenko, own calculation (2015)

special case, as mentioned above. It has a negative international migration balance, but number of people arriving in this district is still significant. There is a certain population ‘turnover’. Migrants from Central Asia are ‘replacing’ emigrants to Germany.

The spatially uneven effects of migration lead to a redistribution of numbers and densities of population. As such, the effects of migration raise the question of sustainable development of the Kulunda region, as migration often is a highly age-selective process. The age structure within the shares of emigration and immigration indicates favourable conditions on the labour market in terms of availability of labour, as well as potential for intervention through education in case of young adults.

However, in almost all districts in the area, there is a negative migration balance of young people (age 15–29), who are the most mobile age group. This age group makes up for 25–80% of all migrants in the districts. Moreover, even in districts where population is growing due to migration, the shares of young people are still in decline. For those districts, however, it will be worth to have a closer look since such statistics may indicate the phenomenon of circular migration, due to mobility for education. The arrivals of young people (age 15–29) are spatially distributed unevenly throughout Kulunda (Fig. 20.8). They appear to prefer suburban districts and those on major arteries: Pavlovskii, Rubtsovskii, Slavgorodskii, Kulundskii,

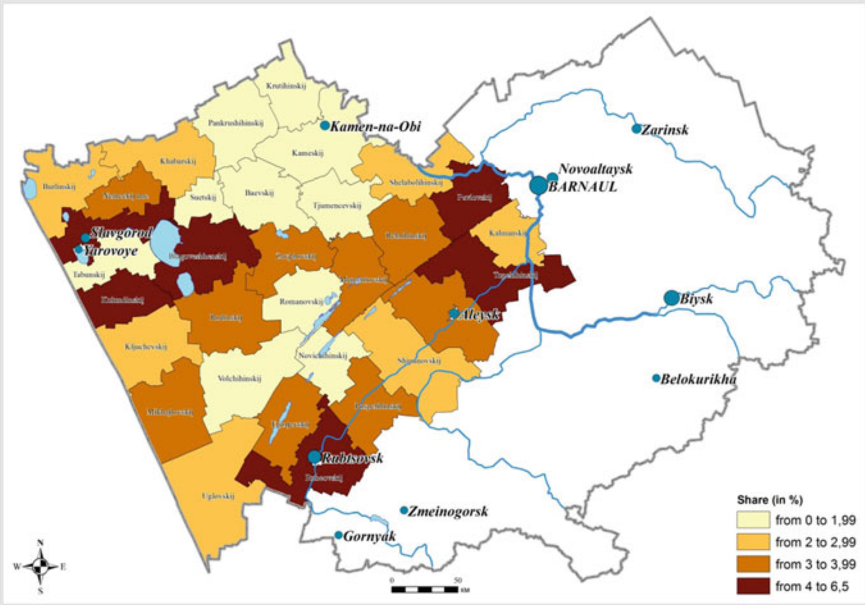


Fig. 20.8 Arrival of young people (age 15–29) in 2012–2015. *Source* Bykov and Borisenko, own calculation (2015)

Blagoveshchenskii and Shipunovskii. To each of these districts, between 1500 and 2200 young people came in the period 2012–2015.

These demographic effects sum up in a long-term tendency of population concentration. In other words: population as a whole declines, and at the same time becomes less scattered. In this spatial redistribution, the countryside shows higher rates of loss. Size of settlements seems to have an effect on migration too: the larger a settlement is, the smaller the losses are or there is even growth. The spatial polarization of population intensifies as a result (Bykov et al. 2014).

20.2 Conclusion

For most of the districts, migration flows are the crucial element influencing their population dynamics. In most cases, the population decline (natural as well as by migration) leads to the ageing of the population. This, in turn, calls for new concepts in the regional development policy (see Chap. 4 this volume).

References

Bykov N, Yeryomin A, Borisenko M (2014) Demographic transformation of municipal districts and settlements of Altai Krai in the post-soviet period. In: Mądry C (ed) The social transformation of the cities and regions in the post-communist countries. Bogucki Wydawnictwo Naukowe, Poznan, pp 23–33

Eremin AA, Bykov NI (2011) Demographic situation in Altai Territory at the present stage (1990–2010). Azbuka, Barnaul

Chapter 21
The Socio-Economic Environment of Innovative Agriculture in Altai Krai

A. M. Nikulin, O. Ya. Vinogradskaya, A. A. Kurakin, S. Lentz, A. Wust, A. Trotskovsky, Y. Perekarenkova and M. Sundeeva

Abstract In order that Kulunda can become a 'learning region' for agricultural and rural development, where the link between ecology and efficiency should be the leading idea, various possible mechanisms of knowledge transfers related to new technologies for agricultural production have to be explored. As a background, this chapter summarizes key data on the agricultural and forestry sector including data on labour force. Aspects of residents' living standards, housing conditions, school system, health care and not to underestimate the role of cultural institutions and job opportunities outside agriculture are discussed as having an effect on the willingness of people to stay in the region.

Keywords Learning region · Regional social capital · Housing · Education · Regional development · Standards of living · Socio-economic development · Socio-demography

A. M. Nikulin (✉) · A. A. Kurakin
Russian Presidential Academy of National Economy and Public Administration (RANEPA), Centre for Agrarian Studies, 119571 Moscow, Russian Federation
e-mail: harmina@yandex.ru

O. Ya. Vinogradskaya
Institute of Agrarian Problems - Russian Academy of Sciences (IAGPRAN), Moskovskaya Street 94, 410012 Saratov, Russian Federation

Rural Research Department, The Russian Presidential Academy of National Economy and Public Administration, Vernadskogo Prospect, 82, 119571 Moscow, Russian Federation

S. Lentz · A. Wust
Leibniz Institute for Regional Geography (IfL), Schongauerstraße 9, 04328 Leipzig, Germany

A. Trotskovsky · Y. Perekarenkova · M. Sundeeva
Institute of Economics and Industrial Engineering, Center for Socio-Economic and Regional Research, Siberian Branch of the Russian Academy of Sciences, Dimitrov Street 66, 656015 Barnaul, Russian Federation

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_21

21.1 Introduction

One of the possible solutions to prevent soil degradation in Kulunda steppe is to implement the idea of ecologically friendly and, at the same time, economically efficient agricultural technologies at the regional level. The link between ecology and efficiency (see likewise the discussion on the impact of efficiency in plant production technologies in Chap. 17) should be the core idea in regional development programmes, business plans of agricultural producers and the educational system. In other words, Altai Krai has to develop some features of the so-called learning region (Healy and Morgan 2012). It could let the region begin the self-sustaining processes of knowledge borrowing and knowledge making without any further efforts from external agencies. Unfortunately, Altai Krai today does not present very good structural preconditions to be or become a learning region. On the one hand, it is a very large region with a poorly developed transport system, meaning that its geographical proximity is not ideal, though the latter is not a key requirement. Regional social capital (Malecki 2012) is also at quite a modest level. As in Russia at large, we can see no rural movements in this area (Mamonova and Visser 2014) or ability for local communities to take collective action (O'Brien et al. 2005). Moreover, local business is atomized and business networks of organizations are not performing as sites for knowledge transfer. In addition, concerning the goal of long-term sustainability, agricultural producers do not consider the regional phenomenon of land degradation to be a primary threat to their business, yet.

On the other hand, Altai Krai has the potential to implement new agricultural technologies. Firstly, many of the Altai farmers are already technically well equipped, are very aware of new methods of agricultural production and are able to produce tacit local knowledge adapted from codified agricultural expertise. Secondly, the educational system in the region is one of the most developed social domains. It could thus be used as the mechanism for knowledge transfer and further development of joint learning. Finally, the socio-economic environment in the region is still strongly influenced by a readiness for innovation.

Therefore, to establish some elements of the learning region in Altai Krai, we can suggest three measures:

- Promote the most efficient and distinguished farmers in the local business community as distributors of new technologies.
- Institutionalize various business organizations and events in order to form solid social ties among farmers and thus foster knowledge transfer.
- Channel the new knowledge and (ecologically oriented) ideology into educational programmes at the school and university levels as well as into further professional training.

It is important that these actions should not be executed in the form of trivial propaganda. These institutional and network structures should in fact serve as spaces and mechanisms for knowledge sharing (rather than transfer) and critical consideration of that knowledge. In other words, they should create a setting of productive tension, where cognitively distant actors create so-called structural folds that promote innovations (e.g. adaptation of codified knowledge into local tacit knowledge) (for the implementation of the structural fold concept see, for instance De Vaan et al. 2015).

At present time, the Kulunda steppe region in Altai Krai is a major staging area for testing the possibilities of agrarian economic diversification and its use as a basis for agricultural innovations. Being rich in natural resources, it has considerable potential—accumulated across all industry sectors during the process of its intensive assimilation, which began in the middle of the last century. At that time, a massive ploughing of fallow lands alongside with the planting of shelter-belts (windbreaks), building irrigation systems and organizing state-run collective farms began, making Kulunda the main agricultural region in Altai Krai. However, in the post-Soviet period, the economy in this area saw a significant decline, which grew into a sustained depression that lasted until the early 2000s. Since then, Kulunda's economy has seen individual successes in the agricultural sector, in particular in developing large and medium-sized farms that can use modern technologies aimed at ecologically sustainable agriculture (see Chap. 16). Successes in the agricultural sector induced other areas of economic life and the region's rural social subsystem. For example, the investment climate improved, the pace of housing construction increased, work performance for infrastructure facilities picked up, and there has been steady growth in the population's standard of living.

However, since 2014 the region's socio-economic development has been in decline again. According to experts from the Altai Krai Main Economics and Investment Administration, it is the consequence of—'high baseline indicators for the previous year and adverse weather conditions' (Administration of Altai Krai 2015, p. 3). They significantly reduced output, especially for agricultural production, up to 89.6% compared to the previous year's level (Administration of Altai Krai 2015, p. 3). According to a study, performed as part of the joint Russian-German research project KULUNDA, the process of decline in the Altai Krai Kulunda steppe region's agricultural sector began back in 2013. This, in turn, indicates effects of other areas of human activity on the area's population.

21.2 Brief Overview of Regional Economics

In terms of regional economic performance, since 2008 Altai Krai has been among the Russian regions that were least exposed to the adverse impact of the global financial crisis. The rate at which Gross Regional Product (GRP) fell in Altai Krai was far lower than the national rate in 2008–2009. The fact that the krai lacked the tremendous advantages of earning high incomes from the export sector played a role: in 2008, per capita exports in Altai Krai were 6.2 times lower than the national figures (USD 0.53 and 3.30, respectively). In the last few years, there has been a positive trend of higher rates of growth, which, e.g., expresses itself in the index of physical investments into fixed capital in Altai Krai compared with Russia. As a result, in per

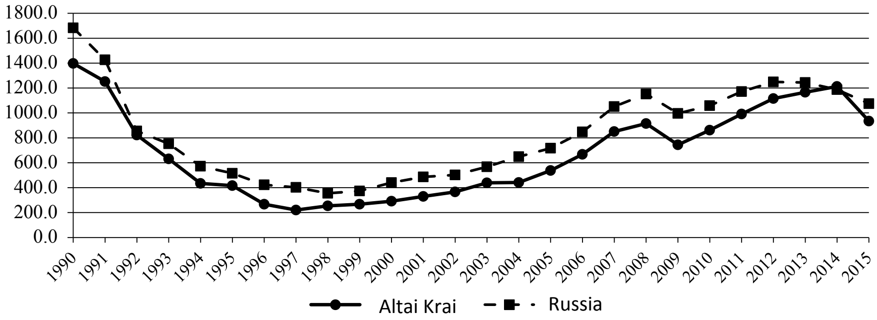


Fig. 21.1 Per capital investments into fixed capital in 1990 prices, RUB. *Source* Rosstat data, authors' calculations

capita investments in comparable prices, the krai is approaching the average national values (Fig. 21.1).

This trend is a result of the fact that the investments into fixed capital as a share of the krai's GRP grew at a rate higher than the national average. The situation in Altai Krai regarding fixed capital accumulation at least has not worsened over the last few years. In 2012, the krai returned to its pre-crisis level for this indicator, and in 2013–2014, it managed to keep this indicator on the same level. This level and, most important, the increased rate of the krai's development are creating propitious conditions for an increase in its economic potential, which to date has not undergone substantial changes.

21.3 Socio-Demographic Characteristics

In recent years, the majority of agricultural enterprises located in the Kulunda steppe region have switched to innovative agricultural technologies and heavy-duty modern equipment, especially for crop farming. As a result, workforce productivity has greatly increased in this field, which, in turn, has led to a reduction in the number of those employed. According to the study, the majority of those rural residents left unemployed have joined the service sector and small urban businesses, but not necessarily in Altai Krai; many do shift working at the mining companies in Russia's Far North (for more detailed migration trends, see Chap. 20). Consequently, many villagers have experienced a decline in the proportion of private farming in their income structure while the proportion from entrepreneurial activity has grown.

According to the Russian State Federal Statistics Service (2016), the official cash income level earned by Altai Krai rural residents is less than 50% of the amount than that of Russia's average, and that gap continues to grow despite the use of innovative technologies. There is a growing divergence between urban and rural residents in the composition of their cash income, with the latter receiving an increasing share of various social welfare payments. The salary of those employed in the agricultural sector in 2015 was 1.5 times lower than the region's average, and the official unemployment rate in rural areas amounted to almost 12%, which is more than two times higher than that of urban areas. It is worth noting that in rural areas, it is common practice for workers hired by farms to go to the unemployment benefits office and receive several months of unemployment benefits during the winter season due to the lack of work, and then continue working at those farms from spring to autumn.

21.4 Key Features of the Agricultural Sector

A share of 32 of the Altai Krai's 59 rural districts is located in the Kulunda steppe region:

- Eleven are located in the forest steppe, comprising 34% of the region's area;
- Four are in the mixed temperate and forest steppe, making up 14% of the region's area;
- Five are in the temperate steppe, comprising 12% of the region's area;
- Six are in the mixed temperate and dry steppe, making up 20% of the region's area;
- Six are in the dry steppe, making up 20% of the region's area.

The entire Kulunda village district occupies an area of mainly mixed dry and temperate steppe—and comprises around 25% of the region's total area.

The area of land devoted to agriculture in the Kulunda region is 6.7 million hectares, or 58% of the corresponding figure for Altai Krai; 4.2 million ha (64%) thereof is arable land. The portion of arable land in the Kulunda steppe region is 62%, which is higher than the corresponding figure of 56% for the average in Altai Krai. In general, the Kulunda area is characterized by a high degree of tilled land.

In the Kulunda steppe region, there are more than 230,000 organizations with various forms of ownership involved in agricultural production—this is approximately half of all the agricultural enterprises in Altai Krai. A number of 1901 enterprises can be considered as professional commercial enterprises; among them are 576 agriculture companies, 1325 peasant farms and individual entrepreneurs. There are additionally 228,750 farms, classified as private farms.

A number of 636 professional enterprises (33% of the total) fall into the category of 'small' in terms of the area of land they use—meaning that each of them cultivates less than 2000 ha of agricultural land; 541 of them, or 28% of the total, are categorized 'medium-sized', cultivating from 2 to 6000 ha. 724 companies, or 38% of the total, have more than 6000 ha of land and are classified as 'large'.

Grain and legume production in the Kulunda steppe in 2011 was 2.43 million tons—almost 62% of the total for Altai Krai; much of that was accounted for by spring wheat, of which there were 1.86 million tons produced, or 77% of the total grain and legume harvest in this region.

In the dry and temperate steppe, crop yields for wheat are lower than in the Kulunda region's forest steppe. For example, in the dry steppe the average wheat yield is 7.7 long hundredweight/hectare, with the maximum being 9.6 cwt.l./ha and the minimum being 5.3 cwt.l./ha. In the temperate steppe the average wheat crop yield is 12 cwt.l./ha, and the maximum is 21 cwt.l./ha.

In relation to the whole Altai Krai, enterprises located in the Kulunda steppe region account for a similarly important proportion of livestock production. For example, in 2011 companies in Kulunda delivered 77% of the total milk production in Altai Krai and 41% of Altai Krai's live-weight livestock and poultry production.

The number of residents in Kulunda employed in the agricultural sector in the same year amounted to 34,040 people, 86.8% of whom were employed in agricultural companies and 13.2% as peasant farmers and individual entrepreneurs. The average size of agricultural companies was 59.3 workers, with an average of 3.9 in peasant farms and individual enterprises. The efficiency of manpower utilization, as defined by annual per capita agricultural output in monetary terms for one person employed in agriculture, differs highly from company to company so that it is difficult to give a general description (for details, see: Ponkina et al. 2014).

The Kulunda steppe region's agriculture sector is actually undergoing major structural changes compared to 2011. For example, experts indicate there is just a handful of livestock companies remaining in the Kulunda steppe region—and despite being equipped with modern technology and having valuable breeds of highly productive livestock, these companies are practically operating at a loss. They attribute this to several main factors, including the inaccessibility of loans, pricing unpredictability and problems with both qualified personnel and output sales. Large farms, those specializing primarily in the cultivation of wheat and sunflowers, are the only ones for which crop farming has been profitable over the past few years. In this connection, the profitability of small and medium-sized companies fell below 10% back in 2013, which primarily affected the wages paid to workers. As a result, according to the Altai Krai's Main Economics and Investment Administration, actual profitability of agriculture companies (taking into account subsidies) amounted to 8.3% in 2014. However, in order to ensure the implementation of Altai Krai's strategy for its socio-economic development by 2025, the agricultural sector's level of profitability for ensuring sustainable development needs to reach 12.5% in 2016, and 13% by 2017 (Administration of Altai Krai 2015, p. 14).

At the same time, switching to innovative agricultural technologies and using heavy-duty modern equipment has increased not just agricultural workforce productivity, but also the area's human migration. In the last five years alone, these processes have affected the commodity component in the makeup of private farms, reducing it to almost zero. Since the majority of the rural population can no longer engage in heavy work due to age, the remaining workforce—those of working age—have abandoned individual farms because of low profitability, high operational costs and the problems with output sales.

21.5 The Forest Engineering Industry

The Kulunda steppe has significant forest resources. In particular, unique ribbon forests run through this region—pine forests in the form of ribbons that grew on ancient alluvial sands. Their structure, ecological conditions, growth and reproduction areas are very specific. They perform the functions of climate control, soil preservation and water protection for majority big part of the Kulunda steppe region in Altai Krai. In addition, these forests are the only source of timber for the area, and in certain regions up to 15–20% of all employees work in the field of forest engineering. Innovative technologies for reforestation and timber processing are tested in the region. This industry plays an important role in the diversification of the Kulunda steppe region's rural economy and in maintaining the area's ecological balance.

Because of its strategic significance, special attention is paid to the forest engineering industry in Altai Krai's socio-economic development strategy by 2025. This document presumes an industrial transition 'to an innovative way of developing production and towards a structure where high-tech production has a leading role' (Governor of Altai Krai 2012, p. 57). The strategy involves not only developing the industry's potential for innovation. Using that basis to create new, modern, high-tech wood processing and wood chemical plants should also ensure the preservation of potential environmental resources and the ecological responsibility of the region's forests through the formation of a 'waste-free, high-performance, competitive, wood processing industry cluster' (Administration of Altai Krai 2015, p. 52, Governor of Altai Krai 2012, p. 58).

21.6 Characteristics of Small and Medium-Sized Companies

As of today, small and medium-sized companies in Altai Krai's rural areas employ less than 39% of all its entrepreneurs, and just 15% of the region's small businesses are concentrated there. Furthermore, revenues for this category of entrepreneurs make up only 11% of the corresponding revenue figure for Altai Krai as a whole. This low level of entrepreneurial activity, according to the authors of the programmes for the sustainable development of Altai Krai's rural land areas from 2012–2020 (hereinafter—Programme for Sustainable Development of Rural Land Areas), is a key factor affecting the standard of living for Altai Krai's rural population (Administration of Altai Krai 2011).

Specialists and experts state that the main obstacles in developing this industry are a shortage of qualified personnel, an inaccessibility of loans and sales outlets, its high costs and excessive government supervision and bureaucracy.

> *"Even if some ideas arise for opening a business or even a small-scale production facility on the part of entrepreneurs, they run into a dead end due to the fact that sales outlets are located far away. Even Altai Krai's capital, and transportation expenses here are becoming more and*

> *more expensive in the cost structure […]"* (personal communication with an administration official in Altai Krai, Uglovsky District, September 2015)

At the same time, entrepreneurs themselves believe that conditions in the Altai Krai do not always allow large-scale, innovative production facilities to be efficient and competitive. According to their statements in interviews, under certain circumstances, small and medium-sized companies in rural areas are not only able to set up innovative and competitive production facilities that provide a sufficiently broad range of services to the population, they can even be more resistant to various kinds of financial and economic crises and disasters.

> *"I think that, for instance, a pig farm is okay, a poultry farm is okay. However, you see, they started to build a huge dairy plant in the steppe. There is nowhere to herd there, the cows are only going to be fed through irrigation […] The thing is that there are some niches where, for example, only a small-scale farming will work. They will get some milk and make some ewe's milk cheese […] You cannot make everything large-scale. Nevertheless, there is also no point in having everything small-scale. Why? A meat packing plant will not be able to make sausages well - one person brings this kind of a pig, another brings another […] One kind of pig lard is this way, another kind of pig lard is that way […] Therefore, I would opt for a mixture of all forms […]"* (personal communication with a farm manager, Altai Krai, Klyuchevski District, September 2015).

To revitalize and stimulate small and medium-sized companies in Altai Krai's rural areas in the framework of a Strategy for its Socioeconomic Development by 2025, an action plan has been worked out for companies that will tackle a number of challenges in this area. Certain tasks were designated with high priority:

- Developing the infrastructure to support small businesses and ensuring easy access for it;
- Concentrating resources to support high-priority business projects to create new, competitive production facilities, including those that promote import substitution;
- Developing the social infrastructure in rural areas and ensuring that a wide range of services is provided to Altai Krai's population;
- Reducing the bureaucratic barriers to business development;
- Promoting entrepreneurial activity in Altai Krai; promoting entrepreneurship on the part of young people (see: Action plan 2015, p. 21).

21.7 Housing Conditions, Utilities' Infrastructure and Social Infrastructure

The condition of the housing and utilities' infrastructure in rural settlements, as well as the social infrastructure and all infrastructure's productive activity, is the most important indicator of residents' living standards and constitutes the basic conditions for further developing other areas of human activity.

It should be noted that, according to some average statistical indicators related to ensuring the population's quality of life, rural settlements appear more attractive than urban ones at first glance. For example, housing space per capita for Altai Krai rural residents exceeds the corresponding figure for urban residents by 11.4% and amounts to 23.6 m^2 per person (in urban areas it is 20.9 m^2 per person). This indicator also exceeds the one for actual housing space for Altai Krai's population in 2014 (22.6 m^2 person) and is getting very close to the corresponding indicator forecasted for 2017 (23.8 m^2 person) that is expected as a result of implementing the strategy for Altai Krai's socio-economic development by 2025 (Administration of Altai Krai 2015, p. 49). However, the high housing space indicator for rural residents compared to the situation in cities is one consequence of migration from agrarian regions into urban ones, an increase of which has been noted in recent years in surveys of rural respondents (see Chap. 20). These surveys confirm observations of a significant increase of houses that were offered for sale over the last years, as well as announcements to this effect—in particular, in local newspapers.

Along with this, according to information in the Programme for the Sustainable Development of Rural Land Areas, the indicators for the provision of public amenities to rural households still lag behind the average indicators for Altai Krai. For example, only 54.6% of the rural housing stock is equipped with water supply pipelines, with the average for Altai Krai being 73.0%; sewage is 39.2 and 63.2%, respectively; heating is 80.4 and 85.3%; hot water is 7.1 and 41.5% (see: Administration of Altai Krai 2011).

This same programme also outlined stepping up residential construction in rural areas during the 2006–2012 period, when housing was commissioned with a total area of about 1.5 million square metres. Moreover, housing commissioned annually in rural areas consistently exceeds 30% of the overall amount for Altai Krai—for example, in 2012 it amounted to more than 40% (Administration of Altai Krai 2011).

It should be noted that the Kulunda steppe region differs from other areas in Altai Krai not only by the severity of its environmental and climatic conditions, but also by the low level at which the housing stock in rural settlements enjoys access to public amenities and the social infrastructure. For example, most rural communities have not yet been supplied with gas, even though this process began in 1995.

Since that time, according to data in the Programme for the Sustainable Development of Rural Areas, 3700 km of gas distribution networks have been built, and around 90,000 apartments and houses were supplied with gas. In addition, 1160 boiler facilities were converted to natural gas. However, at the time the programme was written, the percentage of infrastructure supplied with gas throughout Altai Krai was only 10%, and in rural areas, it was 6%—whereas the average in Russia as a whole reached 58 and 40%, respectively (Administration of Altai Krai 2011).

During the Kulunda research project, respondents in Mikhailovsky District cited a curious and innovative way to heat their homes with coal mixed with sawdust, a method that locals have used here for ages as an alternative to expensive heating coal. According to the director of one local vocational school, one of his female students analysed this process and its calculations as a basis for a project, which she later submitted to an environmental contest. Her analyses showed that the coefficient of performance for this mixture is much higher than that of each component. Her work was not awarded a prize at the competition in Mikhailovsky District, but because it was so interesting, it was sent to Barnaul together with the other prize-winning works. Imagine how surprised the Mikhailovsky District contest jury was when she received first place in Barnaul, and was then invited to a contest in Moscow where her work received a medal. After the contest, the printed version of her work was even borrowed by some of the participating innovators.

In some parts of the Kulunda steppe, problems with the water supply still have not been resolved. These problems are even further exacerbated by the rough temperature and humidity conditions of this area, where there might be no precipitation for several months. This causes the locals to be conservative when watering their household plots. For example, the entire garden area can be fitted out with irrigation canals, allowing water to be saved and eliminating soil degradation, which often occurs when conventional irrigation methods are used.

With regard to housing in rural areas, the main concentrations of stock are mostly in areas that border Altai Krai's capital, as well as in the region's resort and recreational areas.

The actual amount of housing built (purchased) for citizens living in rural areas in 2014 amounted to 19,767 m^2; in 2015, it was 16,800 m^2, (of which 15,400 m^2 were scheduled), including 10,300 m^2 for young families and professionals.[1] In 2017, the forecast plans to bring this number up to 19,000 m^2, which is less than the corresponding figures for 2014 (Administration of Altai Krai 2015, p. 14).

Implementing the Programme for Sustainable Development of Rural Areas in 2015 has permitted 121 rural families to improve their living conditions, including 86 families with young professionals. In 2016, the Altai Krai economy has 1.4% of the overall number of those young families in rural areas, who need improvements in their living conditions and have been registered in this capacity since 1 January 2013 (Administration of Altai Krai 2011).

This programme also pays special attention to the utility infrastructure's decay in the villages. According to its findings, in 2011 almost 31% of the heating system, 39% of the water supply system and 22% of the sewage system needed to be replaced. Moreover, heat loss throughout the networks constituted 22.1% of their total output, and the unproductive loss of water amounted to 15.3% of the total volume supplied to consumers. The number of damages in the water supply network reached 36 per 100 km of networks, and for the heating network, it was 27 damages per 100 km of networks. This level of failure frequency—for example, with the villages' municipal water supply systems—is due to a high degree of wear from long operational periods. Most of these systems were built in the 1960s and 1970s, and are now in need of modernization (Administration of Altai Krai 2011).

According to the Altai Krai administration's official website, in 2015 more than 72 km of gas distribution networks were put into operation in the region's rural areas, as well as more than 30 km of local water supply pipelines (Government of the Altai Territory 2016).

[1]Data for 2015 on the actual amount of housing built (purchased) for citizens living in rural areas, taken from Government of the Altai Territory (2016) Section: Economy of Altai Krai in 2015.

Another important issue affecting the quality of life for the region's rural population is the quality of its drinking water. For example, at the time the Programme for the Sustainable Development of Rural Areas was written, the groundwater supplies used for drinking water in a number of rural settlements—constituting 30% of the entire water supply—did not meet the requirements of sanitary norms and codes, showing a high level of mineralization. This means that their chloride content reached 300–500 mg/l, sulphate content was 400–700 mg/l, and iron content was 0–32.0 mg/l, which is 1.54 times the maximum allowable concentration (Administration of Altai Krai 2011).

At present, the education and health systems in rural areas are in the process of being optimized and streamlined, the purpose of which is to both improve the quality of services and to cut budgetary expenses.

According to the Main Board of Education and Youth Policy, in 2015 there were 1104 educational institutions in the region, including 970 rural schools (87.9%), of which 755 were ungraded (77.8%), 910 preschool institutions, of which 594 were located in rural areas (65.3%), with 405 of those ungraded (68.2%) (Main Board of Education and Youth Policy 2015).

In addition, according to the Programme for the Sustainable Development of Rural Areas, in the 2011–2012 school year there were 971 comprehensive schools operating in rural areas, with an enrolment of 115,900 students that represented 48.3% of the total number of students in schools. However, in the 2009–2010 school year there were 1027 of these schools, with an enrolment of 116,200 students. This means that during the 2010–2011 school year 56 educational institutions were eliminated throughout the region's rural areas (representing 5.5% of all the institutions that existed in the 2009–2010 school year). The streamlining process then slowed down, and over the next three years, only one educational institution was eliminated. In addition, according to the programme, in 2011 in Altai Krai there were 269 comprehensive schools in operation (every fourth school) in 244 school districts, which has allowed the development of different forms of educational networking (Administration of Altai Krai 2011).

According to the Altai Krai's Main Department of Education and Youth Policy, in 2015 a selection process took place for an innovative education infrastructure system in Altai Krai. One hundred and thirty-seven Altai Krai educational institutions were designated as regional innovation platforms. Among the winners selected, 38% are rural and ungraded schools. Ten teachers in rural areas were awarded with the Altai Territory Governor's Prize, named after S. P. Titov, with a prize money of 125,000 roubles. Moreover, Altai Krai is the first and only Russian region to promote educators in rural areas, including those who are already retired, at the Russian Federation regional level. The rating for the top 200 rural educational institutions, organized by the Moscow Centre for Continuing Mathematics Education with the assistance of the Russian Federation Ministry of Education and Science, includes three schools in Altai Krai: Blagoveschensk School#1 in Blagoveschensk Region; Kluchevskaya School#2 in Klyuchevski District; and Shipunovskaya School, named after A. V. Lunacharsky. The number of schools using distance learning technologies and e-learning rose from 3% in 2011 to 26% in 2015 (in 262 schools) (Main Board of Education and Youth Policy 2015).

Rural schools in Altai Krai actively practise innovative educational technologies. The officer cadet school, in the village of Mikhailovskoye, is one example. Not only does the school work with innovative programmes, but its organizational and methodological approach, according to its director, is unique even for major cities—starting with the selection process for first-year students, which takes place once every four years. This school's non-standard educational programme, created at the initiative of Altai State University in 2000, follows the methods of a developmental programme entitled 'School 2100', which is aimed at stimulating children's intelligence, astuteness and aesthetic perception. The idea behind creating this kind of an institution, according to the director, was 'to gather children together from remote Siberian villages in town and give them the opportunity to receive a high-quality education' (personal communication with the director of the officer cadet school April 2013). This school manages this task successfully enough—children come here from tiny villages across 56 municipal districts in Altai Krai, and even from neighbouring Kazakhstan. Starting in 2004, the school introduced senior-level classes for cadets, where training is designed to cover 4 years. In the beginning of the 2000s, the school had seven parallel classes, attended by more than 300 children; in 2013, only three parallel classes remained, attended by 205 children. According to the director, the reduction in the number of students at the school was caused by the introduction of per capita financing in schools, which resulted in school leadership, especially in ungraded schools, trying to persuade the students to continue their studies while promising them conditions that closely resemble tutoring.

There are senior-level classes at schools in the natural sciences, mathematics, humanities and the military arts. There is also an athletic complex in a physical education school where, in addition to the cadets, children from all over the district come to exercise. The school often wins prizes in athletic competitions at different levels, from district level to the Altai Krai regional level.

The school initiates various environmental activities to support the local administration. For example, every year in April, in conjunction with the high school's administration, it holds a 'March for Clean Streets'. The administration allocates money to print flyers and leaflets that urge residents to take part in this event. Before the march, they hold a rally where speakers talk about the importance of environmental activities; various actions are then determined. For example, at one of the last meetings, they decided to collect batteries and energy-saving light bulbs in special boxes to install in stores, schools and other public places. However, the school principle then needs to find a way to turn in the boxes and pay for the activities. The school collects CFL and energy-saving lamps for recycling to the company ANATON for 30 roubles apiece. The 'March for Clean Streets' starts after the rally, with maps of streets needing to be cleaned being distributed to participating teams; the teams then begin the activity, and a contest is held for the cleanest street once the activity is complete.

These successes and achievements in the field of education, culture and athletics in Mikhailovsky District, however, contribute to the outflow of young people from the village. According to the school's director, no more than 10% of its graduates return, with almost none of them working in a field they studied there. Upon graduation from the school, cadets join the Border Guard Service. She believes that young people are now focused 'on simply earning money—they have no ideas for work or their career' (personal communication with the director of the officer cadet school April 2013).

The main problems with rural health care in Altai Krai are the lack of qualified personnel, the weak state of the existing physical infrastructure for rural health care facilities. Medical equipment often is either outdated or almost 70% deteriorated, and community health centres and district hospital buildings need major repairs. As a result, the rural population often cannot get local, quality primary health care to the extent it is needed.

In addition, Altai Krai has a high proportion of rural residents in its total population, a significant number of small settlements and a low population density, which creates certain difficulties in organizing and maintaining a network of health care institutions, both primary care clinics and specialized health care centres, as well as ambulance services.

The main goal of the Strategy for the Socioeconomic Development of Altai Krai by 2025 in the health care industry is to preserve and improve the population's health by increasing the availability and quality of health care (Administration of Altai Krai 2015 p. 30).

According to the Government Programme for the Sustainable Development of Rural Areas in Altai Krai, 56 district hospitals and their structural subdivisions provided medical assistance to the rural population: 39 district hospitals, 191 rural outpatient clinics and 928 rural community health centres. In addition, more than 40% of funds allotted for implementing the programme's measures to modernize Altai Krai's health care industry are earmarked for rural health care institutions (Administration of Altai Krai 2011).

At present, all of Altai Krai's community health centres are licensed, and the health care workers in them not only provide pre-hospital medical care, but also give out the medicines needed by rural residents.

According to the programme, 67 community health centres and 2 outpatient clinics have been refurbished in rural settlements in recent years, and first aid clinics have been set up in 135 villages with populations of up to 100 people. As a result, up to 60% of the primary health care services provided to the rural population are in outpatient settings (on the level of community health centres, rural outpatient clinics and district hospitals). Despite this, the availability of this assistance for the region's rural population, compared with the cities, still remains at a low level. This problem is aggravated by the shortage of qualified medical personnel in rural areas. For example, under the programme 'Country doctor', the availability of rural doctors increased by 5.3% in 2012, reaching nearly 20 people out of every 10,000. In 2011, this figure was 19 people. However, the relative indicator for the shortage of doctors in rural areas is still 1.7 times higher than the same indicator for the cities. In 2012, the number of nurses in rural areas decreased by 0.6%, accounting for 76.0%, while in urban areas it increased by 3.2%. Overall, the proportion of nurses working in rural areas accounted for only 33.4% of the total amount in Altai Krai, while according to the

2010 census the proportion of Altai Krai's rural population reached 45%. In 2012, rural residents gained access to Internet registration services for making a doctor's appointment in district hospitals (Administration of Altai Krai 2011).

In recent years, due to a shortage of personnel and the optimization of the rural health care system, the workload on the staff at medical institutions has increased dramatically. Because of this, many young professionals, after having worked in the 'Country doctor' programme, go to the city.

> *"It is hard working in the villages. People in the city work in clinics, know their job - they do their work and are responsible for it. Here, if a neurologist is in the clinic, and there is no doctor in the hospital, then he needs to treat patients in the hospital in addition his regular shift. Moreover, if there is no one to work in the emergency room, he has to be the doctor on duty in the hospital, and still keep duty at night. These are the peculiarities of the rural health care system. It means that working anywhere in the villages is considerably harder than working in the city. To what extent are there enough young doctors? They will remain here and work, God willing. The boys are young, they can maybe get married […]".*
> (personal communication in Altai Krai, Mikhailovsky district, August 2013)

Out of all of Altai Krai's cultural institutions in 2011, 91% operated in rural areas. To date, however, the tendency has been to close them down, especially rural libraries. This is not only due to the spread of information and digital technologies, but also by the fact that in Soviet times, the huge buildings for cultural centres were constructed in the villages, and modern-day municipal districts do not have sufficient funds to renovate them. This leads to the decay and destruction of these facilities, and the disbanding of organizations based in them, which greatly impoverishes the environment where the rural population lives.

At the same time, according to respondents who work at cultural centres, due to the Federal Law Nr. 131 (Federal Law 2003/2013) the funding has sharply reduced funding for cultural institutions. However, in an interview with one of the respondents, the director of a rural cultural centre, she indicated it was this law that prompted her to seek ways to replenish the centre's budget, in particular by using innovative technologies and new forms of working with the community, as well as participating in a small advertising business. As a result, the public began actively attending the club's events and advertisers started using their services more frequently. Now, this cultural centre cannot only cover gaps in financing, but it also has the funds needed to grow and develop.

On the premise that Altai Krai possesses rich, unique natural resource and recreational potential, the authors of the Programme for the Sustainable Development of Rural Areas establish a connection between the prospects for the development of these rural lands with people being employed in the agricultural sector. In their view, the region needs to renew state support for entrepreneurship and increased flexibility in the rural labour market. They believe that creating comfortable living conditions for the rural population (construction of modern housing and increase the level at which public amenities are provided) will be a key factor in making these areas attractive.

The programme states that results from 2012 show that more than 6 billion roubles were allocated in the framework of targeted regional programmes for the development of municipal districts. The total amount of funds to develop rural areas exceeded 20 billion roubles, including some individual investment projects and that part of the Altai Krai government authorities' activity not covered by the programme (excluding subventions from Altai Krai's regional budget).

However, the authors of the programme believe that, despite its positive effects, the implementation of appropriate measures for the social development of villages was neither sufficient for the effective utilization of rural areas' economic potential, nor for improving the quality of life for its population (Administration of Altai Krai 2011).

For mechanical, relatively simple production processes, investment in innovative activities provides almost instant results. However, for processes that involve complex systems such as nature and society, the impact of innovative activity is not only drawn out over time, it is not always predictable. For this reason, it is important to have a range of different approaches for understanding and eliminating possible risks in the development of these systems.

References

Administration of Altai Krai (2011) Gosudarstvennaia programma Altaiskogo kraia 'Ustoichivoe razvitie sel'skikh territorii Altaiskogo kraia' na 2012–2020 gody [Altai Krai Government Programme for the 'Sustainable Development of Rural Areas in Altai Krai' for 2012–2020]. http://docs.cntd.ru/document/453110670. Accessed 3 Nov 2016 (in Russian)

Administration of Altai Krai (2015) Action plan for 2015–2017 to implement the strategy for the socioeconomic development of Altai Krai up until 2025. https://www.google.ru/url?sa=t&rct=j&q=&esrc=s&source=web&cd=5&ved=0ahUKEwjcmL2jjYzQAhVD_SwKHbUVCj0QFggyMAQ&url=http%3A%2F%2Fpublication.pravo.gov.ru%2FDocument%2FGetFile%2F2200201506020008%3Ftype%3Dpdf&usg=AFQjCNFZrGoDTi4ydpqjJWryKeM5MLZ5ug&bvm=bv.137132246,d.bGg. Accessed 3 Nov 2016 (in Russian)

Governor of Altai Krai (2012) Ob utverzhdenii strategii sotsial'no-ekonomicheskogo razvitiia Altaiskogo kraia do 2025 goda [Action plan for 2015–2017 to implement the strategy for the socioeconomic development of Altai Krai up until 2025]. http://www.econom22.ru/upload/iblock/f3c/Zakon86-zs_121121.pdf. Accessed 3 Nov 2016 (in Russian)

De Vaan M, Vedres B, Stark D (2015) Game changer: the topology of creativity. Am J Sociol 120(4):1144–1194

Federal Law Nr. 131-FZ (2003/2013) dated 6. Oct. 2003 and amended 2. July 2013) 'Ob obshchikh printsipakh organizatsii mestnogo samoupravleniia v Rossiiskoi Federatsii' ['On the general principles of local self-government in the Russian Federation']. http://www.consultant.ru/document/cons_doc_LAW_148889/. Accessed 14 Oct 2013 (in Russian)

Healy A, Morgan K (2012) Spaces of innovation: learning, proximity and the ecological turn. Reg Stud 46(8):1041–1053

Main Board of Education and Youth Policy (2015) Itogovyi otchet [Final report]. http://www.educaltai.ru/education/children_need_care/guardianship/documentation/%D0%98%D1%82%D0%BE%D0%B3%D0%BE%D0%B2%D1%8B%D0%B9%20%D0%BE%D1%82%D1%87%D0%B5%D1%82.pdf. Accessed 7 Nov 2016 (in Russian)

Malecki EJ (2012) Regional social capital: why it matters. Reg Stud 46(8):1023–1039

Mamonova N, Visser O (2014) State marionettes, phantom organizations or genuine movements? The paradoxical emergence of rural social movements in post-socialist Russia. J Peasant Stud 41(4):491–516

O'Brien DJ, Wegren SK, Patsiorkovsky VV (2005) Marketization and community in post-Soviet Russian villages. Rural Sociol 70(2):188–207

Government of the Altai Territory (2016). Ekonomika Altaiskogo kraia v 2015 godu. Osnovnye napravleniia deiatel'nosti na 2016 god [Economy of Altai Krai in 2015. Main areas of focus in 2016]. Official Site. http://www.altairegion22.ru/gov/administration/isp/organizatsionnyy-otdel-administratsii-kraya/edinyy-informatsionnyy-den-altayskogo-kraya/ekonomika-altayskogo-kraya-v-2015-godu-osnovnye-napravleniya-deyatelnosti-na-2016-god.php. Accessed on 7 Nov 2016 (in Russian)

Ponkina E, Belyaev V, Bovarova M, Prishchepov A, Meinel T, Bugai Iu, Kovaleva I, Kozhanov N, Kazardzhian M, Frühauf M (2014) Economic, environmental, and technological factors and the results of agricultural enterprise operations in the conditions of the Kulunda Steppe. Publishing house Alt. University, Barnaul

Russian State Federal Statistics Service (2016) Population estimate of permanent residents as of 2016 and of 2015 average. http://www.gks.ru/wps/wcm/connect/rosstat_main/rosstat/ru/statistics/population/demography/. Accessed 15 Oct 2016 (in Russian)

Chapter 22
The Role of Social Capital and Knowledge Transfer to Adopt Agricultural Innovations

A. M. Sergienko

Abstract Social capital is a precondition for innovation-driven development, which is needed for more sustainable land use in the Kulunda steppe. Based on the socio-economic development background provided in Chap. 21, this chapter will highlight particularly three aspects: the attitude towards innovation, the readiness to adopt innovation, and the availability and accessibility of knowledge transfer channels in the Kulunda region.

Keywords Innovation-driven development · Innovation · Knowledge transfer · Kulunda region

22.1 Introduction

The socio-economic environment is an important dimension to increase the adoption of innovation in agriculture and with this providing more potential of sustainable development in the rural areas. To understand the engines behind innovation-driven development, one can turn to the social capital theories by Bourdieu (2002) and Putnam (2000) that point out social capital and social networks as crucial for innovation-driven development, and the concept of the learning community, which focuses on the state and development of institutions and networks to transfer innovation knowledge (Healy and Morgan 2012; Rutten and Boekema 2007). Based on this theoretical foundation, we can conclude that the scale and spread of innovations in rural communities are largely determined by the socio-economic environment of innovations. Such environments are shaped by socio-economic factors behind the formation of population activity in rural areas and the various social groups who are targeted by such innovations. The key factors here are a culture of innovation (attitude towards innovations, readiness to adopt innovations) as well as availability and accessibility of knowledge transfer channels in rural regions.

A. M. Sergienko (✉)
Institute of Economics and Industrial Engineering, Siberian Branch of the Russian Academy of Sciences, Lavrentyev Street 17, Novosibirsk, Russian Federation
e-mail: a.m.sergienko@mail.ru

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_22

Along with government statistics, research on challenges for adopting innovations in land use in the Kulunda region, which is presented here, is based on empirical material from various surveys conducted in rural communities of the Altai Krai. A row of surveys has been analysed in the frame of the study presented: one with 606 respondents in 2002; one with 1011 respondents in 2008; one with 440 respondents in 2011; one with 150 respondents in 2013, and a final one with 260 respondents in 2016. This has been supplemented with expert surveys conducted among local authorities, rural businesses and social organizations ($n = 56$ in 2002; $n = 280$ in 2008; $n = 75$ in 2011; $n = 40$ in 2013; $n = 60$ in 2014). Further, findings from detailed interviews with experts and rural community members collected during fieldwork in 2013–2015 have been included.

The discussion is based on the changes in the socio-economic characteristics of the rural life in the Kulunda region presented in Chap. 21.

22.2 Changes in the Socio-economic Development of the Village as a Social Background for Innovation

Evidence of changes in the socio-economic development of the village can be seen in changes in the rural people's and experts' perception of the most urgent development issues (see Sergienko 2011, 2013). Public evaluation of rural social problems from the early 2000s shows that by far the most urgent issues remain low income, unemployment, the drift of young people from the village, poor quality and insufficient number of rural housings, all of that leading to the additional problem of alcoholism. In the social sphere, the greatest dissatisfaction among rural people was caused by decreasing healthcare and communal services. Expert opinions sustain these findings mentioning the problems of low income and the drift of young people from the countryside.

In rural areas, the number of basic social amenities has been falling for more than 20 years. Until the mid-2000s, the decline primarily affected obsolete and outdated amenities, but since 2008, there has been an increase in the closure of schools, clubs, libraries, and local healthcare centres because of government cutbacks (see Chap. 21). Yet there are also some positive changes in the state of rural infrastructure achieved with the support of federal and regional programmes. A large number of schools, clubs and other social initiatives were refurbished, regional and municipal roads were repaired, and there was a noticeable increase in the number of new kindergartens, sports facilities and housing. The countryside has now regained one of the benefits it recently lost: greater availability of housing than in urban areas (24 vs. 21 sq. m. in 2013).

Yet, migration is still the key factor in socio-economic development in the rural areas. In the late 2000s, the social mood of rural communities improved significantly and the birth rate rose, but the trend for rural drift remains significant (for more details, see Chap. 20).

The last two to three years of crisis have again seen a rise in the number of people who want to move: a poll in the spring of 2016 showed that 40% of young people wanted to leave the rural areas. Those moving first are those who do not have their own home or well-paid work and who have been educated in the cities and can be supported by their families. According to statistics, in the beginning of 2015 migration resulted in a 1.7 times greater reduction of rural youth compared to 2002.

22.3 Challenges for Innovation-Driven Development in the Rural Areas

Rural communities primarily associate innovation-driven development of the rural areas with information technologies and new opportunities for creating small businesses (for instance, the programme for supporting young agricultural entrepreneurs), which were offered through the government's rural employment schemes until the recent crisis years. Even though the creation of skilled jobs remains a recognized weak link, it is predominantly low-qualified and poorly paid work that encourages young people to leave the village. Knowledge needed for innovation is channelled through the traditional rural networks of friends and family and the mass media (up to half of rural community use them); but the role of the Internet has increased substantially (one out of five people use it). Recent innovation is rooted in the various changes in education and health care, which are associated with upgrading facilities and resources and using new technologies.

The population's attitude towards innovation has changed. Despite the fact that the rural population still holds a predominantly negative or indifferent attitude to change (about 60%), in 2013 positive attitudes outnumbered negative ones by a small margin (40%+ vs. 35%). In addition, active players of change outnumbered their passive opponents, who perceive a lack of long-term opportunities (11% as opposed to 7%).

Above all, rural communities mention local authorities and agribusinesses as the active key players of change and the social drivers of agricultural innovation-driven development (60 and 2% of respondents). That said, the impact of businesses on rural social development and the dependence of local bodies on business' support is steadily growing. The rural community expects greater involvement from the government and local authorities (32%) as the centre (26%). They acknowledge positive shifts in federal policy towards the rural areas, such as support programmes for gas infrastructure development, youth support and import replacement policy. Rural communities still expect governmental support in creating jobs (75% of rural inhabitants), in solving social problems and in boosting the adoption of new technologies in agriculture.

22.4 Social Capital to Adopt Innovations in Land Use

Turning to the agricultural sector, actual technological change in land use only began in the late 2000s when, according to farm managers, enterprises began upgrading their hardware on a mass scale and started using new farming technologies. According to a poll in 2013, managers regarded the technological status of their farms as satisfactory, and only a quarter of farms were actively adopting new technologies and modernizing agricultural infrastructure. Over 80% of farm households used relatively new agricultural equipment (no older than 5 years old), and a share of 25% farm households featured largely brand-new equipment. About half of operators polled were using farm machinery less than 5 years old.

On the one hand, opportunities for employing new land use technologies are made possible by improved loan options and implementation of government programmes to upgrade agricultural equipment and develop the agro-industrial complex. On the other hand, managers have noted that innovation is hampered by increased borrowing costs and generally low incentives provided by the regional or local authorities. Further socio-economic hampering factors are that more than 60% of agricultural farms lack skilled personnel, and young people lack motivation to work in agriculture.

In general, managers and farm machinery operators can be regarded as being aware of innovative land use technologies. One-third of enterprises used them for more than three years on average. Yet the study has shown that in 2013, a share of 20% had only a weak grasp of new technologies, providing room for knowledge transfer improvements.

Based on empirical material, basic channels for knowledge transfer of new technologies are the media (80% of responses), the Internet (50% of responses) and specialized channels such as professional development courses, workshops, agricultural exhibitions ('Siberian field day' and displays of modern equipment by suppliers) (25% of respondents). Managers and farm machinery operators value the benefits of new technologies not just because of increased crop yields and labour productivity, but also for the creation of skilled jobs with a good employment culture. In contrast to low-skilled farm machinery operators, the better educated ones have a positive attitude regarding new equipment.

What keeps households from adopting new land use technologies? Apart from technical problems, polls have identified difficulties with mastering new technical skills. Older generations and less educated workers also prefer the continuity and reliability associated with working with old equipment of domestic origin, but that is not a serious problem. Managers are also held back by redundancies, as many of them regard the social prosperity of the rural areas as a major criterion. At the same time, the motivation to adopt innovative technologies is quite high: up until the last two or three crisis years, about 50% of farm managers were potentially ready to acquire such equipment. The main constraints for them were not only limited financial means (see Chap. 16), but also the lack of information, e.g. based on other household's experience regarding clear advantages of such technologies.

Therefore, an analysis of the social environment for adopting land use innovations shows firstly, unevenness and inconsistency in its development. On the one hand, widespread problems of low pay, unemployment, drift of young people from the countryside, and deteriorating social facilities and infrastructure have persisted and increased in recent years. Further, negative or indifferent attitudes towards rural changes predominate. On the other hand, a crucial change has been taking place since the early 2000s leading to a higher likelihood for adopting agricultural innovations, such as an increased importance of education and skills, and new channels for knowledge transfer. With this the initial requirement for developing as a learning region is based on a sufficiently high motivation to adopt new technologies, as well as workers' desire to get trained and work with such equipment. The generally positive attitude of the rural population towards innovation additionally facilitates this option.

Yet, the recession has 'dented' the likelihood of seeing such potential bringing to fruition since late 2014. It has caused concern about the possible reduction of state support and agricultural programmes in rural areas. But the required innovation potential may still be realized through various means—particularly through the development of traditional and new knowledge transfer channels and active government impetus to adopt innovation practices in agriculture. There should be a special focus on the drift of rural youth, as playing in turn a key role for the adoption of innovation. Apart from facilitating effective employment, this requires the provision of attractive rural housing and diversified support for rural youth as regards their particular socio-economic needs.

References

Bourdieu P (2002) The forms of capital. Econ Sociol 3(5):60–74

Healy A, Morgan K (2012) Space of innovation: learning, proximity and the ecological turn. Reg Stud 46(8):1041–1053

Putnam R (2000) Bowling alone: the collapse and revival of American community. Simon & Schuster, New York, NY

Rutten R, Boekema F (eds) (2007) The learning region: foundations, state of the art, future. Cheltenham; Northampton, Mass.: Elgar

Sergienko AM (2011) Scientific basis and background for the research of rural social sphere In: Trotskovsky AY (ed) The Altai village: modern processes and mechanisms for social development. Altai University Press, Barnaul pp 73–96. (in Russian)

Sergienko AM (2013) Rural poverty: scientific basis and research results in the Altai region. In: Trotskovsky, A. Ya. (ed). Sustainable development of rural regions of the Altai Krai: socio-economic and spatial aspects. Altai State University Press, Barnaul, pp 152–191. (in Russian)

Part III
Potential and Strategies of Adapted Land Use as a Basis for Ecologically and Social-economically Sustainable Development of the Rural Landscape

Chapter 23
Potential and Strategies of Adapted Land Use as a Basis for Ecologically and Social-economically Sustainable Development of the Rural Landscape

T. Meinel

Abstract After what is now more than 60 years of intensive agricultural use of the virgin lands, the soil is damaged in various different ways. However, the area still has a high potential for food production due to generally sufficient amounts of precipitation. The task at hand is to switch from a way of farming which consumes many resources (the Canadian colleagues refer to it as 'mining the soils') to sustainable agriculture and/or husbandry. This represents a challenge, with the consequences described in Chap. 1 of Part I and Chap. 15 of Part II, as the common way of farming is often according to the international standards of the 1970s. It is an immense task to switch to highly modern procedures using GPS and electronically controlled seeders within just a few years. However, it can also be seen as a great opportunity because people will not need to undergo the entire learning process with its many steps in between as was the case in Canada, for instance.

Keywords Adapted land use · Kulunda · Sustainable farming

After what is now more than 60 years of intensive agricultural use of the virgin lands, the soil is damaged in various different ways. However, the area still has a high potential for food production due to generally sufficient amounts of precipitation. The task at hand is to switch from a way of farming which consumes many resources (the Canadian colleagues refer to it as 'mining the soils') to sustainable agriculture and/or husbandry. This represents a challenge, with the consequences described in Chap. 1 of Part I and Chap. 15 of Part II, as the common way of farming is often according to the international standards of the 1970s. It is an immense task to switch to highly modern procedures using GPS and electronically controlled seeders within just a few years. However, it can also be seen as a great opportunity because people will not need to undergo the entire learning process with its many steps in between as was the case in Canada, for instance.

One could assume that the correct or simple way would be to transfer the Canadian concept of min-till or no-till to the steppe lands of southern Siberia which show sim-

T. Meinel (✉)
TOO Amazone, Saifulina Street 3, Office 1, Astana 010000, Kazakhstan
e-mail: dr.tobias.meinel@amazone.de

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_23

ilar climate and soil characteristics. However, there are some small, yet significant, differences in the climate which require adaptation of the procedures (seeding times, cultures and herbicide strategies). The introductory chapter, therefore, outlines the requirements for a suitable and sustainable farming concept.

Then, the most significant results from the extensive field tests on the various tillage methods, from classic to direct seeding, are presented. In addition to the precipitation conditions, the topic of yield-increasing soil water dynamics is also examined. As a next step, this chapter elaborately illustrates the influence of fall tillage on the soil water content and the yield in the subsequent year.

The following chapter on adapted tillage methods for the increasingly interesting row crops, such as corn and sunflower, presents results of the field tests and the potential of the strip-till method. For this method, only the soil directly in the seed furrow is tilled in the fall, which also allows for the fertilizer to be applied at a sufficient depth.

Reduced tillage to limit wind erosion, however, also leads to increased pressure from weeds. This can only be met by a good and effective herbicide strategy. To avoid increasing costs and ecological strain on the soils, a technical solution was developed as part of the Kulunda project which solely applies herbicides where there are weeds. The exact operating principle of the technology and the procedure as well as the cost-saving potential is described in a separate chapter.

Adapted and sustainable farming methods can only be introduced on a large scale and without subsidies if they are economically sound as well. Therefore, the methods used in the field tests were also examined for their economic viability. The corresponding chapter in this part demonstrates that higher contribution margins can be generated for direct seeding systems as they save fuel and introduce alternative cultures such as oilseed rape when compared to traditional systems. The added value of preserving the soil and its fertility was not quantified in this process and therefore represents an additional benefit.

Areas have been degraded so much as a consequence of long-term non-adaptive use that they are no longer suitable for farming should be restored. Within the framework of the project, various tests were conducted to establish appropriate cultures. The final chapter of Part III outlines the results of these examinations.

During the project period, some farms already introduced and implemented many of the procedures and measures described in this chpater. Extensive field tests and demonstrations helped the land users overcome their initial scepticism in this context. As a consequence, ecologically and economically sound, sustainable methods were successfully established in many areas of land use. The result is that the lighthouse farms in the project area managed to make the required leap described above, advancing their technology by 40 years in the process, and now farm their land in a more modern and sustainable manner than many farms in Europe and North America.

Chapter 24
Demands for Modern Cropping Systems

T. Meinel, V. I. Belyaev, K. A. Akshalov, L.-C. Grunwald and L. V. Sokolova

Abstract The article introduces the development of crop farming since the beginning of the Virgin Lands Campaign in the Kulunda Steppe. For this purpose, it describes the significant stages and their influence on the land use, explains the different cropping systems and outlines the consequences of intensive land use. Afterwards, the current limiting factors are classified according to natural and anthropogenic origin, then analysed and assessed. The final part of the article articulates the requirements for a modern farming system to provide a framework of evaluation for the topics and methodology of the examinations which are presented in the following articles.

Keywords Kulunda Steppe · Virgin Lands Campaign · Wind erosion · Black fallow · Direct seeding · Soil degradation

24.1 The Development of Agriculture in the Kulunda Steppe Since the Beginning of Virgin Land Reclamation

During Stalin's change of course in 1927/1928, Soviet agriculture, and smaller farming structures as well as large-scale private farms (run by Kulaks), was forcibly col-

T. Meinel (✉)
TOO Amazone, Saifulina Street 3, Office 1, Astana 010000, Kazakhstan
e-mail: dr.tobias.meinel@amazone.de

V. I. Belyaev · L. V. Sokolova
Altai State Agricultural University, Prospekt Krasnoarmeyskiy, 98, Barnaul 656049, Russian Federation

K. A. Akshalov
LLP «Scientific—Production Center of Grain Farming Named After A. I. Baraeva», Village Shortandy 1 St. Barayev, d. 15, Shortandy District, Akmola, Kazakhstan

L.-C. Grunwald
BBG Bodenbearbeitungsgeräte Leipzig GmbH & Co. KG, Rippachtalstr. 10, D-04249 Leipzig, Germany

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_24

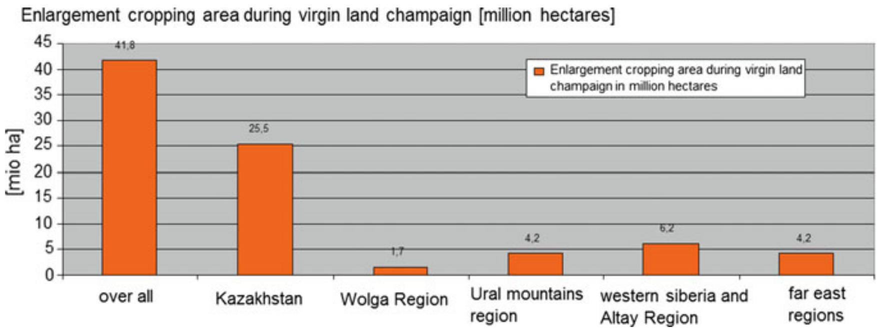


Fig. 24.1 Proportion of the steppe area ploughed up during the Virgin Lands Campaign in the former Soviet Union (cf. Eule 1962)

lectivized. The expansion of cultivated land and the intensification, however, focused primarily on the European part of Russia and the Ukraine before the Second World War (cf. Kramer 1951).

Due to the desolate supply situation in the Soviet Union after the war, the required amounts of grain had to be compensated for by imports from the USA and Canada (Brezhnev 1978 in Meinel 2002). The political leadership was therefore forced to act. In the third five-year planning period from 1946 to 1950, the primary target was to quickly re-establish core agricultural regions in the Northern Caucasus, the Central Black Earth Region and the Ukraine. Consequently, it was decided to increase agricultural productivity for 1948 by 27% compared to 1940. Due to the simultaneous promotion of agriculture in areas outside the core regions, the focal point of farming shifted more and more from the Ukraine to Western Siberia, the Volga region and Kazakhstan. Some remarkable features of this five-year plan are the specifications of including more modern crop rotations with multiple cultures into the farming structures. The plan was to use commercial agricultural crops and better preceding crops for sugar beets and sunflowers (Anissimov 1974). In addition to technical upgrades, the plan also included the introduction of improved farming procedures.

When Khrushchev came to power, however, the party decided on the production of 20 million t (tons) in crops on reclaimed land as part of the Virgin Lands Campaign (Eule 1962). A total of 21.2 million hectares (ha) of original steppe land were ploughed up in the Kazakh regions of Northern Kazakhstan, Pavlodar, Akmola, Kokshetau, Kostanay, Aktobe and Western Kazakhstan. Together with the Western Siberian regions of Tyumen, Omsk, Novosibirsk, Altai and Kemerovo as well as few other areas in the Volga region and Southern Ural Mountains, an expansion totalling 45 million ha was decided upon, of which an actual 41.8 million ha were eventually used for farming (Eule 1962, p. 24) (Fig. 24.1).

Major farming structures in the form of sovkhozy were created in the virgin lands in the shortest amount of time. By 1959, these were already managing as much as 27.9 million ha, which was equal to 27% of the cultivated land in the Soviet Union (Eule 1962, p. 74).

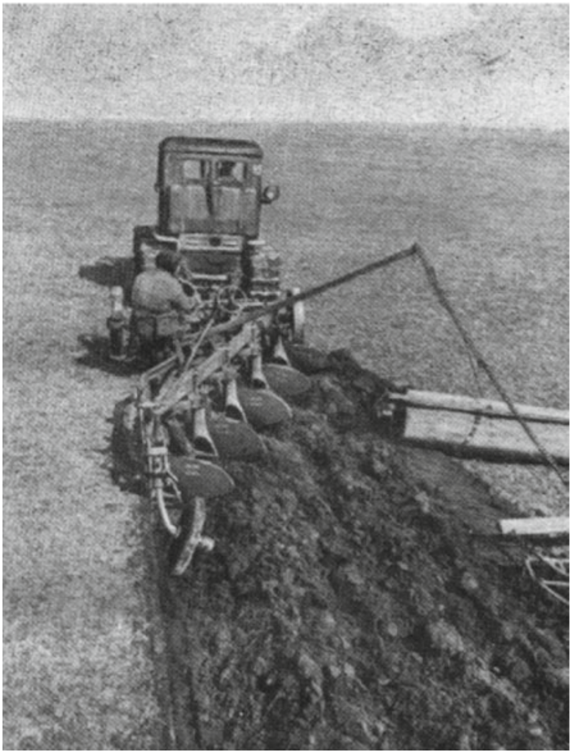


Fig. 24.2 Initial tillage of natural steppe land using a plough—Virgin Lands Campaign 1954 (Meinel 2002, p. 11)

The expansion of cultivated land was mainly focused on the driest regions of the Eurasian steppes. Prior to the Virgin Lands Campaign, 70% of the cultivated land was located in forested steppe regions. After the program, 70% of the entire cultivated land was located in dry steppe areas and only 20% in forested steppe areas (Eule 1962, p. 78) (Fig. 24.2).

The cultivation of summer wheat in monocultures was accelerated due to the climate conditions in the virgin lands and to secure the food supply. The following figure shows the increase in total farmland and the significance of summer wheat by area in the former virgin lands of the Soviet Union (Fig. 24.3).

After achieving good harvests initially following several humid years and a record harvest of 1.13 t/ha (tons per hectare) in 1956 (Wein 1980), only 0.47 t/ha of wheat were harvested in 1957. The soil nutrient depletion as a consequence of years of summer wheat monocultivation, the lack of mineral fertilizer, intensive repeated mechanical tillage (also using mouldboard ploughs) and the lack of fallowing, in combination with serious drought, were accompanied by wind erosion and crop failures (Eule 1962; Wein 1980; Meinel 2002). However, these problems were not met with modern crop rotations or altered farming systems at first but with land expansion, which was decided upon during the December plenum of the Central

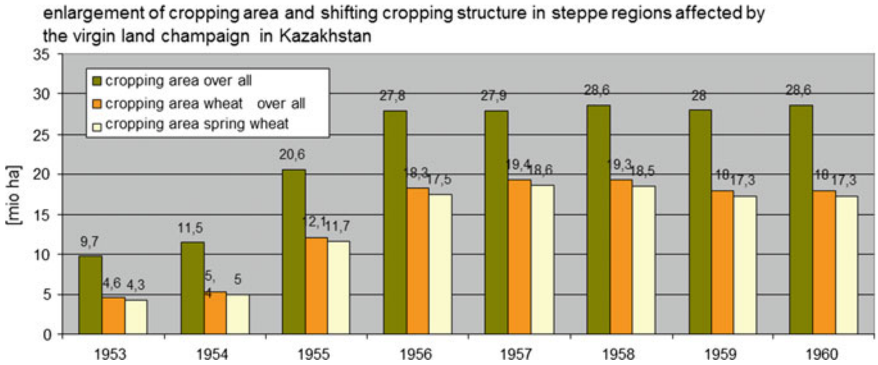


Fig. 24.3 Total area of virgin lands regions in the former Soviet Union and proportion of wheat (cf. Eule 1962, p. 134)

Committee of the CPSU in 1958. Following this, another 3.7 million ha of land had been put under the plough by 1963 (Eule 1962; Brezhnev 1978 in Meinel 2002).

The phase of intensification refers to the years between 1965 and 1986 up until perestroika. Intensification was a plan which was supposed to increase agricultural production through social and technological changes. It was implemented between 1965 and 1980 within the framework of the five-year plans. The socio-political measures were designed to improve life in rural areas. This included the establishment of infrastructure and utilities to improve the living conditions. Material incentives were created for farmworkers.

The term 'industrialization of agriculture' was used to characterize these measures (Meinel 2002, p. 14). Between 1975 and 1985, the government invested a total 35 million roubles in agriculture. This allowed for significant enhancement in the areas of mineral fertilizer supply, equipment/technology, feed additives and chemical crop protection. Due to the intensification, yield increased by 35% on average from 6.8 dt/ha (decitonnes per hectare) (1957–65) to 9.2 dt/ha (1966–76) (Meinel 2002, p. 14). The plan of the Soviet government was for the Omsk region to generate an additional yield of about one million tons thanks to the new cultivation methods. The prescribed crop rotation was black fallow—wheat—wheat. The black fallow was included in the crop rotation for the purpose of storing enough water for the two subsequent wheat harvests (Foreign Broadcast Information Service 1986, p. 14).

Irrigated areas were created during the intensification phase to cultivate root crops and perennial grasses to ensure the supply of basic feed. In most cases, irrigation in the steppe was only possible utilizing fossil groundwater (Meinel 2002, p. 14). The introduction of erosion protection measures had the utmost importance for the virgin lands during the intensification phase. To prevent wind erosion of the soil, the government ordered field protection afforestation. These protective plantings were executed at right angles to the main wind direction at approximately 500-meter intervals. This step resulted in individual subareas which were 2000 m long and 500 m wide (Meinel 2002, p. 14).

The following additional erosion protection measures were introduced:

- non-inverting tillage to maintain stubble;
- plant cultivation in strips with large fields being subdivided by small hedges to only expose smaller fallow areas to the wind and to minimize the wind speed directly over the surface;
- determination of optimum dates for seeding into the stubble;
- introduction of drought-resistant types of wheat;
- utilization of fertilizer and herbicides;
- seeding grass onto eroded areas.

(Foreign Broadcast Information Service 1986, p. 33).

These measures helped to tenaciously contain wind erosion and increase productivity in crop cultivation. It was at this stage that the highest productivity so far was achieved in the Kulunda Steppe. The social conditions in the villages reached their highest level as well.

With perestroika starting in 1985, conditions were supposed to continue to improve. The system was to be democratized and a more liberal market to be introduced. These reforms, and not just in agriculture, led to a stagnation in the Russian economy and eventually to the downfall of the Soviet Union. The conditions in Russian agriculture changed fundamentally as a consequence. For the first time ever, the law allowed individuals to purchase or lease a preassigned amount of land. Many of the former kolkhozy and sovkhozy were transformed into legal entities under the civil code. This transformation was often just executed as a formality with no fundamental staff or organizational changes. Even the superordinate organizational structure did not change. The local authorities continued to issue sales and production figures to the farms (Meinel 2002).

A yield increase could have been expected from the combination of the information obtained on modern farming concepts and the commitment of the newly established farms. However, the diagram shows an ongoing downward trend with regard to yields until 1997 (Meinel 2002, p. 15) (Fig. 24.4).

Between 1992 and 2000, agricultural production decreased by 29%. Due to the politically unstable situation, only short-term profit was sought in agriculture up

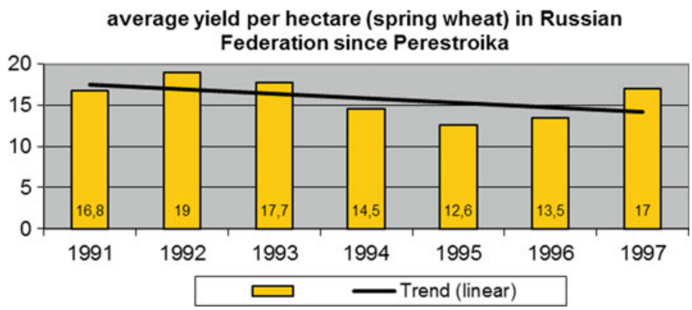


Fig. 24.4 Average yield per hectare (summer wheat) in the Russian Federation (Meinel 2002, p. 15)

until the year 2002. This was pursued using existing resources. The investment in new technology was very problematic in these years, also against the background of constant cuts in agricultural subsidies (Viehrig 2005). In the 1990s, there was a shortage of fertilizer, herbicides and modern agricultural engineering. Therefore, older procedures with a high level of tillage were used. Wind erosion increased as a consequence.

It is not until after 1999 that the economic situation seemed to consolidate. More beneficial lending guidelines allowed smaller start-up farmers to invest in land and technology. These farms are often managed much more effectively than the major farms with structures that are similar to those in Soviet times. People who changed careers from other industries and drove the market after the year 2000 with the help of well-trained agronomists and a distinct sense for business were very successful in many cases.

This fact was reflected by increasing investments in agricultural engineering. Tractors and first-generation airseeders, e.g. Morris Concept of JD 730, were imported from North America. Modern farms, often run by career-changers from other fields of the economy, were established. These farms managed large areas with a small number of staff and productivity which was significantly higher than in the old structures. The types of machines, however, were mainly older airseeder systems of the first and second generation. These were no longer in demand in the North American farming regions but sold well in the Commonwealth of Independent States due to their conventional mode of operation.

24.2 Limiting Factors in Crop Production

1. **Natural limiting factors**

The temperature regime throughout the year is of central importance for agricultural productivity. The annual temperature cycle and accumulated temperature greatly limit the vegetation period in the steppe regions of Eurasia, particularly under the highly continental influences of Northern Kazakhstan and Western Siberia. The Kulunda Steppe has three steppe facies in a WSW-ENE direction, along which the accumulated temperature decreases towards the ENE and the vegetation period, which is relevant to crop production, is reduced. Moreover, the climate in the highly continental steppe regions of Western Siberia is characterized by strong amplitudes in the annual temperature cycle. The maximum temperatures in the summer increase so severely in the dry steppe regions that the evaporation rates are extremely high and therefore limit biomass production and yield. On the other hand, the extreme minimum temperatures in the winter have a limiting effect on the yield as high-yield winter crop varieties can only be cultivated to a limited extent or not at all. Summer crops are cultivated for the most part in the farming areas of the Kulunda Steppe. Due to the very short transition from winter to summer, the window for seeding in spring is limited to only a few weeks. The time period of May 15 to 25 is considered the optimum for seeding summer wheat up to this day.

The greatest climate factor is total precipitation and with its spatial and temporal distribution as well as the strong evapotranspiration against the background of the high summer temperatures. The total amount of precipitation per year presents absolute limits on yields in all steppe regions. In the best case, the balance between precipitation and evaporation is just about equal. Most parts of the Kulunda Steppe, however, are characterized by semi-humid to semi-arid conditions. Most of the annual precipitation falls during the summer half of the year, but the temporal and spatial distribution is highly uneven. Strong drought during the most important weeks for crop development in late spring, which strongly limit field emergence of the seeds or crop growth after emergence, can be expected in five-year cycles. The time between June and early August has the highest precipitation. Most of it, however, falls locally and as intensive convective precipitation. Due to these characteristics, this type of precipitation has a high potential for causing damage by erosion, especially as part of unadjusted farming.

During the winter dormancy and low precipitation period, the snow layer is very thin in most years. Therefore, the water retention in the form of snow is highly limited. The reduction of snow retention on the surface particularly affects soils which were ploughed in the fall due to the size of the areas and strong storms. There have been the first trials to grow winter cultures in the wetter north-eastern regions of the Kulunda Steppe. However, large parts of the winter crops are often affected by winterkill due to a lack of a snow cover and temperatures lower than −40 °C. In addition to the uneven distribution of the annual precipitation, fluctuations during the year are problematic for the agricultural utilization of the region. The precipitation total in the driest regions close to the Russian–Kazakh border is subjected to an annual fluctuation between 200 and 350 mm.

Another phenomenon in the steppes of Western Siberia and the Kulunda Steppe is strong, extremely dry winds from Southwest–Central Asia. Due to high wind speed and the very low atmospheric humidity, this so-called sukhovey diverts air which is saturated with water vapour from directly above the ground and therefore causes steady dehydration. This effect becomes particularly strong on intensively used surfaces as there is no resistance from organic mass or stubble to slow down the wind due to the repeated mechanical working of the soil. Soil particles are set in motion, saltate and fly in accordance with their mass, hitting more soil particles. This often leads to serious wind erosion. On the one hand, the soil is blown away from the surface, which causes degradation with regard to physical and chemical aspects. On the other hand, the flying soil particles act as projectiles which cause significant damage when colliding with the young plants in the early summer and limit the yield.

In contrast to the climate conditions, the soil of the Kulunda Steppe in its natural state only limits agricultural production in exceptional cases and in certain areas. The high water storage capacity, good nutrient supply, good physical characteristics (permeability for roots, temperature regime, aeration, texture) and large extent of its associated black earth make the soil of the Kulunda Steppe its most important guarantor of agricultural production thanks to the naturally high-yield potential. Loess, the loose substrate containing carbonate, is mainly responsible for the good physical characteristics of the soil. The dry regions of the Kulunda Steppe are affected by strong salinization. Solonetz and solonchak mainly form in the lowlands influenced by ground or surface waterlogging. Due to the high evaporation rates, the salt dissolved in the groundwater remains near the surface, making high-yield farming impossible.

2. **Anthropogenic limiting factors**

Many soils in the Kulunda Steppe have been affected by erosion and degradation since the expansion of cultivated land and the mechanization of tillage. Wind erosion plays a major role in this context. The main cause of extensive wind erosion is the tillage adjusted to the location and natural conditions. Intensive agriculture and mechanical management of the steppe soil using ploughs, cultivators and harrows were established in the Kulunda Steppe with the Virgin Lands Campaign. As a consequence, highly intensive inverting tillage was used until the mid-1960s. The lack of herbicides placed mechanical tillage at the forefront as an effective means of weed control. At the same time, the black fallow in the monotonous wheat rotation had the task of storing the water and making the nutrients available to the plants through increased mineralization rates.

In addition to the usual tilling methods, which included harrowing after ploughing to prepare the seedbed and stubble breakage after the harvest and/or fall ploughing using harrow and plough, the soil in black fallow is prevented from any coverage by repeated tillage using a harrow and/or cultivator throughout one vegetation period. Even without black fallowing, the highly intensive tillage and the lack of plant coverage over longer periods of time represent the greatest problem with regard to erosion. The soil mechanics of the working horizon are destroyed, which leaves the soil particles in extreme danger of deflation. Silt and fine sand are blown out of the topsoil and fertile humus with these grain size fractions. This reduces the supply of nutrients in the soil and its water storage capacity.

Intensive tillage can cause capping, which leads to serious water erosion damage, particularly on sloping terrain. The so-called gully erosion can mainly be observed in the agriculturally used terraces of the Ob and Aley rivers. Thousands of tons of fertile farmland are washed away by gully erosion as a result of singular torrential rainstorms and the snowmelt in spring, causing lasting changes to the landscape with the formation of gullies (cf. Dammann 2005). Even if no gullies are formed, the damage from water erosion during the snowmelt is significant. Valuable soil is often washed away even from gentle slopes or alongside flat rills.

When the tilled soils are repeatedly driven upon, compaction horizons form at the sole of the working horizon, which promote waterlogging and salinization in ground depressions and decrease the permeability of the soil for roots.

Erosion of the soil and the decline of chemical and physical characteristics is a process which has been observed in the Kulunda Steppe since the Virgin Lands Campaign and has led to the concentration of natural humus approximately being halved in the soil of this region.

To this day, repeated mechanical tillage of the farmland is a standard procedure in the vast areas of the Kulunda Steppe. Prior to seeding, the seedbed is usually prepared mechanically using a cultivator or harrow in most cultivation systems of the forest steppes and the typical steppe region. The systems of seeding and tillage are often combined in one machine and one process. The machines used in these cases are mostly wing-share cultivators, which are installed before the mechanical seed drill with two-disc shares. This in-depth tillage at the beginning of the early summer dry period costs a lot of groundwater and often leads to premature ripening and harvest shortfalls as a consequence of very dense stands and increasing competition between growing space and water. The working of the stubble from the previous year creates a large contact surface for wind, which diverts air which is saturated with water vapour from directly above the ground and therefore promotes further evaporation. This accelerates the loss of soil moisture.

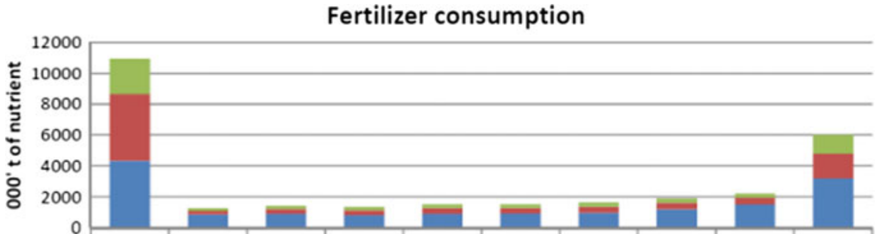
Fall tillage is carried out by some farms in the Kulunda Steppe to this day and is supposed to encourage tilth formation on the field. It is countered by the effect of reduced snow retention. Due to the tilled soil surface, the snow blows over the surface and gets caught in the wind protection systems. This means a loss of valuable soil moisture for the upcoming vegetation period. This is particularly dramatic in the dry steppe regions where approximately one-third of the annual soil moisture consists of meltwater.

Another limiting factor is the lack of committed and well-trained employees. Many people are leaving the villages to work in central cities such as Novosibirsk or Barnaul. This often creates the problem of modern technology not being used properly. The full potential is not achieved, and the equipment wears out very quickly.

Today, it is difficult to find young, motivated employees to work in farming, also internationally speaking. For this reason, many older agronomists still run the farms, applying traditional farming methods. Another important aspect is the knowledge transfer within the business. An agronomist must transfer his or her knowledge on certain works to the executing machinist as the tractor driver is the executing body. If the latter does not complete the tasks correctly, the agronomist's knowledge is of no use. The lack of relevant crop rotations is also a limiting factor in the current farming system. The easiest option is still to cultivate summer wheat. The machines are generally available, and the product is easy to market. Alternative cultures are, presently, more difficult to sell and require initial investment in agricultural engineering.

A problem which disrupts failure-free and timely operation is the availability of hauling systems and agricultural engineering at the right time. It is frequently observed that the technology has not been sufficiently maintained and is not ready for use at the beginning of the season in spring. Most farms do not have the opportunity to maintain the machines in a heated workshop in the winter. In addition to this fact, it is often bad organization and unmotivated staff, because of low compensation, that leaves the technology in a badly maintained state until shortly before seeding.

The machines on most farms are from the 1970s and 1980s and are obsolete. In addition to tractors from the Kirovez series, it is mainly T-75 and T4A track tractors which are used on the farms. Thanks to the substantial experience and good spare parts supply, these machines can be used to this day. The repair work is usually



	1990	average for 1998-2001	2002	2003	2004	2005	2006	2007	2008*	2012**
K2O	2280	175	200	206	241	229	268	278	247	1200
P2O5	4340	230	307	306	379	374	423	422	440	1600
N	4330	859	907	831	897	918	956	1200	1513	3200

Fig. 24.5 Fertilizer consumption from 1990 to 2012 (Ivanova and Nosov 2008)

done by the drivers themselves on the farm. During the season, the downtime for the machines, which cannot be planned, causes problems as it may last several days. In addition to the repair work which consumes a lot of time, the operation of the old technology also requires additional resources.

An important step towards improving the effectiveness of farming was taken in the 1970s by intensifying agriculture in the former virgin lands. In addition to an improvement in the use of machines and the partial conversion of the management practices, it was mainly the increased use of mineral fertilizers which stabilized and increased the yield level in the Kulunda Steppe (Fig. 24.5).

Until the downfall of the USSR, a total of 11 million t/a of mineral fertilizer were spread onto Russian fields (Ivanova and Nosov 2008). The unstable economic situation and the complicated credit schemes force the farmers to focus on short-term fast profit strategies at the cost of the means of production and soil as a resource (Meinel 2002). Mechanical tillage experienced a true renaissance after 1990 while the use of mineral fertilizer and chemical herbicides significantly decreased. Between 1998 and 2001, only a little over 1.5 million tons of mineral fertilizer were spread. The average application amount therefore totalled 32.4 kg/ha (kilograms per hectare) as opposed to 88 kg/ha in 1990. Only from 2006 onwards has there been another slight increase. The reasons for this development are government incentives and subsidies for fertilizer which increased the willingness to invest (Ivanova and Nosov 2008).

24.3 Requirements for Modern Farming Systems

There are generally only two central requirements for farming systems in the Kulunda Steppe:

1. The system must be economically viable and generate enough profit so that even the marginal areas of rain-fed agriculture can earn profits. This also helps in dealing with any subsequent social issues.
2. The farming system must also be ecologically sustainable to maintain the resources required for the production of agricultural goods.

The conventional system is presently only economically viable in years with good weather. The frequent black fallow and yield loss of an entire year contribute to the high cost of the system. The old system described above often uses black fallow as well as frequent and intensive tillage and therefore is not sustainable for the soil.

Every agricultural region has its own specific characteristics regarding possible cultures, climate-related and pedological conditions. As a result, known systems cannot be transferred from other regions, even if they seem similar at first, without extensive examination. The experience from the Kulunda project shows that even established systems, such as the no-till system from Canada, cannot simply be applied in this region. While it is important to reduce tillage intensity to maintain soil as a resource, the concept of no tillage at all must be approached cautiously and gradually. The following paragraphs describe the four main pillars of an effective and sustainable farming system in the Kulunda Steppe.

1. **Omission of black fallow**: An important requirement for a modern and sustainable system is the reduction of black fallow. On the one hand, it is the main cause of wind erosion; on the other hand, it is unnecessarily expensive. In the year of black fallow, the soil is tilled at least five times. So far, it has been claimed that a lot of water could be accumulated in the ground through black fallow, but more recent examinations by Belaev and Volnov (2010) and Grunwald (2010) have shown that this effect is very limited. The farmers' experience, however, shows that the yield is very high after using black fallow. If this is not caused by a better groundwater supply, there must be other reasons. These mainly lie within the better supply of nutrients in the soil after fallow. The organic material in the topsoil is mineralized much faster due to the repeated tillage, and the released nutrients are available to the next culture. This is very positive for the following culture, but it causes a constant reduction of the humus in the topsoil. This effect, which positively affects the yield, can be compensated for by targeted fertilizing (see below). Another effect of black fallow is the reduced occurrence of weeds in the following year. This outcome can also be achieved by good crop protection combined with a suitable crop rotation. Frequent tillage makes the fields very even with a fine crumb structure. While this is very beneficial for high-quality seeding, it also represents high potential for erosion. Modern seeders do not require such a fine seedbed though as they can operate under harsh conditions

and also handle a lot of organic material in the topsoil. This means that all the advantages of black fallow can be replaced or compensated for.

2. **Improvement of crop rotation**: Another very important requirement for a new system is the introduction of an adequate crop rotation. Crop rotations have a lot of advantages from an agronomic standpoint. Weeds can be controlled effectively, and various cultures absorb various nutrients. The different harvest residues can be managed better in the field, and there are fewer pest infestations and diseases. Moreover, growing several cultures decreases yield losses in general. Summer wheat, for instance, depends on precipitation in June, but most precipitation falls in July and August and cannot be used to produce yield. Other cultures such as maize and sunflowers, however, can still use the precipitation effectively. Crop rotations are also helpful from an economic point of view. The conventional focus on summer wheat means a great dependency on individual crop prices. Price fluctuations often concern a specific culture so that they may be compensated for by growing alternative cultures such as maize, sunflower, sorghum, soybean, rape, peas, lentils and flax. Moreover, higher sales revenue can be generated for a lot of the alternative cultures; particularly lentils, rape and flax, than for wheat.
3. **Optimization of crop protection**: Crop protection, which mainly refers to controlling weeds and grass weeds, plays a central role in a modern system with reduced tillage. The weeds are significantly better adjusted to the local conditions and are therefore more vital and effective. For instance, they absorb more water from the soil than the seeded cultures (Meinel 2002). Fields free of weeds are imperative for producing good yields. Weed control has mainly been exercised through tillage. When reducing the latter, measures must be introduced to keep the fields clean. The effective application of herbicides prior to seeding and in the culture is very helpful. The crop rotation also has a significant influence on the occurrence of weeds and diseases. Lafond et al. (2006) were able to prove that crop rotation impacts the occurrence of diseases and weeds more than tillage.
4. **Improvement of nutrient supply**: The soil in the Kulunda Steppe and therefore all cultures grown there suffer from a serious nutrient deficiency. This concerns almost all nutritional elements with the exception of sodium, manganese and magnesium of which there are sufficient levels in the soil-forming substrate. This situation was caused by the extremely low application of fertilizer over the last two decades. If there is any fertilization at all, the focus is usually on nitrogen; phosphorus is used much more rarely. Of course, the application of fertilizer represents a major investment considering the size of the fields. Moreover, the low application and intensive tillage have caused such a C/N ratio that mineralization was seriously hindered and nutrients were barely available to the plants in the first year(s) and therefore only had a small effect on the yield. Nutrients are only released once the microbial activity increases again (sufficient nitrogen). Therefore, it is absolutely necessary to increase fertilization in the first few years when reducing tillage. This issue mainly relates to nitrogen and phosphorus. It is generally advisable to conduct an extensive soil analysis on the farms to determine the status quo. Measures for fertilization to compensate for macro- and micronutrients can be taken as a next step. The idea of compensation fertilization should

be applied as a matter of principle. As part of this process, fertilizer is applied according to the macronutrients, and for some cultures also micronutrients, that have been extracted from the field during harvest (straw + culture). The question is when to fertilize and in what form. Spreading the fertilizer onto the surface of the soil, as is common practice in Central Europe, is not a suitable method for semi-arid regions as a general rule. On the one hand, there is a risk of no precipitation falling for weeks after dispersing the fertilizer and the granulate not dissolving as a consequence. On the other hand, the intensity of the percolation is often not strong enough to reach the roots of the cultures. Therefore, the fertilizer must be worked into the soil. This can be done by using a seeder or tillage. The use of machines with the sole purpose of burying fertilizer (fertilizer applicator) is increasing. When applying fertilizer with a seeder, there are two options. The fertilizer is placed directly into the seed furrow together with the seeds (single shoot). The disadvantage: pure nitrogen can only be applied up to approximately 30 kg/ha without harming the seedlings (Akshalov and Meinel 2013). This dosage is enough for a target yield of 2 t/ha in the dry steppe. An advantage of this method is that the seeder remains easy to pull as there is no separate share for the fertilizer working in the ground. The second option creates a second slit for the fertilizer close to the seed furrow (double shoot). With this method, it is possible to apply high amounts of nitrogen, but the traction force demand is significantly higher due to the additional furrow, which increases the diesel costs per hectare and requires a larger tractor related to the working width. A relatively new, very promising option is the application of liquid fertilizer. High amounts of nitrogen can be applied without using a separate fertilizer share and harming the seedlings. Moreover, other required elements can be added to the liquid fertilizer allowing for perfectly adjusted fertilizing. Due to the low vertical water movement in the project area, the phosphorus, which is not very mobile anyway, remains in the topsoil and is available to the plants only to a limited extent. Either extensive non-desirable tillage or the strip-till method is required to conduct this element to the root horizon. Large amounts of phosphorus can be applied to deeper layers when preparing for row crops such as sunflowers or maize. This allows for a stock fertilization of two to three years.

There are, of course, more requirements beyond these four aspects which are partially related. For instance, a sufficient amount of crop residues must remain in the fields for the purposes of erosion protection, improving the humus balance and reducing evaporation. Furthermore, snow retention in the winter must be improved. This can be achieved through good crop establishment and good harvesting and/or using strippers which only strip off the ears. This is, however, not possible for all cultures.

Costs can also be reduced by using powerful modern machines. The working quality is often significantly better than with old technology, and the risk of downtimes during the season is greatly reduced. The effectiveness of the individual work steps such as seeding and herbicide application should be generally reviewed. These processes can only be effective if they are executed at the right time.

Finally, the processes of cleaning, drying and storing the harvest must be optimized. In particular, the possibility of storing crops for longer periods allows for the realization of the best possible prices.

The requirements and potential for improvement are very thematically heterogeneous. Switching to more effective and sustainable farming concepts requires a very broad knowledge—from technology to crop nutrition—from the responsible decision-makers. Therefore, it is absolutely necessary for them to seize all opportunities with regard to training and expanding their horizon. Only then will a successful transition be possible.

References

Akshalov KA, Meinel T, Klyshbekov T, Baibukanova O, Rakhmanova A, Les' C, Taishukher Zh (2013) Tekhnologiia priamogo poseva kul'tury rapsa effektivnost' preimushchestva [The technology of direct seeding of rapeseed crops efficiency advantages]. In: Conference 01.08.-01.08. 2013: Diversification of crops and zero technologies in arid regions. Scientific and Production Center of Grain Farming im. A. I. Baraeva, Shortandy. [in Russian]

Anissimov N (1947) Die Landwirtschaft der Sowjetunion im neuen Stalinschen Fünfjahresplan [The agriculture of the Soviet Union in the new Stalin Five-Year Plan]. Berlin, SWA-Verl. 1947, [in German]

Belaev VI, Volnov VV (2010) Resursosberegaiushchie tekhnologii vozdelyvaniia zernovykh kul'tur v Altaiskom Krae [Resource-saving technologies of cultivation of grain crops in the Altai Territory]. Barnaul. [in Russian]

Brezhnev LI (1978) Neuland. In: Meinel, 2002, Die geoökologischen Folgewirkungen der Steppenumbrüche in den 50er in Westsibirien. Halle/Saale

Dammann S (2005) Ursachen und Auswirkungen der Ovragbildung in der Südsibirischen Kulundasteppe und ihre Wechselwirkungen zur Naturraumausstattung sowie zur Landnutzung [Causes and effects of ovrag formation in the South Siberian Kulunda steppe and its interactions with natural environment equipment and land use]. Diploma Thesis. Martin Luther University Halle-Wittenberg. [in German]

Eule W (1962) Das problem der Neulandgewinnung in der Sowjetunion [The problem of land reclamation in the Soviet Union]. Dissertation. University of Bonn. [in German]

Foreign Broadcast Information Service (1986) USSR report–agriculture. US Department of Commerce. Springfield, VA.22161: National Technical Information Service

Grunwald LC (2010) Geoökologische und agronomische Effekte der Schwarzbrache in Steppenregionen Russlands [Geoecological and agronomic effects of bare fallow land in steppe regions of Russia]. Diploma Thesis. Martin Luther University Halle-Wittenberg. [in German]

Ivanova S, Nosov V (2008) Development of agriculture in Russia and its influence on fertilizer consumption. International Plant Nutrition Institute. (http://eeca-en.ipni.net/article/EECAEN-2025)

Kramer M (1951) Die Bolschewisierung der Landwirtschaft: In Sowjetrussland, in den Satellitenstaaten, in der Sowjetzone [The bolshevization of agriculture: in Soviet Russia, in the Satellite states, in the Soviet zone]. Rote Weissbücher, Köln. [in German]

Meinel T (2002) Die geoökologischen Folgewirkungen der Steppenumbrüche in den 50er Jahren in Westsibirien [The geoecological consequences of the ploughing up the steppe in the 1950s in Western Siberia]. Dissertation. Martin Luther University. [in German]

Lafond GP, May WE, Stevenson FC, Derksen DA (2006) Effects of tillage systems and rotations on crop production for a thin black chernozem in the canadian prairies. Soil Tillage Res 89(2):232–245

Viehrig H (2005) Russlands Landwirtschaft und ländliche Siedlungen in der Transformation [Russia's agriculture and rural settlements in transformation]. Praxis Kultur – und Sozialgeographie, 34. Universitäts-Verlag, Potsdam. [in German]

Wein N (1980) Fünfundzwanzig Jahre Neuland [25 years Virgin Lands]. Geogr Rundsch 32(1):32–38 [in German]

Chapter 25
Modernization of Current Agricultural Technologies of Grain Production Under the Conditions of a Steppe Zone of the Altai Region

V. I. Belyaev, L.-C. Grunwald, K. A. Akshalov, T. Meinel and L. V. Sokolova

Abstract In the first part of the article, the overview of different periods of agricultural development in Kulunda Steppe is presented. The next part shows the materials and methods of the research as well as the variants of tilling technologies and crop rotations. In the third part, the change of precipitation and temperatures during the growing season 2013–2016 is described. Furthermore, information on the water regime of the soils, an analysis of the rate of moisture from the meter layer of soil during the vegetation, follows. After that, there is crop yield data in dependence of agricultural technologies and conclusions.

Keywords Agricultural technologies · Crop rotation · Grain production · Steppe zone

V. I. Belyaev (✉)
Engineering Department, Altai State Agricultural University, Prospekt Krasnoarmeyskiy, 98, Barnaul, Russian Federation
e-mail: prof-belyaev@yandex.ru

L.-C. Grunwald
BBG Bodenbearbeitungsgeräte Leipzig GmbH & Co. KG, Rippachtalstr. 10, 04249 Leipzig, Germany

K. A. Akshalov
LLP « Scientific—Production Center of Grain Farming Named After A. I. Baraeva», Village Shortandy 1 st. Barayev, d. 15, Shortandy District, Akmola, Kazakhstan

T. Meinel
TOO Amazone, Saifulina street 3, Office 1, Astana 010000, Kazakhstan

L. V. Sokolova
Faculty of Biology, Altai State University, Prospekt Lenina, 61, 656049 Barnaul, Russian Federation

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_25

25.1 Overview of Different Periods of Agricultural Development in the Kulunda Steppe

The Kulunda Steppe is 5.3 million hectares (ha) in size and is very important for the agricultural production of the Altai region.

Before the virgin land policy was implemented, the promoted technology for agricultural production in the forest steppe of Altai region was post-harvest disking tillage to reduce evaporation, deep autumn plowing, snow retention, and accumulation of meltwater, early spring harrowing, pre-sowing cultivation with harrowing, sowing in optimal time high-quality seeds, harrowing before and after germination, distribution of organic fertilizers on the field of fallow and mineral fertilizers in times of sowing and after germination, varietal and species weeding of sowings (Ovsinsky 1911). The application of these technologies resulted on one experimental field (of about 4 ha) on the M.E. Efremov collective farm, in a record high yield of durum wheat of 6.1 t/ha in 1936. In subsequent years, other collective farms reached even higher yields (I.N. Rakitin: 8.0 t/ha; I.E. Chumanov: 8.6 t/ha, A.S. Sergeev: 10.1 t/ha) (Belyayev 2014; Belyayev et al. 2014b).

The plowing of virgin lands in the Altai (1954–1958) was implemented on light-textured soils. On average, the yield of summer wheat was 0.8 t/ha within the ordinary and dry steppe. Sod and soil structure were destroyed by continuous deep tillage. Due to these processes, wind and water erosion in the ordinary and dry steppe occurred. Dust storms started to become a common phenomenon with devastating effects. For example, during the dust storm of 1963, the seeding of spring crops was destroyed on 1.5 million ha. Serious damage to soils and yields was also caused by water erosion. However, this is less visible than wind erosion (Kashtanov 1974).

During the late 1960s, the All-Union Scientific Research Institute of Grain Farming developed strategies for soil-protective farming in the Kulunda Steppe (Goncharov 1988). These strategies included grassing of lands suffering heavy erosion, soil-protective grain-fallow short-term rotations with preservation of the stubble on the surface of the soil during the soil treatment and the lane occupancy of crops (Baraev 1988). Soil-protective farming was implemented in almost all areas of the Kulunda steppe by the late 1970s.

On average, the yield of summer wheat in 1972 reached 1.98 t/ha in the Altai region, including forest, ordinary, and dry steppe. These high yields resulted in a comprehensive policy to develop grain production in the region (1976–1982). However, the policy could not be implemented because of shortages of fertilizers, plant protection products, and other resources. A monoculture of wheat and the spread of weeds resulted in lower yields. During 1983–1989, there was an increase in the supply of herbicides and fertilizers. In addition, fodder rotations and grain-fallow short-term rotations were implemented. As a result, there was an increase of grain production and crop yield, on average, of 0.4 t/ha (Belyayev and Volnov 2010).

With the collapse of the Soviet Union and the subsequent period of economic destabilization (1990–1999), yields and gross harvest of grain production declined significantly. The reasons were of a systemic nature, slow deterioration of agricultural machinery, less government support, increase of input costs, staff not being able to adapt its mindset, and the collapse of extension services. Despite these wider changes occurring, top-down state order for crops continued. Monoculture of wheat was re-implemented without grain-fallow and fodder rotations. Due to the economic transition period, agricultural production was not competitive (Belyayev and Sokolova 2016).

Since 2000, there was a review of agricultural production processes and technologies in the Altai region. It was concluded that deep tillage has many disadvantages and minimal or no-till technologies are preferable due to the energy savings (Belyayev and Volnov 2010; Belyayev et al. 2014d; Belyayev 2015; Kashtanov 2005). Nevertheless, these technologies require the application of herbicides and fertilizers and, therefore, have a larger impact on the soil and agricultural products. Furthermore, a new trend appeared—alternative biological and adaptive farming systems without the need for herbicides. These technologies use the biological abilities of plants to affect each other, either suppressively or stimulatingly. For example, pea–oat intercropping gives higher yields compared to the monoculture of these crops. Winter rye suppresses weeds following the summer crops. These systems also include crop rotation, mulching with straw, green manures, or plant residues to create the organic pillow on the field surface (Gnatovsky 2003).

In the Altai region since 2000, the production of other more profitable crops, such as sunflower, buckwheat, soybeans, flax, and others, has increased significantly. The areas and yields of sugar beets have also enlarged. The structure of croplands was optimized due to the planting of different crops and increasing feed production (Belyayev and Reshotko 2014; Belyayev et al. 2016). This helps to expand energy-saving technologies (Belyayev et al. 2014a; Belyayev and Klishbekov 2014; Donchenko et al. 2008).

As shown in different periods of agro-economic development in the Altai region, significantly, different yields were received. This cannot be explained only by the variability of weather conditions. It depended in no small part on the use of technology as well as on state support.

25.2 Materials and Methods

In the Altai region from 2011 to 2016, an international interdisciplinary research project KULUNDA was implemented (Belyayev et al. 2014c; Illiger et al. 2014). The main purpose of this project was the development and introduction of innovative technologies on the steppe land; designed to prevent further erosion, provide an increase in soil fertility, as well as encourage the efficient use of land resources in the arid regions of the Altai region.

There were stationary base platforms set-up on three farms: Ltd. KH ‘Partner’, Mikhailovsky district, ZAO PP ‘Timiryazevskiy’, Mamontovsky district, and FSUE PP ‘Komsomolskoye’, Pavlovsky district (Fig. 25.1). The monitoring of innovative crop management technologies in crop rotations was integrated in these areas (148

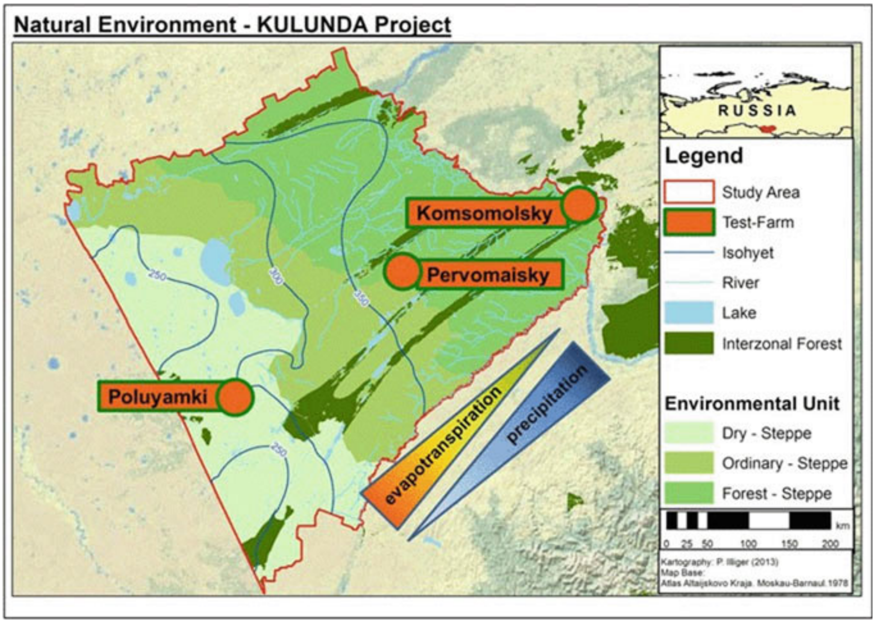


Fig. 25.1 Basic platforms of the KULUNDA project in the Altai region (Map based on Atlas of the Altai region, 1978, modified)

variants of combinations of technological factors on the 356 plots). Modern world-class equipment was used. The experiment began in autumn of 2012. The scheme is shown in Fig. 25.2.

The following variants of tilling technologies were compared:

- CC—No-till technology, without autumn tillage;
- MCC—minimal autumn tillage technology of with KPSH-9 on 14–16 cm depth (Fig. 25.3);
- OCC—deep autumn tillage technology with PG-3–5 on 22–24 cm depth (Fig. 25.4).

The cultivation of crops was carried out in crop rotations:

- CC technology: 1–2–3–4 (wheat–pea–wheat–rape);
- MCC technology: 1–2–3–4 (wheat–pea–wheat–rape);
- OCC technology: 5/6–7/8–9/10 (fallow–wheat–wheat–wheat).

The sowing of crops by OCC and MCC technologies was carried out with the drill C3C-2.1 (Fig. 25.5), and by the CC technology with experimental drill Condor (Fig. 25.6).

The following parameters were used in the sowing process:

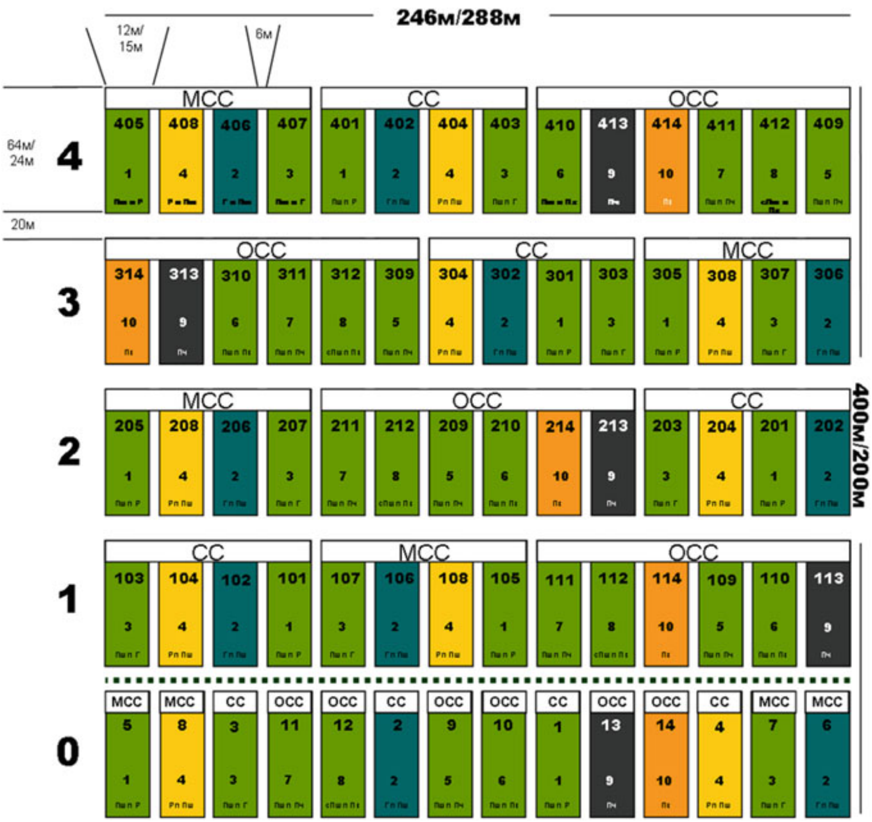


Fig. 25.2 Scheme of the field experiment in LTD KH ‘Partner’, Mikhailovsky district (own data)

1. Spring wheat after rape and peas by CC and MCC technologies: 5 cm depth of seeding, seeding rate of, respectively, 120 and 150 kg/ha, the dose of mineral fertilizers to 100 kg/ha in physical weight;
2. Peas after spring wheat by CC and MCC technologies: 6 cm depth of seeding, seeding rate of, respectively, 180 and 200 kg/ha, the dose of mineral fertilizers 50 kg/ha in physical weight;
3. Rape after spring wheat by CC and MCC technologies: the depth of seed placement 4 and 5 cm, seeding rate, respectively, 4 and 10 kg/ha, the dose of mineral fertilizers to 100 kg/ha in physical weight;
4. Spring wheat after the complete fallow, chemical fallow and wheat by OCC technology: 5 cm depth of seeding, seeding rate 150 kg/ha without fertilizers. On fallow fields, two treatment options were used: mechanical and chemical (glyphosate).

The treatments with glyphosate of continual action were carried out on the plots before sowing. Sowing was done in agrotechnical terms. This was determined by the

Fig. 25.3 Chisel Plow KPSH-9 (Picture by Meinel 2014)

Fig. 25.4 Chisel Plow PG-3–5 (Picture by Meinel 2014)

Fig. 25.5 Sowing machine of the three drills СЗС-2.1 (Picture by Meinel 2014)

Fig. 25.6 Sowing complex Condor (Picture by Meinel 2014)

Fig. 25.7 Soil moisture tester HH-2 (Picture by Meinel 2014)

soil moisture in layers of up to one meter and moisture reserves in the meter layer on the experimental plots in the spring (late April), on shoots (mid-June), and at the harvest (late August) by device HH-2 (Fig. 25.7).

At the time of the shoots, the depth of seed placement, the number of shoots on the rows of crops, and the plant height were determined. At the time of the harvest, evaluations were carried out on a selection of samples of the yield of the plots, the soil moisture in layers, the moisture reserve in the meter layer, plant height, and the elements of the yield structure. The number of shoots, depth of seed placement, and the plant height of the sowed rows were determined at ten different times. Selection of yield's samples was performed five times. The obtained information was processed on a computer to determine the statistics of measured parameters.

In the autumn of 2012 in v. Poluyamki, two PGS were set up to obtain meteorological observations. These stations were placed under the test plots with different cultivation technologies in the rotation: at tier 0, plot 3 (CC technology) and plot 11 (OCC technology) (Belyayev 2015). A full description of the technical characteristics of the automated stations and the features of their installation was published in joint papers.

25.3 Precipitation and Temperatures

Ltd. KH 'Partner' is located in the West Kulunda zone of the Altai region. The amount and distribution of precipitation and temperatures during the growing season according to the weather station in v. Klyuchi for the long-term period were the following (Tables 25.1 and 25.2):

The average yearly precipitation for the long-term period was equal to 328.3 mm.

In 2013–2016, distribution of precipitation and temperatures was the following (Tables 25.3 and 25.4):

Thus, in the years of the research in May–August (growing season), precipitation was in the range of 123.0–180.0 mm with an average value of 148.2 mm. This was below the long-term averages of 20.4 mm in comparison (by 12.1%). Less precipitation during the growing season was observed mainly in June (by 24.7 mm or almost two times less than the norm). Average monthly temperatures for the 4 years of research were similar to the long-term averages, except May, where it was 1.7 °C lower. The sum of growing season temperatures was lower by 38 °C (1.7%) compared to long-term data.

25.4 Soil Water Regime

The data on common moisture reserves in the meter layer of soil on the different variants of technology and cultivated crops for the observed periods of vegetation are shown in Table 25.5.

W_1—rate of water of meter layer of soil during the period from late April to mid-June, mm; W_2—rate of water of meter layer of soil during the period from mid-June to late August, mm; W_0—rate of water of meter layer of soil during the period from late April to late August, mm; Y_f—average physical yield of crops in the different crop rotations and technologies, t/ha.

Table 25.1 Growing season average long-term precipitation, v. Klyuchi

Month	Precipitation in the decade, mm			Total, mm
	I	II	III	
May	7.7	6.0	11.7	25.4
June	16.6	19.1	17.1	52.8
July	24.4	20.1	15.0	59.5
August	16.7	7.0	7.2	30.9
Total	–	–	–	168.6

Table 25.2 Growing season average long-term temperatures, v. Klyuchi

Month	Average temperatures in the decade, °C			Monthly average temperatures, °C
	I	II	III	
May	11.7	16.2	17.0	15.0
June	17.9	19.4	21.2	19.5
July	21.1	21.2	20.6	21.0
August	20.6	19.1	17.2	19.0
Sum, °C	–	–	–	2290

Table 25.3 Growing season precipitation 2013–2016, v. Klyuchi

Month	Precipitation in the decade, mm			Total, mm
	I	II	III	
May	9.3	11.0	13.1	33.3
June	10.3	13.5	4.4	28.1
July	23.0	12.5	23.3	58.8
August	9.0	11.0	8.0	28.0
Total	–	–	–	148.2

Table 25.4 Growing season average temperatures 2013–2016, v. Klyuchi

Month	Average temperatures in the decade, °C			Monthly average temperatures, °C
	I	II	III	
May	13.0	12.7	14.2	13.3
June	17.0	20.6	21.8	19.8
July	20.0	22.2	20.5	20.9
August	20.2	20.1	17.6	19.3
Sum, °C	–	–	–	2252

Analysis of the data shows that in the spring (late April) the common average moisture reserves in the meter layer of soil differed slightly in variants of agricultural technologies for the 4 years of study. The changes were within 179.1–180.3 mm (difference was only 1.2 mm). To mid-June, the difference increased to 11.3 mm (range of changes was 154.5–165.8 mm) and decreased to the end of August to 6.8 mm (range of changes was 97.5–104.3 mm).

During the first observation period (late April-mid-June), the largest rate of soil moisture was produced by MCC technology (24.9 mm) and the minimum—by OCC technology (14.5 mm). During the second observation period (mid-June to late August), the maximum moisture rate was by the CC technology (64.9 mm) and the minimum—by MCC technology (56.3 mm). As a result, during the growing season, the moisture rate of the meter soil layer was practically the same for both MCC and CC technologies (81.2 and 81.7 mm, respectively). For the technology OCC, it was lower—76.0 mm. This was due to the fallow fields in the rotation in OCC technology.

By analyzing the rate of moisture of the meter layer of soil during the growing season on the average yield of grain per field of crop rotation, we come to the conclusion that the lowest value was obtained by the MCC technology (49 mm/t). Differences in water consumption were not significant for both OCC and CC technologies (59 and 58 mm/t) and were much higher compared to the MCC technology.

25.5 Crop Yield

The results of the physical yield of crops by variants of agro-technologies are summarized in Table 25.6.

The yield of spring wheat by the intensive technology in crop rotation 1 (wheat—chemical fallow–wheat–wheat) compared to crop rotation 2 (wheat–complete fallow–wheat–wheat) do not differ significantly, only in the range of 1% (1.92 and 1.93 t/ha, respectively).

The average yield of spring wheat by the technology with the minimum tillage following a rape crop was lower (1.83 t/ha), and after the peas, it was 1.67 t/ha. The respective data for wheat by no-till technology were 1.82 t/ha and 1.62 t/ha.

By both minimal and no-till technologies, a yield of peas of 1.58 and 1.44 t/ha, respectively, was obtained, and the yield of rape −1.49 and 0.74 t/ha, respectively. As

Table 25.5 Averages of moisture reserves in the meter layer of soil on the different variants of technology and water rate during the vegetation 2013–2016, mm

Technology	Dates of the measurements							
	Late April, mm	Mid-June, mm	W_1, mm	Late August, mm	W_2, mm	W_0, mm	Y_f, t/ha	W_0/Y_fmm * ha/t
2013								
MCC	197.2	163.1	34.1	118.6	44.5	78.6	2.46	32
OCC	196.9	181.5	15.5	127.1	54.4	69.8	1.66	42
CC	205.4	184.9	20.5	109.9	75.0	95.5	2.06	46
2014								
MCC	161.3	112.9	48.5	49.5	63.4	111.9	0.86	130
OCC	165.8	120.6	45.2	57.4	63.2	108.4	0.65	167
CC	146.8	96.9	49.9	50.1	46.8	96.7	0.57	170
2015								
MCC	181.2	159.1	22.1	124.2	34.9	57.0	0.74	77
OCC	184.7	166.9	17.8	130.3	36.6	54.4	0.98	56
CC	184.4	172.6	11.7	129.4	43.2	55.0	0.78	71
2016								
MCC	177.9	182.9	−5.1	100.7	82.2	77.2	2.50	31
OCC	173.6	194.2	−20.7	102.4	91.8	71.2	1.74	41
CC	179.9	195.0	−15.1	100.4	94.6	79.5	2.16	37
Average 2013–2016								
MCC	179.4	154.5	24.9	98.3	56.3	81.2	1.64	49
OCC	180.3	165.8	14.5	104.3	61.5	76.0	1.28	59
CC	179.1	162.4	16.8	97.5	64.9	81.7	1.41	58

shown, the minimal technology had a big advantage on fields of rape (by 0.75 t/ha) and peas (by 0.14 t/ha) compared to others.

As a result, for the total crop rotation, the highest yield of grain obtained by technology with minimal tillage (1.64 t/ha), next follows the no-till technology—1.41 t/ha, and last was the technology with intensive autumn tillage—1.28 t/ha. The advantage of the minimum technology in general is comparable to the no-till technology obtained due to the low yield of rape (in two cases).

25.6 Conclusions

1. At different periods of agro-economic development in the Altai region, significantly, different yields were received. This cannot be explained by the variability of weather conditions only. It was no less dependent on the use of technology as well as on state support.
2. General regularities of the water regime and the formation of crop yield were recorded during the 4 years of research in the KULUNDA project.
3. In spring and late summer periods, average moisture reserves in the meter layer of soil do not differ using both MCC and CC technologies (179.4 and 179.1 mm in spring and 98.3 and 97.5 mm in late summer, respectively). But in the first half of the growing season, moisture rate from the meter layer of soil by the CC technology was lower by 8.1 mm and in the second half—higher by 8.6 mm compared to MCC technology. The water rate dynamic varies slightly due to the vegetation.

Table 25.6 Physical yield of crops by different variants of agro-technologies, 2013–2016, t/ha

Technology	Crop in rotation	Yield, t/ha				Average by crop rotation, t/ha
		2013	2014	2015	2016	
MCC	Peas	2.30	0.46	0.74	2.80	1.64
	Wheat	2.47	0.67	1.07	2.48	
	Wheat	2.47	1.09	0.96	2.80	
	Rape	3.15	1.21	0.20	1.38	
OCC	Wheat/complete fallow	2.51	0.99	1.48	2.75	1.28
	Wheat/chemical fallow	2.51	0.97	1.46	2.74	
CC	Peas	2.02	0.15	0.93	2.65	1.41
	Wheat	2.19	0.56	1.01	2.73	
	Wheat	2.19	1.06	0.96	3.07	
	Rape	1.53	0.49	0.21	0.72	

4. With the OCC technology, average common moisture reserves were higher in late summer compared to both the MCC and CC technologies by 6.0 and 6.8 mm, respectively, due to the fallow fields in the crop rotation.
5. As a result, the maximum average crop yield in the crop rotation was achieved by MCC technology (1.64 t/ha). It was significantly higher compared to both the CC and OCC technologies (by 0.23 t/ha and 0.36 t/ha, respectively).
6. The rate of moisture from the meter soil layer by vegetation per unit of yield was minimal when using MCC technology (49 mm/t against 58 and 59 mm/t by the both CC and OCC technologies, respectively).

References

Barayev AI (1988) Selected works. Soil-protective agriculture. Moscow. (in Russian)

Belyayev VI (2014) Ecologic, economic and technological bases of sustainable agriculture in the Kulunda Steppe of the Altai region. In: Digest of the International scientific-practical conference « Environmental and economic strategies for sustainable land use in the steppes of Eurasia under the conditions of global climate change » . Barnaul, pp 65–67

Belyayev VI (2015) Rational parameters of the "No-Till" technology and direct sowing for cultivation of crops in the Altai region. Bull Altai Sci 1(23):7–12

Belyayev VI, Klishbekov TA (2014) Yield of summer wheat in crop rotation in dependence of technology under the dry conditions of North Kazakhstan. Bull Altai State Agric Univ 9(119):9–14 (in Russian)

Belyayev VI, Reshotko NG (2014) The influence of summer wheat fore crops to the soil moisture regime, yield structure and the grain quality. Bull Altai Sci 4(22):221–225 (in Russian)

Belyayev VI, Sokolova LV (2016) The influence of meteorological conditions on the soil water regime and crop yield in the steppe zone of the Altai territory. In: Agricultural science—to agriculture: Digest of the XI international scientific-practical conference (4–5 Feb 2016), in 3 b. Barnaul, b. 2, pp 29–31

Belyayev VI, Volnov VV (2010) Resource-saving technologies for cultivation of grain crops in the Altai region. Barnaul

Belyayev VI, Bovarova M, Priszchepov A, Meinel T, Bugay J, Kovaleva I, Kozschanov N, Kasardzshan M, Frühauf M (2014a) The economic, ecological and technological factors and results of activities of agricultural enterprises in the conditions of the Kulunda Steppe. Barnaul

Belyayev VI, Volnov VV, Fisak IK (2014b) Status and ways of perfection for patterns structure and croplands в in the steppe territories of the Altai region. In: Digest of scientific papers dedicated to the 60th anniversary of the development of virgin and fallow lands. Status and outlook of development of agriculture and crop production. Barnaul, pp 128–135

Belyayev VI, Meinel T, Kozschanov SA, Tissen R, Belyayev VV, Kozschanov NA (2014c) International project "Kulunda": study of innovative systems of machines and technologies for cultivation of crops for the steppe zone of the Altai region In: Agricultural science—to agriculture: Digest of the IX international scientific-practical conference. Barnaul, 2014e, b. 3, pp 3–8

Belyayev VI, Meinel T, Sokolova LV (2014d) Yield formation of spring wheat on various forecrops while minimizing tillage in temperate-arid steppe of the altai territory. In: The role of the virgin and prospects of development of agriculture and crop production in Kazakhstan. Digest of the international scientific-practical conference dedicated to the 60th anniversary of the development of virgin and fallow lands. Shortandy, Astana, pp 158–163

Belyayev VI, Sokolova LV, Chernishkov VN (2016) Comparative evaluation of cropping patterns of West Kulunda zone of the Altai territory. Bull Altai State Agric Univ 9(143):10–17 (in Russian)

Donchenko AS, Kalichkin VK, Soloshenko VA, Altuhov VA, Resnikov VF, Ponko BA et al (2008) Interregional scheme specialization of agricultural production in the Russian regions of the Siberian Federal District. Siberian branch RAS, Novosibirsk, p 95
Gnatovsky VM (2003) Some features of adaptive-landscape systems of agriculture in the Kulunda zone of the Altai region. Siberian Bull Agric Sci 2:91–95 (in Russian)
Goncharov PL (ed) (1988) Farming system in the Altai region. In: Recommendations of all-union scientific research institute of grain farming, Siberian branch. Novosibirsk, p 222
Illiger P, Frühauf M, Schmidt G, Meinel T, Belyayev V, Silantieva M, Kazarian M (2014) Ecosystem conversion and its effects for carbon sink function in West-Siberian Kulunda Steppe. – Accounting and valuation of ecosystem services (ES)—Experience, especially in Germany and Russia. In: Grunevald K, Bastian O, Drozdov A, Grabovsky V (eds) Digest of scientific papers. Bad Godesberg, Bonn, pp 301–320
Kashtanov AN (1974) Protection of soils from wind and water erosion. Moscow. p 215. (in Russian)
Kashtanov AN (2005) Soil-protective technologies—resource bases, and the greening of agriculture. In: Resource-saving technologies for agriculture. Digest of the IX international scientific-practical conference. The All-Russian Research Institute of Agriculture and the protection of soil from erosion RAS, Kursk, pp 15–17
NN (1978) Atlas of the Altai region. Verlag, Barnaul, p 222 (Editor Zarutskaya IP—unknown author)
Ovsinsky NE (1911) New farming system. Moscow, p 279 (in Russian)

Chapter 26
Autumn Tillage, Soil Moisture Content, and Crop Yields

V. I. Belyaev, T. Meinel, R. Meissner, L.-C. Grunwald, V. V. Volnov, E. Stephan and L. V. Sokolova

Abstract The first part of this article gives an overview of soil preparation in the Altai region. In the second step, materials and methods of the research are presented and variants of soil preparation technologies as well as crop rotations outlined. Thereafter, information of water regime of the soils will be provided and the moisture rate of the meter soil layer during the growing season analyzed. Finally, crop yields and relative water rate are considered with respect to soil preparation technologies from which conclusions will be drawn.

Keywords Soil preparation technologies · Tillage · Crop rotation · Soil moisture content · Crop yield

26.1 Overview of Soil Preparation

Soil preparation is an important stage in agricultural production. Tillage is the most important aspect of soil preparation, which is carried out in order to loosen the soil

V. I. Belyaev (✉) · V. V. Volnov
Engineering Department, Altai State Agricultural University, Prospekt Krasnoarmeyskiy, 98, 656049 Barnaul, Russian Federation
e-mail: prof-belyaev@yandex.ru

T. Meinel
TOO Amazone, Saifulina street 3, office 1, 010000 Astana, Kazakhstan

R. Meissner
Helmholtz Centre for Environmental Research- UFZ, Department Soil System Science, Lysimeter Station, Altmaerkische Wische 55, 39615 Falkenberg, Germany

L.-C. Grunwald
BBG Bodenbearbeitungsgeräte Leipzig GmbH & Co. KG, Rippachtalstr. 10, 04249 Leipzig, Germany

E. Stephan
Institute of Geosciences and Geography, Martin-Luther-Universität Halle-Wittenberg, Von-Seckendorff-Platz 4, 06120 Halle, Germany

L. V. Sokolova
Faculty of Biology, Altai State University, Prospekt Lenina, 61, 656049 Barnaul, Russian Federation

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_26

density, to increase organic matter and biogenic elements in the plowing layer as well as to improve phytosanitary and other conditions for the sowing (Belyayev 2013).

In current farming, the basic soil preparation system determines many types of field works and agricultural machinery. Soil preparation, in this case tillage, causes soil erosion and decreases soil fertility. Therefore, practicing deep furrow tillage in steppe regions causes major problems. In addition, soil preparation is an energy demanding activity.

For a long time, the change of understanding of the basic soil-processing system continued. For example, in 1870–1890 in the European part of Russia and abroad the idea about creating a powerful cultivated layer by deep furrow tillage first appeared (Timiryasev 1948; Kostichev 1951). Another approach embraced minimal soil processing. It was shown that not deep tillage in the southeastern part of Russia contributes to better water conservation and improves the availability of nutrients (Ovsinsky 1911; Tulajkov 1963). However, this soil-processing system led to a very large number of weeds in fields and in 1938 was forbidden.

Agricultural science continued to develop. Wiljams (1949) suggested to use a 20–22 cm depth of tillage and to afterward restore the soil structure due to the sowing of legume-grass intercropping of perennial grasses. At about the same time, Malzev (1956) recommended that every year furrow plowing is not needed and is in fact rather damaging. He believed that the less arable horizon is subjected to the treatment, the faster the soil structure is restored. Maltsev's recommendations yielded good results in the Trans-Urals, in the steppe areas of Siberia and in northern Kazakhstan, but only on clean fields and with late sowing dates. At first, one had to destroy the weeds, especially wild oats, due to pre-sowing treatment. However, the system as proposed by Maltsev did not protect the soil from wind erosion in the proper degree.

In the late 1950s, there was a fundamentally new system of agriculture developed and offered for implementation. Barayev et al. (1988) suggested doing tillage with subsurface cultivators to the 18 cm depth. This system allowed saving the stubble and was intended for soils of dry steppes of Northern Kazakhstan and Western Siberia. From then on energy-saving soil-protecting agriculture technologies spread through all of Russia where they were developed further.

In the 1960s and 1970s, some of these studies were carried out in the Altai region. It was shown that subsurface tillage needs lower inputs and in dry years helps saving soil moisture and reduces wind erosion (Kashtanov 1974). However, in years with good moisture and low temperatures, this tillage system did not show any advantages as compared to plowing. There were limiting factors that restrained the extension of the minimal energy-saving soil preparation in the forest-steppe regions of Western Siberia. For example, reducing the depth of the tillage decreased the soil moisture reserves. Reducing the number of treatments of the soil led to a reduction of its aeration, caused reduction in the abundance of aerobic microflora, participating in mineralization of organic matter, and reduced the accumulation of nitrate nitrogen (Kashtanov 1974). Cereal crop yield declined due not only to the deterioration of the soil water regime and plants nitrogen nutrition, but also due to increasing weed infestation (Jashutin 1984; Stolyarov et al. 1998).

During the 1990s, development of minimal tillage was carried out in conjunction with effective herbicides and fertilizers. It was found that the most effective soil preparation system are deep subsurface tillage (24–27 cm) under arid conditions, and furrow, or rotation of furrow and subsurface tillage under high soil moisture conditions (strip plantations, forest belts, snow retention). Without herbicides and fertilizers, minimal subsurface tillage reduced wheat yields by 0.25–0.35 t/ha (Belyayev et al. 2010).

According to many authors, the problem of soil saving is the most acute of modern agriculture (Christen et al. 2002; Unzhakova et al. 2011; Skripko et al. 2013; Belyayev et al. 2014c; Belyayev and Sokolova 2016). Therefore, soil saving and increasing soil fertility are a priority in farming. However, it should be emphasized that this problem cannot be regarded independently. Rather one must take into account economic factors, which largely determine the directions of tillage methods development and hence the improvement of crop production technologies (Belyayev et al. 2014b).

26.2 Materials and Methods

In 2011–2016, the international, interdisciplinary research project KULUNDA was implemented in the Altai region. Its main purpose was the development and introduction of innovative land management technologies for the steppes, designed to prevent further soil erosion, to provide for an increase in soil fertility and efficient use of land resources in the arid zones of the Altai region (Belyayev et al. 2014a).

In 2012 in the Ltd. KH 'Partner', Mikhailovsky district, stationary base platforms were set up in order to monitor the influence of methods of autumn tillage, pre-sowing cultivation, and sowing for the soil moisture regime and yield of crops in crop rotation. The test technology variants are summarized in Table 26.1.

The following cropping technology variants were compared:

1. Autumn tillage—Catros (depth 8–10 cm) (Fig. 26.1), pre-sowing tillage—Catros (depth 6–8 cm), sowing—Condor (depth 4–5 cm) (Fig. 26.2).
2. Without autumn and pre-sowing tillage, sowing—Condor (depth 4–5 cm).
3. Autumn tillage—Catros (depth 8–10 cm), pre-sowing tillage—Catros (depth 6–8 cm), sowing—SES-2.1 (depth 5–6 cm) (Fig. 26.1).
4. Without autumn and pre-sowing tillage, sowing—SES-2.1 (depth 5–6 cm).
5. Autumn tillage—KPSH-9 (depth 14–16 cm) (Fig. 26.3), without pre-sowing tillage, sowing—SES-2.1 (depth 5–6 cm).
6. Autumn tillage—PG-3–5 (depth 20–22 cm) (Fig. 26.4), without pre-sowing tillage,
7. Sowing—SES-2.1 (depth 5–6 cm).

The cultivation of crops was carried out in rotation: spring wheat—peas—spring wheat—spring rape. There were in total four blocks with six variants each.

The following crop sowing process parameters were used:

Fig. 26.1 Machine-tractor aggregates K-701 + Catros (on the left) and MTE-82 + SES-2.1 (on the right) (Picture by Meinel 2014)

Fig. 26.2 Experimental drill Condor (Picture by Meinel 2014)

Table 26.1 Test technology variants, Ltd. KH 'Partner' (own data)

Crop in crop rotation	Plot				Machines		
					Autumn tillage	Pre-sowing tillage	Sowing
A. Rape B. Wheat C. Peas D. Wheat	A1	B1	C1	D1	Catros	Catros	Condor
	A2	B2	C2	D2	–	–	Condor
	A3	B3	C3	D3	Catros	Catros	SES-2.1
	A4	B4	C4	D4	–	–	SES-2.1
	A5	B5	C5	D5	KPSH-9	–	SES-2.1
	A6	B6	C6	D6	PG-3–5	–	SES-2.1

Fig. 26.3 Machine-tractor aggregate K-701 + KPSH-9 (Picture by Meinel 2014)

Fig. 26.4 Machine-tractor aggregate K-701 + PG-3–5 (Picture by Meinel 2014)

1. Spring wheat: sowing rate for Condor—120 kg/ha, SES-2.1–150 kg/ha, doze of fertilizer—100 kg/ha of ammonium nitrate in gross weight;
2. Peas: sowing rate for Condor—180 kg/ha, SES-2.1–200 kg/ha, doze of fertilizer—50, and 100 kg/ha of ammonium nitrate in gross weight for Condor and SES-2.1, respectively;
3. Spring rape: sowing rate for Condor—3.5 kg/ha, SES-2.1–10 kg/ha, doze of fertilizer—100 kg/ha of ammonium nitrate in gross weight;

Before sowing treatments with glyphosate of continual action were carried out on the plots. Sowing was done in agrotechnical terms. By growing spring, wheat treated with tank mixture and peas and rape with 'Forward.' The soil moisture was determined in layers of up to one meter and moisture reserves in the meter layer of soil in the spring (late April), on shoots (mid-June) and during the harvest season (late August) with the help of device HH-2.

At the time of harvest, samples of the yield were taken from the plots; the soil moisture in layers of up to one meter, the moisture reserve in the meter layer and the plant height were determined and the elements of the yield structure evaluated. The obtained information was processed on a computer in order to determine the statistics of measured parameters.

26.3 Results of the Soil Water Regime Determination

Ltd. KH ‘Partner’ is situated in the West-Kulunda zone of the Altai region. The amount and distribution of precipitation and temperatures during the growing season is presented according to the data of weather station in v. Klyuchi.

In 2013–2016, precipitation in May–August (growing season) was 123.0–180.0 mm, on average 148.2 mm. This is 20.4 mm (12.1%) below the average long-term data. Precipitation was especially low in June (24.7 mm less, i.e. almost 2 times lower than the norm). Average monthly temperatures were at the level of the long-term averages, except in May where they were lower by 1.7 °C. The growing season temperatures’ sum was 38 °C (1.7%) lower than the long-term temperatures’ sum.

General moisture reserves in the meter soil layer are shown in Table 26.2.:

As the results show, in late April minimal general moisture reserves in the meter soil layer were found in plots where technologies with autumn tillage by Catros had been applied: №1 (177.7 mm) and №3 (178.5 mm). The maximum was obtained by technology with deep autumn tillage, i.e., PG-3–5 №6 (203.6 mm). The differences are significant. The general moisture reserves in the meter soil layer by other technology variants were very close—187.5–192.5 mm. However, by mid-June, there was an equalization of moisture reserves in the first meter of soil by all technologies. The highest difference was only 6.1 mm and was not statistically significant (174.2–180.3 mm).

During the first observation period (late April–mid-June), the largest spending of water from the soil was by technology №6 with autumn tillage by PG-3–5 (23.4 mm). With regard to technology №1 (tillage by Catros), even an increase of moisture reserves of 1.8 mm was observed. Thus, water spending in the first period of vegetation was significantly reduced when subsurface tillage or no tillage was applied (technologies №1–4) compared to when deep tillage was used (technologies № 5, 6).

In late August, moisture reserves in the first meter of soil were within 122.4–127.0 mm by all technologies and not significantly diverging (only up to 4.6 mm). However, spending of water from the meter layer during the second observation period (mid-June–late August) changed in a wider range (47.2–57.1 mm).

In sum, the maximum spending of water from the meter layer during the growing season could be observed in relation to the application of technology №6 (deep autumn tillage by PG-3–5)—77.1 mm, the minimum in relation to technologies №1 and №3 (autumn tillage by Catros)—52.3 and 52.9 mm. The differences are significant. This means that deep autumn tillage led both to an increase of the moisture reserve in the meter soil layer in the spring as well as to an increase in the spending of moisture during the growing season by the same amount compared with the mulch subsurface tillage technologies.

Table 26.2 General moisture reserves in the meter soil layer and spending water during the growing season 2013–16, mm

Technology, №	Dates of the measurements					
	Late April, mm	Mid-June, mm	W_1, mm	Late August, mm	W_2, mm	W_0, mm
2013						
1	238.8	189.5	49.3	150.2	39.3	88.6
2	217.4	184.9	32.5	130.8	54.2	86.7
3	224.6	186.8	37.8	140.1	46.7	84.5
4	223.3	188.2	35.1	138.0	50.3	85.3
5	214.4	182.9	31.5	145.9	37.0	68.5
6	226.9	190.3	36.6	148.4	41.9	78.5
2014						
1	142.1	108.1	34.0	96.7	11.5	45.5
2	144.5	118.1	26.4	115.0	3.1	29.5
3	128.4	116.9	11.5	98.0	18.9	30.4
4	149.8	113.3	36.5	104.6	8.8	45.2
5	170.8	125.4	45.5	108.9	16.5	62.0
6	153.4	120.7	32.7	109.3	11.4	44.1
2015						
1	168.6	199.1	−30.5	124.3	74.8	44.3
2	190.4	187.3	3.1	125.4	61.9	65.0
3	169.3	177.3	−8.0	130.2	47.1	39.1
4	192.1	193.5	−1.5	123.5	70.1	68.6
5	186.4	165.2	21.2	130.3	35.0	56.2
6	202.1	187.2	14.9	124.6	62.6	77.5
2016						
1	161.3[a]	221.4	−60.1	130.4	91.0	30.9
2	197.9[a]	229.5	−31.6	136.3	93.2	61.6
3	191.5[a]	217.3	−25.8	133.9	83.4	57.6
4	203.8[a]	222.6	−18.8	123.6	99.0	80.2
5	198.2[a]	223.1	−24.9	123.0	100.1	75.2
6	232.0[a]	222.8	9.2	123.9	98.9	108.1
On average 2013–2016						
1	177.7	179.5	−1.8	125.4	54.2	52.3
2	187.6	180.0	7.6	126.9	53.1	60.7
3	178.5	174.6	3.9	125.6	49.0	52.9
4	192.3	179.4	12.8	122.4	57.1	69.8

(continued)

Table 26.2 (continued)

Technology, №	Dates of the measurements					
	Late April, mm	Mid-June, mm	W_1, mm	Late August, mm	W_2, mm	W_0, mm
5	192.5	174.2	18.3	127.0	47.2	65.5
6	203.6	180.3	23.4	126.6	53.7	77.1

W_1: water spending from meter layer of soil during the period late April–mid-June, mm
W_2: water spending from meter layer of soil during the period mid-June–late August, mm
W_0: water spending from meter layer of soil during the period late April–late August, mm
[a]Measurement of the moisture reserve in the meter layer of soil in late April of 2016 was carried out on the block of the plots B

Table 26.3 Crop yield, t/ha, 2013–2016

Technology	Crop/Forecrop				Y_f, t/ha	W_0/Y_f, mm/t
	Peas/Wheat	Wheat/Peas	Rape/Wheat	Wheat/Rape		
A1, B1, C1, D1	1.20	1.11	0.89	1.32	1.13	46
A2, B2, C2, D2	1.14	1.32	0.91	1.38	1.19	51
A3, B3, C3, D3	1.63	1.75	1.29	1.86	1.63	32
A4, B4, C4, D4	1.44	1.69	1.31	1.91	1.59	44
A5, B5, C5, D5	1.44	1.73	1.37	1.83	1.59	41
A6, B6, C6, D6	1.52	1.65	1.43	1.99	1.65	47
On average	1.40	1.54	1.20	1.72	1.47	46

Y_f: average physical yield of crops, t/ha
W_0: water spending from meter layer of soil during the period late April–late August, mm

26.4 Results of the Crop Yield and Relative Water Rate

The crop yield and relative humidity rate are presented in Table 26.3.

The analysis shows that on average across all technologies rape produced the lowest average yield (1.20 t/ha) and spring wheat after rape the highest (1.72 t/ha).

Comparing the average crop yield across technologies, two technologies produced much less than the others: №1 (autumn and pre-sowing tillage by Catros, sowing by Condor) and №2 (without autumn and pre-sowing tillage, sowing by Condor)—with 1.13 t/ha and 1.19 t/ha, respectively. With all other technologies, the yield was within 1.59–1.65 t/ha (without autumn and pre-sowing tillage, tillage by Catros, KPSH-9 and PG-3–5, sowing by SES-2.1). This was due to a significant reduction in the seed rate for sowing by Condor, compared to SES-2.1, because it was assumed that the Condor would provide significantly better seed placement, and the field germination would be significantly better as well.

By analyzing the spending of water from meter soil layer in the rotation during the growing season on the average yield of grain plots, we conclude that the lowest value was obtained by technology №3 (autumn tillage by Catros, sowing by SES-2.1)—32 mm/t, and the maximum value—by technology №2 (without autumn and pre-sowing tillage, sowing by Condor)—51 mm/t. For the other technologies, this parameter was within 4.1–4.7 mm/t.

26.5 Conclusions

1. In late April, minimal general moisture reserves in the meter soil layer were found in plots where technologies with autumn tillage by Catros had been applied: №1 (177.7 mm) and №3 (178.5 mm). The maximum was obtained by technology №6 with deep autumn tillage by PG-3–5 (203.6 mm). The differences are significant. The general moisture reserves in the meter soil layer by other technology variants were very close—187.5–192.5 mm.
2. By mid-June, there was an equalization of moisture reserves in the first meter of soil by all technologies. The highest difference was only 6.1 mm and was not statistically significant (174.2–180.3 mm).
3. During the first observation period (late April–mid-June), the largest spending of water from the soil was by technology №6 with autumn tillage by PG-3–5 (23.4 mm). With regard to technology №1 (tillage by Catros), even an increase of moisture reserves of 1.8 mm was observed. Thus, water spending in the first period of vegetation was significantly reduced when subsurface tillage or no tillage was applied (technologies №1–4) compared to when deep tillage was used (technologies № 5, 6).
4. In late August, moisture reserves in the first meter of soil were within 122.4–127.0 mm by all technologies and not significantly diverging (only up to 4.6 mm). However, spending of water from the meter layer during the second observation period (mid-June–late August) changed in a wider range (47.2–57.1 mm).
5. The maximum spending of water from the meter layer during the growing season could be observed in relation to the application of technology №6 (deep autumn tillage by PG-3–5)—77.1 mm, the minimum in relation to technologies №1 and №3 (autumn tillage by Catros)—52.3 and 52.9 mm. The differences are significant. This means that deep autumn tillage led both to an increase of the moisture reserve in the meter soil layer in the spring as well as to an increase in the spending of moisture during the growing season by the same amount compared with the mulch subsurface tillage technologies.
6. On average across all technologies, rape produced the lowest average yield (1.20 t/ha) and spring wheat after rape the highest (1.72 t/ha).

7. Comparing the average crop yield across technologies, two technologies produced much less than the others: №1 (autumn and pre-sowing tillage by Catros, sowing by Condor) and №2 (without autumn and pre-sowing tillage, sowing by Condor)—with 1.13 t/ha and 1.19 t/ha, respectively. With all other technologies, the yield was within 1.59–1.65 t/ha (without autumn and pre-sowing tillage, tillage by Catros, KPSH-9 and PG-3–5, sowing by SES-2.1). This was due to a significant reduction in the seed rate for sowing by Condor, compared to SES-2.1, because it was assumed that the Condor would provide significantly better seed placement, and the field germination would be significantly better as well.
8. The spending of water from meter soil layer in the rotation during the growing season on the average yield of grain plots was obtained the lowest by technology №3 (autumn tillage by Catros, sowing by SES-2.1)—32 mm/t and the maximum—by technology №2 (without autumn and pre-sowing tillage, sowing by Condor)—51 mm/t. For the other technologies, this parameter was within 4.1–4.7 mm/t.

References

Barayev AI (1988) Selected works. Soil-protective Agri. Moscow: (in Russian)

Belyayev VI, Volnov VV (2010) Resource-saving technologies for cultivation of grain crops in the Altai region. Barnaul

Belyayev VI (2013) Technical and technological support of resource-saving technologies of grain production in the Altai region. Curr Stat Siberia Inf Stat J 1:72–81 (in Russian)

Belyayev V, Bovarova M, Priszchepov A, Meinel T, Bugay J, Kovaleva I, Kozschanov N, Kasardzshan M, Frühauf M (2014a). The economic, ecological and technological factors and results of activities of agricultural enterprises in the conditions of the Kulunda Steppe. Barnaul: p 237

Belyayev VI, Kudryavzev AE, Volnov VV (2014b) Agro-ecological aspects of the fertility of arable soils of the dry steppe of the Altai. In: Digest of the international scientific-practical conference. Ecological and economic strategies for sustainable land use in the steppes of Eurasia under the conditions of global climate change. Barnaul, pp 96–100

Belyayev VI, Meinel T, Sokolova LV (2014c) Yield formation of spring wheat on various forecrops while minimizing tillage in temperate-arid steppe of the Altai Territory. In: The role of the virgin and prospects of development of agriculture and crop production in Kazakhstan. Digest of the International Scientific-Practical Conference Dedicated to the 60th Anniversary of the Development of Virgin and Fallow Lands. Shortandy, Astana, pp 158–163

Belyayev VI, Sokolova LV (2016) The influence of meteorological conditions on the soil water regime and crop yield in the steppe zone of the Altai territory. In: Agricultural science—to agriculture: digest of the XI international scientific-practical conference (2016, February, 4–5), in 3 b. Barnaul, b. 2, pp 29–31

Christen O, O'Halloran-Wietholtz Z (2002) Indicators for a sustainable development in agriculture (English summary of: Christen, O. and O'Halloran-Wietholtz, Z. (2002). Indikatoren für eine nachhaltige Entwicklung der Landwirtschaft. ILU Series 3/2002, Bonn: FIL)

Jashutin NV (1984) Basic principles of design and development of zonal soil-saving agrocomplexes. Bull Agri Sci 3:18–24 (in Russian)

Kashtanov AN (1974) Protection of soils from wind and water erosion. Moscow, p 215. (in Russian)

Kostichev PA (1951) Selected works. Moscow: (in Russian)

Malzev TS (1956) The new system of processing and sowing. Moscow: (in Russian)

Ovsinsky NE (1911) New farming system. Moscow. (in Russian)
Skripko MS, Zavalishin SI, Skripko VV (2013) Research of change of the soils in Blagovezschensky district (taking the example of the 'Novy Put' farm). Digest of the International Youth Summer School 'Lomonosov Readings in Altai', Barnaul, November 5–8, 2013: in 6 books. B .V. pp 360–363
Stolyarov VM, Volnov VV, Stezov GJ, Shott PR (1998) The cultivation of spring wheat on the basis of minimizing the processing of soil in the steppe and forest-steppe regions of the Altai region. In: Agricultural productions in the Altai region in current conditions: problems and solutions. Digest of regional scientific-practical conference, Barnaul, May 4–5, 1998, Part 1, pp 149–158
Timiryasev KA (1948) Selected works. Moscow. b. 2. (in Russian)
Tulajkov NM (1963) Criticism of grassland farming systems. Moscow. (in Russian)
Unzhakova AA, Zavalishin SI, Ananyev YS (2011) Influence of soil enzyme activity on the spring wheat yield formation. Agricultural science—to agriculture: digest of the VI international scientific-practical conference, vol. 2, pp 281–284. Barnaul, February 3–4, 2011 (in Russian)
Viljams RV (1949) Soil science. Moscow, (in Russian)

Chapter 27
Perspectives for a Sustainable Production of Row Crops in Systems of Minimised Tillage—A Special Focus on Sunflower Cropping in Western Siberia

L.-C. Grunwald, T. Meinel, N. A. Kozhanov, N. V. Rudev and V. I. Belyaev

Abstract Sunflower and corn are widely spread row crops in the continental agricultural steppes of America and Eurasia. Sunflower, in particular, is more demanding than other common regional crops regarding the preparation of the soil and nutrient supply. Due to the high profits in sunflower farming, significant investments have been made into intensive mechanical soil preparation and plant nutrition. Due to the open nature of row crops until late in the vegetation season, the soil is exposed to wind and water erosion for long periods of time. Spreading large amounts of required nutrients as mineral fertiliser is only practical to a limited extent due to low precipitation and its uneven temporal distribution. Deep soil tillage in strips with simultaneous fertiliser placement in deeper soil layers represents an economically and agriculturally sound alternative to full-area loosening. The soil is cleared in strips from any harvest residues. This procedure improves germination and emergence conditions in the cold spring. In the deeply loosened strips, plant roots grow more quickly towards the fertiliser depot worked into the soil. The targeted deep growth helps plants to open up more soil water resources and survive drought periods. Traction per unit area and therefore fuel, time and costs can be saved because the soil is loosened in strips only. The agricultural and economic profitability of the strip-till method for sunflower and corn was tested in a dry steppe location for several years as a part of the KULUNDA research project. Optimum values for the working depth and amount of fertiliser were determined for the location.

L.-C. Grunwald (✉)
BBG Bodenbearbeitungsgeräte Leipzig GmbH & Co. KG, Rippachtalstr. 10, 04249 Leipzig, Germany
e-mail: LarsChristian.Grunwald@bbg-leipzig.de

T. Meinel
TOO Amazone, Saifulina Street 3, Office 1, 010000 Astana, Kazakhstan

N. A. Kozhanov · N. V. Rudev
OOO Partnior, Uliza Sovetskaya 31, Poluyamki 658966, Russian Federation

V. I. Belyaev
Altai State Agricultural University, Prospekt Krasnoarmeyskiy, 98, 656049 Barnaul, Russian Federation

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_27

Keywords Row crops · Sunflower · Wind erosion · Water erosion · Strip tillage · Plant available water · Plant nutrition · Nutrient supply

27.1 Introduction

The monoculture of summer wheat and later the use of black fallow for improved weed control, nutrient mobilisation and water storage were extended to about 42 million ha by the Virgin Lands Campaign Tselina primarily in northern Kazakhstan and Western Siberia (Eule 1962; Wein 1980). For a long time, this 'crop rotation' was the most used method of agricultural production in the steppe regions of the Transural. In the early 2000s, businesses started to develop different crop sequences and to cultivate other, more profitable crops beside summer wheat. Apart from grains and buckwheat [*Fagopyrum esculentum*], row crops are mostly grown. Corn [*Zea mays L.*] for corn maize and for corn silage as animal feed as well as sunflowers [*Helianthus annuus L.*] are primarily grown. Due to its continental climate, the region has a high number of sun hours and high temperatures during the summer months which are favourable for sunflower cultivation. The sunflower acreage increased in the last years (see Fig. 27.1). Sunflowers are now the most profitable crop for many businesses because they bring high sales prices.[1] Besides the financial benefits of selling sunflowers, this crop is very resistant to the recurring droughts of the early summers in northern Kazakhstan and Western Siberia. Sunflowers as well as corn are grown at 70 cm row distance.

27.2 Growing Sunflowers—Even Today an Intensive Cultivation System

The effort to grow row crops is generally quite high in comparison with grains. It requires a larger area for each individual plant which explains the large inter-row space and the large distance between the plants within each row.[2] Therefore, weed control and tillage are very important. Because of the wide row distance, the soil is without shade for a longer time in comparison with the more densely planted grains (Bordon et al. 2011) which provide competing weeds and self-set plants from the previous year's crop excellent growth conditions. Therefore, intensive tillage is used in traditional soil management systems for growing sunflowers and corn.

Even businesses, which are already using minimised tillage or even direct seeding systems for growing grains and animal feed, usually apply intensive tillage and hoeing between rows after the seedlings emerged when growing sunflowers (see Fig. 27.2).

[1] Price for common wheat (Altai Krai June 2017): 8800 RUB–7300 RUB; Price for Sunflower (Altai Krai June 2017): 15,000 RUB (Agronovosti 2017).

[2] 70 cm row distance, about 28 cm distance between plants within the rows at 50,000 seeds per ha.

Both methods help to control weeds very well. Furthermore, nutrient availability rises due to increased mineralisation of humus by the repeated tillage and the soil's changing moisture penetration and aeration (Havlin et al. 1989). By mobilising the nutrients of the soils, less additional fertiliser is needed when growing the crop.

Further, the tilth requirements for sunflowers cause many farmers to use large-scale and intensive tillage. Sunflowers require a high temperature sum of at least 1450 °C for optimal growth (Proplanta 2017). The vegetation period is short in north-

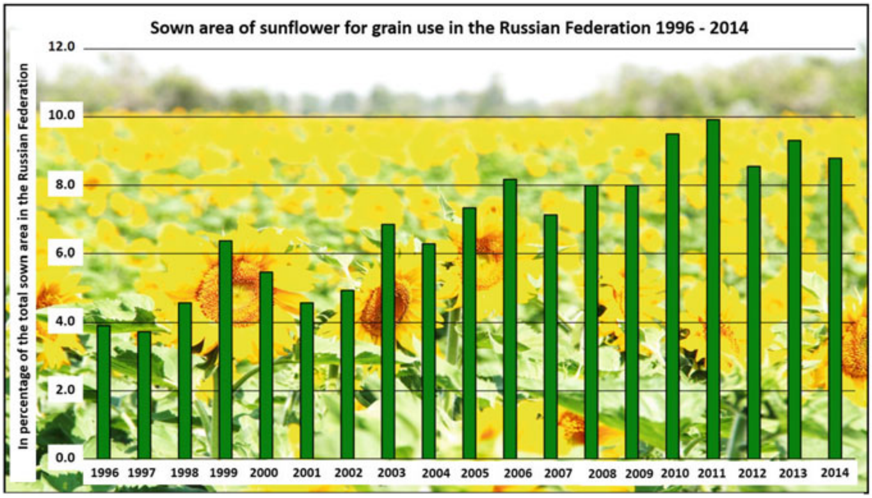


Fig. 27.1 Sunflower acreage relative to the total acreage of arable land in the Russian Federation (RF) 1996–2014 (ROSSTAT 2014)

Fig. 27.2 Tillage for weed control before sunflowers sowing, Altai Krai 2012 (GRUNWALD)

Fig. 27.3 Not harvested sunflowers in the snow, Altai Krai March 2015 (*photograph* Grunwald 2015)

ern Kazakhstan and Western Siberia, and very early sowing is required to achieve the temperature sum during the growth period.

Time for harvest is close to or already during the first frost which often decreases yield quality and sales. Losses are even worse if the sunflowers cannot be harvested until next spring (see Fig. 27.3).

To achieve the ripening as early as possible before the first frost, the maximum duration of the growth period must be used. The time of sowing sunflowers is usually at the end of April/ beginning of May in Western Siberia. Frosts often still occur at that time (Charlamova 2013) which hinders the warming of the soils. By tilling, the soil is kept cover-free, and the soil horizon containing the seeds warms up faster during the day. Germination is stimulated, and the seedlings emerge and develop faster.

A deep loosening of soil promotes the development of a well-established root system. The sunflower's taproots go very deep and develop faster if the soil's bulk density is less (Veihmeyer and Hendrickson 1948). Soil compaction leads to the development of a very flat root ball and, thereby, causes moisture stress and nutrient deficits. Figure 27.4 displays an idealised image of the sunflower's root system. Most of the roots reach a depth of 80 cm. Some long roots grow about 2 m deep where they can tap in water resources which are very important especially during dry spells. A quick root development into deeper soil horizons is very important particularly regarding the frequent early summer droughts because the plants are not completely developed in June.

These are the main reasons why very intensive tillage practises for growing sunflowers are still in use even in the driest regions of the Eurasian Steppe and despite the well-known problems.

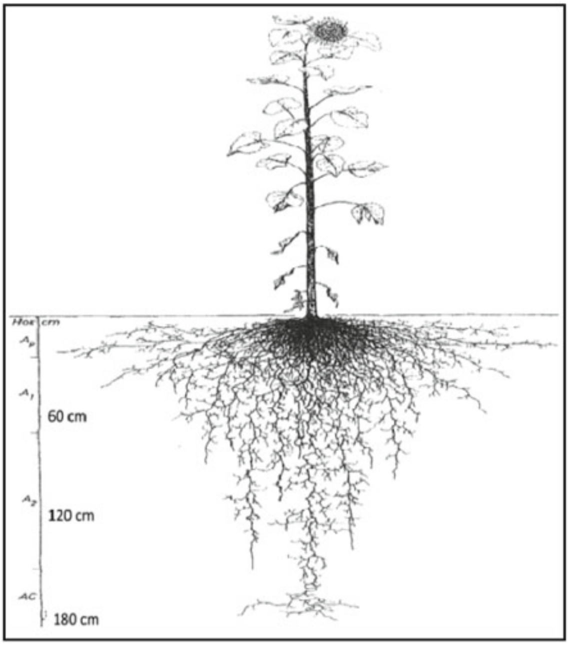


Fig. 27.4 Sunflower with typical root system—taproots up to 2 m deep are common and help to access water in these horizons (Kutschera et al. 2009)

27.3 Risks of Using Intensive Tillage for Growing Row Crops

Due to the very late complete coverage by plants, which is a result of the wide row distance, wind and water erosion are omnipresent risks of growing sunflowers by using intensive tillage systems. The increased loosening of the soil by crushing the soil aggregates, particularly in soils with a high clay percentage, rises the risk of soil compaction caused by the usage of heavy machinery (Sommer et al. 2002).[3] Soil compaction can have a negative effect on corn which can result, for example, in root deformation (see Fig. 27.5, right photograph).

Loosened soil and minimal or even no coverage by plant residue after harvesting due to large-scale tillage results in increased evaporation (Cuthfort and McConkey 1997; McConkey and Stumborg 2003). The weather is often very warm and dry in northern Kazakhstan and Western Siberia at the time of sowing. Sukhoveys[4] cause high losses of soil moisture which can become even greater with wider row distances (Kazhtanov 1974). If the sowing layer is becoming already too dry, sowing needs to be done at a greater depth. Due to the wide inter-row space, the soil is very susceptible to water erosion and siltation during torrential rainfalls (Larson et al. 1983). Especially young crops are sensitive to soil encrustation. Water infiltration and gas exchange

[3] Additionally, often wrongly balanced machines and wrong (too high) tyre pressure are used.

[4] Dry and warm wind in Central Asia during south-west weather condition.

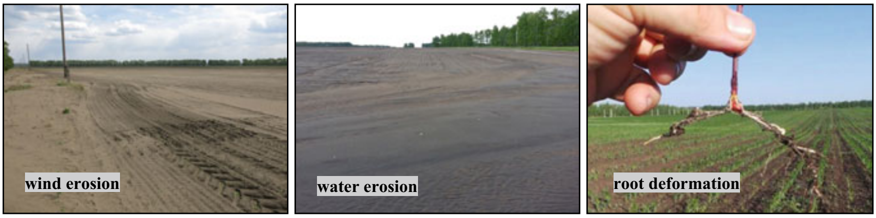


Fig. 27.5 Common problems due to intensive tillage of row crop plots—erosion and stunted growth due to soil compaction (left and middle photograph: Grunwald 2014; right photograph: Bergmann 2014)

Fig. 27.6 Water erosion and siltation after a summer thunderstorm on a field of young sunflower plants, July 2012 (*photograph* Grunwald 2012)

between soil and atmosphere are reduced. The tillage intensity should be reduced, and the tillage system should be technically and agronomically converted to limit the risks of erosion and evaporation and to reduce the costs of large-scale tilling (Fig. 27.6).

27.4 Reducing Tillage in Intensive Crop Farming Systems—Also a Challenge for Plant Nutrition

The sunflower harvest of Western Siberia and northern Kazakhstan is sold to oil mills and—very profitably—to roasting plants. Seed size and quality are crucial and determine the profit. Therefore, the optimal nutrition of the crop is very important. Fertilisation is required to provide the necessary nutrient amount in plant-available form. Fertiliser must be applied in the right form to minimise any losses. The blanket-like application of solid fertiliser is possible, but the weather must be taken much more into consideration in Western Siberia than in other, more humid farming regions. Humidity is for most of the growth period very low. Precipitation occurs seldom and very localised during the summer months. Insolation and potential evaporation are very high (Milkov 1977; Charlamova 2013). Mineral fertilisers cannot be dissolved under these conditions. Instead, they are leaking into the atmosphere by volatilisation resulting in financial losses (PAMI and SSCA 2000). Under these climatic constraints, blanket-like adequate fertilisation is technically and agriculturally very difficult to achieve. Therefore, fertiliser is increasingly applied into the soil and directly close to the seed in the dry farming regions of Western Siberia and northern Kazakhstan.

An initial fertiliser dose containing mainly ammonium and nitrogen can be applied directly into the seed furrow with the right machinery at the time of sowing. The initial fertilisation accelerates germination and crop establishment. If seed and fertiliser are placed in the same furrow, the fertiliser amount must be significantly reduced depending on soil moisture and weather conditions.[5] A limit of 30 kg/ha of nitrogen is recommended. An application of much larger nutrient amounts is possible, too, beside the initial dose. This way, nutrients are available during the entire growth period of the crop. But the separation of seed furrow and fertiliser furrow is essential to prevent damages of the seed (see Fig. 27.7). Germinating sunflowers are very sensitive to high fertiliser amounts in their proximity. Higher fertiliser amounts should be placed separately in a second furrow away from the seed (PAMI and SCCA 2000; NSA 2017). Nitrate and ammonium are very soluble in water and, therefore, transported quickly by soil solution. This, however, requires a sufficient amount of water. Due to low precipitation and high evaporation in the steppes of Western Siberia, nutrient movement by soil water is very localised. Overall, the soil moisture decreases during the growth period due to evaporation and water uptake by plants resulting most of the time in ascending soil water. The deposition of the necessary total nutrient amount into the topsoil is not applicable for the sunflower with its deep root system because of the limited nutrient movement into deeper soil horizons.

For example, phosphorus as the second-most important macro-element of plant nutrition (Baeumer 1992) is a much less mobile nutrient than nitrogen. The smallest amount of soil phosphorus (about 1–2 kg/ha[6]) is available as phosphate in the soil solution. Up to 65% of the total soil phosphorus is organic, and its release is minimal. Only phosphorus bound in microbial mass and plant residue is easily mineralisable. The phosphorus concentration in the soil solution is usually very low, and there is almost no movement of phosphorus by the soil solution.

The plant availability of phosphorus depends on fertilisation (Baeumer 1992).

If phosphorus (P) and potassium (K) fertiliser would be applied on the soil surface and tillage would be reduced, the nutrients could not reach deeper soil horizons due to the dry climate. Potassium and phosphorus are important for strong plant development and resistance to moisture stress (NSA 2017). Plant growth, especially leave size, inflorescence and infructescence depend on phosphorus. A thorough mix-

[5]Ammonium, nitrate and potassium salts can burn seeds and plants if the concentration is too high and soil moisture too low which can result in high yield losses.

[6]As $H_2PO_4^-$ or HPO_4^{2-}—ions in solution.

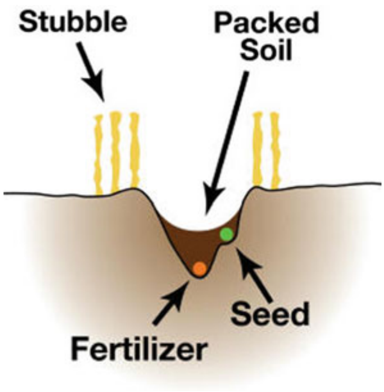


Fig. 27.7 Separate deposition of seed and fertiliser prevents damages of the seed by high fertiliser amounts (courtesy of JOHN DEERE)

ing or even turning the soil with a plough has its advantages regarding the nutrient availability which are lacking in systems with reduced tillage. Intensive tillage and the crushing of soil-humus-aggregates accelerate the mineralisation of soil-carbon-compounds/humus which results in a higher nitrogen availability (Zigon and Mihelic 2015). The nutrients are incorporated into greater depth by thorough mixing or turning of the soil which is advantageous for more immobile nutrients. This is not possible with minimised tillage practises.

If the intensity and depth of tillage are reduced for erosion prevention and cost savings, the development of a nutrient layer in the soil can be a result. Phosphorus and potassium compounds accumulate in the topsoil because of the reduced incorporation of crop residues (Deubel et al. 2011).

A concentrated application of fertiliser during tillage is an option to place primarily immobile nutrients in deeper soil horizons where they would not get due to minimised tillage intensity.

27.5 Strip-till for Growing Row Crops—An Alternative and a Compromise

Soya bean and corn are grown often in a close soya bean/corn rotation in the Great Plains of North America.[7] Over time, the crop rotation became much simpler in North America than in the post-Soviet regions. Beside alfalfa, no other crops are grown in a lot of regions. Tillage intensity was much higher in the past. Many farms employ only a few workers in relation to the farmed acreage, and the productivity/output per acre of large-scale tillage reaches its limits. Work widths cannot be extended endlessly. The required drawbar power would be too high. It would be too high also at higher speeds, beside the material wear.

[7] The purpose is animal feed production (fodder crop farming) for intensive cattle farming.

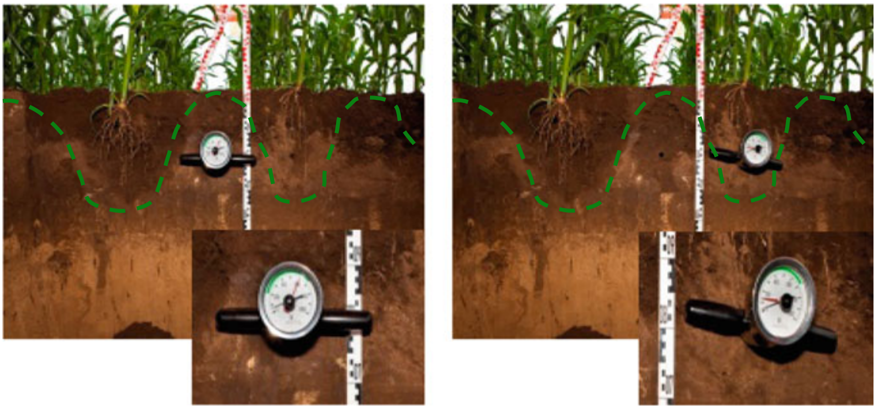


Fig. 27.8 Loosening of a Chernozem by strip-till near Bernburg in Central Germany (Grunwald 2012)

The fuel consumption is already steadily on the rise and is even less justified by increasing fuel costs. In row cropping systems, a new tillage system called s*tipe tillage* or *strip-till* is increasingly used not only in North American farming regions. The tillage/soil loosening is done only for the seed row when strip-tilling (Herrman et al. 2012).

Two-thirds of the soil is not tilled (Hermann et al. 2012; Morrison 2002). The reduced tillage of the soil in strip-till systems has advantages for the soil which are already known from direct seeding system for growing grains. Soil mechanic, especially aggregate stability, pore volume and pore size distribution improve (Simmons and Nafziger 2012). The infiltration rate during torrential rains increases as well as the trafficability. The risk of damaging compaction is reduced.

Especially in dry farming regions, the usage of soil water in greater depths by the crop is very important. Quick, healthy root development is favourable for plant development and can be achieved by strip-till. Compaction of the bottom soil due to conservation tillage can be counteracted by strip-till. Figure 27.8 shows the different penetration resistance of the tilled and not-tilled part of a Chernozem near Bernburg in Central Germany. The loosening in the strip stimulates root growth specifically into the depth. The temperatures of soil and atmosphere are usually very low at the end of April. Fast soil warming is of advantage for the germination of the crop (see Fig. 27.9). The germination conditions improve after sowing in spring because of the wide-tilled furrow in strip-till systems. This is an advantage which strip-till has in common with large-scale tillage.

The deep tillage of strips is a compromise between necessary intensive tillage for healthy crop development in a well-loosened seedbed and the minimisation of tillage to prevent erosion, decrease evaporation and reduce costs.

Strip-till cultivators are usually pulled by a tractor. A combination of several tools is used with this machinery which is completing several tasks during one work

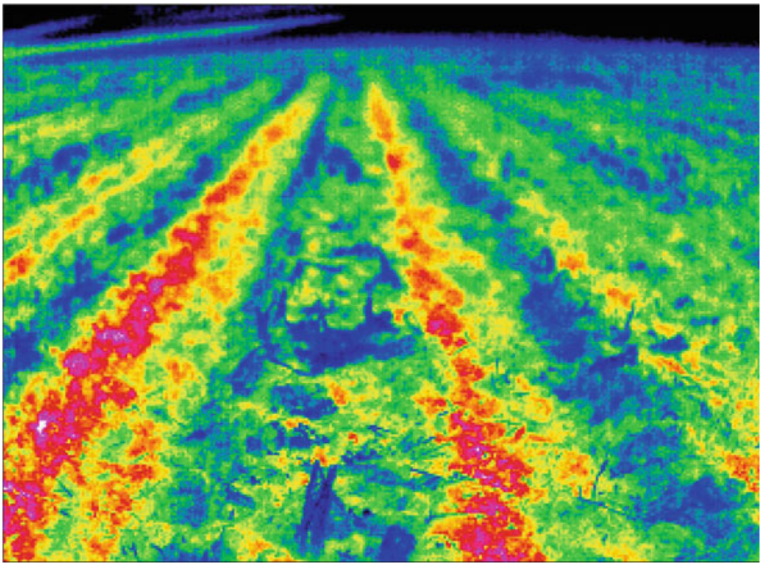


Fig. 27.9 Faster soil warming of the furrows after strip-till—better germination especially during cold weather in spring (Bayerische Landesanstalt für Landwirtschaft—*Source* https://www.lfl.bayern.de/mam/cms07/ilt/dateien/vortrag_strip_tillage.pdf)

cycle. Organic material must be chopped which prevents clogging during the deep loosening later. Clearing tools like star-notched disc blades or wave disc blades, which are installed in a V-like angle in driving direction before the actual loosening tool, clear the working area from the residues from the previous crop. They ensure a wide, uncovered strip and prevent clogging of the whole machinery. The actual tilling tool is either a disc share or a tine share. The advantage of disc shares is less clogging. Disc shares cut the residues of the previous crop and open the soil surface. If the pressure applied to the disc shares is insufficient, residues can get pushed into the soil (hair pinning effect). A dense residue matt can cause problems regarding loosening the topsoil and ensuring access to the soil water of deeper soil horizons. If the disc shares cut through the crop residue and into the soil, particularly wave disc shares produce a lot of fine soil which has many advantages for the seedbed quality. Tine shares as loosening tools clear reliably the furrow from crop residue. There is no problematic pushing of straw into the furrow. Tine shares are easily inserted in the soil and keep the whole cultivator on track on the set tilling depth. The accumulation of crop residue around the share tips is a disadvantage of using tine. Therefore, it is very important to use good clearing tools for the shares. The tillage depth of a tine share is deeper in comparison with the disc share, and soil can be loosened even below the topsoil which facilitates the root development of the crop. The combined usage of soil reflecting discs with tine shares makes sense. They push the soil around the tine back into the furrow and thereby increase the maximal driving speed (Fig. 27.10).

Fig. 27.10 Strip-till cultivator attached behind a liquid manure spreader. To prevent ammonium volatilisation, it is very important to avoid any delays of spreading manure (Edited by the author, courtesy of www.vogelsang.info)

Two contact points keep the depth of the coulter system on track. The front contact point might be a roller paired with the coulter blade. The contact point at the back is most of the time a pair of rollers.

Open cage rollers are common for loosening of the soil's surface as well as V-shaped rollers which apply higher pressure to the furrow sides and thereby ensure secure access to the capillary fringe. The type of rolls used depends on local conditions.

Liquid or granulate fertiliser can be applied with the loosening tine in the soil. A tine behind the share provides a zone with a little or no soil movement while working the soil.

This is the part where a fertiliser supply line can be attached. In regions with a high percentage of fodder crop farming, large amounts of liquid manure are applied to the soil and directly underneath the future seed row by using a tine with the strip-till system (Fig. 27.11).

Organic nutrients can be added at 20 cm or even 30 cm beneath the soil surface. This kind of fertiliser application cannot be realised on an entire plot. The large amount of liquid manures of up to 50 m^3/ha would increase the soil moisture too much, and the incorporation of the fertiliser in the soil by a cultivator would be impossible. The depth for large-scale applications is usually between 8 and 12 cm, and disc harrows are used. The relative acreage of fodder crop farming is very low in the dry farming regions of northern Kazakhstan and Western Siberia. Liquid manure application with a strip-till cultivator is not common but might be possible in smaller mixed-farming businesses and could be a good starting point to improve the nutrient availability and tilth. Crops are primarily grown for direct marketing. If fertiliser is used, mineral fertiliser is applied by blanket-like spreading or by incorporation

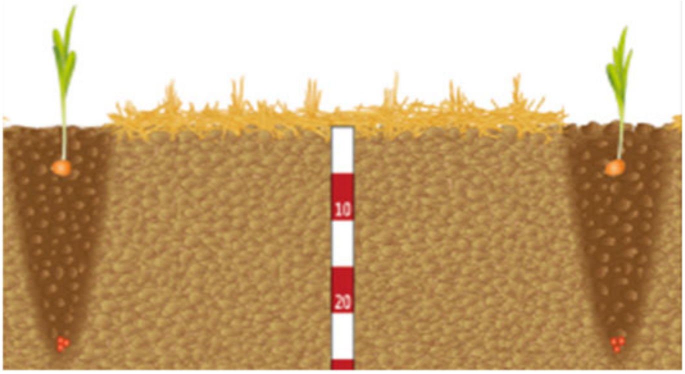


Fig. 27.11 Scheme of the classic strip-till without large-scale deep tillage of the soil. Inter-row spaces stay covered, fertiliser application at tillage depth (courtesy of Amazonenwerke 2013)

into the soil. Here, the potential for improvement must be found and used. Strip-till machinery can combine the steps of tillage and fertilisation and place the fertiliser into the root zone of the crop. Dissolving fertiliser in soil water is still necessary for the plant availability, but it easier to achieve because the nutrients are already inside the soil. This technique might be a promising alternative to large-scale tillage in dry farming regions with an increasing portion of row crops in the crop rotation. Further targets are cost reduction in the operation and stabilisation or even increase in yields.

27.6 Strip-till for Growing Row Crops—Chances to Increase Effectivity

Field tests have been conducted on the topic of strip-till as part of the KULUNDA project[8] since 2012. The test business partner in Poluyamki, Altai Krai (RF), had already started pretests with its own approach during the season of 2011/12 (Fig. 27.12).

A conventional wide wing cultivator intended for deep large-scale tillage was modified. The wing share was cut so that the tillage was limited to the share arm and its 3-cm-long wings and only a small strip was tilled.

The short guidance wings provide the necessary grip to pull the machinery to the right tillage depth in the soil. That helps with keeping the weight of the construction as low as possible. The first prototype of a strip-till cultivator was delivered by the Amazonenwerke in 2012. The tools were still quite simple. The loosening share

[8]Joint research project funded by Germany's Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung—BMBF) to increase the sustainability of land management in the agricultural steppes in Western Siberia. Project period from 2011 to 2016 (www.kulunda.eu).

Fig. 27.12 Tine of a cultivator for large-scale deep tillage, now modified for strip-till after harvest (*photographs* Kozhanov 2011)

Fig. 27.13 First prototype of a strip-till cultivator by the Amazonenwerke—the tilled surface was still very rough because the cultivator was not equipped with tools top crumble the soil clods (*photographs* Kozhanov 2012)

was followed by covering discs and a wheel for reconsolidation. The tilled surface was quite rough, and the reconsolidation of the tilled strip was insufficient. That lowered the work rates of the precision planter which is directed on the tilled furrows (Fig. 27.13).

Testing was continued with a machine ready to go in production in 2013, and tillage tests were initialised. A coulter blade is installed before the tine share. It cuts into the soil and takes off the tension. The soil now moves easier around the share.

Additionally, the danger of clogging is minimised by cutting the harvest residue. The covering discs push a large portion of the soil back to the furrow where it is neatly reconsolidated forming a ridge.

The ridge is important when tilling in fall. Soil sags due to the snowmelt. The ridge prevents that it sags too deeply which would impede seed placement.

Fertiliser application at tillage depth is possible with this system, too. All tools are individually adjustable, and the adaption to local conditions and soils is very easy. The furrow formation is very precise (Fig. 27.14).

Fig. 27.14 Strip-till cultivator with several tools for optimal loosening, fertiliser incorporation, and reconsolidation of the soil (courtesy of Amazonenwerke 2013)

Fig. 27.15 Precisely defined, well reconsolidated and even rows achieved by the combination of several tools and their correct adjustment. Left: tillage of fallow, right: tillage after summer wheat (*photographs* Grunwald 2014)

A good reconsolidation is important during tillage in spring. The connection to the capillary fringe must be made because of the quick prevailing dryness. Reconsolidation is not that important when tilling in fall.

Soil sags in the furrow because of frost tilth and meltwater infiltration during snowmelt. In both cases, the neat return of the soil to the furrow is important. If dispersed soil is insufficiently returned, a dent forms in the furrow area. Soil dispersed to left and right of the row results in an erratic track and poor depth guidance of the later running seeder share affecting placement quality and seed emergence (Fig. 27.15).

Fig. 27.16 KPSH9—Large-scale cultivator for medium depth tillage and seedbed preparation, three-rowed, heart or wing shares, here displayed with pusher blade, heart shares and tandem cage roller for a fine seedbed preparation (http://agromehanika.ru/ proizvodstvoKPSH.htm, 12.02.2017)

27.7 The Strip-till Tests of the KULUNDA Project in 2013/2014

Tests were conducted using the strip-till cultivator of the Amazonenwerke GmbH & Co. KG in the test business partner of the joint research project KULUNDA in 2013 and 2014. Goal was to try strip-till in row cropping systems. Tests were established for growing sunflowers (*Helianthus annuus L.*). Soils were tilled after harvest in fall of the previous year. Tillage depth was changed on several different test lots for strip-till variations. Loosening was conducted, and fertiliser was incorporated at the following depths: 16–18, 20–22, 26–28 and 32–34 cm. Two conventional cultivation methods were used for comparison. The first was large-scale tillage with a three-rowed cultivator with heart shares at 16–18 cm depth (see Fig. 27.16). The soil surface is pried open, and the topsoil is thoroughly mixed. The second conventional method cuts the entire soil surface open to a depth of 20–22 cm. The soil is lifted and cut because the distance between the share arms of the cultivator is 1 m, and the share blades have a wide but very flat orientation towards the soil. But the large-scale breakup of the topsoil is avoided (machinery see Fig. 27.17). To compare with extensive cultivation methods, one test lot was tilled only 8 cm deep by using a compact disc harrow, and another test lot was established as a direct seeding test lot. Here, no cultivation method was used except for opening the soil for seed placement.

Furthermore, different fertiliser amounts were applied to the strip-till test lots. For each tillage depth, fertiliser amounts of 50, 100, and 150 kg/ha were placed at tillage depth. AMMOFOS—10 to 12% N and 52% P based on monoammonium phosphate ($NH_4H_2PO_4$) were used as fertiliser.

Fertiliser was applied during strip-tilling in fall. As described earlier, almost no nutrient leaching is expected because of the hard frosts in winter and the immobility of the phosphates. This fertiliser band at tillage depth is the depot for the crop to be seeded in the next spring.

Fig. 27.17 PG 3-5—deep, large-scale cutting cultivator—mechanical erosion prevention and weed control (*photograph* Grunwald 2013)

The Turkish sunflower cultivar 'Armada' was sown with 55 000 seeds/ha during the first week of May in both years. Before sowing, pre-emergence spraying of glyphosate (2 l/ha per 100 l/ha tank mix) was conducted. The crop protection method was not diversified in relation to the intensity of the cultivation method.

Crop protection measures against insects, crop diseases and further self-set plants from previous crops were applied as usually and in the same way on all test lots during the vegetation period.

The goal of this test was to determine which fertiliser amount results in the highest yield under the given local and weather conditions during the growth period. Another target was to find the optimal tillage depth with regard to the required drawbar power and resulting crop yield.

The tests assume that an optimal strip-till depth exists up to which it is advisable to loosen the soil and place the fertiliser. Crucial for this assumption is the high deficit of water. Below a certain depth, the fertiliser band is probably not accessible in time by the crop's young root system. The result would be financial loss due to excessive fuel consumption and inefficiently applied fertiliser. The test lot's location was not a fixed one on the business's area plan. The location changed on the area plan with the normal rotation of the crop.

The strip-till test lots were located opposite the conventionally cultivated lots and the lots under minimal cultivation and direct seeding.[9]

A depot fertilisation was inapplicable for the not-strip-till lots.

[9]Minimal tillage and direct seeding will be combined to the term min-till when mentioned at the same time.

Fig. 27.18 Precision air seeder EDX-9000TC (*photograph* Grunwald 2012)

The yield difference between conventional tillage methods, min-till methods and strip-till had to be analysed regarding investment costs if the land management method would be changed. The conversion to strip-till requires the indispensable investment in new machinery. This investment must pay off for business. For business management, economic factors are much stronger arguments than ecological considerations.

Running costs of machinery usage were investigated by a test to evaluate the drawbar power requirements. The drawbar power was described as a function of fuel consumption depending on tillage depth and driving speed and was online evaluated.[10] Fuel consumption data were read out from the tractor and recorded. The four tillage depths are described above. The speed was between 4.9 and 8 km/h.

All lots were sown in eight rows with 70 cm row distance using a precision air seeder of the Amazonenwerke (see Fig. 27.18). Fertiliser of the brand Selitra,[11] 120 kg/ha, was incorporated together with the seed on all lots. The fertiliser was placed in a band in 5 cm distance to and 5 cm below the seed via a fertiliser coulter disc running before the sowing coulter disc.

This initial dose provides the young seedling with easily available ammonium nitrate nitrogen during the first weeks.

The conventional combines of the farm were used for harvesting.

A corn header with a width of 12 rows and core threshing (9 m width) were used for sunflower harvest.

[10]The measurement was done and data logged directly during the ride.

[11]34.6% N—NH_4NO_3.

27.8 Weather Conditions in Spring and Early Summer of 2013/2014

The precipitation in May 2013 was twice as high as the average precipitation in the region between 1999 and 2008.[12] Heavy rains occurred especially during the first 20 days of May 2013. The temperature sum of May 2013 was also promoting crop growth. But June was very dry with a rainfall total of 11.5 mm. The average is 52.8 mm. Furthermore, day temperatures were high in June 2013. In spring 2014, day and night temperatures were low for a long time. Beside the growth-inhibiting temperatures, the precipitation was also less than in 2013. The measured amount of 34 mm at the station Klyuchi was only 10 mm more than the average precipitation, and the rain fell during the last ten days in May 2014. With a rainfall total of only 7 mm, June 2014 was even drier than the previous June.

27.9 Results

The yields were the lowest on the test lots under minimal soil cultivation with compact disc harrow and direct seeding in comparison to the methods of intensive loosening by strip-till and large-scale tillage.

As described earlier, reducing the tillage in row cropping often results at first in worse yields.

This becomes especially clear when converting from intensive to minimal soil cultivation methods within one year. Some farmers report a successful growth of sugar beets, corn and sunflowers with direct seeding in Western Siberia and northern Kazakhstan. But it requires a multi-year conversion period during which the yields decrease at first until the nutrient availability is stabilised on a high level (Dinkins et al. 2008). But the changed requirements of crop protection due to the changed tillage intensity are the most important factors. Competition by weeds and self-set plants of the previous crop was the highest on the test lots of low or no-tillage which lead to the worst yields. The average yield did not differ between low tillage with compact disc harrow and no-tillage with direct seeding. Even the yield differences for each single year were not higher than system inherent factors and, therefore, negligible.

The highest yield was produced on the test lot which was completely tilled and mixed between 16 and 18 cm deep using the wing share cultivator in 2014. A sunflower yield of 29.5 dt/ha was harvested. Unfortunately, this lot was not harvested in 2013 because of bad weather conditions and low trafficability at harvest time. That is the reason why the result of this tillage method is missing in the diagram in Fig. 27.19. Nevertheless, it will be discussed in the following. Cool weather and adverse precipitation were unfavourable initial conditions for all cultivation methods

[12] Station Klyuchi—Altai Krai (Russia).

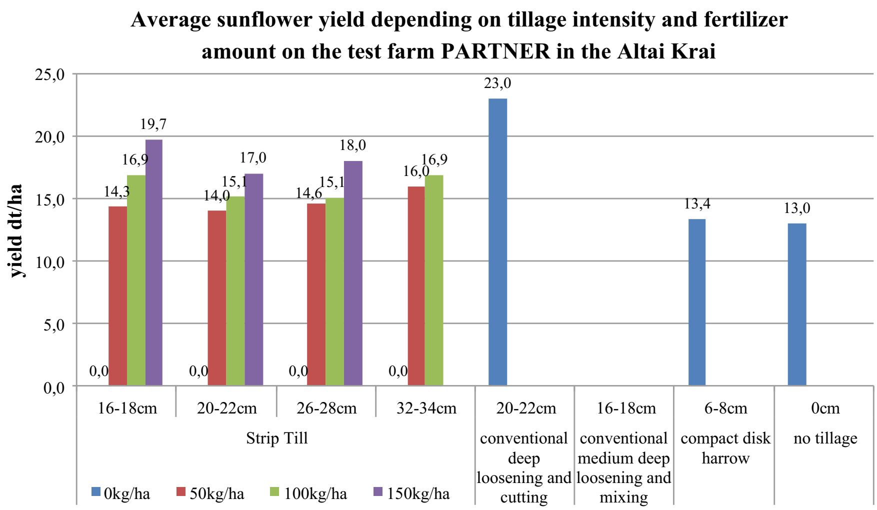


Fig. 27.19 Results of the strip-till tests with sunflowers in Poluyamki. Average yield of the sunflower harvests in 2013 and 2014 depending on cultivation method and applied amount of granular phospho-nitrogen fertiliser (Ammofos) (Kozhanov 2014, unpublished data)

in 2014. The large-scale loosening at medium depth had some advantages for a good crop establishment. Soil warming was better than on minimal tilled or direct seeding lots because of the intensive soil surface tillage. Soil warming was hindered, too on areas with large-scale deep loosening but without soil breakup because of the higher amounts of plant residue from the previous harvest. Large-scale tillage reduces the competition by weeds and self-set plants. The conditions for the crop are much better especially during the initial time of plant growth than on test lots with less intensive cultivation. The average yield of the test lot with deep loosening at 20–22 cm without soil breakup was the second-best result. Good loosening promotes root development.

Cutting 20 cm deep ensures good weed prevention. The root systems of perennial weeds are cut by the knives. Also, the capillary connection between top and bottom soil is severed by the cutting which prevents loss of soil water due to capillary rise to the soil surface and evaporation. This method by A.A. Malzev[13] is even today an effective measure used in many systems (Baraev 2008).

The need of a high drawbar power at a small work width and the risk of soil compaction (because the first 20 cm are very loose and become very compressed by the machinery) are the disadvantages of this soil cultivation method.

The yields of the different strip-till variations did not meet the yield of the large-scale tillage despite fertiliser application. The cultivation method on the respective test lots was very suddenly changed to strip-till from one year to the next. The lower yield is the result of the drastic minimisation of the tillage intensity. The inter-row

[13]Pioneer of erosion-mitigating and sustainable land management of the steppe in the Tselina region in Western Siberia and northern Kazakhstan during the 1960s and 1970s.

space was left undisturbed, and thereby, the competition by weeds and self-set plants increased. Intensity variations of this tillage system have not been tested further. It would have been possible, for example, to till the entire lot at a low depth before sowing. Hoeing of the inter-row space would have been another possibility, one that can be easily combined with the deep strip-tilling of the rows.

In case of a real conversion to strip-till in row cropping systems, this kind of additional cultivation method should be applied—at least during the transition period—as a measure to control weeds and prevent higher yield losses.

Regarding the tillage depth, the yields were comparable. Only the average yield of the lot with the lowest tillage depth was a couple of decitons per hectare higher. Yield increased with the increased amount of applied fertiliser regardless of the tillage depth. The tillage depth of 18 cm also had a positive effect on the yield in comparison with the other, greater tillage depths. Availability and usage efficiency seemed best at the lowest tillage depth. With regard to the dry weather in June of both years, the quick access to the nutrient depot for the plants helped their stable development. No root profile evaluation was conducted, but a faster development of the root system due to the larger accessible nutrient supply is possible. The attractiveness of a well-placed nutrient depot by strip-till has been repeatedly documented (TopAgrar 2011; Hermann et al. 2012; LLG-Sachsen-Anhalt 2017).

Deeper tillage resulted in a deeper placement of the fertiliser. Thereby, its attractiveness for the plant roots might have been decreased. This might be a reason for the lower yields of the strip-till lots with greater tillage depths in comparison with the strip-till lot with the lowest tillage depth.

Adapting the tine and the fertiliser supply line for a more dispersed fertiliser placement might help improve the yield results. Also, a divided fertiliser placement in an upper and a lower depot together with a deep loosening might be successful. A quick nutrient supply would be achieved which would result in a higher water usage efficiency.

The deep loosening and another deeper placed nutrient depot would facilitate strong vertical root growth and a sufficient nutrient supply during the growing season. Large fertiliser amounts would be used more efficiently (Raven et al. 2004).

The second-best yield results by strip-till methods were achieved on the test lots with the highest fertiliser amounts and the largest tillage depth. The root system could access the nutrient depot quite late due to the deep tillage and, therefore, deeper fertiliser placement. But the good nutrient supply during the rest of the growing season promoted the crop development.

The potential yield is set during bloom between July and August (Borodin et al. 2011; Riyabzev et al. 2012). Moisture stress during bloom must be prevented because it results in high yield losses (Rauf 2008). Fortunately, precipitation is usually higher during this time (Charlamova 2013).

Thereby, the good nutrient supply might have had a direct positive effect on the yield and helped indirectly because of the increased water usage efficiency of the well-developing crop during bloom.

Although the annual yields are not displayed in the diagram in Fig. 27.20, the differences between the yields in 2013 and 2014 will be discussed in the following.

Fig. 27.20 Large-scale and deep cutting without large-scale surface breakup after harvest. Proven method for erosion prevention and weed control according to A.A. Malzev (*photograph* Grunwald 2013)

All lots without large-scale tillage had 50% less yield in 2014 compared to the previous year. Beside weather and the advantages for the soil's thermal budget by large-scale tillage, the much better weed prevention by this method is crucial for this result.

Chemical weed prevention was the same on all lots. Glyphosate was applied during pre-emergence. Already emerging weeds and self-set plants were killed before the crop will be sown and emerged. The soil of the lots where large-scale tillage was applied in fall warms up faster in spring. Weeds and residue seeds of last year's harvest germinate quicker. The density of plants which can be wetted by the glyphosate application is higher because of the better germination conditions. Thus, the efficiency of glyphosate application is higher on large-scale tilled lots than on strip-till, minimal or no-till lots. The additional application of soil herbicides could help to improve weed control on strip-till and min-till lots. Due to its long-term effect, even beyond the sowing time, the emergence of weed seeds is prevented. In the test business partner, soil herbicides are usually applied by a self-propelled field sprayer and immediately placed 8 cm deep into the soil by the following disc harrow. The herbicide mixes with the soil water and is activated. This method has been proven to be successful especially regarding recurring droughts in spring. It is an expensive and

Fig. 27.21 Undisturbed space between tilled rows (*photograph* Grunwald 2014)

time-consuming method only used for sunflower cropping where high yields and profits are expected. This measure was not applied for the extensive strip-till because the inter-row space was intentionally left undisturbed to prevent wind erosion. But the application of soil herbicides is possible, too in strip-till systems without large-scale low tillage to keep inter-row space weed-free. One idea is to combine sowing and the application of soil herbicides. The extra ride for weed control would become obsolete. The exact application of the herbicide in the inter-row space would be very important (Fig. 27.21).

Fuel consumption increases if tillage depth is increased. But the rise is nonlinear (see Fig. 27.22). The lowest tillage depth required the least amount of fuel irrespective of the speed. While fuel consumption increased between 17 and 59% (depending on driving speed) from the lowest to the second-lowest tillage depth, the differences were less remarkable between the lowest and greater tillage depths.

The used tractor type and the geometry of the share influenced these results the most. As shown in the diagram, fuel consumption decreased at first even while driving speed increased. Fuel consumption is minimal at the tractor engine's load optimum and torque maximum. Depending on different work widths and different surface resistance, the load optimum is reached at different driving speeds.

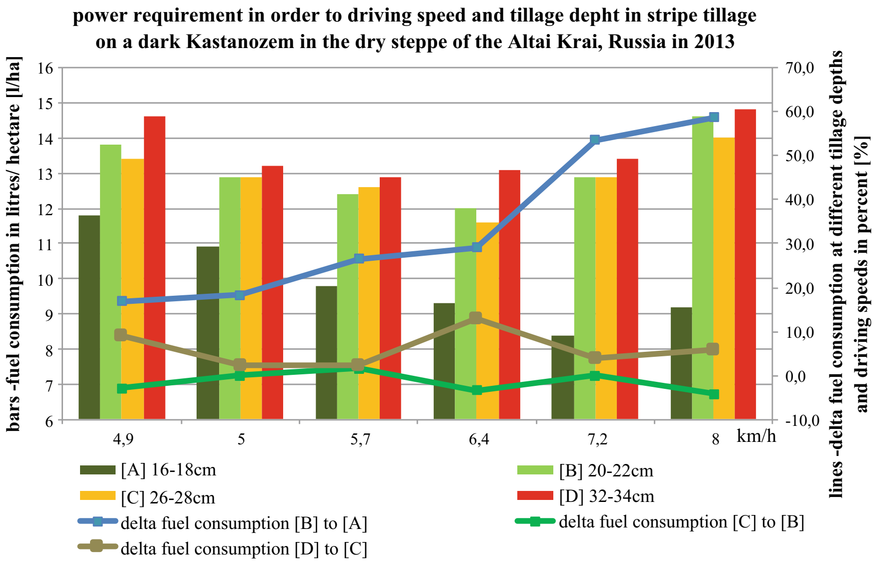


Fig. 27.22 Strip-till fuel consumption reflecting the required drawbar power depending on tillage depth and driving speed (Kozhanov 2014, unpublished data)

The diagram shows also that more power reserve is available at low tillage depth, and thereby, the driving speed must be higher to achieve the tractor engine's load optimum and minimal fuel consumption.

The share's geometry is the reason that much more drawbar power is required at greater tillage depth. The specific resistance of the share is determined by its area in the soil and the soil flow behaviour around the share. Apparently, the resistance is quite similar for the three greater tillage depths.

According to these results, the lowest tillage depth is also the better choice regarding the measurable economic factor fuel consumption in comparison to the tested greater tillage depths.

27.10 Summary

During the two-year test at the location Poluyamki, it was not possible to clarify if strip-till is an acceptable alternative to large-scale tillage for sunflower cropping. Other research results showed a preventive effect regarding erosion and soil degradation (Reeder 2009) for strip-till and similar crop yields to large-scale tillage not only for sunflower cropping (Nowatzki et al. 2008). The crop yield was higher for strip-till than for direct seeding or the large-scale low tillage with the disc harrow in fall. Although the crop yield was less for strip-till than for complete deep conservative tillage, the contribution margin might be higher due to the lower costs of the method. Financial evaluations of other field tests regarding a reduction in cultivation intensity at the same location resulted in these conclusions. But for highly profitable crops like sunflowers, close attention must be paid to grain quality to prevent great losses.

Under the given soil and weather conditions, strip-till at 18 cm depth together with high fertiliser amount of 150 kg/ha AMMOFOS was the most effective and profitable strip-till method. This result can be used for further adoptions of the strip-till system.

Using the same drawbar power, a deeper loosening, which promotes the root development, is possible in strip-till systems than in large-scale tillage systems. Competition by weeds and self-set plants can be controlled by the application of soil herbicides. Regarding crop rotation, the previous crop before the row crop should be one that is ripe early. The remaining vegetation period in fall can be used for weed prevention. Intensive harrowing provokes the emergence of residual grains from harvest and weeds. These can be controlled well by applying chemical plant protection.

A conversion to strip-till requires investment in modern strip-till cultivators. The order of the tools is very important to achieve satisfying and adequate results. Further investments in fertiliser and a more intensive weed management system are required if these measures were not used yet on a farm. The total costs are quite high and must be refinanced by the crop's yield profit. Especially during the conversion phase and the involved extensification of the soil cultivation, greater competition by weeds and self-set plants are expected. This requires timely and effective countermeasures. If soil herbicides or measures for selective weed control are not available, mechanical hoeing of the inter-row space should be applied. To prevent great losses and, thereby, risk the conversion to strip-till, this measure is legit and justifiable even with respect to soil ecology.

References

Agronovosti (2017) Tsena na Pshenitsu/Tsena na Podsolnechnik (wheat price/sunflower price). http://agro-bursa.ru/prices. Accessed 16 July 2017 (in Russian)

Baeumer K (1992) Allgemeiner Pflanzenbau (General crop production). Eugen Ulmer, Stuttgart (in German)

Baraev AI (2008) Zashchita Pochvy ot Erozii (Soil Protection from Erosion). In: Baraev AI (ed) Izbrannye Trudy v trekh tomakh, tom dva (1963–1971). Almaty, pp 137–148 (in Russian)

Bayerische Landesanstalt für Landwirtschaft (without year) Streifenbodenbearbeitung – Strip Tillage bei Zuckerrüben und Mais in Bayern. Online resource: https://www.lfl.bayern.de/mam/cms07/ilt/dateien/vortrag_strip_tillage.pdf

Borodin SG, Bushnyev AS (2011) Rekomendatsii po vozdelyvaniiu podsolnechnika v Altaiskom Krae (Recommendations for the cultivation of sunflower in the Altai Krai). SibAgroTsentr, Rubtsovsk (in Russian)

Charlamova NF (2013) Klimat Altaiskogo Regiona: Uchebnik (Climate of the Altai Region: Textbook). Altai State University, Barnaul. http://elibrary.asu.ru/xmlui/bitstream/handle/asu/64/read.7book?sequence=1. Accessed 19 July 2017 (in Russian)

Cuthfort HW, McCONKEY BG (1997) Stubble height effects on microclimate, yield and water use efficiency of spring wheat grown in a semiarid climate on the Canadian prairies. Can J Plant Sci 77(3):359–366

Deubel A, Hofmann B, Orzessek D (2011) Long-term effects of tillage on stratification and plant availability of phosphate and potassium in a loess Chernozem. Soil Tillage Res 117:85–92

Dinkins CP, McVay K (2008) Nutrient management in no-till and minimum till systems. Montana State University Extension EB0182. Montana State University, Bozeman. http://landresources.montana.edu/soilfertility/documents/PDF/pub/No-tillNutMgtEB0182.pdf. Accessed 06 Feb 2018

Eule W (1962) Das Problem der Neulandgewinnung in der Sowjetunion (The problem of virgin land reclamation in the Soviet Union). Dissertation. University of Bonn (in German)

Havlin JL, Kissel DE, Maddux LD, Claassen MM, Long JH (1989) Crop rotation and tillage effects on soil organic carbon and nitrogen. Soil Sci Soc Am J 54(2):448–452

Hermann W, Bauer B, Bischoff J (2012) Strip-Till: Mit Streifen zum Erfolg (Strip-Till: With stripes to success). AgrarPraxis kompakt. DLG-Verlag, Frankfurt am Main (in German)

Kazhtanov AN (1974) Zashchita Pochv ot vetrovoi erozii i vodnoi erozii (Protection of Soils from wind erosion and water erosion). Moscow (in Russian)

Kutschera L, Lichtenegger E, Sobotik M (2009) Wurzelatlas der Kulturpflanzen gemäßigter Gebiete mit Arten des Feldgemüsebaues (Root atlas of cultivated plants of temperate areas with species of field vegetable cultivation). Root Atlas Series, 7. DLG-Verlag, Frankfurt am Main (in German)

Larson WE, Pierce FJ, Dowdy RH (1983) The treat of soil erosion to long-term crop production. Science 219(4584):458–465

LLG Sachsen-Anhalt (2017) Gülle-Strip-Till. Ergebnisse verschiedener Versuchsstandorte (Manure Strip Till. Results from different test sites). https://llg.sachsen-anhalt.de/fileadmin/Bibliothek/Politik_und_Verwaltung/MLU/LLFG/Dokumente/03_service/broschueren/17_brosch_guelle-strip-till.pdf. Accessed 19 July 2017 (in German)

McConkey BG, Stumborg M (2003) Residue and erosion. In: Masters conservation tillage course—lecture, 17.09.2003, Hohhut

Milkov FN (1977) Prirodniye Zoniy SSSR. Moskva

Morrisson JE Jr (2002) Strip tillage for “no-till” row crop production. Am Soc Agric Eng 18(3): 277–284. https://elibrary.asabe.org/azdez.asp?search=0&JID=3&AID=8593&CID=aeaj2002&v=18&i=3&T=2. Accessed 19 July 2017

Nowatzki J, Endres G, Dejong-Huges J, Aakre D (2008) StripTill for field crop production – equipment – production – economics. AE1370. NDSU Extension Service, Fargo

NSA—National Sunflower Association (ed) (2017) Sunflower fertility. http://www.canadasunflower.com/wp-content/uploads/2012/11/Fertility.pdf. Accessed 16 July 2017

PAMI & SSCA (ed) (2000) Direct seeding manual. A farming system for the new millennium. PAMI, Saskatoon

Proplanta (2017) Infothek Sonnenblume: Pflanzenbauliche Basisinformationen (Information Desk Sunflower: basic plant engineering information). http://www.proplanta.de/Sonnenblume/Pflanzenbauliche-Basisinformationen-Sonnenblume_Pflanze1146030534.html. Accessed 16 July 2017 (in German)

Rauf S (2008) Breeding sunflower (Helianthus annuus L.) for drought tolerance. Commun Biometry Crop Sci 3(1): 29–44

Raven JA, Handley LL, Wollenweber B (2004) Plant nutrition and water use efficiency. In: Backon M (ed) Water use efficiency in plant biology. Blackwell Publishing, Oxford

Reeder RC (2009) Erosion control equipment. In: McNulty P, Grace PM (eds) Agricultural mechanization and automation, 2nd edn. EOLSS Publishers, Oxford, pp 193–218

Riyabzev VI, Deriyanova EG, Olyeshko VP (2012) Vozdelyvanie Podsolnechnika v Aleisko-Rubtsovskoi Stepi Altaiskogo Kraia (Cultivation of Sunflower in the Aleisk-Rubtsovsk Steppe of the Altai Krai). Dostizheniia Nauki I Tekhniki APK 2:34–36 (in Russian)

Simmons FW, Nafziger ED (2012) Soil management and tillage. In: Illinois agronomy handbook. http://extension.cropsciences.illinois.edu/handbook/. Accessed 16 July 2017

Sommer C, Brandhuber R, Brunotte J, Buchner W (2002) Vorsorge gegen Bodenschadverdichtung (Provision against soil damage compaction). In: BMVEL (ed) Gute fachliche Praxis zur Vorsorge gegen Bodenschadverdichtung und Bodenerosion. BMVEL, Bonn, pp 12–40 (in German)
Topagrar (ed) (2011) Platzierte Düngung – Starthilfe für ihren Raps (Placed fertilization—jump start for your oilseed rape). TopAgrar 8: 50–54 (in German)
Veihmeyer FJ, Hendrickson AH (1948) Soil density and root penetration. Soil Sci 65(6):487–494
Wein N (1980) Fünfundzwanzig Jahre Neuland (Twenty-five years Virgin Lands). Geographische Rundschau 32(1):32–38 (in German)
Zigon P, Mihelic R (2015) Dostopnost hranil v odvisnosti od intenzitete obdelave tal (Nutrient availability as a function of soil tillage intensity). In: New challenges in agronomy 2015: proceedings of symposium in Laško, Slovenia, 29–31 Jan 2015. Slovensko agronomsko društvo, Ljubljana (in Slovenian)

Chapter 28
Improving Efficiency of Crop Protection Measures. A Technical Contribution for Better Weed Control, Less Pesticide Use and Decreasing Soil Tillage Intensity in Dry Farming Regions Exposed to Wind Erosion

L.-C. Grunwald, V. I. Belyaev and T. Meinel

Abstract The extensification of tillage in farming the steppe regions of the earth with the goal of reducing erosion and maintaining soil fertility has been leading to a more intensive use of chemical plant protection products for a while now. Field hygiene and stable yields have been achieved as a result of this method to date. However, the excessive application of herbicides leads to an increase in resistance among weeds and higher expenses. The application of glyphosate as an effective and inexpensive general herbicide is very common in the agricultural steppes of America, Eurasia and Australia. However, its use is limited to short periods before seeding and after harvesting due to climate conditions in these areas. An application to the entire soil surface is effective but also very cost intensive against the background of the vast farm lands in these regions. A selective use and targeted application to weeds without coating free soil surface areas saves product and time while reducing the dangers of resistances in the agricultural ecosystem. A technical method of optical selection between weeds which need to be sprayed and areas which do not need to be treated was developed over several years as a part of Kulunda research project. The strong decrease in the overall amount of the applied herbicide results in greater productivity due to a reduction of filling downtimes and higher driving speeds in the field. The money saved is reinvested in better agents and higher concentrations. This promises more treatment success and lower resistance development. Chemical fallow periods therefore represent an effective tool instead of mechanical black fallow in the

L.-C. Grunwald (✉)
BBG Bodenbearbeitungsgeräte Leipzig GmbH & Co. KG, Rippachtalstr. 10,
04249 Leipzig, Germany
e-mail: LarsChristian.Grunwald@bbg-leipzig.de

V. I. Belyaev
Altai State Agricultural University, Prospekt Krasnoarmeyskiy, 98, 656049 Barnaul,
Russian Federation

T. Meinel
TOO Amazone, Saifulina Street 3, Office 1, 010000 Astana, Kazakhstan

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations
in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_28

summer, even without extensive application of chemical agents to the soil, making them an adequate means to fight soil erosion and water loss.

Keywords Reducing erosion · Chemical plant protection · Resistance · Selective application · Increasing efficiency

28.1 Tillage Practices and Chemical Crop Protection—An Interdependency

"Water retention, mitigation of soil degradation, humus accumulation, weed control, yield stabilization and increase"—these are the buzzwords in discussions about crop farming in the world's dry regions (Mathews and Cole 1938; Baraev 1967; Frühauf et al. 2004; Lafond et al. 2006; Lindwall and Sonntag 2010). The goal is an increase of efficiency and sustainability of cultivation methods.

The use of conservation tillage practices proved to be a key measure (with varying progress regarding time and topic) in the dry farming regions all over the world to meet above described targets (Derpsch et al. 2010). Soil degradation by erosion and humus decomposition as well as a yield-limiting soil water deficit and loss by evaporation can be minimized by reducing tillage (McConnkey et al. 2003; Suleimenov et al. 2012). But reduced tillage results in a shortage of available plant nutrients due to decreased mineralization and release of nutrients by microorganisms (Doran 1980; Dinkins and McVay 2008). Applying additional fertilizers and including nutrient collecting and fixing crops like legumes in the crop rotation can compensate nutrient deficiencies. Active fertilization accelerates and stabilizes the transition from intensive crop farming to a stable conservation tillage system (Johnston 2002).

Weed management is another important factor of conservation tillage practices to consider. Repeated tilling efficiently inhibits weed growth which provides improved conditions for crop growth due to minimized weed competition. But if tillage is reduced, weed competition significantly increases if no other measures of weed control are applied (Derksen et al. 1993; Blackshaw et al. 1994; Friedrich 2005).

A review of the development of soil management practices in the industrialized agrarian steppes over the course of the last three decades reveals that reducing the tillage resulted in an increased use of herbicides. Figure 28.1 illustrates the increased application of herbicides in Canada. Especially, the use of total herbicides increased. Since its first commercial introduction in the 1970s, glyphosate is now applied worldwide. It has become THE dominant herbicide, and it is the most important total herbicide worldwide (Duke and Powles 2008).

Since the successful genetical modification of crops to be glyphosate resistant, the usage of glyphosate increased even more and is currently in the USA 15 times higher than before 1996—"Two-thirds of the total volume of glyphosate applied in the U.S. from 1974 to 2014 have been sprayed in just the last 10 years" (Benbrook 2016, Abstract-Results).

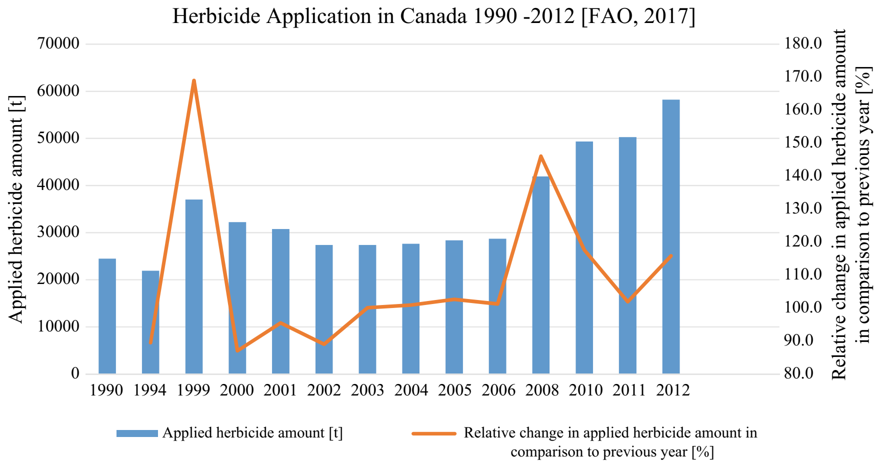


Fig. 28.1 Herbicide use in Canada between 1990 and 2012 and relative change in applied amount in comparison with the previous year. *Source* FAO (2017)

28.2 Glyphosate—An Important Factor in Conservation Tillage Systems

Total herbicides are effective measures of chemical weed management. Weeds and seedlings from previously planted crop[1] are killed by the application. Because of their non-selective effect, total herbicides are usually not used on sown arable crop (Duke and Powles 2008). Therefore, their application time is limited to the period between previous crop harvest and next crop sowing. Total herbicide application is in comparison with selective herbicides, which target only certain plant species, inexpensive and quick.

The goal of (total) herbicide application is to reduce the competition of weeds with crop. In mulch seeding and direct seeding systems, the application of glyphosate is on par with the mechanical treatment of newly germinating weeds and self-set plants. The application is discussed controversially. Glyphosate usage is often the only effective measure to control weeds in direct seeding systems. Glyphosate is traditionally applied by a field sprayer of a defined boom width and is blanket-like dispensed by nozzles installed on the sprayer boom while the sprayer moves across the field. The herbicide concentration in the tank mix is usually regulated by mixing the chemicals with the respective amount of water in the field sprayer. The output is variable and can be adjusted via the sprayer. In modern field sprayers, the dosage is electronically monitored and adjusted depending on the sprayer's speed.

Glyphosate[2] is an important measure of weed control on large-scale fields in agrarian steppe regions which are especially susceptible to erosion by wind and water.

[1] Self-set plants from residue grains from previous harvest threshing.

[2] A widely used active ingredient of total herbicides.

Agricultural businesses often cultivate thousands of hectares in cooperation, and most of the land must be tilled within a short time when the weather is favourable. Weeds can be effectively and inexpensively controlled by tillage. Negative consequences of inadequate tillage management are known and were previously outlined. Glyphosate application is therefore an important factor to increase monetary efficiency and conserve soils.

The Eurasian steppe region of western Siberia and northern Kazakhstan is characterized by a continental climate with harsh winters and short vegetation periods (Lydolph 1990; Müller et al. 2016). That is why until today summer crops are mostly cultivated (Grunwald et al. 2016). The period between frost end and sowing of summer crop is short. Weeds and crops germinate almost at the same time which means a strong crop—weed competition. By a high work rate and efficiency of weed control, the competition should be minimized and the time of sowing optimized because it is delayed as much as possible. The goal is an almost complete germination of seeds of weeds and self-set plants of previous crops and their subsequent treatment. Intensive tillage is the method of weed control in conventional systems, but the application of total herbicides is the weed control practice in systems of reduced tillage and direct seeding systems.

The population density of self-set plants and weeds is usually low at the time of sowing [Fig. 28.2]. Different weeds species germinate at different times. Seed germination is stimulated by rising soil temperature and light, and therefore, different species germinate and grow only at certain times with the right conditions during spring. Common millet (*Panicum miliaceum*) and self-set plants from previous crop (*Triticum aestivum/Hordeum vulgare/Avena nuda,* etc.) are often the first problem species on the fields. The weather is often still cool, and germination is inhibited. When the weather becomes more favourable, seeds of weeds and self-set plants quickly start to sprout. However, the seeds of the current crop need to be sown now as well. Time constraints are increased by using sowing and weed control technologies (tillage equipment and field sprayers) of limited surface coverage.[3] Thus, it is only possible to till and sow the large fields on time under great time pressure. The population density of weeds and self-set plants of previous crops is also low after harvest. The soil is usually dry; the crop's shadow suppresses weeds until threshing. Seeds of weeds and residue grains from the harvested crop germinate only slowly in the dry conditions. Usually, the period between harvest and the beginning of winter is only short in the continental regions, and only part of the seeds can germinate.

Although the blanket application of total herbicides is very effective and inexpensive in comparison with selective ingredients, the efficiency rate is very low as measured by the wetted leaf area in comparison with the traversed total area. Here, possibilities of saving and efficiency improvement exist.

In Canada, modified versions of the herbicide Glyphosate are also allowed for the application on genetically modified, glyphosate resistant crop due to different laws

[3]Surface coverage is determined by speed and width of the machine. Tillage equipment is always smaller than field sprayers because it requires a higher tractive force. 12 m tillage at a depth of 6 cm—ca 350–450 PS, 24 m field sprayer at 12 km h^{-1}—ca 150–200 PS.

Fig. 28.2 Low weed population density at the time of sowing at the end of May 2015 Smolenskii Raion—Altaiskii Krai. *Photo* Grunwald (2015)

in comparison with Russia and Kazakhstan (Uhlmann 2003; Deter 2016). Climatic conditions of Canada's prairie regions are similar to the weather in the Eurasian Steppe regions. GMOs[4] are cultivated almost everywhere in Canada's prairies to increase yields and reduce costs (Baylis 2000; Buiatti et al. 2013). Due to genetic modification, the resistance of crops against certain ingredients of total herbicides permits total herbicide application even after the sprout of the seeds. Thus, work peaks are significantly lowered, and duty cycles are more separated in the operating schedule. Due to limited staff in predominantly family-run large-scale farms, each hour counts during peak time. Plant-available water is limited in Canadian steppes, and tillage is expensive.

Effective and inexpensive plant protection is also of central importance in land management practices in Eurasian regions and Australian steppes. Farms, especially in western Australia, are on average twice as large as in the prairie of Saskatchewan, a Canadian province (Land Commodities 2017; Statistics Canada 2016),[5] and the staff is limited as well. Potential evaporation is significantly higher because of higher solar radiation which makes plant-available water a yield-limiting factor. Chemical weed control is the usual measure of plant protection. Tillage systems have often been changed to direct seeding systems to conserve soils and improve profitability. In Australia, the blanket application of total herbicides is the most important measure of weed control especially in no-till or minimal tillage systems. But due to an often very low population density of weeds and self-set plants, blanket application is usually very inefficient as measured by the actual glyphosate-wetted leaf area.

[4]GMO—genetically modified organism.

[5]Western Australia—average farm size was 1.200 ha; Saskatchewan, Canada—average farm size was 675 ha in 2011.

28.3 Regular Application of Total Herbicides—New Challenges

The regular entry of glyphosate into the soil–soil water–plant–system has been controversially discussed for quite some time now. Glyphosate and its metabolites are suspected to cause cancer by handling glyphosate or consuming food previously in contact with glyphosate although the German Federal Institute for Risk Assessment[6] (BfR) classified glyphosate as non-carcinogen in its communication of March 23, 2015 (BfR 2015). Another concern is a possible glyphosate accumulation in breast milk in toxic levels and, thus, glyphosate being fed to infants. Similarities to the problematic distribution of the herbicide DDT in the 1960s are obvious. For the same reasons, a ban of glyphosate—the most used ingredient in total herbicides—is intensively discussed in Europe. But the latter suspicion could not be confirmed by the BfR (BfR 2016).

Glyphosate application is disputed not only in Europe. The constantly increasing application rate, especially in the context of a negative water balance, must be viewed critically in the dry farming steppe regions of North America, Australia and Eurasia.

The accumulation of herbicide deposits in soils is currently insufficiently researched. Due to dry conditions in summer and low annual precipitation, vertical water movement is limited to the upper soil layer to a maximal depth of 2 m in most regions. Dilution and leaching only rarely occur (Stephan, unpub.). Hence, herbicides are only mobile in soil solution in the upper layers of soils. Research findings show a relation between benthos[7] activity, a crop's root growth and its disease resistance. A connection is considered between excessive glyphosate use, weakened resistance as well as inhibited root growth of crops. The former would mean a crop's higher susceptibility to diseases. The latter leads to increased water stress especially in dry agricultural regions (Johal and Huber 2009; Fernandez et al. 2009; Bott 2010).

Glyphosate resistance in weeds is on the rise. This problem is currently known to exist in agricultural systems in North and South America and Australia with a high percentage of GMO and an intensive long-term usage of total herbicides, and it is becoming increasingly urgent (Powles et al. 1998). Controlling self-set plants from previous crop is difficult in these regions, too, due to their glyphosate resistance (Fig. 28.3). The genetic modification of crops to be glyphosate resistant leads to the usage of enormous glyphosate amounts. Due to simplified and effective weed control, crop rotation is very close and sometimes with only one or two crops in rotation. Soy and corn serve mostly as cattle feed and are cheaply produced in over-optimized farming systems. The regular glyphosate application increased enormously the genetical glyphosate resistance of weeds which can often be controlled only by expensive special treatments (Beckie 2011). Glyphosate resistance is on the rise even in Europe, and resistant weeds become more widely distributed—like Blackgrass (*Alopecurus myosuroides Huds*) in minimal tillage systems. Even crops unintentionally develop

[6]Bundesinstitut für Risikobewertung BfR.

[7]Especially microbenthos.

Fig. 28.3 Self-set plants of previously planted GMO corn in a field of GMO soy—Glyphosate resistance hinder the control of self-set plants, Region Sioux City Illinois USA. *Photo* Grunwald (2016)

glyphosate resistance which is the result of glyphosate overuse in very close crop rotations without any alternative methods (Powles 2008).

Herbicide application is still in its infancy in the large agricultural regions in Siberia and Kazakhstan in comparison with Europe, Australia and America. But the applied annual amounts are on the rise. Yields are currently low and very dependent on the annually varying weather conditions. The economic situation of the countries and varying global crop prices force farms to work under tight financial conditions. To minimize downtime for filling and reduce application costs, tank mixes are often too diluted. Drivers of the field sprayers receive very low wages which often compels them to receiving stolen goods.

Low concentrations are very counterproductive in the medium term. Treatment with too low herbicide doses results in plant selection. Larger, vital plants usually survive the treatment which drastically increases the possibility of gene mutations and the development of herbicide resistance in the weeds.

28.4 Technical Possibilities for Efficiency Improvement of Total Herbicide Application

As previously described, the population density of weeds and self-set plants is very low at the time of the total herbicide treatment. The chance to wet all plants—no matter what size or stage of development—is very high with a blanket application. But the efficiency as measured by the actual traversed area is very low due to the low weed population density. Hence, a lot of money, the immediate efficiency indicator, is wasted in agricultural systems. The goal, however, should be the highest temporal and spatial precision of herbicide application. Technical solutions have been tested in different parts of the world and agricultural systems for a couple of years. New technologies like photo sensors and high performance, mobile control systems become useful for enhancing field sprayers, too (Fig. 28.4).

Fig. 28.4 Low weed population density and large-scale total herbicide application before crop is emerging result in high herbicide losses. *Photo* Meinel (2015)

Spot spraying is a new innovative technology to apply herbicides exactly on a plant's leaf. The selective control of the nozzles helps to cut down the amount of active ingredient as measured by the traversed area. The amount applied on the area is drastically reduced. Time lost due to standstills like refilling stops is reduced. Therefore, the area treated during the same number of working hours increases. Treatment timing improves despite the larger fields because of faster treatment at optimal times. However, there is still space for improving the application efficiency.

The application during night and early morning is much more favourable because of higher humidity above the soil and lower wind speed (Adkins et al. 1998). The wetting of the leaf surface is more even. Droplet roll-off is reduced by a lower surface tension due to the higher humidity and less dust. Less wind means less drift and better wetting (Elliot and Wilson 1983). The field sprayer's boom can be operated at greater height above the crop which helps to prevent damages on machinery and plants. Savings by using less herbicides can be reinvested in more expensive herbicides and in a higher ingredient concentration in the tank mix. The danger of developing herbicide resistance can be minimized by the usage of higher herbicide doses available by the reduced herbicide amount per area.

Investments in these technologies may help businesses to change to erosion mitigating, water saving and yield stabilizing tillage systems more quickly and with less financial risks (Fig. 28.5).

The technology has been used commercially especially in dry farming regions (agrarian steppe regions) during the last couple of years. Light detection sensors, control and sprayer technology were initially installed on rigid, basic booms. Tanks containing the tank mix and the pump system are linked to the boom which is being pulled over the field. Advantages of these so-called field gliders are their simplicity and low costs as well as the smooth operation of the boom across the surface. The implementation of field gliders and spot spraying in south Australian farming regions proved to be cost saving. The usual spray rate between 50 and 60 l ha^{-1} could be increased to 100 l ha^{-1} due to the spot spraying's reduction effect.

Fig. 28.5 Spot spraying technology installed on a field sprayer from Amazonen-Werke, http://go.amazone.de/agritechnica/2017/neuheiten/pflanzenschutztechnik/anhaengespritze-ux-amaspot/

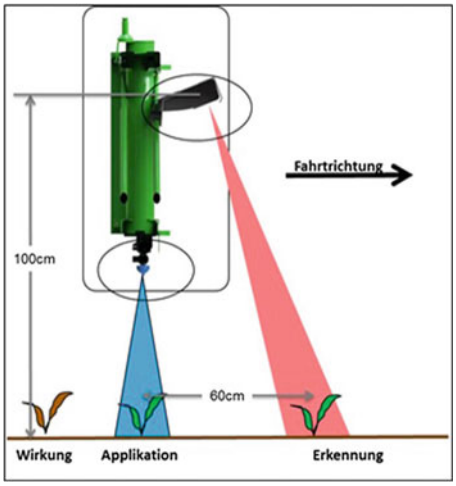


Fig. 28.6 Spot spraying technology—sensor and nozzle technology installed on a conventional boom of field sprayer—work flow diagram. *Source* Amazonen-Werke (2015)

With a spot spraying application, it was possible to treat a 500 ha-area at average operating speed of 22 km h^{-1} using a 5000-litre tank, the same application rate of 100 l ha^{-1} and the same tank mix concentration as for a blanket application. Using the spot spraying system, the treated area was ten times larger than it would have been by using a blanket application. Therefore, the application efficiency improved significantly according to the farmers. The savings of chemical costs were about 85–90% on average with the biggest saving up to 92% (Maitland 2012) (Fig. 28.6).

A pre-emergence blanket spraying of glyphosate and other additives with an application rate of 1.5 l ha^{-1} would cost 14.5 AUD. Due to the cost savings with the spot spraying system, the spray rate of the chemicals was increased to 4.6 l ha^{-1} on one particular farm.

Fig. 28.7 Spot spraying technology on a conventional field sprayer—light sensors active for weed detection on the test farm PARTNER, Altai Krai 2014, during night work. *Photo* Grunwald (2014)

The chemical cost per treated hectare would be 18.65 AUD ha^{-1} for a blanket application. Using spot spraying instead of blanket spraying for the triple treatment of the 7.800 ha over the course of one summer (in chemical summer fallow) saves 304 000 AUD (Maitland 2012). These savings were gained by the significant reduction of applied chemicals at one hectare.

The major technical disadvantage of field gliders is their single purpose of total herbicide application. For a repeated and diverse crop treatment with herbicides, fungicides and insecticides, conventional field sprayers for blanket spraying must be used which means the acquisition and maintenance of two sprayer systems.

The combination of both blanket spraying and spot spraying in one machinery would drastically improve flexibility and reduce costs at the same time. One field sprayer would be sufficient. The research network KULUNDA in cooperation with a German agricultural machinery manufacturer developed and tested such a system on a test farm in the Altai Region in western Siberia. The spot spraying system was installed on a modern, conventional field sprayer (Fig. 28.7). The sprayer has an excellent boom guidance and a speed-dependent control of the application rate which are the technical requirements for a precise application. The test farm cultivates 27 000 ha land and uses this system for traditional pre-emergence weed control and for the treatment of chemical summer fallow. Cost savings were up to 80% for the 2014/15 season in comparison with the conventional blanket application. Average cost savings were about 65%. The speed was between 12 and 15 km h^{-1} which is also practicable for blanket application with only nozzle technique for high-speed runs.[8] The spot spraying system with its sensor and control technology can be used at speeds up to 25 km h^{-1}. Speed-dependent precision and wear and tear must be taken into consideration. Weather (wind, humidity) and surface conditions often limit the effective application at higher speeds.

[8]Excursus high-speed double flat fan nozzle.

28.5 Fallow Management for Intensive Row Crops—Not Necessarily at the Expense of Soil

The test farm uses 9000 ha of its land for growing sunflowers which are used for sunflower oil production and especially for consumption. Sunflowers are one of the most profitable and, therefore, most important crops for this test farm as well as for many other farms in Siberia and northern Kazakhstan. Sunflowers have high nutrient requirements. They are grown in 5–7 year rotations because of their nutrient draining effects on soils (FAO 2009; Tuleuov et al. 2011).

The field is often left fallow the year before sunflowers are grown. The fallow is often a bare fallow. Respective consequences for the soil and its exposure to wind and water erosion as well as the high usage of materials for tilling are well known (Grunwald et al. 2015). Chemical summer fallow is an effective and—regarding soil conservation—a sustainable alternative. Over the course of five years, agricultural systems were tested in field experiments on the test farm PARTNER (Kozhanov family) in Polujamki. The findings show no yield loss if chemical summer fallow was applied before summer wheat cultivation in comparison with bare fallow (Grunwald et al., unpub.). The test farm PARTNER in the Altai Krai could significantly expand the chemical fallow portion without an excessive herbicide usage and input in the ecosystem by using spot spraying systems. The portion of bare fallow before sunflower growth was reduced by 90% compared to chemical fallow (Kozhanov 2016). Hereby, the competition for sunflowers was considerably reduced, and the crop yield could be stabilized. More water is retained in soils due to discontinuation of bare fallow. Evaporation is mitigated by the shade of dry straw of weeds and self-set plants from previous crop. During chemical fallow, organic material is left on the soil surface during the winter months benefiting soil moisture. Snow is kept in straw on the field and not blown away with the wind. Water from thawing snow can infiltrate the soil as plant-available water. The absence of tillage reduces humus mineralization (Fileccia 2009; Grunwald et al. 2015).

Currently, a system prototype runs on-site on a trailed field sprayer. The installation on self-propelled field sprayers can be recommended, too. Self-propelled sprayers are faster, more flexible and precise because the boom guidance is much more accurate due to a better chassis and better leverage from the axes to the boom. The precision remains high even at high driving speed. Transferring the technology from field to field can be done much quicker, too. Modern self-propelled sprayers have very high ground clearance. These sprayers can also be used on tall crops like corn or sunflowers without damaging the plants. The versatility is much higher than on a trailed field sprayer. Their axis height is usually less than a metre which makes a passage through tall crops difficult. Furthermore, some modern self-propelled sprayers have a hydraulic track width adjustment which allows an accurate adaption to the crop's row width. Loss by damages during passage of a field is considerably reduced, too (Fig. 28.8).

The spot spraying system is focused on the detection of green leaf surface and therefore not suitable for the application of post-emergence weed control. Due to

Fig. 28.8 Chemical summer fallow with used spot spraying technology—effective weed control by minimized material cost—financial and agrarian ecological benefits, test farm PARTNER Altai Krai. *Photo* Grunwald (2014)

the enabling technology of single nozzle control, counter steering of wind drift and localized detection of weed clusters are possible. These applications would further specialize pre-emergency weed control and make it even more cost efficient. The system was tested in the research network KULUNDA.[9] The technical realization was achieved by Amazonen-Werke GmbH & Co. KG. This innovation was awarded with a silver medal by the German Agricultural Society[10] at the Agritechnica 2015, the world's largest exhibition of agricultural machinery (Amazone 2015).

References

Adkins S, Tanpipat S, Swarbrick J, Boersma M (1998) Influence of environmental factors on glyphosate efficacy when applied to Avena fatua or Urochloa panichoides. Weed Res 38(2):129–138

Amazone (2015). Innovationen von Amazone. Agritechnica-Silbermedaille 2015 für AmaSpot [Agritechnica silver medal 2015 for AmaSpot]. http://amazone.de/105.asp. Accessed 06 Feb 2018 (in German)

Baraev AI (1967) Nauchnye osnovy zemledeliia i puti uvelicheniia proizvodstva zerna v severnykh raionakh Kazakhstana i stepnykh raionakh Zapadnoi Sibiri [Scientific foundations of agriculture and ways to increase grain production in the northern regions of Kazakhstan and the steppe regions of Western Siberia]. In: Siniagin II (ed) Problemy sel'skogo khoziaistva severnogo Kazakhstana i stepnych raionov Zapadnoi Sibiri. Zelinograd, Kolos, pp 28–49 (in Russian)

Baylis AD (2000) Why glyphosate is a global herbicide: strengths, weaknesses and prospects. Pest Manage Sci 56(4):299–308

Beckie HJ (2011) Herbicide-resistant weed management: focus on glyphosate. Pest Manage Sci 67:1037–1048

[9] www.kulunda.eu.

[10] Deutsche Landwirtschafts-Gesellschaft DLG.

Benbrook CM (2016) Trends in glyphosate herbicide use in the United States and globally. Environmental Science Europe. Bridging Science and Regulation at the Regional and European Level 28(3)

BfR (ed) (2015) Löst Glyphosat Krebs aus? [Does glyphosate cause cancer?] Official note 007/2015 of the BfR from 23 Mar 2015. http://www.bfr.bund.de/cm/343/loest-glyphosat-krebs-aus.pdf. Accessed 21 Jan 2017 (in German)

BfR (ed) (2016) BfR-Studie bestätigt: Kein Glyphosat in der Muttermilch nachweisbar [BfR study confirms: no glyphosate detectable in breast milk]. http://www.bfr.bund.de/de/presseinformation/2016/08/bfr_studie_bestaetigt__kein_glyphosat_in_muttermilch_nachweisbar-196563.html. Accessed 21 Jan 2017 (in German)

Blackshaw RE, Larney FO, Lindwall WC, Kozub GC (1994) Crop rotation and tillage effects on weed populations on the Semi-Arid Canadian Prairies. Weed Technol 8(2):231–237

Bott S (2010) Rhizosphere processes as determinants for glyphosate damage of non-target plants. Dissertation, University Stuttgart-Hohenheim http://opus.uni-ohenheim.de/volltexte/2011/606/pdf/Dissertation_S._Bott_UH2010.pdf. Accessed 06 Feb 2018

Buiatti M, Christou P, Pastore G (2013) The application of GMOs in agriculture and in food production for a better nutrition: two different scientific points of view. Genes and Nutrition 8(3):255–270

Derksen DA, Lafond GP, Thomas AG, Loeppky HA, Swanton CJ (1993) Impact of agronomic practise on weed communities: tillage systems. Weed Sci 41:409–417

Derpsch R, Freidrich T, Kassam A, Hongwein L (2010) Current status of adoption of no-till farming in the world and some of its main benefits. Int J Agric Bio Eng 3(1):1–24

Deter A (2016) Russland verbietet Anbau von GMO-Pflanzen [Russia forbids cultivation of GMO plants]. Topgrar online. https://www.topagrar.com/news/Acker-Agrarwetter-Ackernews-Russland-verbietet-Anbau-von-GMO-Pflanzen-3814950.html. Accessed 06 Feb 2018 (in German)

Dinkins CP, McVay K (2008) Nutrient management in no-till and minimum till systems. Montana State University Extension EB0182. Bozeman: Montana State University. http://landresources.montana.edu/soilfertility/documents/PDF/pub/No-tillNutMgtEB0182.pdf. Accessed 06 Feb 2018

Doran JW (1980) Soil microbial and biochemical changes associated with reduced tillage. Soil Sci Soc Am J 44(4):765–771

Duke SO, Powles SB (2008) Mini-review Glyphosate: a once-in-a-century herbicide. Pest Manage Sci 64:319–325

Elliot JG, Wilson BJ (1983) The influence of weather on the efficiency and safety of pesticide application: the drift of herbicides. British Crop Protection Council, Croydon

FAO (ed) (2009) Kazakhstan: technical assistance to the sunflower seed sector. Report Series N. 14. Sept 2009. http://www.fao.org/docrep/012/k6392e/k6392e.pdf. Accessed 06 Feb 2018

FAO (2017) Dataset provided from faostat edited/processed by the author. Published at the website of FAOSTAT. http://www.fao.org/faostat/en/#home

Fernandez MR, Zentner RP, Basnay P, Gehl D, Selles F, Huber D (2009) Glyphosate associations with cereal diseases caused by Fusarium spp. in the Canadian Prairies. Eur J Agron 31(3):133–143

Fileccia T (2009) Importance of zero-tillage with high stubble to trap snow and increase wheat yields in Northern Kazakhstan. FAO Investment Centre Division, Rome

Friedrich T (2005) Does no-till farming require more herbicides? Outlooks Pest Manage 16(4):145–192

Frühauf M, Meinel T, Belaev VI (2004) Ecological consequences of steppe conversion to arable land in west Siberia. Europa Regional 12(1):13–21

Grunwald L-C, Meinel T, Belaev VI, Frühauf M (2015) Effekte der Schwarzbrache in verschiedenen Trockenfeldbauregionen der GUS [Effects of fallow land in various dry-field regions of the CIS]. Hallesches Jahrbuch der Geowissenschaften 37:163–193 (in German)

Grunwald L-C, Belaev VI, Hamann M, Illiger P, Stephan E, Bischoff N, Rudev NV, Kozhanov NA, Schmidt G, Frühauf M, Meinel T (2016) Modern cropping systems and technologies for soil conservation in Siberian agriculture. In: Müller L, Sheudshen AK, Eulenstein F (eds) Novel methods fsor monitoring and managing land and water resources in Siberia. Springer, Cham, pp 681–715

Johal GS, Huber DM (2009) Glyphosate effects on diseases of plants. Eur J Agron 31(3):144–152

Johnston AM (2002) Fertility issues and long-term no-till. Taken from: Direct Seeding advantage 2002—Reduced Tillage Linkages. http://reducedtillage.ca/docs/Fertility_issues_in_long_term_no-till.pdf. Accessed 06 Feb 2018

Kozhanov SA (2016) Protocol of an interview on the use of the spot—spraying technology in the PARTNER test farm in Altai Krai, Poluyamki

Lafond GP, May WE, Stevenson FC, Derksen DA (2006) Effects of tillage systems and rotations on crop production for thin Black Chernozem in the Canadian Prairies. Soil Tillage Res 89:232–245

Land Commodities (ed) (2017) Variations in farm size across the Australian Wheatbelt. http://www.landcommodities.com/variations-in-farm-size-across-the-australian-wheatbelt. Accessed 21 Jan 2017

Lindwall WC, Sonntag B (eds) (2010) Landscapes transformed: the history of conservation tillage and direct seeding. Knowledge Impact in Society, Saskatoon

Lydolph PE (1990) Geography of the U.S.S.R. Elkhart Lake, WI: Misty Valley Publishing

Maitland K (2012) Selective spray units help war on weeds. SANTFA Cutting Edge Spring 2012:292–295

Mathews OR, Cole JS (1938) Special dry farming problems. In: United States department of agriculture (ed). Yearbook 1938. Washington D.C.: US GPO, pp. S. 679–693

McConkey BG, Liang BC, Campbell CA, Curtin D, Moulin A, Brandt SA, Lafond GP (2003) Crop rotation and tillage impact on carbon sequestration in Canadian Prairie soils. Soil Tillage Res 74:81–90

Müller L, Sheudshen AK, Syso A, Barsukov P, Smolentseva EN, Khodzher T, Sychev VG, Romanenkov VA, Rukhovich OV, Puzanov A, Dannowski R, Schindler U, Eulenstein F (2016) Land and water resources of Siberia, their functioning and ecological state. In: Müller L, Sheudshen AK, Eulenstein F (eds) Novel methods for monitoring and managing land and water resources in Siberia. Springer, Cham, pp 3–110

Powles SB, Lorraine-Colwill DF, Dellow JJ, Preston C (1998) Evolved resistance to glyphosate in rigid ryegrass (Lolium rigidum) in Australia. Weed Sci 46:604–607

Powles SB (2008) Evolved glyphosate-resistant weeds around the world: lessons to be learnt. Pest Manage Sci 64(4):360–365

Statistics Canada (ed) (2016) 2011—Farm and Farm Operator Data. http://www.statcan.gc.ca/pub/95-640-x/2011001/p1/p1-01-eng.htm. Accessed 21 Jan 2017

Suleimenov M, Saparov A, Akshalov K, Kaskarbaev Z (2012). Land degradation issues in Kazakhstan and measures to address them: research and adoption. Pedologist, pp 373–381

Tuleuov AS, Nikishov AV, Dauletalyeva SR (2011) Vozdelyvanie Podsolnechnika v usloviiakh Aktiubinskoi Oblasti [Cultivation of Sunflower in Aktyubinsk Oblast]. Dostizheniia Nauki I Tekhniki APK 11:32–34 (in Russian)

Uhlmann F (2003) Internationaler Handel mit gentechnisch veränderten pflanzlichen Erzeugnissen: Der Versuch einer Statusbeschreibung [International trade in genetically modified herbal products: attempting to describe the status]. Work Report 1/2003. Federal agricultural research center, institute for market analysis and agricultural trade policy. http://literatur.vti.bund.de/digbib_extern/zi031284.pdf. Accessed 06 Feb 2018 (in German)

Chapter 29
Effects of the Modern Technologies on the Economic Efficiency of Cropping Systems

K. Hiller, M. Frühauf, T. Meinel and P. Tillack

Abstract Non-adaptive land use in the Russian dry step generates negative ecological effects and damages arable land. For this reason, research studies have to show how adaptive cropping systems can help to promote soil fertility and economic benefit. This paper represents an examination of the economic effects of alternative cultivation methods which were tested in Southwestern Siberia. For research purposes, a traditional farming system, an expanded conventional system and a direct seeding system were compared to each other, especially the gross margins per hectare as well as by year. Overall, the adapted forms produce higher contribution margins than the conventional system. The main reason for lower contribution margin in the conventional system is the fallow period in the crop rotation, which produces no crop yield. Adding field pea and oilseed rape in rotation with the primary cash crop, wheat, represents an alternative to fallow periods. The reduced intensity of tillage in the adapted systems also helps to decrease labour and machinery costs by saving working hours and fuel.

Keywords Russian dry step · Direct seeding · Gross margin · Alternative farming systems

---

K. Hiller (✉)
Agrar-Genossenschaft Altmärkische Höhe eG, Lückstedt Nr. 77, 39606 Altmärkische Höhe, Germany
e-mail: karsten.hiller@geo.uni-halle.de

M. Frühauf
Institute of Geosciences and Geography, Martin-Luther-Universität Halle-Wittenberg, Von-Seckendorff-Platz 4, 06120 Halle, Germany

T. Meinel
TOO Amazone, Saifulina Street 3, Office 1, Astana 010000, Kazakhstan

P. Tillack
Erlicht 35, 08468 Reichenbach im Vogtland, Germany

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_29

29.1 Goal

Russia is one of the world's largest producers of cereals. Particularly, the wide availability of land and the good quality of the soil represent very favourable conditions for the cultivation of crops. Moreover, the Soviet Union used to strive for the expansion of cereal production to rid itself of imports (Merls 2011). For this purpose, several million hectares of land were transformed into fields in Western Siberia, among other places, in the 1950s as part of the virgin land reclamation. The negative ecological effect resulting from a non-adapted land use is rather apparent in this region.

This paper will examine whether the adaptation of land use systems is economically justifiable. In addition to protecting soil fertility and nature, the new farming system must also be financially viable. The competitiveness of the farms and the social conditions of the population in the area under investigation have to be maintained and improved to stop young people from moving away and prevent the villages and agriculture from dying out.

The research deals with adaptation measures from various fields of arable farming and plant production. Innovation in agricultural engineering, the expansion of the crop rotation, the reduction of tillage intensity as well as the application of crop protection products and fertilizers are meant to increase yield and ensure sustainable soil management in the long term.

In this context, the question arises as to what extent these forms of innovations influence the performance and costs of the farming methods. Within the trial, the extent of the adaptations is reflected in three farming methods. The traditional one is compared to two adapted systems.

Previous research papers assessed the economic benefit of land use systems mainly by calculating partial costs (Heckmann 2013; Ngwira et al. 2012; Ozpinar 2006; Sanchez-Giron et al. 2004). This allows for conclusions on the profitability of the production procedures under the assumption that other conditions within the agricultural enterprise remain unchanged.

29.2 Partial Cost System

The contribution margin calculation, also called partial cost system, is suitable for assessing farming systems regarding their economic viability and comparing them as it only examines the profitability of the production process of an agricultural enterprise and not the economics of the enterprise as a whole. This is also outlined by Doluschitz et al. (2011). It is mainly about evaluating and comparing costs and the performance of the production. The variable costs are deducted from the result as a part of this process.

Various types of costs emerge within an agricultural enterprise which can be allocated to cost centres in a hierarchical order. A rough distinction is made between variable and fixed costs. Whether the costs are fixed or variable depends on how they react when the production volume changes (Doluschitz et al. 2011; Radke 2009).

The final result of a production process has variable costs which are divided into direct costs as well as labour and machinery costs. Direct costs are incurred in plant production for seed, crop protection products and fertilizer. Labour and machinery costs include wages for seasonal workers, input costs for diesel or oil as well as maintenance costs (Mußhoff and Hirschauer 2011; Schneeberger and Peyerl 2011). When examining a production process in a paper like this, the partial cost system should be used as this trial mainly influences variable costs, not the fixed costs (Doluschitz et al. 2011).

However, in addition to the variable costs, costs incurred through investment for the depreciation of a machine, which is required for a certain farming system, must be considered as well. These write-offs are called product fixed costs and are incorporated into the partial cost calculation when assessing a production procedure (Mußhoff and Hirschauer 2011).

29.3 Method

Location

The Kulunda Steppe is located in the Southwestern part of the West Siberian Plain (Rudaya et al. 2012). The area under investigation is characterized by continental climate causing extreme variations in temperature throughout the year from −45 to +35 °C (Meinel and Schmidt 2003; Paramonov et al. 1997). The low annual precipitation of 250 mm to a maximum of 400 mm mainly occurs during the summer months (Atlas Altaiskogo kraia 1987). The annual evaporation exceeds the precipitation amounts which lead to this region being classified as semiarid (Meinel 2002). The main vegetation period is between May and August, limiting the annual biomass production. Soil life is also negatively impacted by dryness and constant frost during the winter months. The mineralization rate of organic substances is low (Meinel and Schmidt 2003).

The predominating soil types are Kastanozems and Chernozems, which are rich in humus (Schreiner 2014).

Both test farms are located in regions of the Kulunda Steppe with different climates.

The agricultural enterprise in Komsomolski in the Northeast near Barnaul is situated in the forest steppe, characterized by high annual precipitation of 400 mm on average (Bergmann and Frühauf 2011).

The second farm in the municipality of Poluyamki is located in the dry steppe, which has low precipitation, in the Southwest of the Kulunda Steppe on the Kazakh border. Over the course of the year, only 250 mm of precipitation are recorded here (Bergmann and Frühauf 2011).

29.4 Variations

The farming systems under investigation include a conventional system, which simulates the traditional farming method in the region under investigation. The second method is an adapted form of the conventional system (expanded conventional system), while the third one is a direct seeding system.

The conventional farming system is characterized by intensive tillage. As part of the trial, the soil was tilled up to a depth of 35 cm using a subsoiler in the fall after the harvest. The soil was loosened but not inverted as part of the process. Prior to seeding, the soil was worked a second time with a tine harrow. A wing-share seeder was used for seeding in the period from early May to early June. The soil was loosened yet again at a working depth of 8–15 cm. The seeds are commonly placed at a depth of 8 cm. This is done to ensure the supply of water required for germination in low precipitation regions. The seeding rate was 150 kg/ha (summer wheat). No further measures were taken in the standing crop. A 320-horsepower articulated tractor was used for tillage and seeding. The harvest was completed in September using a straw walker combine. The straw remained on the field. Two crop rotations were used; summer wheat—summer wheat—black fallow as well as summer wheat—summer wheat—chemical fallow. The black fallow land was also worked with the subsoiler in the fall as well as one or two times during the vegetation period with a compact disc harrow. The chemical fallow ground was treated two or three times with a broadband crop protection product. A 130-horsepower standard tractor with a trailed field sprayer was used.

The expanded conventional system includes soil tillage with a compact disc harrow at a depth of 15 cm with the harvest residues being worked into the soil. Additionally, this causes volunteer grain to germinate. Seeding is similar to the conventional system but for the expanded system, calcium ammonium nitrate is placed into the seed slot together with the seed. The crop rotation was summer wheat—summer rape—summer wheat—summer peas. For both rape and wheat, 100 kg/ha of fertilizer were applied each. For peas, it was 50 kg. The seeding rate was 150 kg/ha for wheat, 10 kg/ha for rape and 200 kg/ha for peas. For every crop, broadband crop protection products were applied pre-emergence. During the vegetation period, crop protection products were applied depending on the occurrence of weeds, pests or illnesses.

The direct seeding system is characterized by the implementation of ideas from a conserving tillage system utilized in Canada.

The soil is only influenced by the shares during seeding. Therefore, there is no further tillage which saves labour and machinery costs. A Condor tine seed drill, which was specially designed by the company Amazone, was used for direct seeding. The drill has a working width of 15 m and a working speed of up to 12 km/h. The amount of seed per hectare is 120 kg for wheat, 180 kg for peas and 4 kg for rape. It also allows for placing fertilizer along with the seed. The dosage is equal to that from the expanded conventional system. A trailing packer wheel ensures reconsolidation of

Performance	Yield
- Direct costs	Seed Fertilizer Crop protection products
- Labor and machinery costs	Wages Consumables Maintenance Product fixed costs
= Direct costs	

Fig. 29.1 Partial cost calculation

the soil. Crop protection and harvest were the same as for the expanded conventional system. Wheat, rape and peas are cultivated in a four-part crop rotation.

29.5 Data Collection and Contribution Margin Calculation

The information needed for the contribution margin calculation was mainly gathered on site from the test farms. This required an examination of the accounting ledgers. The costs and performance were taken from the annual reports of the agricultural enterprises. Data which could not be retrieved from the records were requested from the managers of plant production, also called agronomists, and accounting departments. The bases of the contribution margin calculation are shown in Fig. 29.1.

To record the performance of an individual farming system, the yield from the plots was extrapolated per hectare and the sales prices from the test farms were assumed. Since the farms did not sell every year, the database of the Russian Ministry of Agriculture had to be used as well (MSKH 2015).

The costs of the individual crops were recorded in the annual reports for summer cereals, summer rape and legumes. To differentiate the cultures of summer wheat and field peas from the two supergroups, specific information on these two cultures had to be requested from the agronomists of the respective test farms.

The direct costs and the labour and machinery costs for the crop groups were taken from the annual reports. The direct costs were listed as seed, fertilizer and crop protection product costs and determined for the individual crops using the data provided by the agronomists. The amount of seed and fertilizer depended on the specifications of the trial for the individual farming systems. Crop protection measures and the products applied were recorded by the agronomists for every single year. The prices for crop protection products were also requested from the agronomists, but mainly taken from the dealers' price lists.

Regarding the labour and machinery costs, only the maintenance costs could be taken from the annual reports.

The work stages differ between the farming systems and different agricultural machineries and implements were used. To determine the various fuel consumption and area output of the individual tractor-machine combinations and harvesters, the respective heads of agricultural engineering were polled. There were benchmarks in Komsomolski and Pervomaysky which had been recorded by accounting. The diesel prices per litre were taken from the annual accounts of the administration.

The tractor drivers received fixed salaries depending on the shift when they operated the tractor. The harvester drivers were paid by performance, i.e. they were paid by decitonne/shift with the payment by decitonne depending on the number of bunker fillings per shift.

Finally, the product-related fixed costs in the form of depreciation for agricultural engineering investment were calculated as well. These investments occurred for the two adapted farming systems as agricultural engineering was used which had not previously been available on the farms.

29.6 Trial Set-up and Statistical Evaluation

The statistical evaluation was conducted using the SAS 9.4 (SAS Institute 2015) software in the MIXED procedure. It was a variance analysis to examine the effects of the factors and also their combination on the inspected feature. A probability for error of $\alpha = 0.05$ was assumed.

In the simplest case, the inspected feature *farming system*, which is also the main inspection feature of the trial, is examined. It occurs in three levels—as the conventional, expanded conventional and direct seeding system. In this trial, each variant was repeated four times. This leads to four blocks on the test facility with three sections each.

The model of a complete single-factor block design:

$$\underline{\mathbf{y}}_{\mathbf{ij}} = \boldsymbol{\mu} + \boldsymbol{\alpha}_{\mathbf{i}} + \mathbf{w}_{\mathbf{j}} + \underline{\mathbf{e}}_{\mathbf{ij}} \quad (i = 1, \ldots, a; j = 1, \ldots, r)$$

In addition to the farming systems, the effect of the cultivated crops on the inspected feature *contribution margin* can be examined as well. This leads to a two-factor trial. It must be noted that only the two adapted systems can be compared as the same crops were cultivated here and the extent of the sub-plots created per farming system was identical. Four sub-plots were created per farming system. This corresponds with the four-element crop rotation of wheat–peas–wheat–rape.

The statistical model for a two-factor split design:

$$\underline{\mathbf{y}}_{\mathbf{ijk}} = \boldsymbol{\mu} + \boldsymbol{\alpha}_{\mathbf{i}} + \boldsymbol{\beta}_{\mathbf{j}} + (\boldsymbol{\alpha\beta})_{\mathbf{ij}} + \mathbf{w}_{\mathbf{k}} + \underline{\mathbf{e}}_{\mathbf{ik}} + \underline{\mathbf{e}}_{\mathbf{ijk}}$$
$$(i = 1, \ldots, a; j = 1, \ldots, b; k = 1, \ldots, r)$$

29.7 Results and Discussion

Poluyamki + Komsomolski

The contribution margins for the farming systems at the Poluyamki site in Fig. 29.2 show that the conventional farming system (3) produces the worst results with an average of RUB 868.35/ha in both years of the trial. The direct seeding system (1) is well ahead of the conventional one with an average of RUB 5961.81/ha. However, the highest result has been achieved by the expanded conventional system (2) with an average of RUB 10,661.37/ha. The contribution margins from 2013 exceed those from 2014 many times over.

The results of the Tukey test in Fig. 29.3 show that the contribution margins of the two adapted systems significantly differ from those of the conventional system in 2013.

The mean values of the contribution margins in Fig. 29.4 show the direct seeding system achieved the best results in Komsomolski. On average, a value of RUB 5171.86/ha was achieved. The expanded conventional system only reached RUB 2277.06/ha on this site during the two years. Just like in Poluyamki, the conventional method achieved the lowest values with an average of EUR 603.69/ha.

Mean values (LSMEANS)		
Farming system	**2013**	**2014**
Direct seeding	11,768.00	155.61
Expanded conventional	18,541.00	2,781.73
Conventional	1,932.54	–195.85

Fig. 29.2 Comparison of contribution margin mean values (in RUB/ha) by farming system and test year, Poluyamki site

LSMEANS differences (Tukey)		
Comparison	**2013**	**2014**
1/2	0.1711 (– 6,772.73)	0.2061 (–2,626.13)
1/3	0.0305 (9,835.52)	0.9705 (351.46)
2/3	0.0002 (16,608.00)	0.1355 (2,977.58)

Fig. 29.3 Results of the Tukey test mean value differences (in RUB/ha) for the comparison of the three farming systems; (α = 0.05); Poluyamki site

LSMEANS		
Farming system	**2013**	**2014**
Direct seeding	3,774.93	6,568.79
Expanded conventional	2,118.97	2,435.15
Conventional	−2,112.63	3,320.01

Fig. 29.4 Comparison of contribution margin mean values (in RUB/ha) by farming system and test year, Komsomolski site

LSMEANS differences (Tukey)		
Comparison	**2013**	**2014**
1/2	0.2305 (1,655.96)	0.4553 (4,133.65)
1/3	< 0.0001 (5,887.56)	0.5549 (3,248.78)
2/3	0.0011 (4,231.60)	0.9561 (-884.86)

Fig. 29.5 Results of the Tukey test mean value differences (in RUB/ha) for the comparison of the three farming systems; ($\alpha = 0.05$)

Figure 29.5 shows that the contribution margins of the two adapted systems differ significantly from that of the conventional system in Komsomolski as well for the year 2013.

In the overall comparison, the conventional farming system achieved the lowest contribution margin on both sites. The main reason for this was the fallow periods in the crop rotation. Performance failures occurred due to uncultivated areas. In the two adapted systems, rape or peas were used instead which generated a much better performance with their yield. Peas as a legume accumulates nitrogen in the soil and is therefore a good crop to precede wheat which uses the nitrogen to produce its yield. The conventional system had lower variable costs because of the fallow areas, but it also became apparent that these cost savings could not compensate for the losses due to the lack of yields.

Over the last decades, stubble wheat cultivation with recurring black or chemical fallow periods had established itself. This can be attributed to the relative yield security of this crop rotation which can compensate for the regularly occurring crop failures in the area under investigation.

In the context of this paper, it transpired that both rape and peas produced good yields in the direct seeding and expanded conventional system and that the sales prices for rape significantly exceeded those for wheat.

In addition to yield as performance, the variable costs also influenced the contribution margin of the farming systems in various ways. The direct costs of the conventional systems were relatively low. This was caused by the absence of costs for crop protection and fertilizer as no such measures were taken. Additionally, the costs for seed were lower as there were fallow areas instead of rape and peas in the crop rotation of the conventional method. Moreover, the adapted systems included depreciation for new technology.

The expanded conventional and direct seeding costs were less expensive regarding the labour and machinery costs. Higher performance of the modern machines played a deciding role in this context. Increased working widths and driving speed allowed for the fields to be worked significantly faster, which saved working hours and diesel.

Diesel consumption for the conventional farming system was higher compared to the other system, caused by the intensive tillage. At the same time, additional labour costs were incurred because of the higher number of working hours.

When assessing the adapted systems in both locations, it transpired that the expanded conventional system was more economical in Poluyamki than the direct seeding system. In Komsomolski, it was the other way around. Different research studies have shown that the reduced level of tillage in the direct seeding system is accompanied by certain disadvantages which limited the plant development of the crops. Harvest residue causes problems regarding field emergence as it negatively impacts soil contact and covers the crops (Morris et al. 2009; Schneider 2008; Su et al. 2014).

The difference between the locations could also be explained by the various climatic conditions. From a statistical point of view, however, the difference between the two systems in both locations was not significant. After comparing all systems, it became obvious that the new systems differ significantly from the conventional system and therefore generate substantially higher contribution margins.

29.8 Conclusion

The adapted farming systems are to be recommended from an economic point of view as they generate higher contribution margins than the conventional system.

No significant differences could be noted between the two adapted systems.

The fallow periods in the crop rotation of the conventional system limit the overall contribution margin due to the absence of performance in the form of a crop yield.

Cultivating rape and peas pays off as they generate good yields, particularly rape which additionally has high sales prices. Both crops represent an excellent alternative to black or chemical fallow periods. The reduced intensity of tillage helps to decrease labour and machinery costs by saving working hours and fuel.

The use of modern agricultural engineering has the benefit of increasing output per area while decreasing fuel consumption, which saves labour and machinery costs. Investment-related depreciation on new machines increases the variable costs only slightly.

The variable costs are the lowest for the conventional system as black and chemical fallow periods cost significantly less than used areas. By contrast, crop protection and fertilization have a major impact on the variable costs.

Establishing conservationist farming systems, particularly direct seeding systems, takes time because aspects such as weed suppression and humus formation take several years to develop. Reliable statements can only be made after several vegetation periods (Sime et al. 2015). Harvest residue being shredded and worked into the soil, chemical crop protection, the rotation of cereals and leaf crops and green manuring allow for the suppression of weeds. Additionally, more water is retained thanks to the improved soil structure (Sturny et al. 2007). The yields from the adapted systems can therefore be expected to continue to increase over time.

References

Author (1987) Atlas Altaiskogo kraia [Atlas of Altai Krai]. Moscow/Barnaul

Bergmann A, Frühauf M (2011) Regionalklimatische Untersuchungen in der Südwestsibirischen Kulunda-Steppe [Regional climatic investigations in the southwest Siberian Kulunda steppe]. Geoöko 32:160–194 (in German)

Doluschitz R, Morath C, Pape J (2011) Agrarmanagement – Unternehmensführung in Landwirtschaft und Agribusiness [Agricultural management—business management in agriculture and agribusiness]. Eugen Ulmer, Stuttgart (in German)

Heckmann M (2013) Pflanzenbaulicher und ökonomischer Vergleich des Anbaurisikos verschiedener Ackerbausysteme unter aktuellen und zukünftigen Klimaszenarien [Plant cultivation and economic comparison of the cultivation risk of different crop systems under current and future climate scenarios]. Dissertation, University of Göttingen (in German)

Meinel T (2002) Die geoökologischen Folgewirkungen der Steppenumbrüche in den 50er Jahren in Westsibirien [The geoecological consequences of the steppe breaches in the 1950s in Western Siberia]. Dissertation, Martin Luther University Halle-Wittenberg (in German)

Meinel T, Schmidt D (2003) Ackerbaukonzeption für die Region Altai Krai West-Sibirien [Arable farming concept for the Altai Krai region of Western Siberia]. Eschborn: GTZ, pp 1–47 (in German)

Merls S (2011) Sowjetisierung in Wirtschaft und Landwirtschaft [Sovietization in economy and agriculture]. In: Europäische Geschichte Online (EGO), Institut für Europäische Geschichte (ed.). http://www.ieg-ego.eu/merls-2011-de. Accessed 21 Aug 2015 (in German)

Mußhoff O, Hirschauer N (2011) Modernes Agrarmanagement: Betriebswirtschaftliche Analyse- und Planungsverfahren [Modern agricultural management-business analysis and planning procedures], 2nd edn. Franz Vahlen, Munich (in German)

Morris NL, Miller PCH, Orson JH, Froud-Williams RJ (2009) The effect of wheat straw residue on the emergence and early growth of sugar beet (Beta vulgaris) and oilseed rape (Brassica napus). Eur J Agron 30:151–162

MSKH [Ministerstvo sel'skogo khoziaistva Rossiiskoi Federatsii] (2015) Ministry of Agriculture of the Russian Federation. http://www.mcx.ru/navigation/docfeeder/show/169.htm. Accessed 5 Aug 2015 (in Russian)

Ngwira AR, Aune JB, Mkwinda S (2012) On-farm evaluation of yield and economic benefit of short-term maize legume intercropping systems under conservation agriculture in Malawi. Field Crops Res 132:149–157

Ozpinar S (2006) Effects of tillage systems on weed population and economics for winter wheat production under the Mediterranean dryland conditions. Soil Tillage Res 87:1–8

Paramonov EG, Ischugin JN, Simonenko AP (1997) Kulundinskii step: problemy opustynivaniia [Kulunda step: problems of desertification]. Altai University Publishing, Barnaul (in Russian)
Radke H-D (2009) Kostenrechnung [Accounting]. Haufe-Verlag, Freiburg (in German)
Rudaya N, Nazarova L, Nourgaliev D, Palagushkina O, Papin D, Frolova L (2012) Mid-late Holocene environmental history of Kulunda, southern West Siberia: vegetation, climate and humans. Quatern Sci Rev 48:32–42
Sanchez-Giron V, Serrano A, Hernaz JL, Navarrete L (2004) Economic assessment of three long-term tillage systems for rainfed cereal and legume production in semiarid central Spain. Soil Tillage Res 78:35–44
SAS Institute (2015). SAS/STAT® 9.4 User's Guide. https://support.sas.com/documentation/onlinedoc/stat/index.html
Schneeberger W, Peyerl H (eds) (2011) Betriebswirtschaftslehre für Agrarökonomen [Business administration for agricultural economists]. Facultas Verlags- und Buchhandels AG, Wien (in German)
Schneider M (2008) Fruchtfolgegestaltung und konservierende Bodenbearbeitung/Direktsaat – Eine pflanzenbaulich/ökonomische Analyse [Crop rotation and conservation tillage/direct seed - A plant-based/economic analysis]. Dissertation, Technical University Munich (in German)
Schreiner V, Meyer BC (2014) Indicators of land degradation in steppe regions: soil and morphodynamics in the Northern Kulunda. In: Mueller L, Saparov A, Lischeid G (eds) Novel measurement and assessment tools for monitoring and management of land and water resources in agricultural landscapes of Central Asia, environmental science and engineering. Springer, Cham, pp 535–548
Sime G, Aune JB, Mohammed H (2015) Agronomic and economic response of tillage and water conservation management in maize, central rift valley in Ethiopia. Soil & Tillage Research 148:20–30
Sturny WG, Chervet A, Maurer-Troxler C, Ramseier L, Müller M, Schafflützel R, Richner W, Streit B, Weisskopf P, Zihlmann U (2007) Direktsaat und Pflug im Systemvergleich - eine Synthese [direct seed and plough in comparison - a synthesis]. Agrarforschung 14(8):350–357 (in German)
Wie Su, Lu J, Wang W, Li X, Ren T, Cong R (2014) Influence of rice straw mulching on seed yield and nitrogen use efficiency of winter oilseed rape (Brassica napus L.) in intensive rice–oilseed rape cropping system. Field Crops Res 159:53–61

Chapter 30
Possibility of Natural Steppe Cover Restoration and Its Biodiversity Expansion

M. M. Silantyeva, T. A. Terekhina, N. V. Elesova, N. V. Ovcharova and T. V. Kornievskaya

Abstract The approaches to the rehabilitation of the vegetation cover in the Kulunda steppes and to the increase of their biodiversity under the conditions of the existing nature management system can vary. We investigated only three specific approaches, the implementation of which are much in demand and have already been started. The restoration of steppe ecosystems is an important step in their rehabilitation. The restoration of the sample steppe communities can be passive, through the regeneration of sod lands or degraded pastures through exclusion from use (isolation), or active, by the method of 'agrosteppe'. The data on the improvement of steppe pastures by means of isolation, obtained over a period of three years, indicated a significant restoration of the floral communities' structure. The layerage is re-established, the total projective cover increases and so does the aboveground phytomass stock. The steppe communities' restoration, by the method of agrosteppe with the use of the legume family representatives adapted to the dry steppe conditions of the Kulunda area, showed positive results. A range of drought resistant legume grasses was selected. The most sustainable species in the case of late spring sowing were *Astragalus onobrychis* and *A. cicer*. In the case of underwinter sowing, *Medicago lupulina* demonstrated the greatest survival ability among the lucernes, while *A. onobrychis* proved to have the greatest survival ability among the astragaluses. Optimal seeding time for the legumes is underwinter sowing (November). A very important method of steppe restoration activity is the preservation of areas of natural steppe ecosystems as specially protected natural reserves. The conditions for protection of the steppe and lacustrine-steppe ecosystems have been created in seven state partial reserves and ten natural sanctuaries. Forty plant species of the Kulunda steppe are under the protection of the Altai Krai Red Book.

Keywords Restoration ecosystems · Steppe · 'Agrosteppe' · Biodiversity · Kulunda · Siberia

M. M. Silantyeva (✉) · T. A. Terekhina · N. V. Elesova · N. V. Ovcharova · T. V. Kornievskaya
Faculty of Biology, Altai State University, 656049 pr. Lenina 61, Barnaul, Russia
e-mail: msilan@mail.ru

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_30

30.1 Introduction

Sustainable development in the steppe area is possible only based on the creation of natural ecosystems and agroecosystem complexes, capable of self-regulation or demanding minimal managerial measures to retain the ecological balance. The most important element of the natural vegetation cover in steppes, subject to rehabilitation, is pasture.

Constant patternless grazing has a negative influence on the steppe ecosystems (Chap. 4). The main measures of the natural pasture rehabilitation are the following: introduction of the enclosure-pasturing system (rotational grazing), simplified improvement with the help of fertilizer application, short-term isolation from grazing (reservation), creation of better pastures through agrosteppes as well as the existence of the conservation status of the steppe ecosystem. Now, we shall focus on the projected directions of the steppe ecosystems rehabilitation.

The progressive successions of the degraded natural pastures depend on the nature and climatic conditions. Hence, in different natural zones, there exists a necessity to study the regularities of the natural pasture rehabilitation when the pasture load is reduced (post-pasture demutation).

In the southern Kulunda, steppe pastures have been exploited since the end of the eighteenth century. After the total ploughing era in Kulunda in the twentieth century, grazing sites often remained in the saliferous or inarable steppe phytocenoses.

30.2 Materials and Methods

The study of the stages of the degraded natural rangelands progressive successions in southern Kulunda in conditions of short-term isolation was conducted in the south-western part of the dry steppe area, within the territory of Mikhaylovskiy District, Altai Krai, on the fields of a farm enterprise LLC ‘Partner’. For the purposes of the experiment in the short-term isolation of steppe areas, three monitoring sites, 100 m^2 each, corresponding to the different stages of pasture degradation were chosen and enclosed 5 km west from Poluyamki village in May 2013. The first site was characterized by moderate grazing (forb-fescue-feather grass steppe), the second one was characterized by heavy grazing (lucerne-wormwood-fescue steppe) and the third site could be described as being at the beginning of over-browsing (heavy grazing, fescue-wormwood, heavily degraded steppe). All the sites were situated according to the ecological profile directed towards a cattle camp.

The over-browsed area was not enclosed and did not participate as soon in the experiment on short-term isolation as several decades are necessary to restore frosted orache and ceratocephala-frosted orache over-browsings in the dry steppe conditions (Ivanov 1958). The soils on the test sites (grounds) are of a chestnut (the first site) and dark chestnut (the second and third sites) subtypes (Silantyeva et al. 2015a, b).

The stock of the aboveground phytomass was determined by means of a cut-sample method three times a season, the discount area size equal to 0.25 m^2, four-to-ten-fold replication was applied. The geobotanical descriptions were made in May, June and August. The data obtained in June were used to compare the results as soon as the pastures under study are regarded as early aestival by their developmental rhythm. The natural conditions were rather varied during the experimental years, the growing season of 2013–2014 saw the precipitation equal to 120–140 mm, the year of 2015 was the most humid and favourable for the plants' development.

The true forb-fescue-feather grass steppe, occupying no more than 5% of the total site area and corresponding to the second stage of pasture degradation, is situated 20 m from a treeline in the most remote from the cattle camp location (the beginning of the laid ecological profile). In June 2013, 36 plant species were registered per 100 m^2. The total projective cover equalled 55–60% with the spots of 70%.

30.3 Results

The site of the lucerne-wormwood-fescue steppe is in the third stage of pasture degradation (heavy grazing, fescue stage). In June 2013, 23 plant species were registered per 100 m^2. The projective cover varied from 45 to 50%.

The site of the wormwood-fescue, heavily degraded steppe, corresponds to the third stage of pasture degradation transiting to the 4th (wormwood) stage, and the steppe litter is almost lost. In June 2013, 17 plant species were registered per 100 m^2. The projective cover varied from 30 to 35%.

The short-term isolation (three years) had a positive influence on the value of stock for all the components of the aboveground phytomass. At the moderate grazing stage (forb-fescue-feather grass steppe), the aboveground phytomass stock rose from 324.5 to 596.4 g/m^2 in June 2015, the green shoot productivity rose from 208.5 to 415.4 g/m^2 mostly due to the increase in the cereal crop share (almost twice as much) and the forbs share (by 2.6 times). The legumes share increased by half as well. The dead grass share rose from 9.1 to 12.5 g/m^2, the litter stock grew by half (from 106.9 to 168.5 g/m^2) (Tables 30.1).

In three years of isolation, the cereal species diversity rose owing to *Elytrigia repens, Leymus ramosus, Koeleria cristata, Agropyron pectinatum* at Site 1. By the third year of isolation, the following legumes appeared: the onobrychis milk vetch (*Astragalus onobrichis*) and the white sweet clover (*Melilotus albus*). The group of forbs enlarged due to the appearance of *Artemisia dracunculus, Potentilla canescens, Gypsophilla paniculata, Dianthus deltoides, Veronica spicata*. The total number of plant species remained unchanged (2013–36 species, 2015–37 species), which occurred due to several species mortality: *Poa angustifolia, Artemisia scoparia, Taraxacum officinale, Odontites vulgaris.* One should mention the disappearance of blue-green algae *Nostoc sp.*

The structure of the grass stand changed significantly in a positive way: the number of sublayers rose from 2 to 3. The vertical profile of the steppe community rose from

Table 30.1 The influence of a short-term isolation on the aboveground phytomass stock in the dry bunchgrass steppe at different stages of pasture degradation (Mikhaylovskiy District, the area of Poluyamki village; 18.06.2015; g/m^2)

Aboveground phytomass structure and its components	Degradation stages		
	I (moderate grazing) phytomass on pasture/phytomass at reservation site	II (heavy grazing—fescue stage) phytomass on pasture/phytomass at reservation site	III (beginning of over-browsing—wormwood stage) phytomass on pasture/phytomass at reservation site
Green shoots, inter alia:	208.5/415.4	93.7/204.0	85.0/113.6
Cereals	110.0/217.2	50.4/77.4	47.7/89.9
Legumes	47.1/66.2	2.6/62.0	4.1/5.1
Forbs	51.4/132.0	40.7/65.0	33.2/20.1
Dead Grass	9.1/12.5	6.6/9.7	6.7/8.4
Litter	106.9/168.5	50.8/72.3	20.5/54.7
Total	324.5/596.4	151.1/286.0	112.2/176.7

55 to 60 cm to 85 cm. The total projective cover of the forb-fescue-feather grass steppe enlarged from 55 to 60 to 80%. One should also note the increase in edificators (the feather grass) viability on the isolated ground, which manifested itself in the increase in their height by 30 cm and the twofold increase in the projective cover of *Stipa capillata* (10 and 20% respectively).

At the stage of heavy grazing (the second fescue stage), short-term isolation also had a positive influence on the aboveground phytomass and its element productivity (lucerne-wormwood-fescue steppe). The total aboveground phytomass stock rose from 151.1 to 286.0 g/m^2 in June 2015, the green shoot volume rose more than two times (from 93.7 to 204 g/m^2) owing to the increase in the cereal crops, the legumes and the forbs share, the dead grass share rose by 50% from 6.6 to 9.7 g/m^2 and the litter share grew from 50.8 to 72.7 g/m^2. It is worth noting that the cereal crop and the forb amounts in the structure of the green shoots increased by 50% respectively, while the legume amount rose by more than 30 times.

By the second year of isolation, *Artemisia scoparia*, *A. nitrosa*, *A. frigida*, *Taraxacum officinale*, *Linaria vulgaris*, *Otites parviflora* and *Kochia prostrata* appeared on the site, while they were not noticed in 2013. The sickle lucerne became a co-dominant in the second year of isolation, its projective cover increased from 3 to 7%. New forb species appeared (the tarragon, the bifid cinquefoil, the hoary groundsel, the flat-leaved sea holly), the ones being absent on the areas of the wormwood-cinquefoil-fescue degraded steppe exposed to grazing.

By the third year of isolation, the grass stand acquired a three-layer character. Its height increased from 30 to 35 cm to 60 cm, while the total projective cover went from 30 to 35 to 65%. The viability of the edificator (*Festuca valesiaca*) improved, its height rose from 25 cm to 35 cm, there appeared generative shoots, which were almost completely absent on the ground exposed to grazing. It should be noted that such a high increase in the grass stand structure indications in 2015 is closely connected to high soil humidity and not only to the short-term isolation influence.

At the stage of heavy grazing—the beginning of over-browsing (the third wormwood stage), the isolated site of the cinquefoil-wormwood-fescue degraded steppe also exhibited the increase in the aboveground phytomass productivity from 112.2 to 176.7 g/m^2. The green shoots volume grew by 1.4 times from 85 to 133.6 g/m^2, mostly owing to the cereal crops. The dead grass share increased insignificantly from 6.7 to 8.4 g/m^2. The litter stock rose by 2.5 times from 20.5 to 54.7 g/m^2. At the isolated site, the number of plant species increased from 17 to 22 in 2015; new cereal species appeared, i.e. *Elytrigia repens*, *Cleistogenes squarrosa*, *Setaria viridis* and *Onobrychis arenaria* were noted out of the legumes, *Artemisia frigida*, *Senecio jacobaea* and *Polygonum patulum* were noticed from the forbs. One could observe a greener aspect. The viability of the fescue and the lucerne increased, which manifested itself in an increase in their height from 30 cm to 45 cm and in the number of the generative shoots, the latter being almost absent on the ground of the fescue-wormwood, heavily degraded steppe exposed to grazing.

The grass stand structure improved significantly; the number of sublayers grew from 2 to 3, the height of a single sublayer increased by 15 cm (30–45 cm), the total projective cover increased twofold (from 25% to 50%).

Thus, the conducted experiment in the reservation of an area in the true bunchgrass steppe during the period of 3 years allowed us to make the following conclusions:

- A three-year period is insufficient for the restoration of the species composition at the heavily over-browsed sites (the third stage of pasture degradation, the transition to the fourth stage);
- The cereals, the legumes and the forbs are slow to recover, and so is the dead grass and litter stock;
- The isolation facilitates the improvement of the pasture community's structure; layerage is re-established, the total projective cover increases and so does the aboveground phytomass stock.

Another important path to steppe ecosystem rehabilitation is their restoration. The restoration of the sample steppe communities can be passive through the restoration of lea lands upon availability of the steppe plants genebank, and active by the method of 'agrosteppe' (Dzibov 2001).

Natural rehabilitation of completely destroyed steppe vegetation on a tilled field takes 80–100 years or more, as the weeds are the first to exploit the available ecological resources (moisture, mineral nutrition, light), and afterwards they prevent the wild land steppe plants from entering their environment. The weed plants and their spinney are characterized by rapid growth and abundant fruiting, habitually. They are always stronger and win the competition with the steppe plant sprouts.

Moreover, the difficulties of the natural pasture rehabilitation occur due to the large percentage of the territory under the plough in many Kulunda regions, and as a result, due to the practically total absence of the natural steppe ecosystems which could act as seed grain donors. The area of the individual fields being vast, in cases of the self-organized vegetation filling of lea lands, the central part remains unavailable for the steppe plants for many years.

The method of agrosteppes allows us to restore the analogues of the zonal herbaceous vegetation of a xerophilous type by applying agricultural machines and technological operations used in modern agriculture. The most important positive peculiarity of agrosteppes is their ability to become a full-fledged seed plot after two to three years of existence. This allows us to steppificate new territories at a quickening pace, strengthen the farms' fodder supply and succeed in solving the nature protection problems, inter alia, the connection with the struggle against desertification (Dzibov 2001).

Agrosteppes are similar to true steppes in some basic characteristics: (1) the dominant plant species composition; (2) vertical grass stand structure—the number of layers, which usually equals to 2–3; (3) yield capacity per area unit; (4) fodder value; (5) grass stand thickness; (6) exterior picturesqueness—aspect at different periods of the grass stand existence; and (7) erosion preventive significance and resistance to the animal overload when used as pastures (Dzibov 2001).

A pasture featuring a wormwood-fescue, degraded steppe in the area of Poluyamki village (Mikhaylovskiy District), was chosen for conducting research in grassland improvement under conditions of moisture deficit. In June 2013, we started an experiment in the restoration of pastures at the third stage of pasture degradation (the beginning of overgrazing, wormwood stage) and at the second stage (heavy grazing, fescue stage) with the use of some legume grass species—*Lotus corniculatus*, *Astragalus cicer*, *A. sulcatus*, *A. onobrychis*, *Medicago lupulina* и *Medicago falcata*.

Observations were conducted on specially enclosed plots (10 × 10 m), one half of which is a natural grass stand, while the second half hosts plots of seeded legume grasses embedded in grass sod. The width of the plot in tillage is equal to 15 cm, and the space between plots is 35 cm. Monthly from May till September, we carried out a description of vegetation at the chosen sites, phenological observations (according to Beideman 1974), the estimation of legumes' germinating and survival ability.

In order to study the seeding schedule influence on the germinating ability and the establishment of plants on a degraded pasture, two experiments were launched, the first one started in May 2014 (late spring sowing) and the second one started in November 2014 (underwinter sowing).

At the site corresponding to the third stage of pasture degradation, we used two types of *Astragalus cicer*, *A. onobrychis* and *Lotus corniculatus*.

During the first year of cultivation, we observed a trace quantity of seedlings on the plots. The emerging crops were weak. The field germination rate of *Astragalus onobrychis* equalled 36–49%, *A. cicer*: 20%, *Lotus corniculatus*: 21–35%. By the end of the first year of cultivation, the plants were at the stage of the second true leaf formation. The height of the plants equalled 2–3 cm on average.

In 2015, the quantity of seedlings rose by 20%. The emerging crops were stronger and more even. We observed a gain with all the species, especially with *A. onobrychis*. By the end of the second year, the plants reached the average height of 7.5 cm (Fig. 30.1).

At the experimental sites, we conducted the plants' survival ability observations during the growing season of 2015. The germinating maximum of *Astragalus cicer* fell on the beginning of May (332 units per m^2), however, by August, 83% of the emerging crops died due to the drought. At that time, the soil temperature was at 26 °C, while the humidity equalled 0.3% of water saturation.

The highest quantity of the *Astragalus onobrychis* seedlings was recorded in the first half of July (Fig. 30.2) which was accounted for by the optimal temperature for legume development (20 °C) and by the soil humidity (44.88%). By August (the drought period), 38% of the individual plants had died.

The emerging crop of *Lotus corniculatus* was the weakest in comparison with other legume species on the pasture. The total number of plants being 110 units per m^2, only 9% survived by the end of the season.

In this experiment, the species best adapted to the dry steppe conditions turned out to be *Astragalus onobrychis* (62% viable plants).

In the middle of October 2014, the second sample area of the pasture restoration, the rangeland being at the second stage of degradation, was laid down. Three types of

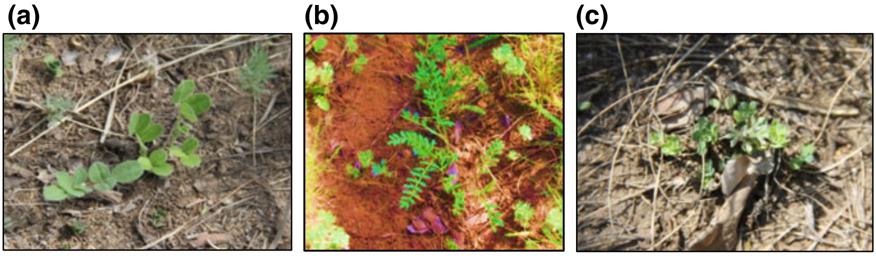


Fig. 30.1 Recultivation of a heavily degraded pasture (the third stage). The plants in the second year of life: (**a**) *Astragalus cicer*; (**b**) *A. onobrychis*; (**c**) *Lotus corniculatus*. *Photos* Silantyeva

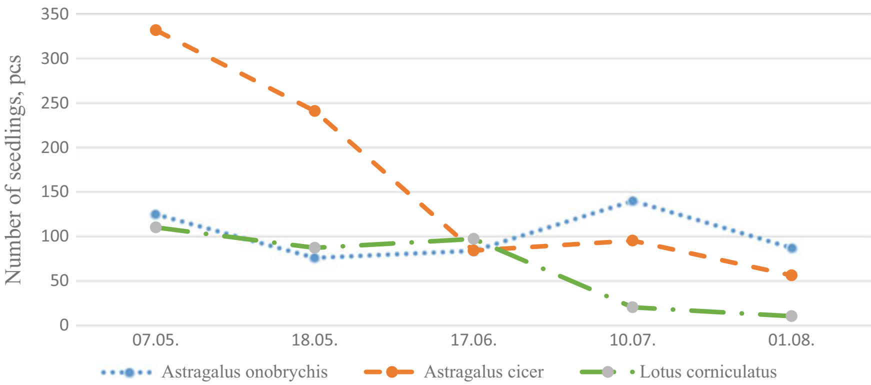


Fig. 30.2 Survival ability of the legumes on the improved pasture (the 3rd stage) in the case of late spring sowing (the growing season of 2015)

Astragalus (*cicer*, *onobrychis*, *sulcatus*), two types of *Medicago falcata*, *M. lupulina* and *Lotus corniculatus* (Fig. 30.3) were chosen for the research. We used the seeds from primary reproduction, obtained from the collection of forage grasses, grown in the conditions of the Kulunda dry steppe area.

Underwinter sowing had several advantages. First, there was no need for the additional scarification of the legumes seeds. They underwent ‘natural scarification’ and stratification. Second, the optimal seeding time, determined; on the one hand, by the soil temperature; on the other hand, by the plant ability to withstand winter frosts, was not missed. The chosen legume species begin sprouting in a laboratory environment at temperatures of 5–15 °C, the optimal germination temperature being 20–25 °C.

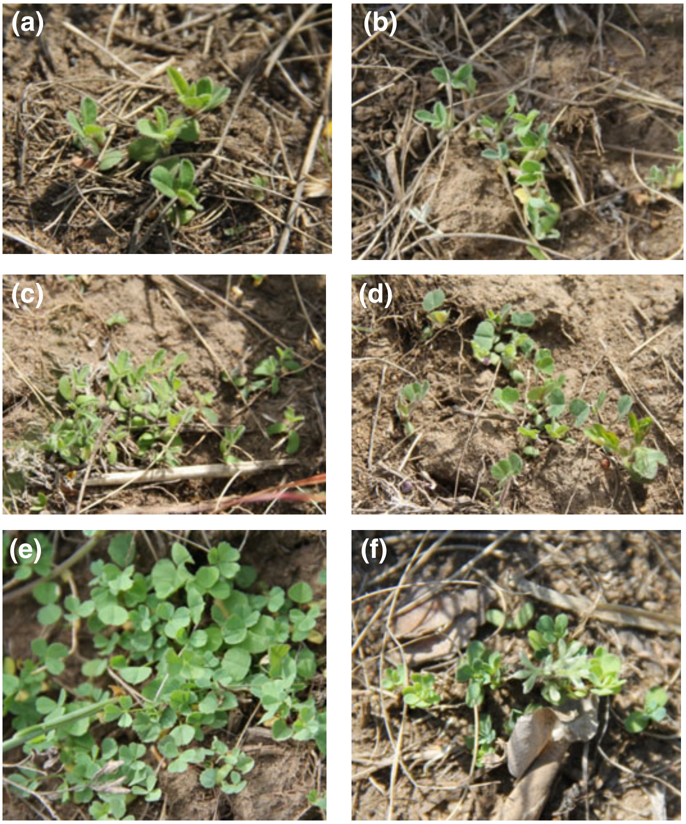


Fig. 30.3 The legume species used for the natural rangeland improvement (the 2nd stage of degradation). The plants in the 1st year of life, sprouts (May): (**a**) *Astragalus cicer*; (**b**) *A. onobrychis*; (**c**) *A. sulcatus*; (**d**) *Medicago lupulina*; (**e**) *M. falcata*; (**f**) *Lotus corniculatus*. *Photos* Silantyeva

Underwinter sowing gave even more sprouts. *Medicago falcata* and *M. lupulina* seeds germinated better than others did. We recorded the maximum number of their seedlings, 1201 and 577 units per m^2 accordingly.

Among the *Astragalus*, we can note *Astragalus sulcatus* (231 units), with a germination capacity twice as high in comparison with *A. cicer* (168 units) and *A. onobrychis* (116 units).

With regard to the quantity of the germinated seeds, *Lotus corniculatus* was at the same level with astragaluses and had the germination capacity of 146 units per m^2.

Observing the germination dynamics, we can note that the highest quantity of *Astragalus cicer* seedlings occurred at the beginning of May (Fig. 30.4). Later on, young plant mortality was recorded. By the end of the growing season, only 16% of individual plants remained.

Astragalus onobrychis and *A. sulcatus* produced the maximum quantity of emerging crops in the second half of May. By the end of June, there was an abrupt decrease in the number of seedlings, about 50% of the plants appeared to be unviable and died during the period of the June drought. By August 1, 27% of *A. onobrychis* young plants, 15% of *A. cicer* young plants and 14% of *A. sulcatus* young plants had survived.

Medicago and *Lotus corniculatus* also gave the maximum of emerging crops in the second half of May. However, in June, similar to astragaluses, significant plant mortality was observed. The total of 9% of bird's-foot trefoil seedlings died and so did 27% of *Medicago lupulina* seedlings and 38% of *M. falcata* seedlings (Fig. 30.5).

By the end of the season, there was grass stand thinning. Overall, 41% (294 units per m^2) of *Medicago lupulina* seedlings, 8.2% (98 units per m^2) of *Medicago falcata* seedlings and 20.5% (30 units per m^2) of *Lotus corniculatus* seedlings survived. Significant mortality of the legumes is connected, to a greater extent, with tougher competition for water among the thick-growing individual plants (*Medicago falcata*).

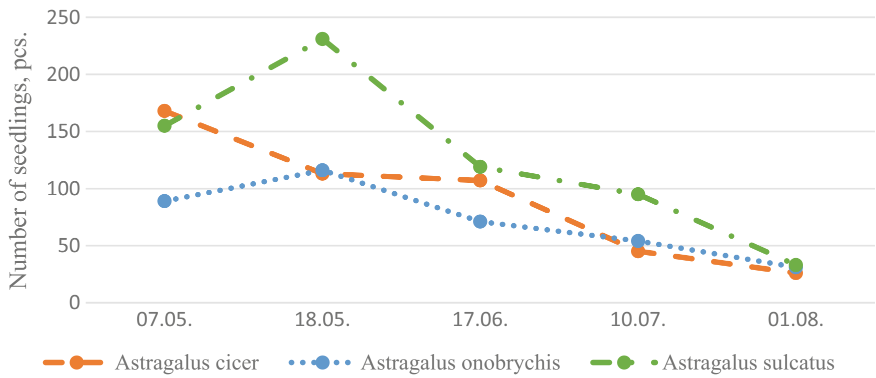


Fig. 30.4 Survival ability of the astragaluses on the improved pasture (the 2nd stage) in the case of underwinter sowing (the growing season of 2015)

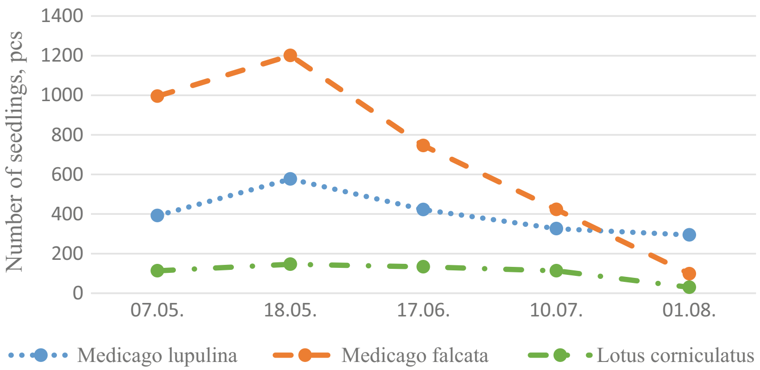


Fig. 30.5 Survival ability of the *Medicago* and the *Lotus corniculatus* on the improved pasture (the second stage) in the case of underwinter sowing (the growing season of 2015)

Regardless of the dead plants high percentage, their quantitative count per unit area testifies to the resistance of all the legume grasses used in the experiment to lack of moisture and high soil and air temperatures.

Thus, two-year experiments in recultivation of pastures in the Kulunda dry steppe area showed positive results. A range of drought resistant legume grasses was selected.

The most sustainable species in the case of late spring sowing were *Astragalus onobrychis* and *A. cicer*. In the conditions of underwinter sowing, *Medicago lupulina* showed the greatest survival ability among the *Medicago*, while *Astragalus onobrychis* showed the greatest survival ability among the astragaluses. Optimal seeding time for the legumes is underwinter sowing (November).

The phenological observations of the legumes used in the experiments showed that during the first two years of life, plants adapt to the new conditions and go through the vegetative stage only (all the species except for *Medicago lupulina*). During the first year of the experimental use, *M. lupulina* goes through all the phenological phases, finishing the growing season with the formation of scanty fruit. In the second year of observation, *M. lupulina* reaches the phase of full semination.

A very important step in the steppe restoration activity is the preservation of the areas of natural steppe ecosystems as an entire system of specially protected natural reservations connected by means of 'ecological corridors'. The role of ecological corridors can be assigned to field-protective and roadside forest belts and shrub belts, isolation spaces beside engineering constructions and other inarable lands. Nowadays in Altai Krai, particular attention is paid to the creation of specially protected natural reservations in Kulunda. The conditions for protection of the steppe and lacustrine-steppe ecosystems with specific complexes of animals and plants are created in seven partial reserves: 'Blagoveshhenskiy', 'Suyetskiy', 'Urzhumskiy', 'Khabarskiy', 'Liflyandskiy', 'Bolshoy Tassor Lake' and 'Loktevskiy', and 10 natural sanctuaries: 'Kurichye Lake and Kasalgach Stow', 'Shimolinskiy Wood', 'Ancient River Bed in Ashhegul', 'Beam System in Novokormikha', 'Shukirtuz

Lake', 'Buldyuk Lake', 'Salinate Fields by Borovskoye village', 'Halophyte Communities of Burlinskoye Lake' and 'Steppes by Parfyenovo'. Moreover, the programme for SPNR development in Altai Krai till 2025 presupposes the proliferation of the steppe ecosystems under protection through the organization of the Kulunda nature park, 2 partial reserves and 10 natural sanctuaries. Forty plant species of the Kulunda Steppe are under the protection of the Altai Krai Red Book (2016): *Stipa pennata* L. s. l., *S. lessingiana* Trin. et Rupr., *S. dasyphylla* (Lindem.) Trautv., *Iris glaucescens* Bunge, *Astragalus arbuscula* Pall., *A. compressus* Ledeb., *A. ammodytes* Pall., *Atraphaxis frutescens* (L.) R. Koch. and others.

30.4 Conclusion

Therefore, the approaches to the natural restoration of the steppe cover and to the expansion of their biodiversity under the conditions of the existing nature management character in Kulunda can be different. We focused only on three main directions, whose implementation is in demand and has already been started. Moreover, the following factors will promote the steppe ecosystems and biodiversity restoration: the introduction of the legal mechanisms of the steppe ecosystems protection in the agricultural areas; ecological restoration of the steppe landscapes, including the restoration of the typical steppe and shrub ecosystems, ravine forests, outliers and flood plain forests, wetlands; the creation of the conditions for additional economic benefits to be derived out of the alternative (non-agricultural) steppes exploitation; the protection of water ecosystems and natural water springs, the restoration of traditional water-supply sources; the formation of the steppe positive image and the perception of the necessity to preserve it in the public consciousness (RAN and MPR 2002).

References

Beideman IN (1974) Metodika izucheniia fenologii rastenii i rastitel'nykh soobshhestv [The methodology of studying the phenology of plants and plant communities]. Izd. Nauka, Novosibirsk (in Russian)

Dzibov DS (2001) Metod agrostepei uskorennoe vosstanovlenie prirodnoi rastitel'nosti: Metodicheskoe posobie [The agro-steppe method accelerated restoration of natural vegetation: Toolkit]. Nauchnaia Kniga, Saratov (in Russian)

Ivanov VV (1958) Stepi Zapadnogo Kazakhstana v sviazi s dinamikoi ikh pokrova [he steppes of Western Kazakhstan in connection with the dynamics of their cover]. Moscow; Leningrad: Academy of Sciences USSR (in Russian)

RAN (Rossiiskaia akademiia nauk) i MPR (Ministerstvo prirodnykh resursov) [The Russian Academy of Sciences and the Ministry of Natural Resources] (2002) Natsional'naia strategiia po sokhraneniiu bioraznoobraziia v Rossiiskoi Federatsii [National Strategy on Biodiversity Conservation in the Russian Federation]

Silantyeva MM, Terekhina TA, Speranskaya NYu, Gal'tsova TV, Shapina MM, Elesova NV, Grebennikova AYu (2015a) Novye perspektivnye vidi i sorta kormovykh trav dlia restavratsii pastbishh sukhostepnoi zoni Kulundi [New promising species and varieties of forage grasses for the restoration of pastures of the dry steppe zone of Kulundi]. Vestnik Altayskoy Nauki 1(23):50–54 (in Russian)

Silantyeva MM, Kharlamova NF, Elesova NV, Speranskaya NYu, Gal'tsova TV, Solomonova MYu, Kurepina NYu, Grebennikova AYu, Plutalova TG (2015b) Restavratsiya stepnykh ekosistem sukhostepnoy zoni Kulundi s uchetom istoricheskoy rekonstruktsii rastitel'nogo pokrova [Restoration of steppe ecosystems in the dry steppe zone of Kulunda, taking into account the historical reconstruction of the vegetation cover]. Vestnik Altayskoy Nauki 1(23):241–245 (in Russian)

Part IV
Towards a Sustainable Future? Challenges for Regional Development and Innovation

Chapter 31
Towards a Sustainable Future? Challenges for Regional Development and Innovation

S. Lentz

Regional development is a highly complex task. Its complexity is made up by the multitude of actors involved. It seems obvious that state institutions, responsible for regional planning and for allocating resources, are in charge professionally. With respect to sustainability as a development goal, the Kulunda research project has used a wider concept of development. The social side of development should be of special relevance. Its starting point was the sensitivity to what can be described as local or autochthonous knowledge. This kind of knowledge exists, of course, in the experiences and the procedures of regional authorities have established over long time. However, the region is facing the challenges not only of technical innovations. Understanding the interdependencies of land use, ecological gentle agrarian technologies and the necessities of enterprises and social and demographic change in a field of tension between cities and villages conceptually requires considering additional stakeholders. In this specific respect, the project defined "sustainability" as the capacity of a region—as the sum of individual and institutional actors—to implement new technologies as well as social innovations "on-site". Such an approach necessarily has to deal with a full range of socio-spatial scales and an understanding of the interconnectedness of spaces as power relations. The following subchapters attend to various aspects of such capacities for innovation, touching issues like acceptance of "external knowledge" as well as implementing new content into the system of education.

Chapters 32–35 delineate the socio-economic regional frame for the Kulunda project. It includes typical elements like the demographic situation in a regional differentiation, but extends also to experts' statements concerning structural changes in the social and economic environment, as well as to experiences of villagers, farmers and agronomists and the "local readiness" for new methods and practices in the land use. Chapter 36–38 then gives insight into how the Kulunda project itself took action

S. Lentz (✉)
Leibniz Institute for Regional Geography, Schongauerstraße 9, 04328 Leipzig, Germany
e-mail: S_Lentz@ifl-leipzig.de

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_31

to spread the news about new technologies to farmers and specialists and to convey new topics to the educational system in its various ramifications.

Chapter 32
Framework for Sustainable Regional Development in the Altai Krai

A. M. Nikulin, S. Lentz, O. Ya. Vinogradskaya, A. A. Kurakin and A. Wust

Abstract In this paragraph, the authors focus on analysing all the factors related to the accumulation of human potential and the integration of new knowledge in rural communities on Altai Krai's Kulunda steppe that are largely responsible for the sustainable socio-economic development of this area. The analysis leads them to conclude that the understanding of the term 'sustainable development' in the directives of the krai and municipal administrations should be expanded in order to allow for the implementation of a number of measures. Those aimed at the socio-economic development of the region to ensure a specific quality of life for all generations in rural communities, both contemporary and future, that would involve the full realization of their human potential.

Keywords Agricultural factors · Climatic factors · Human resources · Regional development · Rural communities · Sustainable development programme

---

A. M. Nikulin (✉) · A. A. Kurakin
The Russian Presidential Academy of National Economy and Public Administration, Centre for Agrarian Studies, Vernadskogo Prospect, 82, 119571 Moscow, Russian Federation
e-mail: harmina@yandex.ru

A. A. Kurakin
National Research University Higher School of Economics, Myasnitskaya Street 20, 101000 Moscow, Russian Federation

O. Ya. Vinogradskaya
Institute of Agrarian Problems - Russian Academy of Sciences (IAGPRAN), Moskovskaya Street 94, 410012 Saratov, Russian Federation

Rural Research Department, The Russian Presidential Academy of National Economy and Public Administration, Vernadskogo Prospect, 82, 119571 Moscow, Russian Federation

S. Lentz · A. Wust
Leibniz Institute for Regional Geography, Schongauerstraße 9, 04328 Leipzig, Germany

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_32

32.1 Results and Discussion

This chapter discusses central points identified during the implementation of the Kulunda project that are related to the accumulation of human potential and the integration of new knowledge. The integrating background is to expand and enrich the understanding of the term ‘sustainable regional development’, which is prominent in planning directive documents of the krai and municipal administrations of Altai Krai’s Kulunda steppe.

The study on the social framework for sustainable regional development in the Altai Krai (cf. Chap. 15) showed that sustainable development of Altai Krai’s Kulunda steppe largely depends on the interaction of two complex factors—natural climate and agricultural production. In a broad sense, scientific literature defines sustainable development as a process of coordinated economic and social transformations intended to ensure the quality of life of both current and future generations.

> The key elements for the sustainable development policy concern the efficient use of resources, encouraging the development of new productive technologies, extending the use of productivity and efficiency enhancement schemes and encouraging both innovative and productive activities. Within this framework, socio-economic development increasingly relies on information and knowledge, and creates value through their ability to manage these valuable assets. (Korres et al. 2014, p. 9)

The authors of the Sustainable Development Programme for the Rural Areas of Altai Krai for 2012–2020 (‘Programme’) emphasize the steadiness of social aspects. The programme aims at ‘the stable socioeconomic development of rural areas on the basis of a diversified rural economy that ensures a high quality of life and rational and environmentally sound land use’. Such stability should be considered sustainable (Adminstration of Altai Krai 2011). The Strategy for the Socioeconomic Development of Altai Krai until 2025, adopted in 2012 by Altai Krai law N86-ZS, defines the strategy’s main goal as follows: ‘Achieving the high standard of living and quality of life for the population based on accelerated innovative economic growth and the strengthening of the region’s strategic positions in Russia’s agricultural, industrial and tourism industries’.

The particular goals of the programme for this sustainable development are:

– creation of liveable conditions for vital activities in the countryside;
– encouragement of investment into the agro-industrial complex by creating favourable infrastructure conditions in the countryside;
– aiding in the creation of high-tech jobs in rural regions;
– energizing the participation of rural residents in the implementation of socially meaningful projects;
– forming a positive attitude towards the countryside and the rural lifestyle.

To achieve such sub-goals, the strategy specifies the accomplishment of basic economic and social objectives such as:

– a substantial increase in labour productivity;

– the creation of geographic clusters in the krai that are competitive on the global market, in particular in agro-industrial and tourism/recreation branches;
– the development and modernization of the krai's transport and communication infrastructure;
– the development of human potential and improvement of the quality of human capital;
– full-scale support for small business;
– assurance of the environmental security of the krai's population and ecosystems;
– efficient use of the krai's unique natural resource potential in the development of a world-class tourism and recreation industry (see: Strategy 2012, 39–40).

To such goals, the Kulunda research project adds specific perspectives to the term 'sustainable', as there are specific ecological pre-conditions for agriculture on the one hand and a very dynamic young history of societal transformation on the other. The joint starting point for the scientific investigation as well as the perspective for the conclusion is the region, which is considered an expression of temporal settings of socio-spatial relations. Under such an evolutionary perspective, the capacity of adopting and regionally distributing new knowledge becomes a further element in the definition of sustainable development.

32.2 Setting of Natural and Climatic Factors and Their Significance for Sustainable Regional Development

Altai Krai's Kulunda steppe is extremely diverse in its natural conditions, but a large part of it is in zones of arid and typical steppes, geographically distinguished by variations of climatic factors. In certain districts, the mean annual precipitation is less than 350 mm. On the other hand, in an arid steppe zone the annual bio-necromass and the lack of humidity for its complete chemical dissolution resulted in the generation of, for example brown soils in which the humus content is as high as 67%. These unique natural and climate conditions provide bases for the kind of agriculture, predominant in the majority of Kulunda steppe districts. Most of the farms concentrated in this area therefore specialize in raising drought-resistant crops: winter and spring wheat, corn, sunflower, millet, etc. A key factor for good harvests is the soil moisture, which should be available during spring and early summer as the crucial phases in the vegetation period. Hence, farmers are making considerable efforts to conserve moisture: snow capture in winter, capture of melt water on the fields in spring, installing natural and technical windbreaks and no-till farming are some of the traditional measures. If traditional cultivation and planting methods are applied, furrows in the fields are often additional 'rolled' in order to condense and ensure the optimum contact between seeds and moist soil.

The Kulunda steppe is a huge ecosystem consisting of numerous elements. One of the key elements in this system, without which soil diversity would be impossible, is a unique ecological formation called 'ribbon pine forests'. They include forests of the ribbon-outlier type, which typically evolved in Western Siberia and Kazakhstan in the harsh soil and climate conditions among unforested spaces. Such forest strips are important for regulating the regional climate, protecting soils and conserving, respectively, renewing groundwater. In Altai Krai's Kulunda steppe, these forests consist of pine forests in the form of ribbons on ancient alluvial sands. They stretch among steppe spaces in the southern part between the Ob and the Irtysh River. They are the only source of lumber throughout the extensive steppe area.

Regional specialists, interviewed in the course of the Kulunda project, however, worry that due to the new planning conditions, the ecosystem of the entire region might be disrupted. The background is a re-categorization of forest types in Kulunda. On the basis of the Rosleskhoz [Federal Forestry Agency] order N 84 dated 20.03.2008, formerly 'especially valuable forest lands' and the protected 'ribbon pine forest' category were re-categorized as producing and reserve forests. According to those specialists, this order allows for uncontrolled felling of huge relict woodlands on ancient alluvial soils, which are not only crucial for wind protection, but also form a specific climate zone here. The state of these forests not only determines the diversity of endemic plants, animals and water resources, but also the vital activity of the local population.

32.3 Agricultural Factors and Their Significance for Sustainable Regional Development

A dynamic in-migration of a larger population, intending to increase agricultural production in the Kulunda steppe and to establish principals of industrial production of food began back in the late 1960s. Since then, until the end of the Soviet Union a long series of experiments, experiences and development in cultivating virgin lands, in land-use technologies, in the composition of agro-industrial farms, and establishing a permanent and enduring system of settlements were the major trajectories in the area. Crucial framing conditions for this period were a nationwide planned and coordinated national economy and the idea of natural spatial resources, which had to be unlocked and developed in a process of societal progress. The shift in the economic paradigm in the 1990s had a deleterious effect on agricultural production and the social infrastructure of the Kulunda steppe. This was partly compensated by the transition of most of the agricultural organizations to private enterprises, the majority of which now concentrates on monocrops, primarily the cultivation of grains. Despite the breakdown of many social infrastructures, one must noted that the majority of rural areas still have a kind of margin of strength, which, for instance, ensures the viability of local areas on a certain level. However, this level is endangered by the further loss of population, mainly migration to the cities.

Most of the municipal districts in Altai Krai's Kulunda steppe have natural and climate conditions that are challenging for farming. In Soviet times, therefore, providing feed for livestock required farms to engage in intensive irrigation and to support grain production despite the low yield, large areas of cropland were cultivated. Now almost none of the farms in this area can afford to use these kinds of resource-intensive technologies. As a result, they prefer to give up raising livestock and specialize in growing grains instead, as a typical quotation from the interviews in the region may show:

> R.: […] we can't raise flax here — it doesn't grow. We can't get canola, because it likewise doesn't produce the yields at which a farm is more or less profitable. I think that sunflower is the most cost-effective crop in Altai Krai, maybe with the exception of sugar beets. However, before, back in Soviet times, the farm where I worked had 16,000 hectares of tillage, and 8,000 ha were planted, but we were allowed to plant only 400 ha with sunflower, no more, out of the 16,000! This year we have 27,000 ha in the district planted with sunflower and 24,000 planted with cereals. Truth be told, there can't be so much sunflower in the rotation… Because it depletes the soil, and quarantine weeds grow, and there are all kinds of pests, anything you want! What are we to do? It drives the economy, and the farmers live and survive because of it. So, a planned economy is probably necessary now. (Altai Krai, Uglovsky district, Uglovskoye village, administration employee, September 2015)

Private farms now are a key component of the sustainable regional development of Altai Krai's Kulunda steppe. The majority of them operate under austere conditions, which in turn pushes them to use innovative technologies at different stages of the production process: equipment is modified to local conditions, and a specific process flow is developed, for instance, for each individual sowing system. On innovative farms, biological growth stimulants, micro fertilizer and microelements replace expensive chemical fertilizers. This creative approach enables these farms to obtain a yield in certain years up to 14.5 hwt/ha, even on poor brown soils near forest ribbons. Sometimes they exceed the results for the rich soils of the Altai piedmont.

Furthermore, private farms in high-risk soil and climate zones choose a variety of means that enable them, even in years with low precipitation, to obtain small, but stable yields. For example, farmers buy or lease plots of land in microzones with relatively different soil and climate conditions, sometimes even in neighbouring districts that are comparatively accessible to their farm equipment. This type of risk behaviour is reasonable under the atmospheric conditions summer with mainly convective rainfall. According to the farmers, it might happen that one field periodically gets at least a little rain, but not a single drop falls on an adjacent one throughout the season.

In the wider settings of factors for agricultural production, the problem of credits has to be emphasized. The majority of farms has an insufficient capital stock to update their equipment regularly, so almost all the district's farms use leasing or credit. However, many respondents note that banks have recently been unwilling to lend to farmers, even at very high interest. This fact most painfully affects farmers just starting out, who have almost no start-up capital and for whom state support programmes have been cut back recently.

At the same time, lending makes sense only if private farms are highly profitable, e.g. when the price of wheat stays on the global level and prices for fuels and tariffs are moderate (cf. Chap. 15). In general, the current situation on the credit market for farms is less positive, especially in years with low yields, since the change in prices for farm products lags significantly behind the overall rise in prices and rates on loans. Given the current market, interests for loans have risen to a level that even the most successful, technologically advanced farms with modern equipment have to struggle. The majority of farmers therefore are cautious about loans.

One more challenge for both farmers and other participants in farm production is the pricing system, in which in recent years, according to respondents, price fluctuations have intensified significantly and have become less predictable. As a result, enterprises are having difficulties setting up their crop rotations, obtaining credit and calculating the costs of innovations.

Moreover, the main externalities that are prerequisites or conditions for technological innovations in agricultural enterprises include government policies on pricing, insurance, lending, leasing and various kinds of subsidies. Internal factors of this type include having people on their teams with creative potential, leadership skills or a specific attitude towards and a direct relationship to farm labour. These factors come into play when either the directors of production or professional specialists have these qualities.

Sometimes the failures experienced by a leader in other fields of endeavour or a kind of battle or stress fatigue, when competitors are constantly 'nipping at your heels', could also been seen as externalities.

> R.: I believe that this life forced me to finagle […]. What else could I do? When, in 1992, my wife and I worked at a school – we're both teachers – and somehow had to feed our family, we decided: I'll go into business and she'll stay at the school. Therefore, I went into trade. I worked 10 years in trade and had enough. I no longer needed it […] I had enough money in trade. So, I began slowly, not buying on credit and not going up to my eyeballs in debt, like many enterprises now. But, on the long run, I didn't want to do it any longer, because it takes a lot of energy that I wouldn't want to waste. I like this better, so I came here and specially set up two enterprises. One manufactures production tools; the other is a farm enterprise. I keep it to be on the farm tax. That is, all the costs and sales of farm products go through it. But the banks don't like that I'm the founder and director there. Therefore, I pump money back and forth. I have the right to do that and it's convenient for me that way […]. It upsets them [the banks] a lot. They start tossing extra paperwork at me for me to write reports […] For example, I buy a harrow from one of my enterprises – I buy my own product from myself. It suits me that way, because I have to make the enterprise profitable. Uh, that's how we finagle […]. It's — not a work of art, it's — life after all. Everyone figures this out, everyone operates this way. How do you think we operate? So, now I need to get an order so lucrative that everything is the way I need it to be. That's how we operate […]. (Altai Krai, XX district, XX village, director of an LLC, August, 2013)

Moreover, local residents are wary of technological innovations in industries such as farming and forestry and not without reason. There is a concern about a change in their environment, even among specialists. Looking at the changes related to these kinds of innovations, they discover that replacing traditional, time-tested techniques and methods for working the soil or exploiting forest lands, on the one hand, drastically increases production efficiency but, on the other, leads to irreversible transformations in their environment. For example, a number of specialists and local residents we surveyed were sceptical of no-till technology, considering it chemically aggressive towards the soil. They think that the use of these kinds of technologies requires approaches tailored to each specific situation.

For example, one farmer reported that his farm is oriented towards environmentally friendly production without the use of chemicals, although this product is not yet in demand on today's market. He believes, however, that farm owners should take an interest in conserving land both for themselves and for future generations. He therefore uses traditional practices with minimum tilling, which enables him, using certain farming techniques, to obtain good yields with negligible use of herbicides.

> R.: I don't accept these new technologies (meaning no-till), that is, I accept them in general, but I'm convinced that they're not for our area. Our other farmers say the same thing. They don't have enough straw. We have very low-growing cereals. This is, again, because of the dry conditions. But it needs straw. Therefore, there will be a field white with straw, and less chemicals will have to be applied. Our neighbours, for sure, are operating with these technologies, but they use a lot of chemicals. I am absolutely against chemicals, I'm opposed to them. Moreover, our results are no worse. Over the last 5 years our yield was 14.5 hwt/ha, and we got it without chemicals. The yield last year for the district as a whole was 6, ours was 9.5. The year before last, it was 7 for the district, and I got 11.5. That is, a difference of one and a half times, and it's happened that in different years it was as high as double. (Altai Krai, Mikhailovsky district, Rakity village, head of a private farm, April, 2013)

Usually, the director or an experienced specialist determines the need to use particular technological innovations at an enterprise. One of the respondents, the head of a large agricultural enterprise in Mikhailovsky district, believes that the real, genuine goal of using innovations in farming is not limited to merely the need to make profit. It is deeper and related to the calling of an innovator, the opportunity for him to implement certain creative visions. It is only this goal, he believes, that will make it possible to preserve the harmony between man and nature and maximize the effectiveness of innovation.

> R.: I was born here and I really know farming from the very beginning, so we naturally have classic cultivation technology. We haven't switched to no-till, or gone completely to herbicides. I'm a little opposed to it. So, I see here, among us, how well it all turns out for them […] But I still stick to my opinion that all this will spoil nature. Uh, I spend a lot of time in the fields and where they apply chemicals I don't see any wild fowl. Good plants are growing there, but wild fowl don't live there. They live where the land isn't tilled. Because the animals probably sense that it's not right. Of course, in the new technologies, they make good use of chemicals. If the corn is three meters tall and there's not a single weed, that means that it's all pesticide treated. Fundamentally treated, right? So, this somehow worries me […] Because not a single rabbit or anything else lives there […]. (Altai Krai, Mikhailovsky district, Mikhailovskoye village, director of a farm enterprise, August, 2013)

At the same time among farmers, there are those who are optimistic about the use of new technologies in farming, but they are pessimistic about the variability of human nature, so in their opinion, only the succession of generations will bring a change in the mentality of everyday habits and professional skills of rural residents.

32.4 Practices of Applying Land Legislation that Interfere with the Innovative Development

One of the fundamental barriers to innovation in farming remains the land issue and practice of applying land legislation. Despite the continuous improvement of the legislative environment pertaining to these issues, their resolution locally comes up against a number of administrative, financial and economic problems that at times lead to results that are the opposite of the legislative logic.

Sometimes on the ground, the best farmlands are allocated on the principle of proximity to administrative resources. Farms and agricultural specialists believe that on the district level, everyone involved in this business knows one another quite well and understands who can do what. Even the leadership of both, the municipal and district administrations, is aware of this. Officials therefore believe that the farmland and targeted support should be allocated to truly capable farms and energetic, aspiring farmers under the supervision of both the administration and specialists. They believe that the future of not only individual farms, but also of all of Kulunda depends on the solution to this problem.

One must note that even today the land market in Kulunda steppe districts has not completely evolved. Therefore, for example, in 2014 the price of a land share—about 25 ha—was fairly low and did not exceed RUB 25,000. Closely connected is another current topic: the problem of surveying farmlands. Today the owners of land shares by law must register the land in the land register, but to do this, they first have to determine the boundaries, which is a relatively costly procedure for the local populace. Shareowners therefore lease their land to farmers on condition that the farmers have the land surveyed at their own cost, additionally to their own lands. All these mandatory procedures require not only time, but also money, and have nothing directly to do with the production cycle. The majority of new and small private farms do not have spare money for survey and registration, so they have to spend funds that they might have spent directly on production. This disturbs the farms' entire production cycle, or farmers encumber the enterprise with debts.

In the opinion of the majority of residents, solving land problems, like developing practices for the application of land legislation, largely depends on the establishment of realistic and fair partnerships among farm producers, local administrations and various departments on all levels.

32.5 The Effect of Human Resource Problems

In the majority of districts in Altai Krai's Kulunda steppe, it is almost impossible to find an area of endeavour or production that does not need specialists. Organizations are experiencing a special need for young, well-educated personnel. This problem is particularly acute in healthcare and other social services. Therefore, a number of federal and regional programmes are employed to recruit young specialists for work in the countryside. In particular, these are programmes such as:

- The Governor's Programme for Training Professionals for Small and Medium Business in Altai Krai in 2013–2016;
- The subprogramme 'Staffing the Altai Krai Healthcare System' under the government programme 'Development of Healthcare in Altai Krai until 2020';
- The Altai Krai governmental programme 'Development of Education and Youth Policy in Altai Krai' for 2014–2020;
- The subprogramme 'Gasification of Altai Krai in 2015–2020' under the Altai Krai state programme 'Supplying the Altai Krai Population with Housing and Utility Services' for 2014–2020;
- 'The Governor's Programme for Training Professionals for Small and Medium Business in Altai Krai in 2013–2016' [sic];
- The Altai Krai government programme 'Development of Education and Youth Policy in Altai Krai' for 2014–2020 [sic];
- The federal programme 'Local Doctor'.

The last programme started on 1 January 2012. It provides for the allocation of relocation allowances of RUB 1 million for each doctor up to the age of 50 who relocates to work in the countryside for five years. The practical implementation of this programme, however, has turned out somewhat differently from how it was imagined when it was developed.

> R.: Now we have mostly retirees working here. Basically there's no one to do the work. There used to be young people. This year four young doctors who had not yet finished their 5-year stint left us. Do you know why? Because this Local Doctor programme exists. Under it a specialist graduates from the institute and relocates to work in a village or moves from village to village or from town to village. Then he gets 1 million roubles in relocation allowance. So, we had two young couples leaving. For those two million they abandoned their jobs, apartments, and left to get 2 million rouble over there. I believe that it's absolutely wrong when they run from village to village for this million. That's not how to solve the staffing problem. I mean, two couples, husband and wife – four people. To get this precious million they have to move to another village. But they can't get this money from us, because they were working before this law, this programme, was adopted. After graduation, they started working for us before the law was passed, so they weren't eligible for the million. Nevertheless, they moved to another village and they were. They closed down, uh, they moved there, and left us stranded. What kind of solution to the staffing problem is that? (Altai Krai, XX district, XX village, district hospital doctor, August, 2013)

Meanwhile, the shortage of specialists is being felt even in municipal and national government bodies. For example, it was noted in an interview with district administration employees that it is not easy to find qualified specialists for the position of mayor or for administrative work in municipal government bodies.

> R.: We have to woo people for the position of mayor. It used to be, 8 years ago, we had five or seven candidates for this position, but now it's very hard to find even one. Primarily, this is because of the salary. For example, it used to be that specialists among esteemed, experienced people with some time on the job were selected for the district administration, but today we'll take those who have even the slightest knowledge of their profession and

> who have at least a bit of education […]. (Altai Krai, Mikhailovsky district, Mikhailovskoye village, administration employee, August, 2013)

Some respondents who are producers and heads of farm enterprises cited as main problems difficulties related to intergenerational working relationships. In their opinion, difficulties of this kind primarily result from the difference in the interests and values between the generations. One of the significant challenges for small farm enterprises is the use of modern computers, the servicing and repair of which requires that they keep employees with fairly narrow specializations who know computer technologies and have the skills to set up the equipment. There are no such specialists in the countryside. Therefore, the heads of these enterprises often limit themselves to Russian-made equipment that is simpler to operate with and to maintain. They believe that overly computerized imported equipment is not adequate to local conditions.

32.6 Interaction of the Community and Authorities as a Condition for Regional Development

It is vital that local communities usually react very thoughtfully to any cultural initiatives that originate from those communities or from outside. An example might be the travelling interactive exhibit 'Barnaul in a Suitcase'. This project was prized not only in Altai Krai, but also at the cultural mosaic national competition for village and small town development projects, which is supported by the Timchenko Foundation. The project is targeted primarily at residents, particularly children, of the rural districts in Altai Krai, who have few opportunities to visit their krai centre, Barnaul. It was to them that the travelling exhibit successfully showed historical and modern Barnaul and its relationship to the rural areas surrounding it, using both traditional museum and the latest computer technologies. The drama of the historical and modern regional centre and its relationship to its environs played out before villages in virtual space. It helped them understand and make sense of the migration between the capital and rural districts of Altai Krai. It is profoundly symbolic that the travelling exhibit began its journey in the Kulunda steppe—Aleisk, Mamontovsk and Slavgorodsk districts, attracting tremendous interest among local residents—adults and children alike.

By the way, some sceptics responded to the exhibit saying that it in fact fosters merely a 'suitcase' mood and actually tempts Kulunda's residents to migrate from their humble rural reality to the attractive life of the regional capital. Sceptics also stress that one cannot get away with merely the cheap virtual charms of the region and its capital, insisting on the quite real and tangible contributions that the region has made to rural Kulunda's development.

Kulunda's rural communities naturally aspire to participate in regional and federal competitions for the support of rural development. One must note, however, that it is often possible to find resources for local cultural development in the most rural communities. An example might be the support for athletic projects in Kliuchevsky and Mikhailovsky districts. For example, one of the strongest football teams in Altai Krai has traditionally been the Kliuchevsky district team, which attracts the attention of the district administration, local business and, of course, local fans. Respondents who live in Kliuchevsky district stressed that their football success has a positive impact on social well-being in Kliuchi village. In nearby Mikhailovsky district, a local children's and youth hockey team has been successfully organized and expanded with the support of large, influential farmers.

By the way, even the most remarkable athletic successes are naturally not enough to energize the generally depressed social life of Kulunda. A great deal of attention is therefore being given to a wide range of sociocultural initiatives. For example, in addition to the birthdays of a particular village that are now celebrated throughout Russia, some districts in Kulunda are organizing work parties focused on the development of local recreation areas, especially, for example, the shores of the local steppe lakes. On the other hand, respondents in Kulunda said that, despite individual initiatives to improve local areas and hold cultural events, in general the population and, often, young people are indifferent towards supporting and developing a civilized lifestyle. They gave examples when recreation areas, built by young activists for young people were later vandalized by the same local young people. The respondents also noted that in Kulunda communities, local associations of government, business, the intelligentsia and public organizations are short-lived and impermanent.

A number of respondents believe that changes related to new technologies and the refurbishment of farm and forestry enterprises have a questionable effect on the areas where they live, and they express pessimistic concerns that in the future Kulunda steppe, districts will be left with only relatively large villages in which an ageing population will live out its years. However, the introduction of engineering, cultural and economic innovations and technologies that help to increase labour productivity, and as a result free, the surplus workforce and intensify migration, especially in agriculture, will generally provide new opportunities for vital activity in each individual community.

References

Administration of Altai Krai (2011) Gosudarstvennaia programma Altaiskogo kraia 'ustoichivoe razvitie sel'skikh territorii Altaiskogo kraia' na 2012–2020 gody [Altai Krai Government Programme 'Sustainable Development of Rural Areas of Altai Krai' for 2012–2020]. http://docs.cntd.ru/document/453110670. Accessed 3 Nov 2016 (in Russian)

Administration of Altai Krai (2015) Postanovlenie ob utverzhdenii plana meropriiatii po realizatsii strategii sotsial'no-ekonomicheskogo rasvitiia Altaiskogo kraia do 2025 goda na 2015–2017 gody [Decree on the Action Plan to Implement a Strategy for the Socioeconomic Development of Altai Krai until 2025 for 2015–2017]. http://www.altairegion22.ru/upload/iblock/8fb/202_2015.pdf (in Russian)

Korres GM, Kourliouros E, Tsobanoglou E, Kokkinou A (eds) (2014) Socio-economic sustainability, regional development and spatial planning: European and international dimensions & perspectives. In: Proceedings of the international conference on 'socio-economic sustainability, regional development and spatial planning: European and international dimensions & perspectives', 4–7

July 2014, Mytilene, Greece. http://www.aegean.gr/ergaxia/Socio–Economic%20Sustainability.%20Regional%20Development%20and%20Spatial%20Planning.pdf. Accessed 16 Nov 2016

Strategiia sotsial'no-ekonomicheskogo razvitiia Altaiskogo kraia do 2025 goda [Strategy for the Socioeconomic Development of Altai Krai in the Period to 2025] (2012). http://www.econom22.ru/upload/iblock/f3c/Zakon86-zs_121121.pdf. Accessed 3 Nov 2016 (in Russian)

Chapter 33
Implications for Administrative Measures: Economic Institutions and Policy

E. V. Ponkina, A. S. Manicheva and M. Bavorová

Abstract The chapter is devoted to processes in the formation of the institutional environment in Russia's agricultural sector over the last 25 years that define the current trends and trajectory of future economic development. The first part of the chapter reviews the creation of formal and informal rules that influence the Krai's land use system. The second part presents an analysis of the institution of ownership of agricultural land and the features of its establishment in Altai Krai. The third part analyses current trends in the development of the agrarian sector.

Keywords Institutional change · Agriculture · Crop production · Yield insurance

33.1 Introduction

The evolution of institutions and society is largely determined by the transformation of the national socio and economic system. Subsequent changes in the institutional environment, the creation of new formal and informal norms and rules, and the degeneration of values take place gradually and go unnoticed in the short term. Institutional changes, accumulating and mutating, create new formal and informal norms and rules depending on the specific history of the region and affect the region's land use system. Key institutional factors in the development of the agricultural land use system are private ownership of land, private ownership of property, and the right to engage in economic activity, sell and resell goods, provide services, and perform work. Equally important is the establishment of institutions governing commercial farming activities, in particular, the tax system, the system for government support for funding of the development of the agricultural industry, mechanisms for fund-

E. V. Ponkina (✉) · A. S. Manicheva
Faculty of Mathematics and Information Technologies, Altai State University, Lenina prospect, 61, 656049 Barnaul, Russian Federation
e-mail: ponkinaelena77@mail.ru

M. Bavorová
Faculty of Tropical AgriSciences, Czech University of Life Sciences Prague (CULS), Kamýcká, 129, 16500 Prague, Czech Republic

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_33

ing the revitalization of the enterprises, etc. Flaws in the institutional environment create barriers, restrictions, and traps that adversely affect the revival of fundamental system-creating processes in the agricultural industry. The focus of study in this chapter is the basic steps and results of the establishment of key elements of the institutional environment in the agricultural sector, especially in plant husbandry, and the resulting barriers and institutional restrictions that have a positive or negative role in the development of the agricultural sector in Altai Krai. The main conclusions and postulates of the study are based on empirical data obtained in interviews with executives and specialists at agricultural facilities performed in 2013–2014 as part of the Kulunda project.

33.2 Features of the Formation of the Institutional Environment in Today's Russia

The problem of analysing institutional changes and their interaction within the system of macro-, meso-, and micro-levels, especially as a consequence of profound social shocks, when some institutions lose their influence and others are just being created, is very interesting and complex. In Russian scientific literature, issues of the analysis of institutional conditions and their influence on the agricultural economy primarily address the clarification of the terms 'institutional factor', 'institutional conditions', and others, elaborating on them in various different intonations (Yurin 2008; Goretov 2010; Babayan 2011; Maksimova 2011; Martynov 2014). Using the fundamental precepts of North's institutional theory (North 1997), we will analyse the features of the formation of formal and informal rules and codes in effect in the agrarian sector of Russia and of Altai Krai in particular.

National legislation is the basis for the system of society's formal rules. The hierarchy of Russian legislation reflects the inter-subordination of formal rules and aligns with the hierarchy of the system of governmental authority in the Russian Federation (Table 33.1). The top level of the hierarchy consists of the RF's federal laws adopted by RF legislative bodies (Federal Assembly) and laws adopted by national referendum. These enactments have the highest legal force. The second level of the hierarchy consists of presidential decrees and then RF Government enactments. The fourth level consists of ministry and departmental decisions. The next level of the formation of formal rules is defined by decisions of the legislative bodies of RF constituents. The bottom level is the legislative norms of municipalities. The formation of formal rules and their scope are subordinate to this hierarchy.

The structure of the model of institutional changes that affect current formal rules and the adoption of new norms comprises social actors endowed with the right of legislative initiative. On the macro-level, they include the President of the RF, the RF's Government, including ministries and departments, members of the RF's Federal Legislative Assembly, and the Federation Council. On the meso-level

Table 33.1 Hierarchy of formal rules (legal documents) in modern Russia

	Kind of regulatory enactment	Author of the regulatory enactment	
Federal level	RF constitution	The people of the RF	Legislation
	Federal constitutional laws	Federal Assembly	
	International enactments	International organizations	
	RF federal laws	RF State Duma, RF Federation Council, President of the RF	
	Enactments (decrees and orders)	President of the RF	
	Enactments (decrees and orders)	Government	
	Departmental enactments (orders, letters, etc.)	Ministries and departments	
Regional level	Enactments of RF federal authorities (laws, orders, rules)	Dumas (legislative assemblies)	
	Enactments of authorities of RF constituents (orders, rules)	Governors of regions and Krais, presidents of republics	
	Regional subordinate legislation (decrees)	Administrations of regions and Krais, governments of republics	
Local level	Enactments of local governments (decisions)	Heads and representative bodies of municipalities (administrations of towns, districts, rural settlements, village councils)	
	Corporate enactments	Organizations	

Source Compiled by the authors (Kirdina et al. 2010; Centre for Russian Education)

(RF constituents, specifically Altai Krai), the main actors with the right to initiate legislation under the Altai Krai's charter (Charter of 1995) are:

– members of the Altai Krai Legislative Assembly;
– standing associations of assembly members;
– standing committees and commissions of the Altai Krai Legislative Assembly;
– the Governor of Altai Krai;
– local representative bodies;
– constituents of Altai Krai numbering at least one per cent of the total;
– members of the Federation Council—representatives from the Altai Krai Legislative Assembly and the Altai Krai Administration;
– the Altai Krai Court;
– the Altai Krai Arbitration Court;
– the Altai Krai Human Rights Commissioner;

– the Altai Krai Prosecutor;
– the Altai Krai Trade Union Association;
– and the Altai Krai Election Commission.

On the municipal government level, they include the district council of people's deputies, on the rural settlement level—the village council.

The population, including entrepreneurs, can participate in solving important problems through elections, referenda, the submission of collective appeals (petitions), a Krai popular legislative initiative, a Krai popular poll (plebiscite), and others. A legislative initiative follows the procedure specified by a law (Law N 3-ZS 2002; Charter 1995). This requires the submission of a petition, which must be supported in writing by at least 300 other citizens. The Altai Krai Legislative Assembly reviews a petition to initiate a regional popular legislative initiative if it meets the requirements set by the law of Altai Krai. A draft regulatory legal enactment is deemed supported if the number of citizens who support it with their signatures is no less than one per cent of the total number of citizens determined according to the state system for registration (accounting) of the electorate in the Russian Federation (Law N 3-ZS 2002).

An initiative to change the current formal rules received directly from agricultural producers may originate during the routine interaction of farmers and representatives of governmental authorities and by a collective justification of proposals. The intermediate link that makes it possible to focus on farmers' proposals and submit them to the administrative and Krai Legislative Assembly are non-profit organizations whose mission is to represent farmers' interests at the regional and federal levels. In Altai Krai, such public organizations include the Altai Union of Entrepreneurs, the Union of Peasant (Private) Farms and Farm Organizations of Altai Krai, the Altai Meat Alliance, the Altai Dairy Alliance, and others.

The pace at which formal rules and norms were created during the transitional period varied. In Russia's transition to a market economy in 1990–1995, during the creation of the institution of private property from state-owned enterprises, it was necessary to introduce new rules quickly, conditions, and relationships in which economic activities could be carried out in a market environment. The transformation of the government system took place vertically—from the top down. In 1990–1993, the Russian Parliament passed 222 laws; in 1994–1995—464 laws (Kirdina et al. 2010). A large proportion of them pertain to economics and finance. In subsequent years, the average number of constitutional laws adopted in the RF was more than 300, decrees—more than 100, government enactments—more than 900, ministry and department decisions—more than 2000 per year (Kirdina et al. 2010). This does not count the regional legislation. In 1995–2015, basic laws were passed that governed the activities of farm enterprises and the trade-in and distribution of farm lands (Table 33.2).

Current federal laws are amended almost annually. The total number of amendments to basic enactments peaked at 72 (in 2015). On average in 2000–2015, there were 37 amendments per year. Figure 33.1 shows the trend in the number of amendments to basic legislative norms in agriculture and the increase in 2006–2016. Clearly,

Table 33.2 Basic current federal laws governing the farming activities of organizations and private citizens in the RF

Law	Year adopted	Number of amendments, total	Average number of amendments per year
Federal Law on Cooperation	1995	19	1
Federal Law on State Registration of Real Estate Titles	1997	92	5
Federal Law on State Regulation of Assurance of Farm Land Fertility	1998	8	0.5
RF Tax Code (part one)	1998	90	5
RF Tax Code (part two)	2000	204	12
RF Land Code	2001	93	6
Federal Law on Circulation of Farm Land	2002	24	2
Federal Law on Financial Turnaround of Farm Enterprises	2002	4	1
Federal Law on Peasant (Private) Farming	2003	10	1
Federal Law on Private Farm Holdings	2003	5	1
Federal Law on Recategorization of Land or Land Parcels	2004	21	2
Federal Law on the Development of Farming	2006	14	2
Federal Law on the State Real Estate Cadastre	2007	53	6
Total amendments	–	637	–

the trend is ascending. On the one hand, these data indicate the high variability or instability of the resulting institutional environment (Shastitko 1999; Bazueva 2011). On the other hand, it is obvious that the high rate of change in the institutions keeps the society from completing its adaptation and reveals its objective, stable reaction to current formal rules. *The necessary institutional changes require systematic efforts and expenditures over* ***fairly long time periods*** (Kuzminov et al. 2005). Given the current rate of change, a formal rule that has not been 'codified' and 'taken root' in society will mutate.

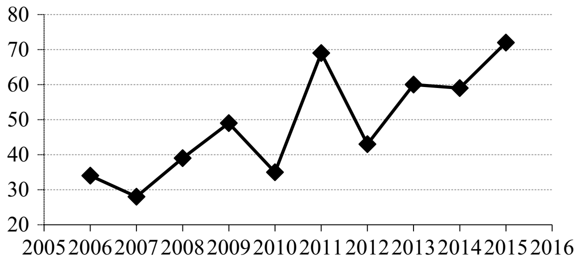


Fig. 33.1 Total number of amendments, including the adoption of new laws, to basic federal laws governing farm production in Russia. *Source* The authors' calculations based on the RF legislative database (www.consultantplus.ru)

As for changes, e.g. to the terms for subsidies to farm producers, they are made annually and are approved by both regional and federal authorities (Altai Krai Main Agricultural Directorate, Altai Krai Administration, and Russian Ministry of Agriculture). Approval of subsidy rates and the procedure for granting subsidies requires the adoption of more than 15 regulations.[1] This is attributable, on the one hand, to the country's persistently high inflation rates and the need to index subsidy rates denominated in roubles and, second, to aspects of the RF budgetary system expressed in the need to adjust funds transfers on all hierarchical levels (between RF constituents). This makes it hard to take decisions and increases institutional risks.

An analysis of the general hierarchy of lawmaking in the RF supports the claim that most of the activity in the formation of institutions is carried out on the federal level by the RF Government, the Federal Assembly, and the President of the RF. On average, they account for more than one thousand norms per year (Kirdina et al. 2010).

On the regional level, the level of activity in the creation of formal rules is lower and, on average, comes to 144 norms per year. The largest proportion comes from the Altai Krai Administration (52 per year) (Altai Regional Legislative Assembly 2016). In 2015, the Governor of Altai Krai alone initiated 55 regulations, enactments, and amendments to RF laws. The main initiatives therefore originate from the 'top' level of the hierarchy (federal), while adjustments to their implementation and their adaptation on the level of the region and individual district take place on the meso-level.

A major role in the adaptation and implementation of formal norms and rules belongs to informal rules and restrictions that, in North's opinion, are a 'continuation, development, and specification of formal rules and contribute to survival because *they constitute a part of people's customary behavior*' (North 1997). Moving along the hierarchy of power (from the macro- to the micro-level) and during the implementation of formal rules there is often a change in ambitions and motivations, and the mechanism for implementing a law becomes inadequate, which results in a

[1]Adopted enactments are posted at the website of the Main Agricultural Directorate under the section 'Government Support'. URL: http://www.altagro22.ru/apk/gospodderzhka2016/.

multitude of informal rules or institutional traps and degenerates into a special form of institutional rent.

A clear example of this phenomenon is the current institution of crop yield insurance, which was introduced by a number of legislative enactments and decrees in the RF in 2012[2]. The main goal of introducing crop yield insurance is to lower the risks of farming related to bad weather. Under the current rule, the conclusion of a crop yield insurance agreement is voluntary for farmers. To increase farmers' use of yield insurance, a system of government supports for 50% of the cost of the insurance. Subsidies are granted from the federal budget to reimburse 40% of farm producers' costs to cover insurance premiums, plus 10% subsidies from local budgets. Each region has the right to increase its share of the reimbursement.

In 2006, Altai Krai ranked first in the Russian Federation and Siberian Federal Territory in the number of farms that had concluded yield insurance contracts with government support. The Krai accounts for 24% of yield insurance contracts throughout Russia. The area planted with farm crops in 2006 covered by insurance contracts constituted 68% of the total area under crops in the Krai. Obviously, insurance companies are interested in creating a large pool of clients and maximizing profit, but at the same time are not interested in potential insurance payouts. Farm producers in turn are interested in obtaining state support as reimbursement of a portion of their payments under an insurance contract. Insuring the risks of a poor harvest is a relatively new tool for them and they are ready to assume this risk, even more because they assumed these risks before this mechanism was introduced. Furthermore, a shortage of funding for farm producers is a negative factor that limits the scope of this rule. They have to conclude a yield contract in the spring—during the preparation for fieldwork. 'Discrepancies' in the insurance terms give insurance companies extensive opportunities to refuse to pay benefits, which discredits the idea of insurance among farm producers and deepens the distrust of this financial transaction (Gainutdinov 2010). For this reason, a number of insurance companies have introduced a 'grey' scheme into insurance practice. When the insurance company 'lends' to the farm producer to conclude a yield insurance contract, and after the farmer receives the subsidies on the insurance contract it receives a certain proportion of that amount and full repayment of the 'loan', thereby creating institutional

2

- Russian Federation Government decree N 758 dated 1 November 2001 'On Government Support for Insurance for Agroindustrial Production';
- Order No. 1070 of the Russian Federation Ministry of Agriculture dated 5 December 2001 'On the Establishment of the Federal State-Funded Institution Federal Agency for Government Support of Insurance for Agroindustrial Production' at the Russian Federation Ministry of Agriculture in Moscow';
- Federal Law N 264-FZ dated 29 December 2006 'On the Development of Agriculture' 10 [sic] codified the legal institution of agricultural insurance with government support;
- Rules for Granting and Allocating Federal Budget Subsidies to the Budgets of Russian Federation Constituents to Compensate a Portion of Costs to Insurance Farm Crop Harvests, Harvests of Perennial Plantings and the Planting of Perennial Plantings11 [sic], adopted by Russian Federation Government Decree N 1199 dated 31 December 2009.

rent for all ‘farm producer—insurance company’ participants in the process. The insurance contract in this case is a sham and was concluded on terms under which a covered event cannot occur. This problem has been the topic of a multitude of scientific studies in various fields of science and has appeared in different regions in Russia (Nikitin and Shcherbakov 2006; Chaika and Stadnik 2008; Gainutdinov 2010; Sushkov and Petrova 2013; Shestakova 2014; Borovskikh 2016).

According to heads of farm enterprises, yield insurance is interpreted as: ‘*We see harvest insurance as a no-interest loan. This suits both us and, apparently, the officials’*; or ‘*We see yield insurance as a special form of government support for farm production’* (Article 2009).

As Chaika and Stadnik noted, ‘*The flaw in the mechanism by which insurance participants interact to obtain government subsidies creates a huge sham market for government-supported harvest insurance’* (Chaika and Stadnik 2008). In the opinion of executives at the RF Ministry of Agriculture, these schemes soak up almost 90% of government subsidies, which is bad for the market (Shestakova 2014). Therefore, a nudge from a federal branch was transformed by the motives and goals of decision-makers, and actual economic conditions rendered a formal rule ineffective and ‘shifted’ the goal. New rules for calculating subsidies and requirements for insurance organizations that limit sham schemes have now been introduced. These steps involve the following changes: to receive support, a producer must conclude a farm insurance contract, and pay 50% of the insurance premium. The balance will be paid directly to the underwriter out of the appropriate budget based on the farm producer’s application.[3] This step diminishes the farmers’ heavy financial burden during the planting season. The problem of the frequency of ‘grey schemes’ must be resolved through the establishment of a professional underwriters’ association, whose members must have a certain amount of authorized capital, a farm insurance licence, and a reliability rating (Sushkov and Petrova 2013). The institution of agricultural insurance in Russia is still in its infancy. The implementation of formal rules will have a genuine positive impact on farm production as an effective risk management mechanism only as the insurance mechanism is refined, and positive practice of the influence of crop insurance on farm producers’ results is gained.

33.3 Conclusion

Russia’s market system is characterized by labour, capital, and land markets that have not fully formed yet (Goretov 2010; Maksimov 2011; Martynov 2014). The agricultural economy is being transformed by the gradual degeneration of the institutional environment. Old institutions are changing; their movement from the macro- to the meso- and micro- level as they are adopted by the society is leading to the creation of new informal rules that initially alter the assigned function of the institution. The

[3]Per art. 3 of Federal Law N 260-FZ dated 25 July 2001 ‘On Government Support in the Area of Farm Insurance’ and amendments to the Federal Law ‘On the Development of Agriculture’.

marked centralization of the governance system, the consolidation of basic functions and legislative initiative on the federal level, federal authorities' lack of awareness of the functioning of production processes on the level of a federation constituent, and specific regional features are resulting in the creation of macro-methods[4] for solving problems of farm production. They are not fully aligned with capabilities for their implementation in the real economy. The adoption of new formal rules and of market conditions involves the formation of a new 'owner's mentality' which will take several decades.

References

Altai Regional Legislative Assembly (2016) Parliamentary hearings. http://www.akzs.ru/activity/depperf/26aprelya2016.html. Accessed Day Month Year

Article (2009) Krai farmers don't want to give up gray insurance schemes. http://test.altapress.ru/connected/story/42122

Babayan IB (2011) Institutsional'naia sreda i institutsional'nye faktory razvitiia prodovol'stvennogo rynka [Institutional Environment and Institutional Factors in the Development of the Food Market]. Izvestißa Orenburgskogo gosudarstvennogo agrarnogo universiteta 29(1):144–146 (in Russian)

Bazueva EV (2011) Institutsional'naia sreda sovremennoi Rossii: gendernyi kriterii effektivnosti [Institutional Environment of Modern Russia: Gender Criterion of Efficiency]. Vestnik Permskogo universiteta 2:47–60 (in Russian)

Borovskikh RN (2016) Kriminologicheskie, ugolovno-pravovye i kriminalisticheskie problemy protivodeistviia prestupleniiam v sfere strakhovaniia [Criminological, Criminal Law and Forensic Problems of Fighting Insurance Crime]. Alpha Porte LLC, Novosibirsk (in Russian)

Center for Russian Education (n.d.) Ierarkhiia rossiiskikh normativno-pravovykh aktov [Hierarchy of Russian Laws and Regulations]. https://rusedu.center/articles/pravo/151-ierarkhiya-rossijskikh-normativno-pravovykh-aktov.html. Accessed Day Month Year (in Russian)

Chaika IA, Stadnik AI (2008) Problemy i perspektivy razvitiia strakhovaniia sel'skokhoziaistvennykh riskov krest'ianskikh (fermerskikh) khoziaistv [Problems and Prospects of the Development of Agricultural Risk Insurance of Peasant (Private) Farms]. Ekonomichesky vestnik Rostovskogo gosudarstvennogo universiteta 6(4) part 4, 88–92 (in Russian)

Gainutdinov FF (2010) Razvitie rynka strakhovaniia v sel'skom khoziaistve [Development of an Insurance Market in Agriculture]. Akutalnye problemy ekonomiki i prava 1:32–38 (in Russian)

Goretov IN (2010) Institutsional'nyi podkhod k regional'nomu razvitiiu agrarnogo sektora [Institutional Approach to Regional Development of the Agrarian Sector]. Ekonomika i upravlenie 7(78):89–92 (in Russian)

Kirdina SG, Rubinshtein AA, Tolmacheva IV (2010) Nekotorye kolichestvennye otsenki institutsional'nykh izmenenii: opyt issledovaniia Rossiiskoi zakonodatel'stva [Certain Quantitative Assessments of Institutional Changes: Experience Studying Russian Legislation]. TERRA ECONOMICUS 8(3):8–22 (in Russian)

Kuzminov Y, Radaev V, Yakovlev A, Yasin E (2005) Instituty: ot zaimstvovaniia k vyrashchivaniiu (opyt rossiyskikh reform i vozmozhnostei kul'tivirovaniia institutsional'nykh izmenenii) [Institutions: From Borrowing to Nurturing (Experience with Russian Reforms and Opportunities to Cultivate Institutional Changes)]. Voprosy ekonomiki 5:5–27 (in Russian)

[4]Methods aimed at solving problems as a whole on the national government level without regard for a region's specific features.

Maksimova TP (2011) Institutsional'nye preobrazovaniia v agrarnoi sfere Rossii [Transformations in Russia's Agricultural Sphere]. Rossiiskoie predprinimatelstvo 7(2):112–116 (in Russian)
Martynov KP (2014) Institutional conditions for the development of agricultural areas of Russia. Teoriya i praktika obshchestvennogo razvitiya 19:81–84
Nikitin AV, Shcherbakov VV (2006) Strakhovanie sel'skokhoziaistvennykh kul'tur s gosudarstevennoi podderzhkoi [Insurance for Farm Crops with Government Support]. Michurinsk State Agricultural University Publishing, Michurinsk (in Russian)
North D (1997) Institutions, institutional changes and the economic performance. Nachala Economic Books Foundation, Moscow
Shastitko AE (1999) Institutional environment of business in Russia: main characteristics. In: Zaslavskaya TI (ed) Kuda idet Rossiya? Krizis institutsionalnykh system: Vek, desiatiletie, god. Logos, Moscow, pp 201–205 (in Russian)
Shestakova MB (2014) Rynok sel'skokhoziaistvennogo strakhovaniia v Rossii i za rubezhom [The Agricultural Insurance Market in Russia and Abroad]. Vestnik KrasGAU 4:27–30 (in Russian)
Sushkov SY, Petrova TG (2013) Perspektivy razvitiia rynka gosudarstvennoi podderzhki sel'skogo khoziaistva (na materialakh Cheliabinskoi oblasti) [Prospects for the Development of a Market for Government-Supported Agricultural Insurance (based on materials from Chelyabinsk Region)]. Vestnik YuUrGU. Econ Manag Ser 7(3):22–27 (in Russian)
Ustav (Osnovnoi zakon) Altaiskogo kraia [Charter (Fundamental Law) of Altai Krai] (1997) dated 5 June 1995, N 3-ZS. Adopted by the Altai Krai Legislative Assembly on 26 May 1995. Altai Krai official website. URL: http://www.altairegion22.ru/official_docs/one-4.html (in Russian)
Yurin SV (2008) Institutsional'nye faktory razvitiia agrarnoi ekonomiki [Institutional Factors in the Development of the Agrarian Economy]. Author's Abstract for a degree as candidate in economic sciences. Saratov: Saratov State Agrarian University
Zakon o nardodnoi zakonodatelnoi initsiative v Altaiskom krae [Law on "On Popular Legislative Initiative in Altai Krai"] (2012). Altai Krai Law N 3-ZS dated 11 February 2002. Adopted by Decree N 6 of the Altai Krai Council of People's Deputies. Latest version 05.09.2014. http://docs.cntd.ru/document/940001594 (in Russian)

Chapter 34
Changes in the Educational System and Cross-Sectoral Co-operation

A. M. Sergienko and O. A. Snegireva

Abstract We present the results of the analysis of changes in the education system of the Altai region. The shifts in the structure of education of the population and its rural part were analysed in comparison with Altai region with the regions of Siberia and Russia as a whole. Changes in development of the educational institutions network and in the rural population perception the quality and accessibility of education as a social problem of rural areas development and social exclusion were discussed. The authors identified features of the impact of education on employment and migration of rural young people as well as the conditions of their re-migration after higher education receiving in the cities. We concluded an increased relevance of education to improve the social position of rural residents and to ensure sustainable socio-economic development of rural areas and the region. The authors identified ways of improving the educational policy for reducing the migration of rural youth. The findings based on data from nationwide surveys of 2002 and 2010 and other statistical data of Rosstat as well as on data of sociological surveys of the rural population and mass media of Altai Krai.

Keywords Rural population · Level of education · Educational system network · Educational institutions · Employment · Migration · Rural areas · Altai Krai

A. M. Sergienko (✉)
Institute of Economics and Industrial Enginneering, Siberian Branch of the Russian Academy of Sciences, Novosibirsk, Russian Federation
e-mail: a.m.sergienko@mail.ru

O. A. Snegireva
Centre of Special Communications and Information of Federal Security Service of Russian Federation in Altai Region, Barnaul, Russian Federation

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_34

34.1 Results and Discussion

34.1.1 *Shifts in the Level of Education of the Population*

Changes in its structure towards higher levels of education attest to the growth in significance of education in society and the development of tendencies to form a "knowledge society". In the Altai Krai, just as in Russia in general, these tendencies have clearly manifested themselves in the new millennium. They are the consequence of trends laid down in the preceding decades. Thus, according to data from the all-Russian censuses of 2002 and 2010, the level of education in the Krai grew considerably. The portion of the population (aged 15 and above) with a professional education did not grow very substantially (from 56.5 to 58.7%). However, there was a cardinal change in its structure focusing on the growth rates. While the share of the population with primary professional education contracted significantly (more than half), the share of residents with incomplete higher and secondary professional education grew slightly. The share of residents in rural areas with higher education, however, had a growth rate of 54% (Table 34.1). There was a noticeable reduction in the share of the population with basic general and primary education. The share of the illiterate population was cut by half (from 1 to 0.5%), and the share of children in preschool education grew slightly (from 54.8 to 63.5%).

Among the rural population of the Krai, the trends in changes to the structure of professional education during the period between the censuses were very comparable, although the contraction in the portion of rural inhabitants with primary professional education was slightly less widespread than was generally true in the Krai (Table 34.1). Illiteracy among rural residents contracted from 1.6 to 0.9%.

Table 34.1 Characteristics of the professional education of the population of the Altai Krai (according to data from the all-Russian censuses of 2002 and 2010), %

	Census of 2002		Census of 2010	
	Entire population	Rural population	Entire population	Rural population
Higher and postgraduate education	12.3	7.4	10.5	11.4
Incomplete higher and secondary professional education	28.5	23.7	34.0	28.9
Primary professional education	15.7	18.9	7.4	10.0

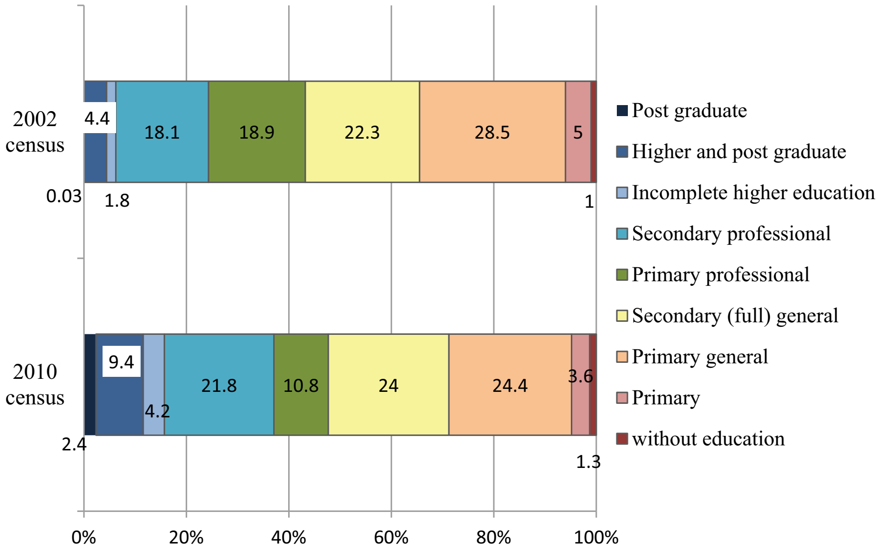


Fig. 34.1 Structure of rural youth of the Altai Krai per level of education, % (according to data from the censuses of the population in 2002 and 2010)

Table 34.2 Characteristics of the education of rural youth of the Altai Krai, regions of the Siberian Federal District and Russia in general (*according to data from the all-Russian censuses of 2002 and 2010*), %

	Census of 2002			Census of 2010		
	Altai Krai	Siberian Federal District	Russia	Altai Krai	Siberian Federal District	Russia
Higher education	4.4	3.9	5.2	9.4	8.6	11.4
Secondary professional education	18.1	16.7	18.7	21.8	21.0	22.4
Elementary professional education	18.9	15.6	15.3	10.8	9.0	15.3

The chance in the level of rural youth was more significant (Fig. 34.1). According to the census of 2010, it was higher than the respective indicator in the regions of the Siberian Federal District, but lower than average for Russia as a whole (Table 34.2). The percentage of rural youths having a professional education constitutes almost half, and this growth has come about due to higher and secondary professional education. The relative portion of rural youths with higher education more than doubled (almost 10%).

Table 34.3 Educational structure of rural and urban youth, of the able-bodied rural population of working age from 30 and higher in the Altai Krai (*according to data of the all-Russian censuses of the population of 2002 and 2010*), %

Level of education	Census of 2002			Census of 2010		
	Rural youth	Urban youth	Rural residents of working age, 30+	Rural youth	Urban youth	Rural residents of working age, 30+
Higher education	4.4	11.7	10.4	9.4	20.7	11.6
Secondary profes-sional education	18.1	22.5	31.8	21.8	24.8	32.9
Elementary profes-sional education	18.9	12.0	25.8	10.8	5.2	12.8
Secondary general education	22.3	29.6	18.7	24.0	22.8	26.5

In the level of education among the rural youth of the Krai is noticeably lagging behind the rural residents of working age and urban youth, especially in terms of higher education (about half the share of urban youth). In professional education, overall, the lag is by almost one and a half times (Table 34.3). For the period between censuses, the distinction in terms of level of education of rural youth compared to older rural residents was reduced, while their lagging behind urban youth became still greater (in terms of professional education—by 1.5 times).

34.1.2 Changes in the Development of the Network of Educational Institutions

Since the beginning of the millennium, in the Altai Krai there have been significant changes in the network of educational institutions, above all through the restructuring of the general education institutions. According to data from Rosstat, from 2000 to 2015 the number of general education institutions lowered by one-third—from 1598 to 1045. However, 105 affiliates were created. The main part of general education institutions comprises institutions in rural areas (79.8% in 2015). One of the drivers in the reduction in general education institutions is the decline in the numbers of residents of the Krai, and especially of the rural population, together with the reduction in the number of rural settlements. Consequently, the average number of students in general education institutions increased slightly (from 238 to 241).

In rural areas, the most important indicator of steady social development of the countryside is the presence of a school in a settlement; its crisis state or liquidation attests to destructive social processes. The steady reduction in the number of schools and other general education institutions since the beginning of reforms and of the number of those pupils and students indicate the demographic crisis of the contemporary countryside. The introduction of governmental measures to raise the birth rates (among them the institution of maternal capital is especially important), and the support of socio-economic development of rural settlements has not changed this trend, yet. The most significant contraction occurred in the first half of the first decade in the new millennium when every year the rural settlements "lost" almost nine students per 10,000 inhabitants. To a large extent, as a result of the state policy of optimising educational services from 2005 to 2014 inclusively, the number of rural general educational institutions in the Altai Krai contracted almost one and a half times, and the number of students declined by 21% (Table 34.4).

34.1.3 Quality and Accessibility of Education as a Problem of Social Development of the Rural Settlements and Social Exclusion of Residents

The results of sample surveys of rural residents of the Altai Krai in 2008, 2011 and 2013 show that the decline in quality and accessibility of education are among the first of ten social challenges the countryside faces (Fig. 34.2) (Sustainable development, 2013). In 2013, 13% of rural residents ranked them among the most acute social problems.

Territorial or material inaccessibility of school education is the most important indicator of social exclusion of those living in rural areas (Sergienko et al. 2014). According to data from a poll taken in 2011, more than 70% of rural residents having school-age children had material problems with accessibility to education. The forms by which inaccessibility manifests itself were inability due to poverty to provide school reading and writing implements and textbooks (this affected 24% of those having school-age children, every third of the underprivileged), to pay for their meals in school (17% of the underprivileged), other evident problems of bad general operational and sanitary conditions in the school (heating, condition of the building, organisation of meals). Due to the lack of means, children of nearly every fifth rural family (and 29% of the underprivileged) could not continue studying after the end of secondary school. In every ninth or tenth case, insufficient technical equipment of the school was an obstacle (computers, access to the internet, textbooks, etc.), along with the low quality of instruction, all of which deprived students of the chance to successfully pass the Unified State School Exams and so to participate in the competition to enter institutions of higher learning. Only around 30% of those living in rural areas and having school-age children said there were no problems with school education.

Despite the development of preschool education and the increase in the number of preschool educational institutions and places in them (Table 34.4), there is still insufficient provision of such establishments for preschool children. According to a 2011 poll, due to lack of preschool institutions in rural settlements or shortage of places in them, as well as inability to provide children with clothing and shoes as well as pay for their stay in kindergartens, the children of 46% of people living in rural areas (and having school-age children) did not go to kindergartens. Social exclusion from preschool education for children from among the underprivileged

Table 34.4 Number of educational institutions and their coverage of rural areas of the Altai Krai during the years 2005–2014

	2005	2008	2009	2010	2011	2012	2013	2014
General educational institutions, units (affiliates)	1255	1099/82	1031/84	992/58	971/52	943/56	903/79	874/92
Students in general educational institutions, individuals	137,913	120,002	118,028	116,268	115,885	114,709	112,914	113,553
Preschool educational organisations, units (affiliates)	560	548/14	547/16	543/11	551/9	564/10	569/11	579/3
Number of children in preschool educational organisations, '000 persons	24.9	33.8	34	33.9	35	37.5	39.7	41.6

families reached 77%, and among the leading reasons were lack of places and means to cover their staying in kindergartens.

34.1.4 The Influence of Education on Employment and Migration

Pavis et al. (2000) as well as other researchers state that the level of education attained is an important factor, not only for choosing the type of employment of rural youths but also for forming the attitude to the local community and to rural life as a whole. According to data of the 2002 and 2010 censuses, there was an increase in the percentage of rural youths engaged in the economy when they have a professional preparation (to 60%), as well as those with secondary and higher professional education (to 28 and 14%, respectively) (Table 34.5). Analysis of the results of a poll of the rural population in Altai Krai in 2011 shows that the higher the level of education of those living in rural areas, the higher the level of employment and

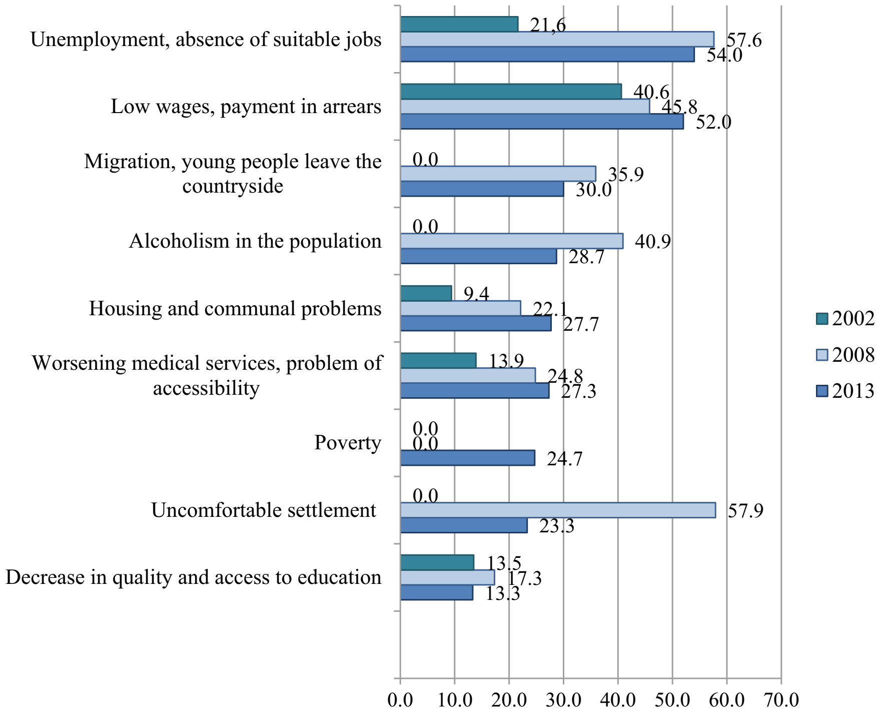


Fig. 34.2 Evaluation by people living in rural areas of the most acute social problems in the development of the rural settlement in 2002, 2008 and 2013 (*% of all aggregate respondents*)

Table 34.5 Educational structure of those rural and city youths engaged in the economy, of rural able-bodied population ready to work aged 30+ in the Altai Krai (*according to data from the all-Russian census of the population of 2002 and 2010*), %

Educational level	2002 census			2010 census		
	Rural youths	City youths	Rural working-age people 30+	Rural youths	City youths	Rural working-age people aged 30 +
With higher education	7.6	20.2	12.9	14.0	31.4	14.4
With secondary profes-sional education	24.9	33.3	33.9	28.1	32.7	33.5
With elementary profes-sional education	24.3	16.4	25.3	12.9	6.0	12.8
With secondary general education	20.8	16.7	18.0	22.8	14.8	24.4
With elementary general education	16.7	14.7	6.8	4.3	7.0	10.9

economic activity. Among the rural unemployed, we see clearly a higher percentage of people with less than secondary general education (26% versus 8% among those employed).

Education largely is becoming a social ladder, which ensures access to high-quality jobs. From an interview with a young entrepreneur in 2015, settlement of Novye Zori, Pavlovsky district: "*Up to the moment of completing my programme of higher education, I already decided that I would continue to live in my rural settlement, and I began to think about various ways of finding employment. I settled on the idea of opening up my own business. In the employment centre, they made available a small amount of money. I opened a bakery. The main thing is not to sit with your arms folded and do nothing*". From the start of the new millennium, there was an increase in the differentiation among rural youths having various levels of education according to the status and sphere of employment. In the sectors of the social sphere, there was a greater concentration of young rural people having higher education, while in agriculture, on the contrary, were those with lower educational attainments. Among young people without professional education, there were more engaged in agriculture, as well as more unemployed and housewives.

A determination to raise their level of education is one of the most widespread reasons for the migration attitude of rural youths. According to data from sample polls, the significance of this reason is growing. In 2011, this was characteristic for almost every tenth young person living in rural areas. This is encouraged by the worsening situation with accessibility and quality of professional education in the rural areas of the Krai, all of which leads to rising problems finding qualified personnel. Thus, precisely the closure of a professional school becomes the cause of an outflow of young people from rural settlements. From the materials of the article "The calculation in favour of optimists" in the newspaper "Altaiskaya Niva", No. 48 (459) 8–14 December 2011: "*This year a new cause for the outflow of young people from the district (Ust-Pristansky) was the closure of professional school No. 59. We will begin to feel the consequences of this in three—four years… Previously from all the settlements of the district young people flowed into the school, got married and settled down in the rural settlements. A third of the working population of the district surely passed through this route*". In the words of the leader of one of the agriculture cooperatives, "*we must stop the mass outflow of young people from the rural settlements. Already there is no clear picture of who will be working in the fields in 5-10 years. However, this problem requires a multi-faceted solution from the state—the businesses by themselves do not have sufficient strength to deal with this question*".

Polls of leaders of businesses in 2008, 2011 and 2013 showed that in most businesses, there was a shortage of staff, primarily qualified staff, and the acuteness of the problem was growing. In connection with the changed situation in the labour market, there has been a change in the evaluation of the quality of workers. If in 2008 heads of companies mostly worried about lack of discipline among workers, drunkenness, indifference to work and their inclination to steal, by contrast in 2013 the first challenge was the low level of professional preparation of workers. This was one of the factors for change in the personnel policy of businesses. Whereas in 2008 the personnel policy was built on principles of holding onto existing staff and sorting out those who did not abuse alcohol, five years later apart from the wish to have permanent staff, many heads of businesses prioritised higher qualifications at company expense and incentivising workers.

Meanwhile, the presence of appropriate employment and compensation for labour in rural areas helps ensure that a significant per cent of rural youths consciously rejects raising their education in the cities: "*I didn't go anywhere to study after finishing school, although they told me that you have to receive a professional education. However, that wasn't for me. I stayed at home for a long time, then I found steady work and made some money in various places… Finally I took a job guarding the forest; there no special education is needed*" (from an interview with a young worker in the Cheremnovsky forestry company, Komsomolsky settlement, Pavlovsky district in 2015). "*I finished 9th grade in school and did not want to study any more. I went to do milking on a farm. That's all I need, and I don't want anything else. I, for example, earn 30 thousand a month*" (from an interview with Sergey K, operator of a milking machine at CJSC SKhP “Urozhainoye” in the Sovetsk district—the “Altaiskaya niva” newspaper, No. 8 (572) 6–12 March 2014).

A propitious factor restraining the migration outflow of rural youths is the development of distance learning in rural areas. From an interview with a young worker in the rural administration in 2015, the Smolenskoye settlement, Smolensky district: “*I have been working for several years in the finance committee. When there was a prospect of a promotion, they told me that I must receive a higher education. It’s fine that one can get it by distance learning, otherwise I would have to turn down this idea, because you are not going to go to the city during the session*”.

The results of focus group research on rural youths who are studying in the institutions of higher learning in Barnaul (2016) show that the most powerful condition for their return migration to the countryside after studies is, above all, the possibility to find work. Although without a doubt you have to take into account the whole complex of conditions of vital activities of rural youth, including the characteristics of housing being available and its quality, the development of the social infrastructure, the availability of regular transportation services and roads of good quality linking the rural settlements to the nearest large- or medium-sized cities. From an interview with a temporarily unemployed woman in 2015, Komsomolsky settlement, Pavlovsky district: “*After completing the pedagogical college, I returned to my native rural settlement, but I did not succeed in getting a job in the local school, and I don’t want to go work in an agricultural enterprise ‘for a few cents.’ Therefore, I will have to go to the city and find work in my specialty. My parents have promised to help me pay the rent for housing […]*”. To resume only young people living in large settlements with gas connections, district centres seriously consider returning after a further step in their education. The focus groups showed that the overall potential for return migration constitutes less than 5–10%. It rises steeply if the aforementioned conditions are given—to 30–50%.

34.2 Conclusion

The relevance of education for improving the social status of people and ensuring steady socio-economic development of rural communities and the region has grown substantially. This results from the analysis of socio-economic shifts since the beginning of the new millennium in the level of education, accessibility of educational services and influence of education on employment and other related spheres of vital activity of the rural population and residents of the Altai Krai. An area especially important for the improvement of government policy in the field of education in order to reduce the permanent out-migration of young people is the development of professional orientation. This should raise the accessibility and stimulate people to get a professional education. It should include distance learning, targeted education of young specialists, implementation of a system of municipal order for preparation of staff taking into account the needs of local labour markets and facilitating job placement of graduates of institutions of higher learning in the specialties obtained.

References

Pavis S, Platt S, Hubbard G (2000) Young people in rural Scotland: pathways to social inclusion and exclusion. York Publishing Services Ltd., York

Sergiyenko AM, Anisimova MM, Ivanova OA, Perekarenkova YA, Rzayeva SV, Reshetnikova SA, Rodionova LV, Sergiyenko YV (2014) Bednost’ sel’skoi Rossii v usloviiakh modernizatsii ekonomiki: protsessy i mekhanizmy formirovaniia i preodoleniia [Poverty of rural Russia in the context of economic modernization: the processes and mechanisms of formation and overcoming]. AZBUKA, Barnaul

Trotskovsky AI (ed) (2013) Ustoichivoe razvitie sel’skikh territorii Altaiskogo kraia: sotsial’no-ekonomicheskie i prostranstvennye aspekty [Sustainable development of rural territories of the Altai Krai: socio-economic and territorial aspects]. Altai State University Press, Barnaul (in Russian)

Chapter 35
Scenarios for Regional Development in the Altai Krai and Long-Term Trends

A. M. Nikulin, O. Ya. Vinogradskaya, A. M. Sergienko, A. A. Kurakin, D. Dirin, S. Lentz and A. Wust

Abstract This study detects and describes a specific set of possible alternatives to local rural development, as exemplified in Altai Krai's Kulunda steppe that can be implemented in a number of so-called analytical scenarios that the authors substantiate. The first scenario, which involves the natural deterioration of the settlement milieu of Kulunda steppe communities, has already begun and, in the authors' opinion, is being aided by the state's inarticulate agrarian policy and the nature of the agricultural market. However, under certain conditions, the authors concede that it might be displaced by a second scenario, which leads to a transformation of Altai Krai's Kulunda steppe into an area with high-tech farming and processing enclaves that dominate the backward rural district, which is distinguished by unsustainable, inert and intermittent development that allows for only fragmentary modernization.

A. M. Nikulin (✉) · A. A. Kurakin
The Russian Presidential Academy of National Economy and Public Administration, Centre for Agrarian Studies, Vernadskogo Prospect, 82, 119571 Moscow, Russian Federation
e-mail: harmina@yandex.ru

A. A. Kurakin
National Research University Higher School of Economics, Myasnitskaya Street 20, 101000 Moscow, Russian Federation

O. Ya. Vinogradskaya
Institute of Agrarian Problems - Russian Academy of Sciences (IAGPRAN), Moskovskaya Street 94, 410012 Saratov, Russian Federation

Rural Research Department, The Russian Presidential Academy of National Economy and Public Administration, Vernadskogo Prospect, 82, 119571 Moscow, Russian Federation

A. M. Sergienko
Institute of Economics and the Organisation of Industrial Production, Siberian Branch of Russian Academy of Sciences, Prospect Akademic Lawrentieva 17, 630090 Novosibirsk, Russian Federation

D. Dirin
Faculty of Geography, Altai State University, Lenin Prospect, 61, 656049 Barnaul, Russian Federation

S. Lentz · A. Wust
Leibniz Institute for Regional Geography (IfL), Schongauerstraße 9, 04328 Leipzig, Germany

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_35

The authors believe that the third scenario—the overall sustainable socio-economic development of this area based on a policy of 'manageable contraction' and 'diversified development' would be the most desirable.

Keywords Agricultural market · Agricultural policy · Economic diversification · High-tech farming · Modernization · Rural development · Socio-economic development

35.1 Scenarios for Regional Development in the Altai Krai

The territories of the Kulunda steppe in the Altai Krai are defined not only by their unique natural climatic conditions that enable a large range of agrarian products, but also by the wealth of their social capital, accumulated from various migration waves that have formed the actual settlement since the eighteenth century. Thus, this area is currently inhabited by the descendants of migrant peasants, who moved here from the Central European part of former Russia after the Emancipation Reform of 1861 and the Stolypin agrarian reform of 1906–1910. It is also the home of migrants, who came to this region following the experiments in intensive virgin land farming conducted by the Soviet government. One can expect such a socio-economic mixture having an effect on local or regional attitudes, as the communities repeatedly had to cope with the introduction of new regimes of rural production, technologies and national as well as societal frameworks. As research has shown, the population as a whole is positively preset about technical innovation and acquisition of new skills. There is no noticeable distance-dependent gradient of innovation from the centre Barnaul to the geographical margins of the region. Even in regions remote from the district centre, sometimes up to 500 km away, the locals are active Internet users, enjoy the latest technical developments and make use of state-of-the-art technologies in their economic activity.

Given the wealth of both natural and socio-economic potential, the future development of rural territories of the Kulunda steppe may take different directions that are not always obvious. Some trends in this development have been presented in previous chapters. The basic findings of the interdisciplinary research are

– a long-term trend to degrade the potential of the natural environment, especially soils, through inadequate technologies of agricultural production;
– a position of the regional agrarian production system which is still coined by the struggle against the consequences of undocking from the national economic system and at the same time increasing dependencies in national interrelations;
– migration flows of especially young people, who leave the rural areas for obtaining professional of higher education but do not return, even if they had planned to do so, due to a lack of perspectives for adequate professional opportunities and the low standards of local infrastructures;

– the long-term trend to reduce the number of employees in agriculture due to the pressure to increase productivity and further development of technology.

This sub-chapter translates and extrapolates these framing conditions into three scenarios of regional development, taking into consideration possibly discouraging as well as encouraging configurations, in order to inspire experts as well as a broader public to discuss on a desirable future of their region.

35.2 Scenario 1: Uncontrolled Contraction of the Settlement Milieu in Rural Communities

Socio-economic research carried out in the 'Kulunda' project showed that a significant number of respondents living in the territory of the Kulunda steppe believe that many of the small- and medium-sized rural communities in this area have no future. They express both concern and a gloomy conviction in the lack of prospects for such communities. They back such perception with examples of Kulunda population dwindling, if not disappearing altogether ('small villages here will die out', 'villages have no future' and 'you open a newspaper these days and all you see is people selling their houses').

> R.: Mikhailovka will soon be a village of pensioners. It's all very sad […] Our People are, after all, our wealth. Who would stay in the village with neither a school, nor a kindergarten? No-one, that's who! The village is the capillaries that feed all of Russia. (Altai Krai, Mikhailovsky district, village of Mikhailovskoe, local resident, August, 2013)

The villagers' pessimistic outlook ranges from extremely to moderately discouraging. Their perceptions of the problem contain more or less severely the following elements: the regional emigration of young people because of a lack of adequate labour, the crumbling of infrastructures (mainly education and culture) and the breakdown of what one might call local communities.

It should be noted that local residents according to their perception of the actual processes consider an unabated contraction of the settlement milieu, quite likely to occur. Furthermore, they see not only people leaving the area and whole villages disappearing, but that something worse will happen: the 'capillaries that feed' other regions will decompose. Here, in our understanding, respondents refer to what can be described as 'milieu': a medium, which represents statement for the fundamental functioning of a society and the key processes currently unfolding in these regions.

The specific concept of the milieu, we apply here, was developed by the historian, philosopher and one of the founders of the French structuralism school, Michel Foucault, in the late 1970s. Milieu, then, is the medium of action and the element in which action circulates. It is, therefore, the problem of circulation and causality that is at stake (Foucault 2007, 2021).

In other words, any kind of social environment is not an independent element of a system. It is the medium, which ensures a specific way of 'circulation' of cause-and-effect links focused through it. According to Foucault, the milieu becomes a field of intervention in which the only actor with any influence is the population and not the totality of any legal subjects or the many individuals subservient to a particular discipline. By ‘population’, he means a multiplicity of individuals who fundamentally and essentially only exist biologically bound to the materiality within which they live. ‘I mean a multiplicity of individuals who fundamentally and essentially only exist biologically bound to the materiality within which they live’ (Foucault 2007, p. 21). Therefore, according to Foucault, the only purpose of this milieu is the unification of a whole range of individually caused events, population groups and surrounding quasi-natural phenomena.

A sequential comparison of maps from Soviet times, showing administrative and economic classification and sizes of settlements and infrastructural facilities (e.g. irrigation systems), with today’s situation, as shown in satellite images (cf. Chaps. 1 and 2), gives insight to the spatial consequences of such complex processes like economic and social ‘shrinking’. Many indicators stand for the startling degradation and deterioration of the rural Kulunda landscape: the increasingly sparse and fragmentary nature of the forest belts neglected and partly ruined of irrigation systems and especially the substantial reduction in the number of small rural communities. Respondents from Tabunsky and Mikhailovsky regions, for example, have predicted the final disappearance of their settlements in the next 15 years or so.

> R.: We’re left with one bus to the regional centre per day, and the inter-district bus commute covers 23 populated areas, apart from the Naumovka village. We called for proposals from passenger carriers but received none because the route is unprofitable. (Altai Krai, Uglovsky district, village of XX, chairman of the committee for the economy and property relations of the district administration, September, 2015)

Most respondents assume that the rural settlement milieu in the Kulunda steppe will not disappear but the situation in the rural locality will deteriorate through the unpredictable nature of the socio-economic environment. Many farmers and municipal officials among our respondents emphasized that they neither see a coherent agricultural policy from the government nor predictable signs for development from the market. In these conditions, they stressed, the drift to other regions and cities will continue, mostly by the active and able-bodied rural population from Kulunda. This conforms to the findings from studies on the development of income in Kulunda. In the ranking for average wages, the area has the lowest position. Even taking into account the influence of the social policy, the redistributive processes in the socio-economic sphere, new chances of the economy developing in the agrarian districts linked to the policy of import substitution and the stimulating effect of innovations, planning a living is at risk for many young people, especially families who want to stay in the region.

As a result, Kulunda will shrink in an unpredictable and chaotic manner in terms of both the population and agricultural output.

> R.: The population works on their own household plots. They keep cattle, milk cows, sell milk and the young animals are butchered for beef. There are many pensioners, and even those who are not can ask a much simpler question: how do they live? Some of the young people go north to work in rotations [i.e. long term shifts in oil and gas industries]. We have

> those. And the rest? (Altai Krai, Mikhailovsky district, village of Nikolaevka, assistant head of a farming business, September, 2015)

> R.: Many young people, of course, leave. I don't see any recent school-leavers working in agriculture. Among those of the earlier years, there are some youngsters aged 30–35. They are the ones who could not continue their education after leaving school for whatever reason, and so stayed on here. But they don't have any prospects here […] Three years ago they even closed the Altai State University campus here in Mikhailovka […] (Altai Krai, Mikhailovsky district, village of Nikolaevka, local resident, September, 2015)

What respondents describe here is the central position of migration processes for regional development. The decision of young people to leave the region is crucial insofar as they are the only ones who have emotional roots and a feeling of 'home' connected with the Kulunda steppe.

There is, of course, a historical perspective on processes of societal and economic transformation, which found this scenario as a kind of historical counter-development to the intensive in-migration of large numbers of people and enterprises into the Kulunda steppe in the late 1960s. While the state-run economy could afford to fund such experiments society and politics today, consider the 'shrinking' of the region a quasi-natural process. It is the consequence of the radical system change with the disintegration of agrarian production units in the region and the disconnection of the region from the national production system. Migration then is the result among the population, especially if among young people a discourse becomes self-evident and dominant, that for them there will be no alternative to emigration. There is no halt to this decline of the cultural and social landscape, which will experience very harsh deterioration for the next decades until the system will have reached a new low-level equilibrium of production, infrastructure and population density.

35.3 Scenario 2: Transforming the Rural Locality Through Economic Development

Scenario 2 points out that the development of scenario 1 might unfold less dramatically if regional policy and rural society succeed in creating grass-root and small-scale economy in the non-agrarian or in the agro-oriented sector. Respondents, including representatives of the district and municipal authorities, business and ordinary residents, forecast a low-key and slow development of rural territories in the Kulunda steppe in the near future. To this goal, a general idea is to mitigate and stop decay with the help of a structural transformation, mainly diversification, starting with small-scale business, which is based on local and trans-local demand for goods and services. One origin for such a vision is the socio-economic development strategy of the Altai Krai as conceptualized in the regional Action Plan for 2025. Some fundamental impulses for a sustained turnaround should stem from socially oriented non-commercial organizations (hereinafter SONCO). They are considered equipped with 'significant potential […] for the active use of the resources of civil society in solving the problems of the Altai Krai community' (cf. Action Plan 2015, p. 61).

Such actions are intended to 'improve the institutional and infrastructural conditions' and the milieu for the development of the SONCO sector in order to increase the momentum of the socio-economic development of the Altai Krai' (ibidem: 62), which then should foster further enhancements for conventional small- and medium-scale business. Such further development is defined by many federal, regional and local economic initiatives intended to modernize agrarian manufacturing and create new employment possibilities. As a part of the measures to create conditions for stable economic growth, the Strategy for socio-economic development of the Altai Krai by 2025 envisions the share of small business production increasing. Its contribution to the general volume of gross regional product should grow from 17.5% (2014) to 20% in 2017, and up to 30% in 2025 (see: Action plan 2015, p. 70).

Respondents sometimes doubted the efficiency of such, especially supra-regional programmes, memorizing that, with the launch of national projects, e.g. they did have to become involved in dairy farming or support farmers new to the business and private household plots, or create their own personal business initiatives such as new farming enterprises. However, most of these undertakings, in the opinion of the respondents, did not have the desired effect, as earmarked funds were often wasted and local changes and reforms were not completed. For instance, in national agricultural projects programmes, substantial resources were allocated to create large livestock complexes both in the Altai Krai and the Kulunda steppe. To this day, many of these complexes have not delivered the expected results and some have gone out of business. Farming enterprises and household farming plots, with one or two exceptions, have not delivered steady results either, remaining at their previous level or even scaling down.

Part of this low-key development could be the touristic sector (see box Dirin et al.: Opportunities for Economic Diversification…). How high hoping vision may be: the transport and touristic infrastructure within the region is weak and there is no experience in regional competition with a traditional touristic region like the neighbouring Altai Mountains. The problem of possibly contradicting touristic use (touristic protection vs. touristic exploitation of natural resources) has to be taken into account.

Other respondents attributed unstable development not to systematic but to fragmentary modernization of rural Kulunda. Their observations are that only very large and successful agrarian enterprises, which are few and far between in Kulunda, can afford to buy expensive hardware and state-of-the-art equipment. This trend continuing they, despite the generally depressing background, foresee a scenario of fragmentary modernization. Spatially, they materialize in island-like territories, where hi-tech agrarian and processing industries emerge.

In other words, the decline of public infrastructure and the constantly increasing productivity of highly professional farming are two reactions on either side of the same coin in this process. However, it is not given, that economic progress will lead to a quantitatively increasing demand for labour, with a remarkably positive impact onto the settlement system. It is very likely that the demand for other, new and higher qualified workforce in agriculture will rise. As some of the necessary structural precondition for further automatization in farming is very good in the

Kulunda area, for the future, one can imagine a very sparsely populated agro-steppe landscape to develop, with huge high-tech farms that get along with a minimum of employees.

Examples from the regional development paradigm of ‘growth poles’ show that enterprises, which themselves have risen under the paradigm of constant rationalization and automatization are not likely to create regional overspill effects in terms of a constant demand for the further human workforce. Thus, the effects of such an evolutionary path would not mitigate the existing type of settlement system and its infrastructure. The potential for a positive impact on the existing cultural and economic landscape is low. This type of regional economic specialization would rather accelerate the decay of the actual settlement system and as such cannot be considered ‘sustainable’ from the social perspective.

Box Opportunities for Economic Diversification: Recreation and Tourism

Dirin D.A., Krupochkin E. P., Rygalov E. V.

Tourism and recreation represent one opportunity for economic diversification and improvement of public social services. These sectors are characterized by rapid capital turnover and a significant multiplier effect. Although tourism and recreation are not a traditional specialization for the Kulunda steppe, this area has some potential for its development in the region.

1. ***Significant and Diverse Tourism and Recreation Resources***. The primary potential for the development of the tourism and recreation sector lies in natural, cultural and historical features and conditions that define interest in visiting the area for travel or recreation. The resource potential for the development of tourism and recreation in the Kulunda steppe is seen in several aspects.

   – The climate is characterized by Siberia’s highest solar radiation and a high number of sunny days per year. This provides good opportunities for climate therapy.
   – The area has several hundred large lakes, which are ideal for a beach vacation and the development of water sports and activities. It has both fresh and salt water bodies, many of which have reserves of therapeutic muds. Salt water and salt also have a therapeutic effect.
   – Some areas have preserved unique natural landscapes, which can be the basis for the development of eco- and science tourism. They include relic pine forests and wetlands that are part of the global routes of migratory birds. The rich bio resources of this area define its high potential for the development of hunting and fishing tourism.
   – The area’s ethno-cultural areas and specific cultural ranges of Russian, German, Ukrainian and Kazakh populations are the basis for cultural, educational and ethnographic tourism.

2. ***An advantageous economic and geographic position and infrastructure development***. Kulunda's geographic location and existing transport infrastructure can serve as a base for the development of tourism and recreation. There are rail and air connections with the densely populated districts of Altai Krai, Novosibirsk Region and East Kazakhstan. Within a 400-km radius of the centre of Kulunda steppe are about 4.5 million people and the cities of Slavgorod, Yarovoye, Rubtsovsk, Kamen-na-Obi, Barnaul, Novoaltaisk, Novosibirsk, Iskitim, Berdsk, Pavlodar, Semei, Ust-Kamenogorsk and others.
3. ***Positive social milieu***. Kulunda's social milieu, with its political stability, low crime rate and tolerance of outsiders, promotes the development of tourism. Common attitude towards the development of tourism and the readiness to work in this business is very positive among the inhabitants of villages in the Kulunda steppe.

In an evaluation of Kulunda steppes touristic potential, eight potential clusters with three major specializations could be identified (Fig. 35.1).

35.4 Scenario 3: Sustainable Socio-Economic Development of Territories

Among the wide spectrum of answers to our question about the future of the Kulunda area, and among the opinions expressed freely in group discussions or dialogues, a third evolutionary line can be identified. Remarkably, experts from the Altai Krai's administration as well as local experts, officers as well as entrepreneurs, and inhabitants of the villages formulate visions, which complement each other about the management of the current decline and allow for a diversified development of the region.

> R.: We are currently adopting programmes for the sustainable development of rural territories. Certain units are defined within it, for example the social sphere, the communal sphere, and cultural sphere in some extent. These programmes must be implemented in the village. But these spheres will not be needed if the rural locality is depopulated, and that's why first and foremost measures must be taken to improve employment in the village. If there is no work, then there won't be anyone to use these systems, including communal amenities, healthcare facilities, and schools. Employment is one of the most urgent problems in the district. (Altai Krai, Uglovsky district, village of XX, chairman of the committee for the economy and property relations of the district administration, September, 2015)

> R.: We are implementing programmes for sustainable social development of the village and the sustainable development of rural territories. 6 or 7 young doctors have received support under these programmes over the past few years. They come from Rubtsovsk or Barnaul because they get a million as relocation expenses. He receives an apartment for five years, or buys one with that million, and after five years he can move somewhere else or stay here.

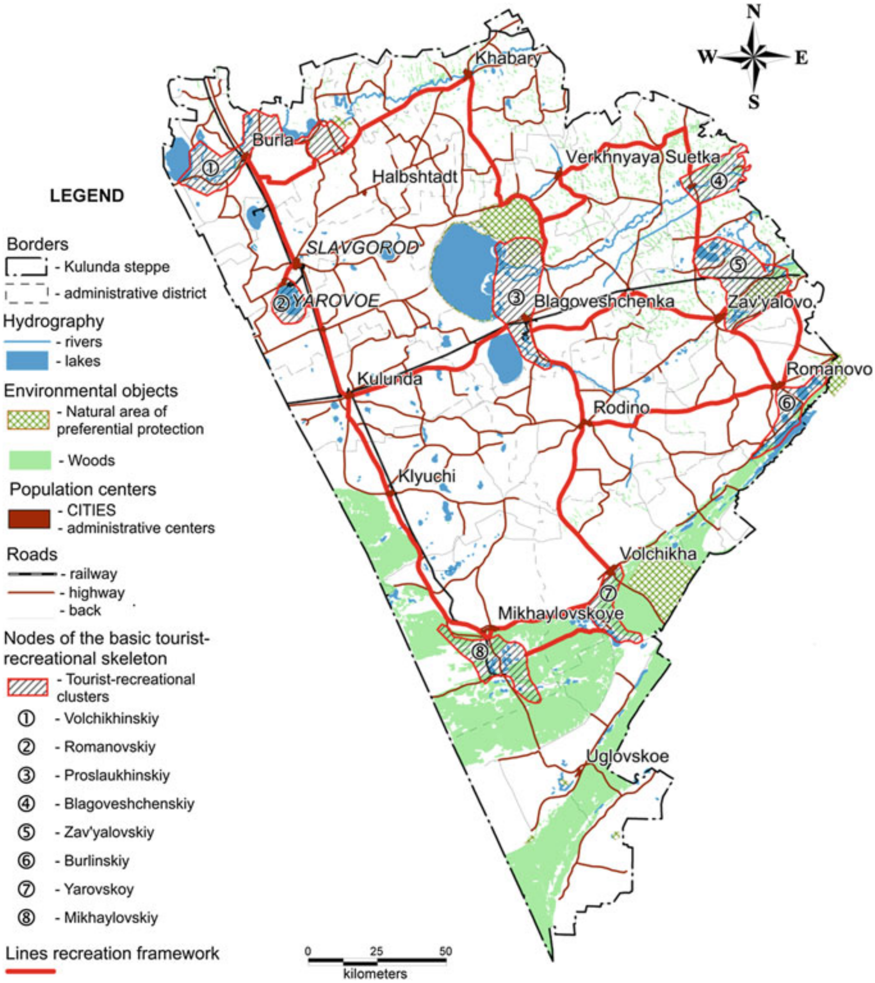


Fig. 35.1 Exoskeleton of the regional tourism and recreation system of the Kulunda steppe. *Source* Dirin et al. (2014)

(Altai Krai, Uglovsky district, village of XX, deputy chairman of the committee for agrarian issues and environmental protection of the district administration, September, 2015)

The strong in-migration in order to cultivate new land and to contribute to the national wealth remains in the collective sense of self among many inhabitants of the Kulunda steppe, even today. The change in the economic paradigm in the late 1980s and early 1990s and the definition of new development priorities put the most achievements of the past decades at stake. Most rural territories, however, retain some inner strength, which allows them to preserve some collective vitality, despite the experience of young people drifting to the cities, infrastructure collapsing and mono-specialization of big businesses, setting free workforce. However, the situation began to change for the worse after the recession of 2008.

Nonetheless, Kulunda respondents stress the will of workforce, which has been set free, to stay in the region and to engage in a local business. They estimate such behaviour a social resource to be employed for a diversified development of Kulunda.

Diversified development is usually understood as the expansion of various spheres of socio-economic activity associated with efforts aimed at a more balanced and varied coexistence of agricultural sectors, including not only the monocultures of the recent decades (wheat and sunflower) but also fodder crops that facilitate the development of local livestock husbandry. In addition, the development of modern dairy farming, poultry farming and sheep farming is seen as viable in the long term. Finally, there is great potential in orienting modern agriculture towards the production of good-quality wholefood. The workforce that is freed from agricultural production could be reassigned to those traditional local industrial sectors such as forestry and timber industries. It could also shift to the sphere of recreational services and tourism, as well as the development of the local social and transport infrastructure, which would contribute to the greater integration of rural Kulunda with other regions of the Russian Federation and former Soviet states, such as Kazakhstan. In addition, the implementation of the sustainable diversified development scenario in the rural territory of Kulunda is possible primarily in the context of a productive dialogue and collaboration between the basic actors of this process: the local authorities, business and broad population.

Kulunda is clearly an agricultural region and its fundamental agrarian focus is predetermined for the next decades. At the same time, this region would gain significantly from a modernization of the quite extensive agrarian and industrial legacy of the Soviet period. On the other hand, opening up new opportunities to develop the Kulunda countryside would be the cultural 'greening' of the pine forests, salt water lakes and parts of the virgin steppes. Initial steps in this direction have been taken with the establishment of comfortable recreation camps, increasingly built in Kulunda's places of natural beauty: on the borders of its forests, steppes and lakes (cf. box Dirin/Krypochkin/Rigalov: 'Diversification possibilities…'in this chapter).

Opportunities for a frequently spontaneous and informal professional reorientation of the Kulunda population are expanding. Those who do not move to large cities and rich regions try to learn new, occasionally rare, vocational skills for the Kulunda steppe. An example is the development of professional competences among local entrepreneurs and wageworkers. The steady development of the service industry in the form of cafés and tourist leisure facilities in the Kulunda steppe in recent years, which validates the importance of casual employment and economy, is hard to grasp in the course of sociological research even through methods of participant observation.

Another example is the foundation for diversified development of the Kulunda steppe territory. It is tied to the forestry industry, for example, which has recently become a factor in the integration of new technological changes, affecting primarily processes associated with the cultivation of economically valuable species of trees. An example of this is the commissioning in 2012 of a unique selective seed farm in the village of Bobrovka in Pervomaysky district for the cultivation of ball-rooted planting stock. This technology reduces the cultivation term of nursery plants to from 24 to 12 months.

35.5 Conclusion

The interdisciplinary research project showed that Kulunda steppe in the Altai Krai now is a peculiar laboratory of search of possible ways to sustainable development of rural communities in a zone of droughty and risky agriculture. The area comprises a wide variety of practices of rural existence—from depression and stagnation to growth of social-economic and technical innovative activity. From the actual trends, one can derive scenarios for future regional development, positive as well as negative. In our opinion, the main obstacle to rural innovative development is dissociation and inconsistency of actions of the major institutional factors responsible for the social stability of territories of this or that region. As a consequence, local communities, households and the farmer enterprises often excluded from decision-making processes in the social and economic life of municipalities and the region, or participate in it only formally. We consider the development of measures that support the initiatives of local groups and communities and connect them with innovative solutions and technologies crucial to promote positive development of the Kulunda zone of Altai Krai.

References

Dirin DA, Krupochkin EP, Golyadkina EI (2014) Metodika kompleksnoi otsenki turistko-rekreatsionnogo potentsiala regiona (Methodology for Comprehensive Evaluation of the Tourism and Recreation Potential of a Region). Geografiia i prirodopol'zovanie Sibiri 18:64–78 (in Russian)

Foucault M (2007) Security, territory, population: lectures at the College de France, 1977–78. Palgrave Macmillan, New York

Chapter 36
Practices and Constraints of Further Education of Farmers in the Kulunda Steppe

V. N. Chizhov, N. A. Ryzhkova and P. Liebelt

Abstract The goal of the Kulunda project was to generate innovative research results to ensure a sustainable economic, social and ecological development of agriculture in the Russian part of the Kulunda Steppe and in comparable regions as well. The analysis of the agricultural development through interviews with experts and stakeholders in the Altai Krai revealed a cyclical trend. Knowing its steering factors is essential to influence this trend. Among those, humans and their capacities are crucial, especially the professional education of the workforce. This chapter is firstly focusing on opportunities to improve professional education and on problems to provide further education to the agricultural workforce in the area. Secondly, it outlines respective findings of the Kulunda project and their implementation into the regional training system for the workforce of the agro-industrial complex. Special emphasis lies on the perspective of the Altai Institute for Advanced Training of Manager and Specialists of the agro-industrial complex (AIPK).

Keywords Capacity building · Knowledge transfer · Professional growth · Vocational training · Professional education · Agricultural innovation · Stakeholder · Stakeholder network · Field day · Development of agriculture

36.1 Problem Description and Discussion

National or regional or micro-economic growth—of a small business, a transnational corporation or an economic branch like agriculture in a country like Russia—largely depends on the professional skills of its workforce. The quality of vocational training and further education is the basis of professional development. Its goal is not only

V. N. Chizhov (✉) · N. A. Ryzhkova
Altai Institute for Advanced Training of Manager and Specialists of the Agro-Industrial Complex, Ostrovskogo Street 14, 656019 Barnaul, Russian Federation
e-mail: aipk.apk@list.ru

P. Liebelt
Institute of Geosciences and Geography, Martin-Luther-Universität Halle-Wittenberg, Von-Seckendorff-Platz 4, 06120 Halle, Germany

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_36

gaining knowledge in a specific profession but also developing skills to apply this knowledge. Teaching the latest scientific results ensures the qualification and competency of professionals. Consequently, professional education in agriculture depends on both, high-quality scientific publications created by scientists and practical experience of farmers. It requires access to current development in science, practice and education. A well-educated agricultural workforce is the key to productivity and innovation and, therefore, to economic growth in agriculture.

Russia's agriculture changed in waves during the past hundred years. Due to financial and political support, and economic reforms that supported effective research, agricultural innovation, and improved professional development of the workforce, Russia's agricultural production increased and led to significant growth and technical progress in some years. In contrast, economic instability and decline in economic power resulted in decreasing knowledge transfer of new scientific developments, less efficient agricultural production and impeded professional development of the workforce (Kulik 2016).

Particularly, innovations are the most significant factor to ensure continuous performance in the agricultural sector. Innovative development of Russia's agriculture is one of the most important ways to increase the welfare of the country, strengthen its economy, increase its financial revenue and, most important, ensure the country's food security (Minselkhoz Rossii 2016).

The following factors are commonly considered as main components for an innovative development of agricultural production (Fig. 36.1):

– new plant varieties and animal breeds
– new efficient land use technology
– high-performance machines and equipment
– timely and adequate financial support (investment).

Russia's government has developed and implemented several programs to promote innovative activity in the agricultural sector. Most agronomists believe that breeding, seed, breed livestock determines half of the success in agriculture; mechanization generates the other half. It is noteworthy that the workforce as a factor is ignored (Nivy Rossii 2016).

A big part of seeds, animal breeds and technologies currently used in Russia's agriculture were imported from countries with a highly developed agricultural sector, while the pace of Russia's agricultural innovative development is still on a low level. As noted in the interregional agronomical magazine 'Fields of Russia' unfortunately,

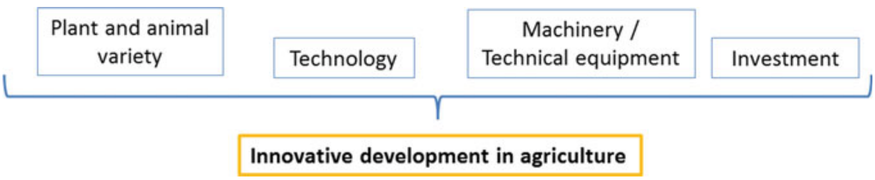


Fig. 36.1 Factors for innovation (Chart by Chizhov)

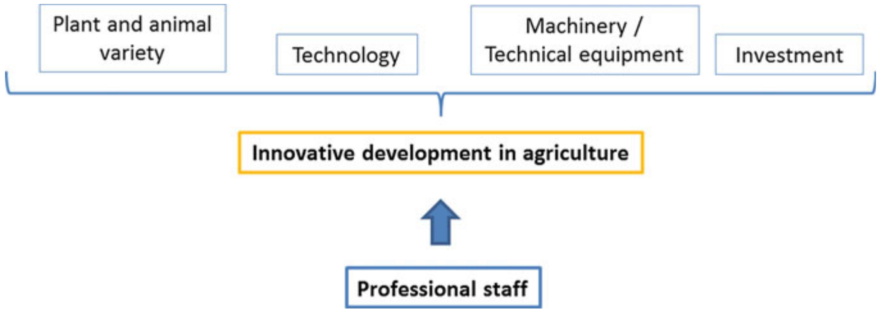


Fig. 36.2 Innovative development in agriculture (Chart by Chizhov)

we have not yet reached the food production level of 1990 [based on the results of 2015] (Nivy Rossii 2016, p. 49). At that time, the annual grain production amounted to 117 million t in the RSFSR[1] and more than 200 million t in the USSR. The current grain yield is about 100 million t in the Federation. The output of milk and dairy products was 389 kg per capita in 1990 and is now much less with 247 kg per capita. Agricultural productivity is 6–9 times lower than in Western countries, and the energy consumption is 2–3 times higher […]. Such data raise the question about the causes of low agricultural productivity. Materials and technology utilized in Russia's agriculture today are much better than at the beginning of the 1990s. Newer, far more productive varieties of plants and animal breeds are used. Agrarian technologies evolved significantly with increased financial support. As one reason for the low productivity, despite all those investments, remains a lack of human capital in Russia's agriculture (Fig. 36.2). Insufficient training and little effort to improve the qualification and competence of the workforce cause low innovative growth. Since the collapse of the Soviet Union and Russia's transition to a market economy, the agrarian sector has lost 7.5 million workers and professionals. The annual loss of agricultural production staff was between 400,000 and 450,000 people. People went to businesses offering higher wages (Chizhov 2014). The human capital in agriculture decreased sharply. Drastic measures were required to remedy the situation and ensure sustainable professional growth in the agro-industrial complex.
Main factors for professional growth in agriculture (Fig. 36.3)

– professional education (this is the basis for professional growth)
– innovation (based on scientific publications and the farmer's own experiences)
– practical work (as a base for the implementation of acquired knowledge)
– analysis of work experience (the interpretation, continuous analysis and synthesis of the farmer's practical experience)
– training courses (activities of the educational institutions to increase competence and further education of the workforce)

[1] Russian Soviet Federative Socialist Republic.

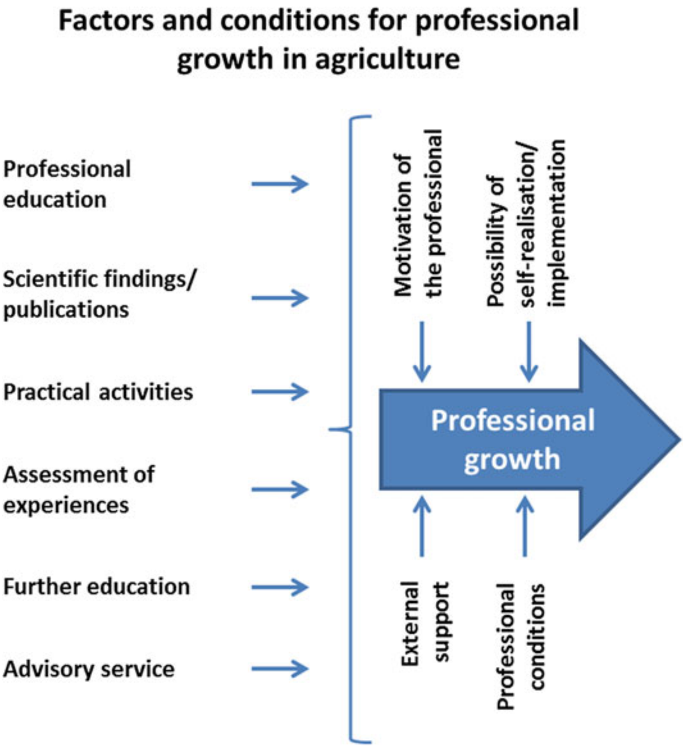


Fig. 36.3 Factors for professional growth (Chart by Chizhov)

– providing consulting support to farmers (solve complex problems by applying innovations).

The efficacy of above-mentioned factors depends on several individuals and organizational preconditions like the professionals

– motivation (target-oriented work to increase professionalism)
– possibility of self-realization (household, financial and social conditions of the farmer) or are set by authorities and management of agricultural enterprises:
– state support (targeted programs, policy decisions, etc.)
– professional environment (the preconditions that promote the professional growth of a farmer's competitiveness, the support and assistance of colleagues).

These factors and preconditions raise the question of how they can be managed to achieve sustained professional growth of the farmer. Our findings indicate that scientific publications and education are the most influencing factors for professional growth of farmers in the Kulunda Steppe.

A sustainable, high-quality education and the utilization of new scientific results as well as other factors can lead to sustainable professional growth of agricultural workers.

Fig. 36.4 Development of sustainable professional growth/capacity building (Chart by Chizhov)

Figure 36.4 shows the most important factors for a successful capacity building of the personnel in the agricultural sector. As many employers reported, Russia's agricultural education and its need for modernization are not the only important factors for the workforce's professional growth. The motivation of future farmers is important, too.

Scientific results are insufficiently used in agriculture. Even in the Soviet era and today, too, innovative research in the field of agricultural sciences has been conducted worldwide. The application of international research results in Russia's agriculture could drastically improve the country's land management practices but currently, only 3–4% of farmers utilize this information. This raises the question of which factors hinder the knowledge transfer to agricultural education.

The lack of knowledge transfer is caused by reasons like these:

– no clear concept for the transfer of scientific developments to the consumer
– educational institutions' and agricultural producers' lack of awareness and information about the new scientific results/products
– farmers' insufficient training to adopt scientific developments
– inability, or rather the uncertainty about how to implement these new products
– no attention is given (no motivation) by a large part of agricultural producers to the application of scientific innovations (still waiting for someone trying to take advantage of his experience)
– lack of the necessary preconditions for implementation by farmers
– no insurance protection for farmers for the implementation of innovations
– partially insufficient support to implement innovative scientific knowledge by agricultural authorities.

There are no clear guidelines for the implementation of new scientific developments in the production process.

The professional's practice and analysis of experiences depend on several factors. A lack of good education and missing ability to understand new scientific findings are the main hindrance for implementing new effective land management methods. The farmers are also often afraid of innovations. Vocational training and agricultural consultations at the beginning can help to overcome these barriers. However, to provide this service, the educational institution AIPK and agricultural consulting centres need highly qualified professionals and access to scientific results including knowledge about how to implement the results into the agricultural production process (systematic and prompt knowledge transfer). This is often not the case. The preconditions for improving these above-mentioned factors are often insufficient. Employers often do not have a professional environment to implement innovative agricultural methods. Accordingly, the workers' motivation and the possibility of self-realization are relatively low. The government does not always support the farmers in a timely and sufficient manner. These are, perhaps, the main factors inhibiting innovative development in Russia's agriculture and sustained professional growth of its workforce.

Thus, sustainable professional growth of workers in agricultural production can only be achieved by addressing the complex organizational tasks and by creating clear guidelines for the knowledge transfer of scientific developments into production. The AIPK is working to solve these tasks, among other things, by applying the scientific results of the Kulunda project (www.kulunda.eu). But some of these problems cannot be solved by project participants and staff of the Altai Institute for Advanced Training of Managers and Specialists of the agro-industrial complex (AIPK) alone and require the involvement of authorities of the Altai territory, employers and the scientific and educational community of the Altai Krai.

The Kulunda project's goal was the development and implementation of innovative land use strategies in the steppe part of the Altai Krai. The project is the basis for building a development program in the field of crop production in the Kulunda Steppe.

The Kulunda area includes 13 districts according to the zoning of the Altai territory. About 2500 managers, professionals and farmers work in crop production. During the Kulunda project, 1543 participants from the Kulunda area were educated in training programs focused on the implementation of the project findings.

Figure 36.5 shows the participants' shares by age and Fig. 36.6 displays the shares by gender in the training programs (the participants originated from areas of the Kulunda Steppe).

Figure 36.5 shows that 30% of the participants were between 30 and 39 years old. 26% of the participants were of the age between 50 and 59 and 23% between 40 and 49. The small share (3%) of young farmers under the age of 25 is noteworthy.

The majority (60%) of the participants in the AIPK's training programs are male due to still difficult conditions in agriculture (Fig. 36.6).

Regarding the education level, most participants are professionals with a secondary special education degree, which indicates a greater motivation for further education of this group of farmers. Obviously, they want to work more efficiently. The analysed period between 2012 and 2016 corresponds with the timeframe of the Kulunda project. The analysis shows the project's positive impact on the process of

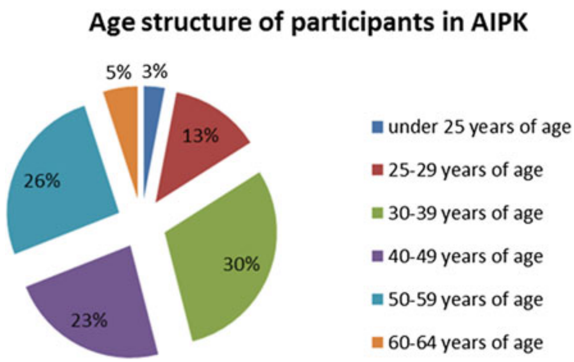


Fig. 36.5 Age structure of participants in the AIPK's training programmes (Chart by Ryzhkova)

Fig. 36.6 Share of men and women in the AIPK's training programmes (Chart by Ryzhkova)

further education of farmers. The inclusion of the project in the teaching process motivated the participants and encouraged them to study.

Scientists of the Altai Krai, the AIPK and scientists from the Kulunda project participated in the training program for agronomists. In 2015, the AIPK, in cooperation with scientists from the Martin-Luther-Universität Halle-Wittenberg, offered a seminar regarding the scientific modules of the project. Currently, information about new adaptive agricultural technologies is in great demand and the AIPK's consulting service can provide targeted advice based on results of the Kulunda project. The actuality and practicality of the project's results allowed the AIPK to use this data to organize and conduct field studies in the region. Farmers learned about soil fertility preservation, implementing the knowledge into practice, and enhanced their skills. They themselves were mostly interested in the topic of economic activity of agricultural businesses based on resource-saving technologies. Using the project's results to improve the qualification of managers and professionals of the agro-industrial complex allows developing knowledge and practical skills. Improving their methods and attitudes increases the labour resources in the area. The project's results help to promote sustained professional growth of the staff of agricultural enterprises and farmers in the Kulunda area of the Altai territory. The increase of agriculture's human capital based on the use of the Kulunda project's results is an important outcome for the implementation of the strategy of socio-economic development of the Altai territory until 2025.

Such projects help to create an innovative environment in the region and to develop the workforce of the agro-industrial complex. The establishment of an advisory and management platform within the Kulunda project helps to promote understanding and awareness for new ecological and economic strategies for sustainable development of agriculture and thus supports the implementation of the project results (Rivera and Sulaiman 2009).

Implementation of results and recommendations, generated in the Kulunda project at the regional level—in the Kulunda Steppe of the Altai Krai and beyond

This contribution focuses on possibilities for effective and target-oriented implementation of project findings and recommendations generated in the international Kulunda project in the investigation area. In terms of content, the implementation includes economic, ecological and social strategies for sustainable land use management in Russian steppes. Specifically, it is about adapting the agrarian land use to landscape conditions and climate change, reducing greenhouse gas emissions and sustaining regional development in the Kulunda Steppe.

36.2 Processes of Implementation

The successful implementation of project findings strongly depends on the local/regional stakeholder participation.

Step 1 **Identifying regional stakeholders**

Based on the project's targets and objectives, a screening study of Agricultural Knowledge and Innovation Systems (AKIS) was conducted. An in-depth literature review, Internet and in-place research identified relevant stakeholders including policymakers and various authorities, research and education institutions, extension services, and the AKIS support system (including mass media sources) on national, krai and raion levels. Thus, in the first step, 93 stakeholders organized in four AKIS fields were identified. The guideline of GLUES hand-out for projects within the BMBF program 'Sustainable Land Management' Module A (Moll and Zander 2011) was followed for successful stakeholder identification and involvement.

Step 2 **Selecting the most relevant stakeholder**

The initial list of Kulunda project stakeholders was reduced to those key stakeholders who are involved in innovative activities (research, education, extension, policymaking, lobbying, control and practice). Crucial were sustainable land management, ecology and environmental issues. Stakeholders should have decision-making power, act as leaders in different fields of AKIS elements, have a broad knowledge of sustainable land management and environmental issues related to the implementation-oriented targets of the project, and should hold relevant expertise to support the stakeholder

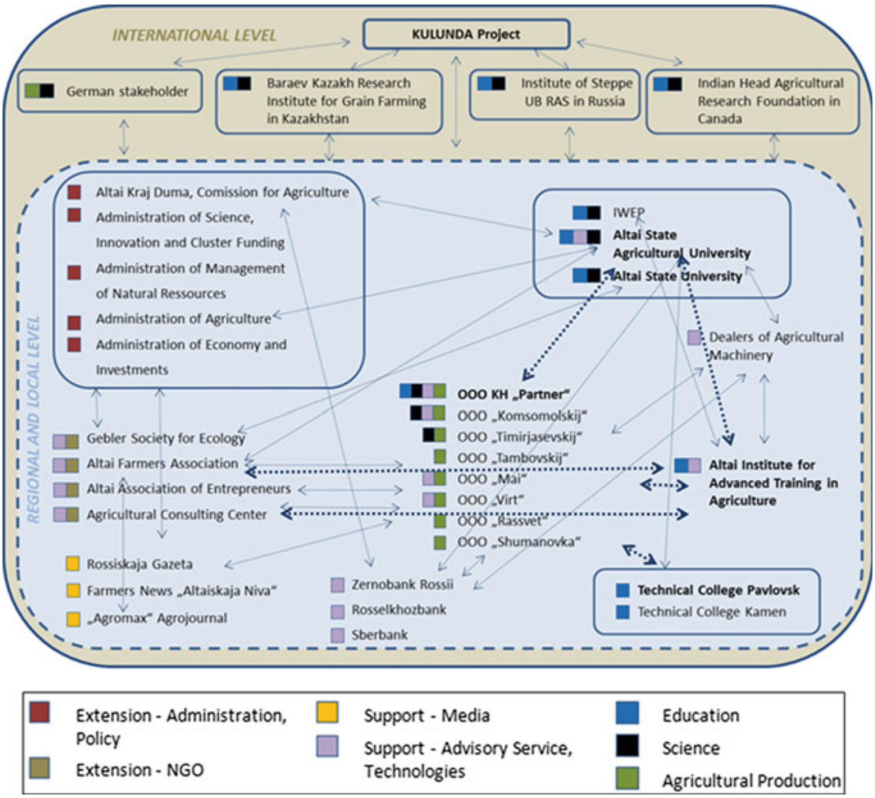


Fig. 36.7 Stakeholder network within the Kulunda project (Chart by Liebelt)

process. These stakeholders acted as the main participants and multipliers of innovations, which were derived from the project's research findings.

Step 3 **Analysing the AKIS network**

The idea of Agricultural Knowledge and Information/Innovation System's (AKIS) approach is that a system consists of different contributors who impact the know-how creation and the knowledge transfer (Röling 2009).

The AKIS's main components are research, education and extension services linked to agricultural producers (Fig. 36.7). Research, education and extension present the so-called knowledge triangle of AKIS which was developed by the Food and Agriculture Organization of the United Nations (FAO) and the World Bank (WB) in 2000. AKIS's efficiency depends further on the Ministry of Agriculture, local government, non-governmental organizations (NGOs) as well as media, financial institutions and other stakeholders.

Links between education, research, consulting and end-users became very weak or non-existent in the AKIS network of the Altai region after the collapse of the Soviet

Union resulting in an urgent need to develop and expand these to ensure a more effective knowledge gain and transfer. Therefore, the Kulunda project is working in the field of knowledge implementation precisely at this point (Janakiram 2000; World Bank 2000).

Step 4 **Implementing methods and products**

Several events and measures were developed based not just on the results of face-to-face interviews and regular meetings with regional stakeholders but also under consideration of the existing culture of farmer-to-farmer learning. Events and measures included interactive workshops, vocational training courses, field days, presentations and circulation of print materials like project flyers and brochures in Russian.

36.3 Selected Approaches for the Knowledge Implementation within the Kulunda Project

1. **Advanced training of local professionals and farmers**

'Training of local professionals and farmers' means further teaching to professionals and farm managers in the field of sustainable land use management and monitoring in the agrarian sector for better consultation and land use management in rural areas.

The goal is a joint Russian–German concept for further education/vocational training in sustainable agriculture and monitoring, especially for the Barnaul Institute of Qualification in Agriculture. Continuous lectures (Fig. 36.8) are offered, related to current research results. They concentrate on the field of sustainable land management (SLM) technologies and modern monitoring systems. As a further training for members of state organizations, they deal with institutional measures to improve ties between agricultural consulting systems, universities and vocational training facilities to enhance the capacity building and knowledge transfer in the region.

2. **Field day/field seminar** (cf. Chap. 37)

At a Field Day event, interested farmers from the investigation area can discuss the scientific needs of the agricultural workforce and get information about activities and results of our project work on the test sites and about new methods and technologies for soil conservation (Fig. 36.9).

Goal number one is the implementation of new soil conservation methods and technologies such as direct seeding or minimum tillage. The Field Day at our partner farm OOO KH Partner in Poluyamki (Michailovsky Raion) provided an excellent opportunity to introduce farmers to these soil conservation methods. The second goal is the implementation of SLM technologies by capacity building and an increased acceptance of new technologies.

The investigation area is in great need for measures to improve knowledge transfer and capacity building. Therefore, it is important to continue the activities of knowledge implementation and stakeholder participation and to maintain and strengthen

Fig. 36.8 Training seminar in the Barnaul Institute of Qualification in Agriculture (Photograph by Liebelt 2015)

Fig. 36.9 Presentation of project findings and innovative technologies at the Field Day (Photograph by Liebelt, 2015)

the AKIS network. One possibility would be building a competence centre for sustainable agriculture in Altai Krai.

36.4 Conclusion

Further strengthening of the agricultural sector depends strongly on innovative activity. Science is essential because it delivers innovative information. Therefore, in addition to investing in technology, it is particularly necessary to promote innovations in agriculture through a stronger commitment to education and vocational training for the agrarian land user.

The Kulunda project has made an important contribution towards this goal. The innovative results developed in this international research project can be used by the AIPK and other regional educational and consulting organizations to build or complement their information base and consequently to improve the quality of their educational programs. The transfer of high-quality research results to the land users strengthens their abilities and motivation to implement innovative strategies and thus strengthens the sustainable agricultural development of Altai Krai.

References

Author unknown (2016) Vmesto poslesloviia. Informtsiia k razmyshleniiu i sravneniiu (Instead of an afterword. Information for reflection and comparison). Nivy Rossii (139): 49 (in Russian)

Chizhov VN (2014) Professionalnoe soprovozhdenie rukovoditelei sel'khozproizvodstva (Professional accompaniment of heads of agricultural production). Altai Institute for Advanced Training of Manager and Specialists of the Agro-Industrial Complex, Barnaul (in Russian)

FAO and World Bank (2000) Strategic vision and guiding principles: agricultural knowledge and information systems for rural development. FAO and the WB, Rome

Janakiram S (2000) Innovative ICT approaches for development of rural information and advisory services in transition economies. The World Bank, Washington, DC

Kulik GV (2016) Predstoit sdelat' bol'she, chem uzhe sdelali (We have to do more than we have already done). Informacionnyj byulleten Minselkhoza Rossii 3:17–23 (in Russian)

Minselkhoz Rossii (2016) „Global'nye vyzovy": Prognoz nauchno-tekhnologicheskogo razvitiia agropromyshlennogo kompleksa Rossii na period do 2013 g ("Global Challenges": Forecast of scientific and technological development of the Russian agro-industrial complex for the period until 2013). Informacionnyj Byulleten Minselkhoza Rossii 4: 14 (in Russian)

Moll P, Zander U (2011) Guideline: Stakeholder analysis and Involvement – Hand-out for Projects within the BMBF Programme "Sustainable Land Managmeent" (SLM) Module A, Version: May 2011. http://modul-a.nachhaltiges-landmanagement.de/fileadmin/user_upload/DOCUMENTS/INTERN/Intern_Guidel_STA_Analysis_Involvement_2011.pdf (downloaded September 30, 2019)

Rivera WM, Sulaiman VR (2009) Extension: object of reform, engine for innovation. Outlook Agric 38(3):267–273

Röling N (2009) Pathways for impact: scientists' different perspectives on agricultural innovations. Int J Agric Sustain 7:83–94

Chapter 37
Field Days for Technology Transfer and Knowledge Exchange of Dealers and Farmers

V. I. Belyaev, M. M. Silantyeva, T. Meinel, L.-C. Grunwald, D. V. Belyaev, N. A. Kozhanov and L. V. Sokolova

Abstract For the regional implementation of new land-use technologies, the practical cooperation of science, enterprises of the agricultural sector, machine builders and dealers are crucial. The knowledge exchange of these actors makes a great contribution to the introduction of new technology, their adaptation to regionally specific requirements and further development of innovative practices. 'Field days' have proven to be a very effective model in bringing engineers, dealers and farmers together to dispute over usage and perfection of new machines.

Keywords Field day · Technology transfer · Knowledge exchange

37.1 Teamwork

In October 2016, Russian and German partners summed up the five-year work on the international research project 'Kulunda' (2011–2016). The goal of the project was the development and implementation of innovative technologies for steppe land use,

V. I. Belyaev (✉)
Engineering Department, Altai State Agricultural University, Prospekt Krasnoarmeyskiy, 98, 656049 Barnaul, Russian Federation
e-mail: prof-belyaev@yandex.ru

M. M. Silantyeva · L. V. Sokolova
Faculty of Biology, Altai State University, Prospekt Lenina, 61, 656049 Barnaul, Russian Federation

T. Meinel
TOO Amazone, Saifulina Street 3, Office 1, 010000 Astana, Kazakhstan

L.-C. Grunwald
BBG Bodenbearbeitungsgeräte Leipzig GmbH & Co. KG, Rippachtalstr. 10, 04249 Leipzig, Germany

D. V. Belyaev
OOO Kompleks Agro, Nikitina 163, Barnaul, Russian Federation

N. A. Kozhanov
OOO Partnior, Uliza Sovetskaya 31, 658966 Poluyamki, Russian Federation

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_37

Fig. 37.1 Discussion during a Field day

designed to prevent further development of erosion processes, to ensure soil fertility and efficient use of land resources in the dry territories of the Altai region (Illiger et al. 2014). For those five years, German scientists and their Russian colleagues (Altai State University, Altai State Agrarian University, Institute of Water and Environmental Problems of the SB RAS) established a unique monitoring network in the Altai region. Its task was and still is to observe the main climatic and soil parameters, which have a significant impact on crop yield under the complex diverse conditions of this region (Belyaev 2013; Ponkina et al. 2014).

An important feature of the Kulunda project was the work on the implementation of its research findings, especially through practitioners, including farmers and farm machinery dealers. In the Altai region, the Department of Agriculture, the Department of Economic Development, the Department of Natural Resources and Environmental Protection, the Office for International and Interregional Relations, the Committee for Agrarian Policy and Nature Management of the Altai Regional Legislative Assembly supported this strategy.

37.2 Materials and Methods

For the transfer of knowledge to farmers and its implementation, the Days of Crop Production (Field Days) were held by the farm OOO KH Partner every year in early August. The number of participants was up to 450–550 people each year, including heads of the Altai region, from the Altai Regional Legislative Assembly, the Department of Agriculture and the participating regions, heads and chief specialists from other farms, scientists, researchers from the Kulunda project, dealers of machinery manufacturers and others (Figs. 37.1, 37.2 and 37.3).

The events included a plenary part where project participants reported the results of research over the past years, and the practical part with a visit to the base experimen-

Fig. 37.2 Participants in a Field day

Fig. 37.3 Scientist explaining test arrangements during a Field day

tal sites and the demonstration of innovative machines for prospective agricultural technologies. This form of knowledge transfer has aroused a high interest among farmers, has excellent visibility and application value.

Interim results and the progress of the 'Kulunda' project were covered for the federal, regional and district media: VGTRK Altai, Katun-24, TV Mikhailovskoye +, Rossiyskaya Gazeta, Altai Pravda and Silver Rain were represented at regional Agronomic Conferences on agriculture in other districts of the Altai region, in Kazakhstan, on the Days of Plant Growing of the Amazon Company in Germany.

Participants of the 'Kulunda' project took part in seminars organized by the Institute for Advanced Training of Agroindustrial Complex Workers. Now, special educational programmes are being developed in Altai State University and Altai State Agricultural University with an emphasis on resource-saving technologies in agriculture. The project team together with practitioners published the collective vol-

Fig. 37.4 Machinery exhibition during a Field day

Fig. 37.5 Students at gaging station

ume 'Economic, ecological, technological factors and results of activity, agricultural enterprises in conditions of the Kulunda Steppe'.

37.3 Stationary Base Sites and Experiments

Constant measuring and test sites were created on three farms: OOO KH 'Partner', Mikhailovsky district, ZAO PP 'Timiryazevskiy', Mamontovsky district, and FGUP PZ 'Komsomolskoye', Pavlovsky district of Altai region. Scientists and practitioners conducted complex observations and exercise of innovative technologies for crop cultivation in crop rotations (148 variants of combinations of technological factors at 356 plots, including 'strip-till' and 'no-till' technologies), using modern and excellent equipment (Figs. 37.4 and 37.5).

The company 'Amazone' technical provided equipment for new land-use technologies, namely two experimental drills for 'no-till' technology (Belyaev and Meinel 2013; Belyaev et al. 2013, 2014; Belyaev 2015), which allow to change seeding characteristics (seeding rate, fertilizer application rate, depth of seeding, row spacing, type of working elements), and also a 'strip-till machine with adjustable parameters. The EDX precision drill was purchased by the farm OOO KH 'Partner'.

The Kulunda project installed the first lysimetric station in the dry-steppe ecosystem in Russia. It measures precipitation and evaporation in the soil in real-time mode, the accumulation and migration of nutrients in the soil, as well as other important soil parameters at various depths. Long-term analysis of these data, which is performed by the local University partners, will reveal the dependence of crop yields on a variety of climatic and soil parameters. In combination with experimental data on soil cultivation technologies in test fields, those results will allow for developing recommendations for farm enterprises to reclaim saving technologies that include technical re-equipment, soil treatment, fertilization, plant protection, etc. The uniqueness of the lysimetric station is its ability to measure these parameters simultaneously in soils used for arable land and in soils of the natural steppe. This provides the basis for research and helps making the right decisions in the selection of long-term strategies for the development and more rational use of the resources of the Kulunda steppe (Belyaev et al. 2016).

For the same purposes, three automatic meteorological stations and four stations for measuring soil moisture in the forest-steppe and steppe zones of the Altai region have been installed. They allow for the retrieval of more detailed data, which, combined with the results of space probing, will make it possible to predict the crop yields.

37.4 Main Scientific Results

The impact of climate on crop yield is highly significant (Belyaev and Sokolova 2015, 2016). Preliminary results on climate change in the Altai region were obtained. In the distribution of the surface air temperature in the flat territory of the Altai region (Barnaul), a statistically significant positive trend was revealed, more intense than the average for Russia (0.9 °C for 1901–2000). In the distribution of precipitation, a secular cycle (1862–1976) with the duration of 115 years was identified. Since 1977, the ascending branch of a new century cycle began, the maximum of which is likely in 2038 with the subsequent reduction of precipitation. Currently, after a wet period of 1986–2002, the cycle of lowered moistening develops. It can accelerate desertification processes in the Altai region and change the ratio of areas occupied by one or another type of vegetation, because the rate of air temperature growth outstrips the rate of increase in precipitation.

In the framework of the study of soil degradation, an electronic data bank has been established that clarifies and extends the technical capabilities of soil monitoring in the Altai region (Grunwald et al. 2015).

Fig. 37.6 Sprayer ‘AmaSpot’ ‘Amazone’ for weed control. *Source* Meinel (2014)

On the basis of KH Partner LLC (Altai Territory, Mikhailovsky District, Polumyuki Village), unique experiments were conducted to assess the condition of degraded pastures in the dry steppe zone of Kulunda. The experimental site has been laid for testing 28 varieties and plant species that can be used for pasture restoration. As a result of observations 2011–2016, four key species of the legume family were identified, which were sown on experimental sites to improve haylands and degraded pastures. The restoration of the true steppe has not only scientific, but also great practical significance. Socially and economically, this will mean a gradual transformation of the steppe from the zone of risky farming into a zone of harmonious combination of stable cattle breeding and a sparing natural farming environment. The solution of the problem of ecological transformation of the landscape and land fund will favourably affect the water regime of the steppe, will contribute to the conservation of biological diversity, and will significantly weaken the anthropogenic factor in desertification of the steppe zone of the Altai region.

In addition, experiments were undertaken to restore natural haylands and pastures using a combined soil cultivator Catros-6001-2 Green, equipped with a device for sowing grass seeds. Seeds were obtained from the collection site in local conditions.

This combined machine has been manufactured to introduce the technology liquid fertilizers, including microelements, in fields with crops. Field experiments have been established, and significant results have been obtained on the effectiveness of the developed technology (the yield increment in individual fields was from 0.2 to 0.9 t/ha).

The technology of weed control using the ‘AmaSpot’ system on the sprayer was successfully tested and implemented in the OOO KH ‘Partner’ on fallow fields, which makes it possible to significantly reduce the use of plant protection products due to selective exposure to weeds (up to 70–80%) and to reduce chemical load on the soil (Fig. 37.6).

On the test fields, studies were carried out comparing three different types of farming technologies and four levels of intensity of autumn soil cultivation in crop rotations. As a result, practical recommendations for cultivating crops with the use of new generation techniques, perfect agricultural practices for tillage, methods for applying fertilizers and plant protection systems in the dry and real steppe, as well as forest-steppes of the Altai region, have been developed.

37.5 Conclusion

Preliminary analysis of experiments, as well as previously conducted studies, confirms a number of advantages of preserving technologies from the energy, agrotechnical, ecological and economic point of view. The introduction of the research results will significantly reduce the operational costs of grain production and increase the productivity of arable land. This includes an increase of productivity up to 35–45%, achieving significant reduction of fuel consumption of the machinery (1.5–2.6 times), reducing the negative impact of machinery on soil (reducing the number of passages over the same lot 3–5 times), saving seed material by 15–20%, increasing the average yield of cereals to 2.0–2.5 t/ha.

Thus, the practical cooperation of science, enterprises of the agricultural sector, machine builders and dealers made a great contribution to the development of innovative practice in perfection and introduction of perspective agricultural technologies and machine complexes for cultivating agricultural crops under dry climate conditions. Field days for technology transfer and perceptions of dealers and farmers play an important role in this process.

This work, performed on the base sites of the 'Kulunda' project, is very much significant in terms of volume and obtained results and only large research institutes are able to do it. Therefore, in the long run, it seems adequate, to install a regional research centre for the study of climate, soil conservation/degradation and approbation of adaptive farming technologies. It should be based on the test fields, which are already laid. It can serve as a basis for disseminating information on the best land use practices and create a stable scientific and practical advisory platform in the implementation of the programme 'Sustainable Development of Rural Territories of the Altai region' until 2025.

References

Belyaev VI (2013) Tekhnicheskoe I tekhnologicheskoe obespechenie resursosberegaiushchikh tekhnologii proizvodstva zerna v Altaiskom krae (Technical and technological support of resource-saving technologies of grain production in the Altai region). Curr Stat Siberia. Inf Stat J 1:72–81 (in Russian)

Belyaev VI (2015) Ratsional'nye parametry tekhnologii «No-Till» i priamogo poseva pri vozdelyvanii sel'skokhoziaistvennykh kul'tur v Altaiskom krae (Rational parameters of "No-Till" technology and direct sowing in the cultivation of crops in the Altai Territory). Bull Altai Science 1(23):7–12 [in Russian]

Belyaev VI, Meinel T (2013) Sravnitel'naia otsenka tekhnologii vozdelyvaniia yarovoi pshenitsy v usloviiakh Vostochnoi zony Altaiskogo kraia (Comparative assessment of spring wheat cultivation technologies in the Eastern zone of the Altai region). In: Digest of the international scientific-practical conference diversification of crops and zero technology in drylands. Shortandy, Astana, pp 22–27 (in Russian)

Belyaev VI, Meinel T, Grunwald L, Schmidt G, Bondarovich AA, Shcherbinin VV, Ponkina EV, Matsura AV, Stefan E, Illiger P, Kozhanov NA, Rudev NV (2016) Vodnyi rezhim pochvy i urozhainost' sel'skokhoziaistvennykh kul'tur pri razlichnykh tekhnologiiakh vozdelyvaniia v Kulundinskoi stepi Altaiskogo kraia (Water regime of the soil and yield of agricultural crops with various cultivation technologies in the Kulunda steppe of the Altai region). Bull Dnepropetrovsk Univ. Biol Ecol 24(2): 531–539 (in Russian)

Belyaev VI, Meinel T, Sokolova LV (2014) Formirovanie urozhaia iarovoi miagkoi pshenitsy po razlichnym predshestvennikam pri minimizatsii obrabotki pochvy v umerenno-zasushlivoi stepi Altaiskogo kraia (Yield Formation of Spring Wheat on Various Forecrops while Minimizing Tillage in Temperate-Arid Steppe of the Altai Territory). In: The role of the Virgin Lands and prospects of development of agriculture and crop production in Kazakhstan: digest of the international scientific-practical conference dedicated to the 60th anniversary of the development of Virgin and Fallow Lands. Shortandy, Astana, pp 158–163 (in Russian)

Belyaev VI, Meinel T, Tissen R (2013) Tekhnologia Strip-till: osobennosti konstruktsii mashin vedushchikh mirovykh proizvoditelei i ikh primeneniia (Strip-Till technology: features of machine designs of the world's leading manufacturers and its application). Bull Altai State Agric Univ 11(109):86–91 [in Russian]

Belyaev VI, Sokolova LV (2015) Izmenchivost' urozhainosti sortov iarovoi miagkoi pshenitsy razlichnykh grupp spelosti v vostochno-kulundinskoi zone Altaiskogo kraia (Variability of the Yield of Spring Soft Wheat Varieties of Different Maturity Groups in East Kulunda Zone of the Altai Region). Bull Altai State Agric Univ 4(126):16–21 [in Russian]

Belyaev VI, Sokolova LV (2016) Vliianie ekstremal'no zasushlivykh uslovii na vlazhnost' pochvy i urozhainost' iarovoi miagkoi pshenitsy v usloviiakh umerenno zasushlivoi i kolochnoi stepi Altaiskogo kraia (The effect of extremely dry conditions on soil moisture and the yield of spring soft wheat in the moderately dry and forest steppe of the Altai region). Bull Altai State Agric Univ 4(138):82–89 (in Russian)

Grunwald L-C, Meinel T, Frühauf M, Belyaev VI (2015) Effekte der Schwarzbrache in verschiedenen Trockenfeldbauregionen der GUS (Effects of bare fallow in various dry-field regions of the CIS). Hallesches Jahrbuch für Geowissenschaften 37:163–193 (in German)

Illiger P, Frühauf M, Schmidt G, Meinel T, Belyaev V, Silantieva M, Kazarian M (2014) Ökosystemkonversion und ihre Folgen bezüglich der Kohlenstoffsenken-Funktion in der westsibirischen Kulundasteppe (Ecosystem conversion and its effects for carbon sink function in West-Siberian Kulunda Steppe). In: Grunwald K, Bastian O, Drozdov A, Grabovsky V (eds) Erfassung und Bewertung von Ökosystemdienstleistungen (ÖSD) – Erfahrungen insbesondere aus Deutschland und Russland. BfN-Skripten 373. Bundesamt für Naturschutz, Bonn, pp 300–319 (in German)

Ponkina E, Belyaev VI, Bovarova M, Prishchepov A, Meinel T, Bugay Y, Kovaleva I, Kozhanov N, Kazarjan M, Frühauf M (2014) Ekonomicheskie, ekologicheskie, tekhnologicheskie faktory i rezul'taty deiatel'nosti predpriiatii v usloviiakh Kulundinskoi stepi (Economic, environmental, technological factors and the results of agricultural enterprises in the Kulunda Steppe). Altai State University Press, Barnaul (in Russian)

Chapter 38
Technology Learning and Transfer of Knowledge—Practices and Lessons Learned from the German-Language Study Programme in Barnaul

M. Zierdt, N. I. Bykov, D. Kley, A. A. Bondarovich and G. Schmidt

Abstract A very important element to implement findings from the Kulunda project sustainably in the regional educational system is the German-language study programme at the Altai State University. It offers an in-depth training in Geo-Ecology, which lays the base for a special education as a specialist in various fields related to agriculture and regional development. This chapter outlines some of its core elements and achievements.

Keyword Education

38.1 Goals of the German-Language Study Programme

Geographers of the Martin-Luther-Universität Halle-Wittenberg have been teaching in the German-language study programme Environmental 'Management and Monitoring' at the Altai State University, Barnaul, since 2007. This programme is supported financially by the German Academic Exchange Service (DAAD) to keep German alive as a scientific language in the countries Eastern Europe, Russia and Central Asia. The students are introduced to German research literature during their in-depth training in Geo-Ecology. This enables them to communicate and discuss respective topics in German as well as in Russian using correct scientific terms and expressions. All students attend a one-year German language course. The best receive an invitation to a two months study stay at the Martin-Luther-Universität Halle-Wittenberg in Germany. The goal is not just to deepen the scientific knowl-

M. Zierdt (✉) · D. Kley · G. Schmidt
Institute of Geosciences and Geography, Martin-Luther-Universität Halle-Wittenberg, Von-Seckendorff-Platz 4, 06120 Halle, Germany
e-mail: michael.zierdt@geo.uni-halle.de

N. I. Bykov
Faculty of Geographie, Altai State University, Street Lenina 61, Barnaul, Russian Federation

A. A. Bondarovich
Altai State University, Lenin St., 61, Barnaul 656049, Russian Federation

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_38

edge but also to improve the language skills and the knowledge about Germany itself.

The German-language study programme ‘Environmental Management and Monitoring’ has the following specific learning objectives and goals of qualification:

- **1:** Qualification of Russian graduates to monitor the environment based on qualitative indicators in the landscape and on data acquired in the field, the laboratory and from other sources like aerial photographs and satellite images. A priority is the collection of quantitative data in the landscape using field instrumentation, an important tool of modern geographic work, which is currently underrepresented in Russian environmental monitoring. The study area is situated in the foreland of the Altai Mountains, which is part of the Eurasian Steppe. It consists mostly of grassland and forest steppe (grassland interspersed with woodlands or forest) and is extensively used for agriculture and pasture. Therefore, the detection of changes caused by agricultural usage like degradation and desertification is one focus of the monitoring. Further topics of the study programme are the determination and evaluation of the soil-water budget, the interdependency between types and intensity of land use, weather conditions, degradation, desertification, and the effects on crop yields and run-off as well as subsequent measurements for an agricultural usage suited for the respective location and ecosystem.
- **2:** For the German Ethnic District, situated in the Western part of the Kulunda Steppe, the Altai State University in Barnaul serves as the most important institution for higher education. Hence, one goal is to support young Russian Germans by offering this special training to enhance their chances in the local job market. Methods and exercises help students get to know German tools, machinery and enterprises, which produce or use measurement and/or monitoring instrumentation so they may use these contacts later when working as professionals.
- **3:** Involvement of the best students in the interdisciplinary research and scientific qualification process, provided through the collaboration with Martin Luther University and German companies, to enable them to apply and extend their knowledge and language skills by working in research projects.

A side effect of the programme, very welcome in the context of the Kulunda project, is the wider availability of German as a scientific language. Often, during fieldwork or scientific meetings direct communication in German and Russian reduced sources of misunderstanding. Occasionally, the language teachers of the German-language study programme would work as interpreters, applying their knowledge of both the language and the scientific terms as well.

38.2 The German-Language Study Programme

The German-language study programme is currently offered as a postgraduate programme. It consists of the language course and the environmental course. The course is taught in German by lecturers from Altai State University, Barnaul, and Martin-

Luther-Universität Halle-Wittenberg. It is segmented into the following learning modules:

1. Indication of environmental degradation;
2. Environmental analytics and field instrumentation;
3. Environmental monitoring and data interpretation;
4. Environmental medium soil;
5. Electronic and mechanical data loggers;
6. Indicators of environmental anomalies;
7. Field excursion;
8. Field training;
9. Final thesis (in German).

Modules 1–6 consist of lectures and seminars, in which the theoretical fundamentals are taught by lecturers as well as compiled by the students themselves. The set-up of different environmental measurement systems in the region provides the students with their first hands-on experiences in empirical data acquisition. The students can work on meteorological stations, soil moisture measurement fields, or at the Lysimeter stations of the Kulunda project. Sensors to measure water quality parameters like pH-value, electrical conductivity, and oxygen concentration are available for the students, too. Furthermore, a field unit to measure other environmental parameters like phosphate or nitrate concentrations is provided.

After finishing the theoretical fundamentals and practising empirical data acquisition, the students are offered a two-month-long stay at Martin-Luther-Universität Halle-Wittenberg to extend their practical skills and deepen their knowledge especially during an excursion and the field training.

During the excursion, students get to know the German environmental observation and management system. They visit several measurement stations and conservation areas of different protection statuses and attend lectures about spatial and environmental planning in Germany.

During the field training, the students and lecturers spend a week together in the field in a rural area. The lecturers are the scientists from Germany who taught before at Altai State University, Barnaul. The students are introduced to the following environmental observation methods (Figs. 38.1 and 38.2).

Fig. 38.1 Students of the German-language study programme at the Lysimeter station in the Kulunda Steppe, Russia. Photo Bondarovich 2012

Fig. 38.2 Students of the German-language study programme at the field training in Wohlmirstedt, German. Photo Kley 2012

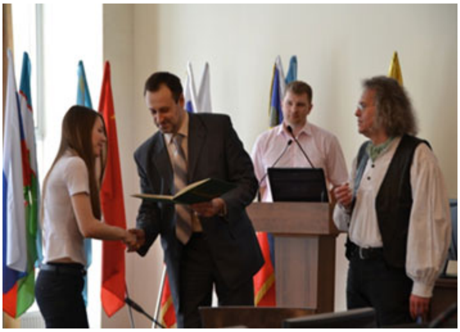


Fig. 38.3 Student reciving their certificate in the German-language study programme. Photo Kley 2012

- Quantitative hydrological measurement methods
- Qualitative hydrological measurement methods (water quality parameters);
- Mapping;
- Soil identification and basic soil parameters;
- Acquisition of meteorological data using traditional and electronic data collectors;
- Development of a Geo-Information System based on the collected data as the field training's documentation.

Optionally, the students may analyse the collected water and soil samples, regarding further parameters like micronutrients or heavy metals at the Physical-Geographic/Geo-Ecological Laboratory.

At first, the German-language study programme was offered only to students of geography, but soon biology and chemistry students showed interest in this postgraduate programme as well. At the start of the Kulunda project in October 2011, the first students had just graduated from the German-language study programme (Fig. 38.3). Because of the programme, they had experiences in empirical data acquisition and German language skills—excellent prerequisites for the start of the fieldwork of the Kulunda project in spring 2012.

38.3 Research-Oriented Education in the German-Language Study Programme

New research questions arose from the preliminary results of the above-mentioned fieldwork to such an extent that they resulted in several doctoral projects. Graduates from the German-language study programme now have, with support of the DAAD, the opportunity to work on their doctoral project in Germany. The following doctoral projects (2nd thesis) defended between 2012 and 2016 from the DSG-programme were related to the research of the Kulunda project:

Semikina, Svetlana S. (2nd thesis):	Эколого-географическая оценка туристско-рекреационного потенциала озер боровых лощин Степного Алтая. (*Ekologo-Geograficheskaya otsenka turistsko-rekreatsionnogo ozer borovykh loshchin Stepnogo Altaya)*. 2013. Perm. Defended at Perm State National Research University, 2013
Harms, Evgenya O. (2nd thesis):	Оптимизация рекреационного природопользования в Алтайском трансграничном горном регионе *(Optimizatsiya rekreatsionnogo prirodopolzovaniya v Altayskom transgranichnom gornom regione)*, 2016. Defended at the Institute for Water and Ecological Problems of the Siberian Branch of the Russian Academy of Sciences at Barnaul.
Gensch, Konstantin V. (2nd thesis):	Равновесные состояния органических электролитов в бинарном дифференцирующем растворителе ацетонитрил – диметилсульфоксид *(Ravnovesnye sostoyaniya organicheskikh elektrolitov v binarnom differentsiruyushchem ractvoritele atsetonitril – dmetilsylfoksid).* 2012. Defended at St. Petersburg State University for Technology and Design.

Furthermore, the following doctoral theses were conducted during the courses in Barnaul and Germany:

Construct the GIS 'Natural resources, potential utilization and current usage of the Kulunda Steppe'. Focus of the doctoral work is the creation of a bilingual GIS, which should support binational scientific collaboration in the Kulunda region. Particular challenges were the terminologies of several disciplines, ranging from spatial planners to botanist, both in Russian and in German.

The forest steppe—A natural or anthropogenic ecoregion? Answering this question is of fundamental importance to the Kulunda project. The question relates to the region of Central Germany with an agricultural usage of its chernozems since the Neolithic Age (traceable in the dry region of Central Germany for more than 5.000 years) and the post-glacial climate change. The deforestation of just developed woodlands and a very dry climate inhibited the degradation of chernozems to brown earth soils. The Institute of Geobotanic at Martin Luther University has a long research history regarding this topic. The goal of the doctoral project is to compile and review the results of this previous research to make them more accessible for current research projects in this area.

Ecological restoration under the conditions of the temperate continental steppe—Stipa and Artemesia Steppes. The doctoral project was developed as part of the Kulunda project's module 'Development of region-specific agricultural management and steppe restoration practices in different steppe types with focus on carbon sequestration (soils, vegetation) and stabilization/improvement of yields'.

38.4 Future Entanglements of the German-Language Study Programme and Research on Land-Use-Systems in Kulunda

The biology and the geography faculties of Altai State University, Barnaul, are heavily involved in the Kulunda project and so are most of the students of the German-language study programme 'Environmental Management and Monitoring'. The German-language study programme is currently offered as a postgraduate programme for students working on their master's degree in geography or biology. That means the students take an extra workload in addition to their regular master's courses. On ground of a sound methodological training, graduates from the programme have proven their readiness to step into empiric research on a high-quality level during the Kulunda project. Hence, in order to improve a research-oriented education, the environmental course of the German-language study programme will be offered every year as an optional course within the master's degree programme. Hereby research fundamentals, methods, usage of high-tech instruments and analytical techniques, which Russian and German partners have developed in modules of the Kulunda project, are implemented permanently in the regional system of higher education.

Part V
Beyond Kulunda

Chapter 39
Beyond Kulunda

M. Frühauf, S. Lentz, T. Meinel, G. Guggenberger and I. Theesfeld

Abstract The setting of the KULUNDA project, its research questions as well as the answers and practical solutions, as they have been presented in the previous chapters, are principally restricted to the geographical limits of the research area itself. However, a wider horizon for the findings that it is given is of utmost importance, as steppe ecosystems worldwide are the world's breadbaskets and one of the greatest sink of (soil) carbon in the carbon cycle. A formal background for such a claim is the project's funding and organizational embedding into the FONA initiative of the German Ministry for Education and Research. FONA's determination is research on sustainable development, in the case of KULUNDA focused on questions of sustainable land management. In this respect, results from the KULUNDA project strongly relate to regional development policy in the Altai Krai. As an overarching programme, FONA expects that some outcomes from the individual projects should be—given a certain amount of effort—transferable to other sites and situations. Even though the individual projects have not been designed with comparative approaches, FONA promoted and demanded exchange of experiences between research projects.

M. Frühauf (✉)
Institute of Geosciences and Geography, Martin-Luther-Universität Halle-Wittenberg,
Von-Seckendorff-Platz 4, 06120 Halle (Saale), Germany
e-mail: manfred.fruehauf@geo.uni-halle.de

S. Lentz
Leibniz Institute for Regional Geography, Schongauerstraße 9, 04328 Leipzig, Germany
e-mail: s_lentz@ifl-leipzig.de

T. Meinel
Amazonen-Werke, Rippachtalstraße 10, 04249 Leipzig, Germany
e-mail: Dr.Tobias.Meinel@amazone.de

G. Guggenberger
Institute of Soil Science, Leibniz Universität Hannover, Herrenhäuser Str. 2,
30419 Hannover, Germany
e-mail: guggenberger@ifbk.uni-hannover.de

I. Theesfeld
Institute of Agricultural and Nutrition Sciences, Martin-Luther-Universität Halle-Wittenberg,
Von-Seckendorff-Platz 4, 06120 Halle (Saale), Germany
e-mail: insa.theesfeld@landw.uni-halle.de

M. Frühauf et al. (eds.), *KULUNDA: Climate Smart Agriculture*, Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-15927-6_39

Despite such a formal framework, the concept of regional geographic research itself carries a chance for comparison to validate findings and interpretations. This chapter tries to outline preconditions, structures and contexts of the KULUNDA project, which allows for conceptual conclusions about potential transfer to other regions and case studies.

Keywords Steppes regions · South Siberia · Soil types · Climate conditions · Land use history

39.1 The Physical Environment of the Research Region

The Kulunda region is part of the Eurasian temperate grass-steppe, one of the world's very important ecosystems. Typical steppe soils such as Chernozems and Kastanozems cover large regions. These soils do not only store tremendous amounts of organic matter and are thus significant players in the global carbon cycle, they also belong to the most fertile soils on earth. Therefore, large parts are intensely used for agriculture, which also holds true for the Kulunda steppe.

The region is characterized by a climatic gradient, ranging from forest steppes in the northeast to typical steppes in the central parts and dry steppes in the southwest. In terms of utilization, this translates into a mosaic of different land use and soil management systems. Consequently, less than 17% of the land is grassland in a broader sense, with native steppe only occurring as small and disjunct areas.

39.2 Changes in Land Cover, Use and Societal Transition

Like many steppes, the Kulunda steppe has been extensively used for a few millennia by humans as a pastoral ecosystem. Such utilization had only minor impact on the flora and barely any impact on soils. This regime changed in the late eighteenth and early nineteenth century, when the first peasants from European Russia settled in the region, and by the late nineteenth century, the Kulunda region was integrated into the agricultural trade system of Tsarist Russia. This notion is important to bear in mind with respect to the evaluation of land-use change. It contradicts the general perception that agriculture in the region only started with the Virgin Lands—*Zelina*—Campaign of 1954–1963. One should rather associate this period with a tremendous intensification of agricultural activities. Converting grassland into arable land and intensifying usage of formerly cultivated acreage was successful only during the first few years. Later on, the general conditions for farming turned out to be very dependent on climate and weather. Furthermore, the technology used for working the soils led to tremendous soil degradation, particularly erosion and humus losses, and to declining and variable crop yields. This history of agricultural practice in this delicate ecosystem and the consequences of mechanization show parallels to other agricultural systems, e.g. in North America (USA, Canada) as well as in other parts of Siberia, Kazakhstan, Mongolia and Western China.

With the collapse of the Soviet Union, the major sociopolitical framework for the region's economy fell apart, too. As a consequence, the sectoral and regional disintegration led to the abandonment of large agricultural areas. However, in the past twenty years, the production system was restructured on every scale and in almost every sector. During the past decade, this resulted in re-cultivation of formerly abandoned acreage. Since 2014, this positive trend has been reinforced by new political priorities in the Russian Federation. Agricultural production as a whole and especially farmers are better supported now, enabling them to use more fertilizers, but also to modernize their machinery and invest in new, resource-saving technologies. This has recently made Russia the world's biggest wheat exporter, with the Kulunda steppe being an important regional producer.

From the perspective of a national economy, the region's restructuring is a success at first glance. Such process suggests comparisons with other transition regions. However, the economic development has not solved structural problems in the regions such as an ageing population, the out-migration of young, highly qualified persons, and the deficits in transport infrastructure. Moreover, improved productivity in farming does not necessarily comprise sustainable land use. With regard to climatic change, the Kulunda region is facing a trend of decreasing precipitation with a presumable increase in variation, rising mean annual temperature (during the last 50 years at an average rate of 0.4 °C per 10 years) and corresponding increase in evapotranspiration. Hence, the search for new farming technologies becomes an imperative and should aim at not only stabilizing yields under drier conditions but also at improving soil protection.

Given the complex situation of regional development, of specific, endogenous knowledge on farming technology and conditions, and of economic and sociopolitical circumstances, it was clear from the beginning that a complex and integrative research approach was needed.

39.3 Success Factors for Research, Transfer of the Results and Sustainability

The KULUNDA project started under very favourable conditions. This is primarily due to a fruitful history of 15 years of cooperative relations with universities and academic institutions in the field of geographical research and teaching but also with stakeholders from agriculture, administration and politics. The Chair of Geo-Ecology from Martin-Luther-Universität Halle-Wittenberg had a thematic and regional focus on agricultural steppes and had maintained a scientific and teaching cooperation with the Kulunda (within the Altai Krai) region since the early 2000s. As a result, the requirements of the FONA initiative, especially with regard to establishing new (stable) contacts and forms of cooperation as well as the sustainability of this research project, could be met in an almost ideal manner.

These relations were the basis for a network of geographical research and education, which involved universities, non-university research institutes and other academic institutions, stakeholders from agriculture, particularly practitioners, and participants from administration and politics. Focusing on the question of how to develop and implement a soil-friendly key technology, the participation of an agricultural engineering company was crucial to develop and test innovative farming procedures together with farming enterprises from the region. The latter, again, were of tremendous help when it was necessary to present, discuss and disseminate research findings and practical experiences from test sites to the community of farmers in a sparsely populated, economically underdeveloped region.

Another asset from which the overall project benefitted was the major involvement of a German agricultural engineering company (Amazonen-Werke GmbH), with its scientific and technological experience in developing and testing innovative farming techniques, mainly in the Eurasian agricultural steppes, as well as the involvement of a German manufacturer specializing in environmental monitoring equipment (UGT Müncheberg).

The active support of Canadian experts from the fields of climate-friendly tillage systems was equally valuable for the execution of the project.

Finally, the assistance provided by an advisory board consisting of representatives from science, politics and local stakeholders from administration and management as well as academic institutions was important for the successful completion of the project.

39.4 Comprehensive Research Themes I: Natural Resources

In order to evaluate and estimate the degree of land-use change since the Virgin Land Campaign the first research step was an analysis of the status quo, backed up by historical data and material. This included a detailed analysis of soil properties and processes as well as vegetation cover under different land-use and soil management systems. An extensive land-use change analysis (combination of satellite data, calibrated with aerial photographs) linked to a retrospective and projective land-use model was also carried out. Thus, Kulunda's land cover change since the 1960s could be quantified for the first time.

The flora of the Kulunda steppe region consists of 785 species, of which 69 are endangered. A problem encountered with the patchy distribution of the native steppe sites is the large fragmentation of plant species, leading to poor genetic diversity, as has been shown for the key species *Stipa pennata*. This is further complicated by the fact that nine types of forest ecosystems and four types of grasslands could be distinguished by species composition as well as climatic and edaphic criteria.

The results of soil investigations revealed that the agricultural soils suffer from erosion, salinization, deterioration of soil physical properties, and soil organic matter losses. For the whole study area, a close relation has been found between the level of soil and vegetation degradation as well as yield decline, being accentuated by the steppe type, i.e. climatic condition. Despite very visible effects of water erosion (channel and gully erosion), wind erosion is the primary problem concerning land degradation. In this respect, the existence and spacing of windbreaks are of importance. A lack of maintenance affected windbreaks in the last decades, potentially leading to increased deflation. New plantings and better care are strongly recommended. Salinization was found to be a problem throughout the research area, but particularly in pastures and where groundwater levels were relatively high.

The issue of utmost importance to soil degradation in Kulunda's loess soils/Chernozems is loss of aggregate stability, which is linked to soil cultivation and its intensity. At this, intensively tilled soils showed the highest and no-till soil management the lowest losses of aggregate stability. As both, wind and water erosion, are directly related to aggregate stability, the development and implementation of minimum or no-till management are very relevant to decreasing soil erosion. Aggregate stability, in turn, is strongly related to the decline of soil organic carbon contents and stocks. Throughout the whole study area, soils lost about 30% of their organic carbon. Most of the losses occurred within the first five years after land-use change. Thereafter, a lower, steady-state equilibrium developed quite rapidly in soils. In contrast to the expectations, not only particulate organic matter but also primarily organic matter, stabilized by interactions with minerals, was lost, demonstrating that mineral-associated organic matter is vulnerable to land-use change as well. As for aggregate stability, loss of soil organic carbon was least with no-till soil management.

Expected future soil carbon contents were modelled using a process-based agriculture, vegetation and hydrology model (LPJmL). The model simulated a continuing climate-change-driven carbon loss from soils, which corroborates results from soil analysis along the climatic gradient. Based on the space-for-time approach, experimental data suggest that a drier climate will enhance organic carbon losses under both grassland and cropland due to generally reduced biomass inputs under dry conditions.

Decreased intensity of soil management was correlated with increased soil moisture. Different processes contributed to that: (i) higher field capacity due to higher organic carbon content and enhanced soil aggregation, (ii) reduced evaporation due to crop residues on the soil surface, (iii) different root distributions and depths of water uptake.

In summary, the key findings are:

– Concerning vegetation degradation, land-use change resulted in changes in species composition and decreases in biodiversity as well as genetic diversity of individual species. This has to be considered in future steppe protection and restauration activities.
– There is a close interrelationship between erosion, soil aggregation and soil organic carbon storage, with aggregate stability being the decisive parameter. Aggregate

stability declined strongly after land-use intensification. No-tillage and minimum tillage have been found to increase aggregate stability and, thus, to decrease soil erosion, possibly increasing long-term soil organic carbon storage.
- Vegetation and land use strongly influence soil hydraulic conditions. No-tillage and minimum tillage have been found to be superior to conventional tillage with respect to plant available soil water. In terms of water management, bare fallow is most likely not useful for water conservation.
- The need for protection and conservation of still intact grasslands. This can be realized by a restoration of steppes on degraded soils, and the establishment of corridors between the different disjunct regions of native steppes.

From a soil ecological perspective, it can be concluded that no-till soil management is an appropriate way to reduce soil erosion and increase organic carbon storage, and thus provide a successful measure for making agriculture in the Kulunda steppe more sustainable. We emphasize that in the case of the Kulunda steppe, smart and more intensive land management will lead to more sustainable conditions. Investment into new technologies (no-till agriculture) along with optimized fertilization strategies will increase biomass production and, with that, organic matter input into soils. Likewise, aggregate stability will increase as a result of less soil disturbance and higher organic matter stocks. This, in consequence, will lead to lower soil erosion, a higher soil resilience, and with that, a higher yield security.

Future studies on the relation of land use and soil protection in steppe areas should focus on physical and hydrological parameters of soils as they are decisive for erosion control and the soil water budget. In addition, studies on optimizing management of macro- and micronutrients appear to be necessary.

39.5 Comprehensive Research Themes II: Technical Cooperation and Joint Learning

The KULUNDA project installed three test sites on farms in different ecological steppe zones: These test sites served as an empirical basis for studying and measuring the effects of conventional land use and comparing it to innovative land management systems, primarily no-tillage technologies. In order to assess ecological and economic effects, important variables such as tillage intensity, disposition to erosion, soil water balance, soil quality and, of course, yields and their stability were investigated in field experiments. From the findings of these studies, the working groups derived various farming concepts, which in turn were tested on larger sites in close cooperation with the companies working the land.

Introducing cultivation technologies that protect the upper soil showed immediate improvement of soil physical factors, increasing particularly the effectiveness of the water use. This in turn led to more stable and higher yields than at the traditionally farmed locations. A permanent residue cover, provided by leaving up to 80% of the plant mass from previous crops on the soil surface, contributed not only to higher soil moisture, but also to a better protection of soils against wind and water erosion. Furthermore, microbial transformation of plant remnants aids carbon sequestration. Such forms of agriculture could lead the way to more sustainable farming in the steppe areas of the Northern hemisphere as they would contribute to soil protection and mitigation of climate change.

But the path to sustainable agriculture is not without obstacles. Early effects after converting to no-till management are an increase of weeds, the necessity to use more herbicides and the evolution of herbicide-resistant weeds. The remaining challenge is therefore to optimize crop protection. One step in this direction was to develop a machine system that detects weeds and treats them accurately with herbicides at working speeds of up to 25 km/h. Performance improvements allowed for savings of up to 80% regarding the amount of herbicides used compared with conventional techniques. Another finding from the field experiments was the sometimes heavily deficient nutrient supply to soils. In other dry regions, like the Canadian prairies, this condition is amended by applying liquid fertilizer. The development of such machinery is one of the mutual learning projects of agricultural engineering, induced by technological cooperation.

One of the main findings is that a sustainable cultivation of arable crops meeting ecological and economical standards and responding to future climate challenges is possible. No-till management is an important technology in this system, but should not be considered a universal remedy due to its complexity and challenges, e.g. concerning crop rotation and plant protection. Establishing such a system requires well-trained personnel, investments in machinery and a certain period of systematic transition.

Nevertheless, it became evident that various methods and approaches tested on the test fields showed ecological as well as economic benefits after only a few years when compared to the traditional tillage and crop rotation procedures. And, it is of particular importance that this mainly applied to years with an annual precipitation below average, such as it is forecasted by some climate scenarios for the near future of these regions.

The factor of 'local and regional knowledge' played a crucial role in the concept of the Kulunda project, as the 'import of external knowledge' to the region seems to be problematic. The academic members of the project tried thus to be particularly sensitive to consider experiences, wishes and opinions of stakeholders. In this sense, joint field experiments and technical cooperation were not only important in order to learn and develop a joint body of knowledge. Such joint work became also a platform for exchange, building trust and learning together. Especially, technical cooperation provided a perfect 'material' basis for this strategy. Moreover, this part of the project turned out to be a kind of articulating element between different sub-projects, researchers and practitioners with their sometimes very different backgrounds.

39.6 Comprehensive Research Themes III: Socio-Economic Structures and Institutional Contexts

Sustainable development comprises the sociopolitical background of a region to the same extent as the ecological conditions. But other than the natural features of a region, the agencies of subjects and societies are often considered as individual and hard to compare. As the Kulunda region and the Altai Krai have been transformed from a centrally planned economy to a market-oriented regime, it appears logical to make comparisons to states and regions like Kazakhstan, Mongolia and Western China. States like the USA or Canada, however, seem unsuitable for such comparisons due to their long-standing democratic systems and market economies.

As the main research themes around ecological and technical issues have been inspired by ideas and (former) research experiences from those regions, it would be unfortunate to disregard such a potential not to use for socio-economic questions and her solutions as well.

The socio-economic part of the Kulunda project aimed at creating an understanding of the agendas of stakeholders in the region and their customary behaviour. The empirical work hence consisted of quantitative analyses (e.g. a description of demographic processes) and qualitative interviews with experts from politics, regional and local administrations, and villagers.

In order to think beyond KULUNDA, we therefore propose to systematically compare our results obtained on a regional scale with other regions in order to make statements on national levels as well as on global statements. The first step in this process is to consider our findings in the context of (existing) regional development concepts, which in turn are embedded in the national (federal) framework.

The Regional Development Concept of the Altai Krai mentions regional demographic trends as a major threat to future development of the region as analyses showed a constant decrease of population. Its main driver is the regional out-migration of young people, while other factors are not as important. This out-migration has two components, a structural and a geographic one, which make it problematic for regional development: The amount of highly qualified persons among the migrants is high and the structurally weakest, peripheral settlements were hit hardest by the migratory balances. The latter result could not be fully confirmed, so further research with more detailed data is urgently needed. Nonetheless, the observed demographic processes are comparable to weakly structured, agricultural regions worldwide. Our qualitative interviews showed that highly qualified graduates are actively looking for adequate employment in their home region, but often decide to leave Kulunda and the Altai Krai after being unsuccessful in their search. Mobility studies, however, emphasize that the character of migratory movements has changed to circular processes, and that peripheral regions may have specific strengths that may attract flows of return migration. Of particular interest is the question then, if migrants are willing to come back. The respondents in our interviews stressed quality of life as a pulling factor for them, implying that not the highest level of income but good infrastructure, a social sphere and professional chances for both partners in marriage are important.

This has implications for strategies of settlement development, particularly the distribution of social infrastructure, as villages and larger settlements already suffer from a lack of well-educated professionals in many fields of local administration, health services and business services.

A lack of professionals is also a concern of farmers. They witness a multitude of new operational tasks for their enterprises, starting with modern IT equipment on site, gaining economic knowledge and experience about obtaining credits, reacting to subsidies and their policies, forecasting price developments for agro products and many more. But the introduction of new land management that should follow no-till technology requires much new knowledge around the ecological and economic consequences, which circle around the questions of applying new crop rotations and on the long run reducing the use of herbicides. Obviously, such innovation lessens demand for low-skilled labour due to performance benefits of the machinery, while at the same time more specialists for services and new economic knowledge are much needed. Coping with the preferences of those human resources whom the regional economy and politics want to attract, as returnees or even as immigrants, will continue to be a major challenge for the next years. Interestingly, some large agricultural enterprises have already started measures on their own to improve social life and the social sphere in the villages, even if the motivations rather stem from a sense of responsibility than from rational calculations for the need of human resources.

Another conclusion from researches to the institutional background of regional development are the different timescales of actors from economy, administration and politics. Most protagonists feel the pressure to take measures which show positive effects in rather short time, e.g. increased yields, increased regional output, decreased unemployment rates, etc. In such a 'climate' for development support schemes are created, which more or less intentionally favour large enterprises or support the growth of large enterprises.

KULUNDA project's research for the institutional background and its capability for change showed that such a slow drift is fuelled by many sources: The experiences of creditors, entrepreneurial professionalism, capacity for process innovations, economies of scale and a kind of tradition or heritage that goes back till to time of Soviet Union and the steered national economy at that time, are in this case ever yet important steering factors and influence factors of the present.

In many aspects, large farms and enterprises, if they are managed well, are more likely to show the effects desired by national and regional development policies. They are capable of absorbing subsidies in a proper way, they often have the capital stock to invest in new machinery and they have the knowledge to deal with new market regulations. There is, nonetheless, an aspect of sustainable development in a social and economic sense that should be a warning light. Innovation research in economic geography shows that there is also a negative effect of a 'landscape' of large enterprises when it comes to flexibility and innovation of businesses. With respect to highly qualified labour, that should find the region attractive and consider it as a future base for living, it is necessary to offer more than jobs as employees in administration, public services or private companies. Creating an atmosphere that is friendly to start-up businesses, which can survive among large companies, is vital for the economic diversity and sustainability of the region. The possibility of fulfilling personal goals would be an additional incentive for young people who consider moving to the region.

As already mentioned, the Kulunda project tried to be sensitive towards local and regional knowledge and values. While many regional stakeholders were willing to think and discuss about the introduction of a new agricultural technology and—consequently—new forms of land management, research on socio-economic and institutional aspects revealed rather sceptical voices, which were not simply against such innovations but claimed a conceptual bias and self-confinement of the project, which considered itself to be integrative. As the starting point of the project dealt with concerns about soils as a vulnerable resource for generations of agricultural producers and as a fundament for the regional economy, the definition of problems as well as the search for solutions mainly focused on soil preservation as well as capacities for production and carbon sequestration. Discussing economic prerequisites and consequences with farmers using narrative interviews disclosed that many of them cultivate an awareness for ecological relations that reaches far beyond the aspect of soil and beyond the consciousness and rational choices for productivity and efficiency of their enterprises. They contributed to a more modest interpretation of the project's findings, relativizing them in the best sense of mutual learning of scientists from practitioners.

39.7 Relating to Concepts for Regional Development in the Altai Krai

In 2003, the government of the Altai Krai installed a strategic programme regarding medium-term development. It considers the region's geostrategic position as well as its structural strengths and weaknesses. The Kulunda project's findings relate quite well to some of the strategic goals set in the programme, hereafter referred to as 'Altai 2025'. However, as the Kulunda project was designed and carried out independently of political programmes, its epistemic goals are not congruent with the strategic goals of 'Altai 2025'. We, therefore, ascribe our findings to three selected goals of the programme.

The most noticeable link is to goal no. 6, which can be summarized as 'accelerated development of the agricultural sector while not overusing the natural resources of the region', which should be connected to goal no. 7: 'rational use of natural and land resources'. As the Kulunda project started, the region was characterized by non-sustainable use of the potentially very productive soils. Therefore, the project aimed at creating new knowledge for the development of a more sustainable, namely soil preserving, land-use system. This approach centres on no-till technology, which provides better soil protection than conventional ploughing and stabilization of soil structure. Furthermore, it aids in preserving higher soil moisture contents, thereby counterbalancing the high variation of precipitation during the vegetation period in dry years.

As investments for this technology are rather high, it is mainly affordable for very profitable and financially sound enterprises and agro-holdings. Other companies strongly rely on credits, a fact that links to strategic goal no. 2 of ‘Altai 2025’ which generally addresses ‘improvement of productivity’. The findings of the Kulunda project concentrate on agricultural farms, where productivity can still be improved, even though growth rates have recently increased. However, the capital stock of many companies often does not allow for larger investments. Furthermore, many farmers and smaller companies are sceptical about their debt burden and about the conditions for obtaining new credits. Understanding ‘improvement of productivity’ as a regional goal, what then should include a larger number of agricultural enterprises in the region, makes access to credits for investments in order to improve productivity a crucial requirement. The project’s empirical work shows, though, that in the financial system, including banks and agricultural policy, there is still a lot to do to improve the support for agricultural entrepreneurs.

‘Altai 2025’ is very aware of the necessity to improve the living conditions for a larger share of the population of the Altai Krai. Key tasks include the increase in employment rates and living standards. The Kulunda project confirmed the overall tendency regarding the decline in population, as it is predicted in the programme. However, the project did not primarily aim at an accurate estimation of population development but rather at understanding the regional dynamics behind it. In this respect, we find an internal differentiation, from which consequences for regional development policy should be derived: Young adults prove to be the most active part of mobility processes. Searching for further education, they move to the larger settlements and particularly to Barnaul, the region’s capital. The level of attachment to their home village or small town in this phase is still high, expressed by their wish to work in the Altai region after finishing their studies. Many of them consider emigration from the region only when the search for adequate employment based on their qualification does not seem to be particularly promising. Nevertheless, when they return to their region of origin, they often do not move to their parental villages, but to settlements, which rank higher in the hierarchy of centrality. Over time, this will result in a process of concentration, affecting all levels of centrality in the settlement system. In-depth research could provide valuable insights regarding the underlying motivations and structures.

The search of young people with higher qualification for employment in the region matches quite well with the complex knowledge and information, developed within the KULUNDA project. Results showed that agriculture and land-use management relies on constantly renewed technological and systematic innovations and therefore needs highly developed skills. The demand for low-skilled labour, in contrast, will further decline. Here, continuous research and development is required, as initiated through the Kulunda project together with regional partners from universities and farms. This is the key to a process of transformation towards sustainability, which integrates the need for increased productivity in agriculture. The requirement of better qualification of the agricultural workforce will go along with the demand for higher standards of living by young people, who have adopted urban standards.

At this point, another link to one of the 'Altai 2025' goals becomes relevant: Employing the region's geo-strategical position more consequently. One option would be to increase regional creation of value by processing agricultural products to a much higher extent than at present. The quality of many raw products is high, so that a regional branding, supported by marketing measures seems promising. Settlements of medium centrality should be strengthened through allocation of production plants and manufacturing works so that their spectrum of economic branches diversifies and employment for medium and higher qualification develops. It will be crucial that those sections of companies, that pursue innovation and development, are allocated in the region. The founding of new and innovative companies should therefore be particularly supported.

39.8 Lessons Learned Beyond the Project

The Kulunda project's overarching goals were to ignite a debate and to initiate impulses for sustainable development in the Kulunda region. Despite numerous industrial and trade activities, agriculture is still comparatively important for economic performance in the area but is confronted with many and complexly interwoven challenges for its development. As the Kulunda project was part of the German FONA initiative, its starting point was research on sustainable land management systems. The approach of the geo-scientists involved was to identify problems of sustainability as problems within a regional system which itself is embedded in larger systems like a national or the world economy. This system is on the regional scale in smaller geographical and thematic units, e.g. divided villages and districts. Attached to it are often institutions and plans of administrative policy as well as official development concepts. The respective administration and policy attempt to complexly link and shape these in their impact on the development of the region. The Kulunda project's central working principle was to cooperate intensely with partners from the region and to hand over as much responsibility and knowledge as possible to the region. Such an actor-oriented approach proved to be successful in most fields of the project but also had its limits.

Based on KULUNDA's main goal of sustainably improving land use in order not only to conserve natural resources (soil, vegetation), the results of the project also make a contribution to climate protection and sustainable regional development.

The socio-economic sphere, its structures and recent trends in the region are considered as the crucial environment for the implementation of new procedures in land use and land management. New knowledge about agricultural machines should allow for soil-protecting cultivation, but first of all should increase or secure agricultural productivity. Around such rather technological key questions, several subsequent research issues arose: Which trade-offs do farmers consider and accept, if they invest in their future machine park? What are the mid-term consequences of such investments? Which education and training are necessary for the intermediate-term to maintain a continuing level of innovation in the region? How does a technological innovation path match the requirement for a stable supply of skilled labour in a region that is known for the exodus of young skilled labour? To what extent do regional policies already cover measures that support such an innovation path?

A key factor for the success of the Kulunda project was measures of public relations and dissemination right from the start of the project. While mass media reported several times on the activities of the project, it was particularly important that two groups of partners were intensely involved in the project: The first group included those farmers who provided land for testing the various farming methods and the machinery that were adjusted to local conditions. During ‘field days’ (open events for farmers of the entire region), up to 300 colleagues witnessed and discussed the pros and cons of new machinery and new methods of cultivation. The second group included regional experts in agricultural education of all levels, from professional schools to universities. Their analysis of curricula and descriptions of training courses gave valuable insights into the regional system of education and helped develop strategies on how to implement new information and knowledge.

39.9 Impetus for Cooperation and Continuing Research

The experience gained and the cooperative relations between German and Russian scientists, farmers and representatives of the administration established as a part of the KULUNDA project represent an excellent foundation for the continuation and expansion of the cooperation after the funding period. Evidence for this is the continuation of the field tests (monitoring) and the establishment of new research projects (DFG) in the region with the involvement of more scientists. Moreover, KULUNDA also gave new impetus to the continuation of the teaching cooperation (DAAD project) and, therefore, a stabilization of academic collaboration within the context of internationalization of research and instruction. This will benefit all of the involved academic and research institutions in Germany and Russia.

The KULUNDA project also contributed to the strengthening of economic relations between Germany and the Kulunda region as well as to the exchange of experiences between land users from the project area and the state of Saxony-Anhalt. This exchange was further extended when German and Russian farmers jointly visited colleagues in North America.

Consequently, the sustainable cooperation of science and economy with and within the research region of Altai Krai eventually led to an improved visibility and competitiveness for everyone involved.

Based on the KULUNDA experience and the established cooperative relations, a group of project leaders and representatives of German SMEs successfully applied for the continuation of a research and development undertaking within the framework of the CLIENT II funding initiatives of the German Federal Ministry of Education and Research and its Research for Sustainability (FONA) platform. The main goal of

CLIENT II is the promotion of sustainable international partnerships in the fields of climate, environment and energy. CLIENT II represents another contribution towards the implementation of the BMBF-FONA[3] activities with a special focus on bundling economy-oriented international cooperation between Germany and various target regions of the world.

One result is the joint ReKKS project (innovation for sustainable agricultural use of resources and climate adjustment in the dry steppes of Kazakhstan and Southwestern Siberia), which was approved and launched in fall 2017 by a group of KULUNDA stakeholders. This can be considered as another contribution towards the implementation of the FONA framework programme as well as the EU's Central Asia strategy for the same region, using Kazakhstan as an example. ReKKS (www.rekks.eu) linked experiences and methodical approaches from the Eurasian steppe belt in Southwestern Siberia to the agricultural lands in Northern Kazakhstan, characterized by (high-continental) dry steppes with even less precipitation and mainly Kastanozem soils. These areas were the prime targets of the Soviet Virgin Lands Campaign during which, in today's Northern Kazakhstan alone, a total of 25 million hectares of steppes were converted to arable land between 1954 and 1963. This ecosystem conversion was accompanied by an expansion of settlements and infrastructure as well as a population increase.

Compared to the KULUNDA project in the Russian Altai foreland, the ReKKS project area is characterized by steppes with a drier and more continental climate, but also by different political and economic factors affecting agricultural land use and, consequently, the development of ecosystems. By drawing from the experiences and findings of the KULUNDA project as well continuing field experiments in test areas in Northern Kazakhstan representing a soil-climate gradient, ReKKS wants to develop, test and implement intelligent forms of land use which conserve natural resources. It is important to take into account the effects of a changing climate and therefore contributes to the sustainability of these rural regions with a special focus on integrated ecosystems and climate protection. Both projects, KULUNDA and ReKKS, provide exemplary impetus to use natural resources in these tempered grassland biomes in a more sustainable manner. This is meant to contribute not only to the adjustment of land use to changing natural and socio-economic conditions but also to global climate protection. At the same time, the experiences gained from this model region can also help to increase the significance of the Eurasian steppes as a part of the world's 'bread basket' regarding their potential for easing the world nutrition problem. The research findings from KULUNDA and ReKKS not only contain incentives and methods which have already been tried and tested in practice but also unlock research and land potential existing in these regions. The latter relates to the former agricultural land which in part remains unused to this day after it was abandoned following the political change. Results that show opportunities and perspectives for a restoration of this ecosystem and an optimization of ecosystem services beyond the function of carbon sinks will be in high demand in the future.