27

Biological Techniques to Increase the Fertility of Sandy Soils and Cropping Sustainability in Glacial Agricultural Landscapes of the Non-Chernozem Zone of Russia

Tatiana Yu. Anisimova

Abstract

Many landscapes of the Russian Non-Chernozem zone are shaped by former glacial periods. The relief is sloped, soils are of sandy to loamy texture and some adverse factors restrict soil fertility and crop yield potentials, such as erosion risk, imbalanced water regime, and acidification. However, if located in the vicinity of big cities, they have potential for agriculture. Soil-conserving management approaches are required. We developed a system of innovative measures for improving soil fertility on sandy soils in a glacial landscape of Central European Russia. The measures enhance agricultural productivity and reduce the negative impacts of agriculture on the environment. They include landscape-specific cropping of perennial legumes and a comprehensive method for protecting sloped soils from water erosion. The method consists of using contour bands of crops on the slope, combined with the cultivation of perennial lupine as a green manure in bands between grain and tilled crops, and the technique of applying green manure as an organic fertilizer. We have tested this on eroded soddy-podzolic sandy soils in the Vladimir area. It is shown that sowings of perennial lupine not only prevent the erosion of soil and the leaching of mobile nutrients beyond the root layer: the test also had a positive effect on the productivity of winter rye and maize for silage, on indicators of soil fertility, on the agrophysical properties of soil, and on stocks of productive moisture in the vegetation period. The possible implementation of this approach in the landscape requires landscape planning and design work. This includes finding the optimum structure of cropped lands by distinguishing them further from arable land, in order to fully use the bioclimatic resources of an agrolandscape by cultural plants, on the one hand, and the achievements of compulsory improvement of the environmental features of the cultivated plant kinds, on the other. Agricultural experiments and the expertise of the All-Russian Research Institute of Organic Fertilizers and Peat are part of national and international innovation projects and monitoring programs. They provide a basis for the sustainable development of agricultural systems and the creation of landscape-adapted local food chains in Central Russia.

Keywords

Agricultural landscape · Soil erosion by water · Arable slopes · Perennial lupin · Green manure · Sod-podzolic sandy loam soil · Soil fertility

T. Yu.Anisimova (✉)
All Russian Research Institute for Organic Fertiliser and Peat, Pryanishnikov Str. 2 Sudogotskiy Rayon, 601390 Vladimir Oblast, Russia
e-mail: anistan2009@mail.ru

L. Mueller et al. (eds.), *Exploring and Optimizing Agricultural Landscapes*,
Innovations in Landscape Research, https://doi.org/10.1007/978-3-030-67448-9_27

27.1 Introduction: The Need for Conservation Farming on Sloped Land

The most widespread kind of soil degradation in the world is water erosion. In Russia, the land degradation due to water erosion at the end of the last century was caused by excessive plowing of sloped soils and irrational farming practices by agricultural enterprises. The proportion of plowed land in relation to total agricultural land is particularly high in Russia. According to statistical data, it was about 60% at the end of the last century, while it was only 29% on a global scale (Gordeev and Romanenko 2008). Many sloped lands were converted to cropland and were plowed annually in the second half of the last century (Gordeev and Romanenko 2008; Savich et al. 2015; Anisimova 2015a). More land was plowed along slopes. It is a well-known fact that the formation of runoff begins at slopes of 0.5–1°. Water erosion effects are complex and diminish the soil's fertility, ecological performance and security for plant cropping (Nemtsev 2005). As a result of surface runoff and erosion, soils lose particularly fine clayey particles and humus (Pannikov 2003). The potential compactibility of the soil substratum increases. This can lead to a very deep compaction of soil caused by heavy agricultural machinery. The consolidation of arable and cultivation horizons is assured thanks to the great depths of agricultural machines. But all of these factors contribute to the ecological degradation of land due to water erosion, and demand urgent systemic measures (Rasmussen et al. 1998; Kiryushin 2010; Masyutenko 2016; Pimentel 2006; Naliuhin et al. 2018).

Soil fertility and production efficiency are related to the soil properties, mechanization, fertilizers, the farmer's knowledge, soil deficiencies, and other factors. Crop yields are largely restricted if these factors are set at a minimum (Zaydelman 1991; Grunark et al. 2001; Mueller et al. 2010). On sloped land, available soil moisture for plant growth can be one such limiting factor. In crop rotations in adaptive landscape systems, attention must be paid to the revitalization of biological factors (cultivation of leguminous and bean cultivars, farmland leveling of green manure, straw, crops of intermediate cultivars), their placing depending on the slope exposure, the influence of culture on conservation, etc.

27.2 Glacial Landscape Under Study: The Meshchersky Lowland

Glacial landscapes cover a large part of the Russian Non-Chernozem zone. The Meshchersky lowland is located in the center of the East European lowland, includes parts of the Moscow, Ryasan and Vladimir Regions and covers about 40 thousand square kilometers. In geomorphological terms, the territory of the Meshchersky lowland represents a typical rolling glacial landscape, consisting of moraine deposits, sandy outwash and further elements of the glacial series. Its geomorphology is characterized by relatively small differences between high and low plains. Most soils in the glacial part of the landscape (Fig. 27.1) are sandy to light loamy in texture and mainly of the sod-podzolic type (Luvisols, Albeluvisols/Retosols and Regosols) (Fig. 27.2). Regional parts of watersheds and gentle slopes up to 2° are suitable for arable lands.

The Meshchersky lowland is well-studied and has undergone increasing dynamics within the past 250 years (Matasov 2017). According to the existing land use classification scheme, the best soils are in the leveled plains (Kiryushin 2010). Flat surfaces are of little use for the cultivation of winter grain and row cultivars, owing to their limited soil drainage and the heterogeneity of the soil cover. Sloped lands are better drained and subject to agriculture. However, erosion control actions are required here to prevent soil washout and the loss of biogenic substances from arable land.

Fig. 27.1 Agrolandscape at the Vyatkino research site, located in the north of the Meshchersky lowland. The research site is located in a relatively level part of the slightly rolling landscape. Harvested field of cereals with Lucerne underseed. Photo courtesy of Lothar Mueller

Fig. 27.2 Typical sandy sod-podzolic soils on Pleistocene parent material at the Vyatkino research site. Using the international soil classification system WRB, the soil on the left is a Cutanic Albeluvisol (Dystric, Densic, Arenic) (WRB 2006). The soil on the right is a Haplic Stagnosol (Arenic). These soils are found in moist parts of the landscape. Photos courtesy of Lothar Mueller

27.3 Properties of Sandy Soils in the Region

Sod-podzolic sandy soils are widespread in the Meshchersky lowland. They formed under coniferous and mixed coniferous-deciduous forests on carbonate-free rocks in a cold climate and leaching water regime. They have adverse hydrophysical properties, alternating between a lack and surplus of moisture. The structure and agronomically valuable properties of these soils require permanent improvement (Zaydelman 1991; Lukin 2009; Ivanov 2014).

Soils are characterized by a low humus content (1–4%), the acid reaction of the soil solution, a low absorption capacity, and unsaturated bases. The thickness profile is 70–100 cm deep, but the upper humus (topsoil) is shallow: about 12–20 cm. The bulk density of soil ranges from 1.2–1.7 g/cm^3, with values of 1.5–1.7 already indicating a certain level of soil compaction.

The soil's light texture, especially in its upper part, determines its chemical properties and fertility. The organic matter (humus) shows not only a predominance of fulvic acids over humic acids (HAs), but also the very special qualities of HAs. They are dominated by brown HA, which results in certain properties which are unfavorable for agriculture: insolubility in water, which limits their bio-stimulating effect on plant growth, and —most importantly—a poor ability to keep calcium from leaching. This makes it impossible to achieve durable liming effects to eliminate their acidity. This technique must be repeated periodically, within a few years.

The total nitrogen content in the topsoil does not exceed 0.1%, and hydrolysable nitrogen compounds are 6–56 mg per 100 g of soil. The total phosphorus content is also low, not exceeding 0.03–0.05%; based on the weight of the plow layer this is about 0.9–1.5 t/ha. At first glance, these stocks may seem sufficient. However, most phosphorus in these soils is associated with single oxides and does not contribute much to plants' intake of phosphorus.

A lack of clay minerals and low absorption capacity are the reason for the low potassium content in these soils. The total potassium content in the topsoil is 0.3–0.5%, rarely exceeding 1%. No more than 1–2% of soil potassium is found in forms available to plants.

The reaction of the arable layer is in the slightly acidic range, due to the periodic liming of arable land. With depth, the acidity increases to medium acid values in the middle part of the profile and strongly acid and very strongly acid values in the lower part.

The content of exchange bases in the arable horizon is low. However, given the low hydrolytic acidity, the base saturation of the arable horizon is low to moderate. At lower depths, hydrolytic acidity increases more substantially than the content of exchange bases. Therefore, the degree of saturation of the soil-absorbing complex falls.

Overall, sandy to loamy soils in the region have a poor to moderate soil structure and a low overall soil quality and crop yield potential as compared with other soils in Russia and around the globe (Mueller et al. 2013). However, the regional market situation for agricultural products is very favorable. The cities of Moscow and Vladimir are located within the region, and Nizhny Novgorod is also not far away. Thus, the potential for profitable agriculture is high.

27.4 Lupin Cropping to Improve Soil Fertility and the Crop Yield Potential

The systematic application of organic and mineral fertilizers allows the fertility and productivity of soils to be increased. Traditional fertilizers should be applied first of all to the best land, instead of eroded land (Edmeades 2003). This especially concerns liquid manure: on slopes it can be used only in the presence of intrasoil entering techniques to prevent liquid fraction washout.

In crop rotations in landscape-adaptive farming systems, we should pay attention to the activation of biological factors (cultivation of legumes, incorporating green manure), and their placement in the soils prone to erosion.

Organic fertilizers, including green manures, help improve many agronomically important properties of soils (Lukin 2009). Nitrogen-fixing legumes play an important role in agricultural systems as well. They are important for human nutrition, as forage crops and for improving soil fertility and productivity (Reckling et al. 2018, Franco et al. 2018, Cernay et al. 2018). Other deep-rooting plants can be important as pioneer plants for soil improvement, too (Dresbøll et al. 2019).

Lupin (*Lupinus spec.*) (Fig. 27.3) plays an important role in improving sandy, poorly cultivated soils of low fertility in our study region.

Fig. 27.3 Perennial lupin is a deep-rooting crop. It is used for subsoil improvement and as green manure. The preparation of a lupin plant is presented by Dr. Sergei Lukin. Photo courtesy of Lothar Mueller

Lupin promotes the formation of a suitable soil structure. Lupin has a powerful root system which enters deep soil layers, reclaiming them and paving the way for other crops to form deep roots. (Solovyev 1971). Perennial lupin crops not only prevent various kinds of erosion, but also reduce the leaching of mobile nutrients from the root zone. In connection with a severe deficiency of manure and composts (now used to fertilize no more than 9.2% of crops in the agricultural enterprises), the use of peat as a fertilizer triggers increasing the mobilization of vegetative resources directly at the place of their growth. Using locally available peat can compensate for unproductive, irrevocable humus losses.

In adaptive agriculture on sloping lands, erosion-protecting crop rotations are important, forming a protective plant cover in the most critical periods of heavy rainfall. When creating rotations in agrolandscape farming systems, we have difficulties in meeting plants' nitrogen requirements. The nitrogen problem in agriculture possibly needs to be addressed through biological nitrogen, without the need for costly nitrogen fertilizers. For these purposes, the rotation should include more legumes, which are widespread and adapt to all forms of green manuring.

Lupin acts as an economical biological ameliorant and prevents the migration of mobile nutrients in groundwater or the accumulation of nitrogen, phosphorus and other plant nutrients in soil organic matter (Trepachev 1999). Lupin's ability to absorb phosphorus compounds is associated with the high cationic and aminoalkanoic capacity of the roots of this cultivar in comparison with other plants (Kupsov and Takunov 2006).

Aerial organs of lupin mineralize faster than other plant residues, and are to a greater extent humic with the formation of "labile" humic substances, which are a measure of effective soil fertility (Pannikov 2003). Experiments have shown that green manures contribute to the mineralization of humus in the soil and thus increase the availability to plants of soil nitrogen. In addition, the plants themselves, developing a stronger root system in the fertilized environment, are naturally able to use more soil nitrogen.

Lupin can be grown on very different soils. In connection with the presence of a powerful root system—a tap root with side branches (Fig. 27.3)—lupin is also able to improve heavy, moist, tight clay soils with a dense subsoil, and soils with stagnating groundwaters. A very important feature of lupin is its ability to fix atmospheric nitrogen with the help of specific races of nodule bacteria. As it produces its own nitrogen, lupin is independent of the nitrogen supply in the soil, explaining its low demands regarding soil fertility.

With regard to potassium, lupin is the most demanding of all legumes. It vigorously absorbs potassium at low or high soil contents, especially when growing on loose soils (Kuptsov and Takunov 2006). Potassium reduces the growing period, hastens the ripening of beans and seeds. Its deficiency adversely affects nodulation and nitrogen fixation activity. With a lack of potassium, the flow of phosphorus to the plant slows down, which reduces the intensity of metabolic processes and the level of productivity.

Agronomic practices such as timing and methods of their incorporation influence the effectiveness of cover crops. One of the reasons hindering the effective use of green manure is the lack of machinery for its incorporation into the soil. The greatest effect of green manure is achieved when chopping, disking and subsequent plowing takes place 2–3 weeks before the sowing of winter grain crops (Anisimova 2002). In this case, by the time the winter cereals sprout and are tilled, the mass of green manure is decomposed to a state that has a positive effect on the development of plants.

Thus, the role of leguminous cover crops in the environment is that they require little or no nitrogen fertilizer and thus protect water sources from contamination by nitrates, without at the same time reducing the yield and quality. Leguminous cover crops not only enrich the soil with nitrogen, but also protect it from wind and water erosion, and recycle residual nitrogen and ash fertilizers.

27.5 Our Contoured Cropping Approach: Experimental Setup and Control Parameters

Our approach consists of contoured soil management and cropping in combination with perennial lupin growing as green manure, crop rotation and optimization of the organic and mineral fertilization of plants.

Contoured tillage and cropping are interesting approaches for reducing erosion on sloped lands (Quinton and Catt 2004). The role of root systems in the formation of humus and improved soil fertility is greater than the above-ground plant mass (Summerell and Burgess 1989). The lupin root system structures and fixes the soil, reducing surface runoff and increasing vertical drainage. In the fields occupied by the green manure, the wind speed in the surface layer is curbed, so wind erosion is drastically reduced. Cover crops prevent mobile nutrients from leaching beyond the root layer.

Research has been conducted on the land of the All-Russian Research Institute of Organic Fertilizers and Peat (VNIIOU), located in the Sudogodsky district, in the Vladimir area. A stationary field experiment was conducted. The soil is a sod-podzolic sandy loam soil, formed on red-brown loam covering the moraine; according to IUSS Working Group WRB (WRB 2006) these are Umbric Albeluvisols. The average annual temperature in the Sudogodsky area of the Vladimir region is 3.9 °C. The sum of biologically active temperatures is 2000–2100 °C. The annual rainfall is 560–590 mm. In most years of research, the meteorological conditions were close to the mean multiyear observations.

The experimental layout was designed according to the standard techniques on a slope of a south-southwest exposure, with a slope of 2–3.5° (Lyakhov 1975; Dospekhov 1985; Romanenkov and Kuzyakova 2000).

All mechanized means of soil processing and their direction coincided with the isolines of altitude (contours), except for a control site performed across a slope. A strip with perennial lupine was placed between the grain and row cultivars. Strips of identical width (10–12 m) were located along the contours (horizontals) of a slope, running parallel to each other (Fig. 27.4).

The volume of eroded soil on the slope was determined by the total volume of erosion rills and gullies, formed due to the erosion and denudation of soil by meltwater streams and storm water. After the flow of meltwater or rain falls across the slope perpendicular to the flow lines for a length, for example, of 100 m, a stretched measuring tape is used to measure the width and depth of all the resulting rill erosion, and calculate the total cross-section. Then the weight of the washed-away soil is determined, if the average density is known (Surmach 1976).

Fig. 27.4 Contour-band placement of plantings on the slope. The photo shows that the strips with the lupine are located between the bands of grain and row crop cultivar. The bands contour the slope

The row crops were cultivated with corn and winter rye. Before the cultivars were planted, a mineral fertilizer (N60P60K60) was introduced into the soil. Green lupin biomass was added during the bean ripening phase and scattered on the soil using the KIR 1.5 mower. Figure 27.5 shows a green lupin biomass under a winter rye enclosed in soil after mowing and crushing, 10–14 days prior to crops.

An essence of the technique for calculating the erosion is as follows: after thawed snow or a downpour has drained off across a slope or perpendicular line of a contour, for example, the width and depth of all washouts are measured for 100 m along the stretched measuring tape and then their total section is calculated (Anisimova 2015b).

If the section of undermining remains invariable for a slope strip of 10 m width (5 m uphill and 5 m downhill from the planned alignment), then the volume of the washed-off soil is calculated in an area of 0.1 hectares. Further, the weight of the washed-off soil is known if its average density is defined (Solovyev 1971; Surmach 1976).

27.6 Main Results of the Soil Conservation Farming System

The tested system performed well. It showed that for differentiated use of slope soil fertility placing the crops in contoured strips with a combination of long-term lupine application and fertilizer is highly agroeconomically efficient. The positive influence of this combination on the efficiency of cultivars, soil fertility indicators, agrophysical soil properties and the stocks of productive moisture in plant vegetation is thus established.

Decrease in soil loss due to erosion. The soil washout when cultivars are placed on contoured strips was compared with the traditional longitudinal method. As a result of research, it was established that the soil washout after 3 years of supervision decreased on average by 2.9–3.7 t ha^{-1}: the soil contained an additional 200 kg humus, 10–15 kg of nitrogen, 50–60 kg of phosphorus and 120 kg potassium. Long term, for the second year of lupine, in the ripeness phase there was 28.7 t ha^{-1} of elevated weight on average, containing 300–370 kg NPK.

Fig. 27.5 The introduction of green lupine mass on the adjacent lane

Improved agrophysical properties. Superficially leveled green lupin biomass is promoted by its fast mineralization, resupplying the arable layer of earth with nutrients, positively influencing its agrophysical properties (Table 27.1).

The improvement of the agrophysical properties of the soil under crops planted in strips across a slope has positively affected the process of water infiltration, as confirmed by the stocks of productive moisture in the soil. The lowest stocks of productive moisture were on a control area of longitudinally plowed land and inter-row processing in a root penetration layer of earth when corn was planted from May to September. On a watershed and an average part of a slope, this indicator was higher in comparison with the bottom part of a slope and the control with longitudinal processing.

The improvement of the soil's agrophysical properties under crops placed in strips across the slope had a positive impact on the process of water infiltration, as confirmed by the figures for the stocks of productive moisture in the soil (Table 27.2).

Thus, in the case of winter rye cultivation, springtime stocks of productive moisture at the top and middle part of a slope after the plants had grown were half again in comparison with the bottom part of a slope and the eroded control area, when corn was cultivated on silage. Towards the beginning of the crop harvesting (August), the difference in stocks of productive moisture on different elements of a slope leveled out.

The reserves of productive moisture were the lowest during the control longitudinal plowing and inter-row cultivation at a soil depth of one meter, when growing corn for silage and winter rye for grain from June to September. When using the contoured placement of crops, reserves of productive moisture were higher than the control on all elements of the slope, mainly due to a decrease in water runoff, and in the watershed area also a high content of clay particles and

Table 27.1 How organizing land-use areas into contoured strips affects some agrophysical properties of soil

Placing of crops concerning a slope	Dry bulk density, g/cm^3	Particle density, g/cm^3	Porosity, %	Total moisture capacity, %
Along a slope (control)	1.37	2.58	47.0	25.6
Across a slope, contoured cropping	1.30	2.50	48.0	28.7

Table 27.2 Stocks of productive moisture in soil, mm

Variant	Cultivar	Layer of soil, cm			
		0–60		0–100	
		June	August	June	August
Control	Winter rye	42.4	85.8	54.7	100.8
Watershed (top position)	- ″ -	57.5	88.3	116.4	170.9
Middle part of slope	- ″ -	81.0	84.2	134.0	161.0
Bottom part of slope	- ″ -	40.5	87.0	78.4	169.0
Control	Corn on silage	55.2	58.2	124.6	118.6
Watershed (top position)	- ″ -	60.7	73.7	113.1	134.8
Middle part of slope	- ″ -	66.0	68.7	126.0	124.0
Bottom part of slope	- ″ -	34.0	75.4	130.0	136.1

the proximity of the occurrence of an impermeable horizon. Thus, during the cultivation of winter rye, stocks of productive moisture at a depth of one meter below crops grown across the slope in June, in the period of intensive growth of above-ground plant biomass, was 2.1–2.5 times higher compared to the control eroded area and was estimated as good and satisfactory according to the classification of Vadyunina and Korchagina (1986). When corn silage was cultivated in the same period, the stocks of productive moisture exceeded the control by 1.6–1.7 times and were assessed as satisfactory. At the beginning of crop harvesting (August) with maize and winter rye on the different elements of the slope in variants across the slope, reserves of productive moisture were estimated as good, and in the control as satisfactory. A strong inverse relationship was established between the stocks of productive moisture in the soil and yield of crops: when growing winter rye, the correlation coefficient was 0.97, while it is 0.86 when cultivating corn silage. Thus, the contour-band placement of crops combined with the application of green manure had a significant positive impact on stocks of productive moisture at a soil depth of one meter.

Improved agrochemical indicators. It has been established that there is a positive influence regarding soil protection and the amount of green manure entering the soil, as agrochemical indicators, on an arable land layer. The greatest maintenance of mineral nitrogen was noted on a separate water segment and average parts of a slope. The decrease in the humus during longitudinal processing was about 0.14–0.16 t per year, which is 15–18% more than when land use is organized in contoured strips. Average losses

Table 27.3 Influence of application fertilizers and slope elements on the productivity of grown cultivars (an average on 3 years), t ha^{-1}

Variant	Winter rye		Corn on silage	
	Productivity	Increase	Productivity	Increase
Placing crops along a slope				
Control	1.64	–	11.5	–
Placing crops across a slope				
Watershed (top position)	2.49	0.85	19.0	7.5
Middle part of slope	2.62	0.98	14.7	3.2
Bottom part of slope	2.65	1.01	15.8	4.3
Least significant difference (LSD 0.05)		0.42		3.0

of biogenic elements in the control sample in comparison with other variants of the experiment were greater for mobile phosphorus (by 18.5%), exchange potassium (by 37%) and the sum of exchange bases (by 44%).

Higher crop yields. There is a marked difference regarding the productivity of crop yields between slopes, along slopes (control) and across slopes (experiment), with a significant increase in productivity for the experimental crops. For winter rye, the increase in green biomass is between 51.8–60.1% and for corn it is 27.8–65.2% (Table 27.3). The highest increase in the grain yield of winter rye was observed in the lower part of the slope, and that of green corn mass in the watershed, which may also be due to the botanical characteristics of the cultivated crops.

27.7 Conclusions

1. Most soils of the Non-Chernozem zone of Russia are located in the boreal zone, many of them in glacial landscapes. They are of sandy to loamy texture and some adverse factors restrict the soil fertility and crop yield potential, such as erosion risk, imbalanced water regime and acidification. However, if located in the vicinity of big cities, they have great potential for agriculture.
2. Agriculture requires skilled and innovative soil and land management to achieve high crop yields and avoid negative impacts on the soil, water quality, atmosphere, and biodiversity.
3. We tested a contoured cropping approach in combination with soil improvement thru perennial lupin growing on buffer strips. Perennial lupin growing was the most efficient as green manure and a soil stabilizer. The approach performed well in terms of significantly lower erosion rates, better agrophysical and agrochemical soil properties and higher crop yields.
4. The practical application of the approach is still an unresolved problem. However, the experiment shows that landscape-adapted approaches are a feasible means of solving key problems of agriculture on sandy and sloped soils.
5. The expertise of the All-Russian Research Institute of Organic Fertilizers and Peat is part of national and international innovation projects and monitoring programs. This is a basis for the sustainable development of agricultural systems and the creation of landscape-adapted local food chains in Central Russia.

Acknowledgments This chapter is based on an article by the author as published under: Tatyana Anisimova, Ways of Fertility increase on eroded slopes in non-chernozemic zone in Russia, J. Wetlands Biodiversity, Volume 5, 2015, Pages 39–45. Reprinted with the kind permission of Journal of Wetlands Biodiversity.

References

Anisimova T (2002) The agrochemical and technological efficiency of lupine and straw in crop rotations of the Central-Chernozem zone (Агрохимическая и технологическая эффективность использования узколистого люпина и соломы в звеньях севооборотов Центрального Нечерноземья) Abstract of the thesis of candidate agricultural Sciences. Moscow. (in Russian)

Anisimova T (2015a) Ways of increase of fertility of arable slopes in the Central Nonchernozemic Zone (Способы повышения плодородия пахотных склонов в Центральном Нечерноземье) //Zemledelie. 1:18–20 (in Russian)

Anisimova T (2015b) Ways of Fertility increase on eroded slopes in non-chernozemic zone in Russia // J. Wetlands Biodiversity. 5:39–45

Cernay C, Makowski D (2018) Pelzer E (2018) Preceding cultivation of grain legumes increases cereal yields under low nitrogen input conditions. Environ Chem Lett 16:631–636. https://doi.org/10.1007/s10311-017-0698-z

Dresbøll DB, Rasmussen CR, Thorup-Kristensen K (2018) Capacity of Deep Rooted Species to Take Up Water and Nutrients from Deep Soil Layers. Poster at: ISRR 2018, Jerusalem, Israel, 8–12/7–2018. https://orgprints.org/34364/3/Poster%20-%20Dorte%20Bodin%20Dresb%C3%B8ll_34364.pdf. Accessed on Oct 30, 2019

Dospekhov BA (1985) Methodic of field experiment (Методика полевого опыта). Moscow Agropromisdat 1985. pp 351 (in Russian)

Edmeades DC (2003) The long-term effects of manures and fertilisers on soil productivity and quality: a review. Nutr Cycl Agroecosyst 66:165–180. https://doi.org/10.1023/A:1023999816690

Franco JG, Duke SE, Hendrickson JR, Liebig MA, Archera DW, Tanaka DL (2018) Spring wheat yields following perennial forages in a semiarid no-till cropping system. Agron J 110(6):2408–2416. https://doi.org/10.2134/agronj2018.01.0072

Gordeev AV, Romanenko GA (eds) (2008) Problems of agricultural land degradation and rehabilitation of its productivity in Russia (Проблемы деградации и восстановления продуктивности земель сельскохозяйственного назначения в России) Ministry of Agriculture of the Russian Federation and Russian Academy of Agricultural Sciences. Moscow. Rosinformagrotex. 67 p. Online at:https://agro.geonet.ru/publications/degradation.pdf. Accessed 30 Oct 2019

Grunark S, Rooney DJ, Sweeney KMc, Lowery B (2001) Development of pedotransfer functions for a profile cone penetrometer // Geoderma. 2001. 100:1–2. pp 25–47

Ivanov DA (2014) Monitoring of agrochemical properties of soils within an agro-ecological experiment(Мониторинг агрохимических свойств почв в пределах агроэкологического стационара) // Agricultural Chemistry (Агрохимия). 5:27–31 (in Russian)

Kiryushin VI (2010). Agronomy soil science (Агрономическое почвоведение) Moscow. Kolos. pp 687. ISBN 978–5–9532–0763–8 (in Russian)

Kuptsov NS, Takunov IP (2006) Lupin: genetics, breeding, heterogeneous seeds (Люпин: генетика, селекция, гетерогенные посевы). Bryansk. 2006. (in Russian)

Lukin SM (2009) Agroecological substantiation of fertilizer application systems in crop rotations on sod-podzolic sandy-loamy and sandy soils (Агроэкологическое обоснование систем применения удобрений в севооборотах на дерново-подзолистых супесчаных и песчаных почвах), Doctoral dissertation Vladimir 2009, pp 404. (in Russian)

Lyakhov AI (1975) Guidelines for conducting field experiments with fertilizers on eroded soils and agrochemical mapping Методические указания по проведению полевых опытов с удобрениями на эродированных почвах и агрохимическому картированию). Moscow: VIUA. pp 47. (in Russian)

Masyutenko NP (2016) The system of indicators of agro-ecological evaluation of eroded chernozems (Система показателей агроэкологической оценки эродированных черноземов) The achievements of science and technology AIK. T. 30(11):7–11 (in Russian)

Matasov VM (2017) Intralandscape Dynamics of Land Use within the Meshchera Lowland over the Last 250 Years. Vestnik of the Moscow State University. Series 5. Geography. 2017. No 4, 65–74 (In Russian: Матасов В.М. Внутриландшафтная динамика использования земель мещерской низменности за последние 250 лет. Вестник Московского Университета. Серия 5 . География. 2017. 4:65–74)

Mueller L, Schindler U, Mirschel W, Shepherd TG, Ball B, Helming K, Rogasik J, Eulenstein F, Wiggering H (2010) Assessing the productivity function of soils: a review. Agron Sustain Dev 30(3):601–614. https://doi.org/10.1051/agro/2009057

Mueller L, Shepherd G, Schindler U, Ball BC, Munkholm LJ, Hennings V, Smolentseva E, Rukhovic O, Lukin S, Hu C (2013) Evaluation of soil structure in the framework of an overall soil quality rating. Soil & Tillage Research 127:74–84. https://doi.org/10.1016/j.still.2012.03.002

Naliuhin AN, Belozerjv DA, Eregin AV (2018) Changes of agrochemical parameters of light loamy sod medium podzolcs soil and crop rotation productivity at different fertilizer systems (Изменение агрохимичнских показателей дерново-среднеподзолистой легкосуглинистой почвы и продуктивности культур севооборота при применении различных систем удобрения) Zemledelie. 8:3–7. DOI: https://doi.org/10.24411/0044-3913-2018-10801 (in Russian)

Nemtsev SN (2005) Agro-ecological features of conservation cropping systems in agricultural landscapes of forest-steppe of the Middle Volga region (Агроэкологические особенности почвозащитных систем земледелия в агроландшафтах лесостепи Среднего Поволжья). Diss. Dr of agricultural Sciences : 06.01.01 Kinel, pp 417. (in Russian)

Pannikov VD (2003) The high culture of agriculture and the growth of crops (Панников В.Д. О высокой культуре земледелия и росте урожаев). M. Russian Academy of Agricultural Sciences. 2003. (in Russian)

Pimentel D (2006) Soil Erosion: A Food and Environmental Threat. Environment, Development and Sustainability, (2006) 8:119–137. Springer. https://doi.org/10.1007/s10668-005-1262-8

Quinton JN, Catt JA (2004) The effects of minimal tillage and contour cultivation on surface runoff, soil loss and crop yield in the long-term Woburn Erosion Reference Experiment on sandy soil at Woburn, England. Soil Use and Management 20(3):343–349. https://doi.org/10.1111/j.1475-2743.2004.tb00379.x

Reckling M, Döring TM, Bergkvist G, Chmielewski FM, Stoddard FL, Watson CA, Seddig S, Bachinger J (2018) Grain legume yields are as stable as other spring crops in long-term experiments across northern Europe. Agron Sustain Dev 38:63. https://doi.org/10.1007/s13593-018-0541-3

Romanenkov VA, Kuzyakova IF (2000) New methodological approaches to agroecological field experiments in landscape agriculture (Новые методологические подходы к проведению агроэкологических полевых опытов в ландшафтном земледелии). In: International scientific and practical conference “current problems of experimental studies”, vol 1, St.Petersburg, pp 140–146 (in Russian)

Rasmussen PE, Goulding KWT, Brown JR, Grace PR, Janzen HH, Körschens M (1998) Long-Term agroecosystem experiments: assessing agricultural sustainability and global change. Science 282:893–896. https://doi.org/10.1126/science.282.5390.893

Savich VI, Gukalov VN, Mansurov B (2015) Agroecological assessment of erosion development in time and space (Агроэкологическая оценка развития эрозии во времени и в пространстве) //Plodorodie. 3:40–42 (in Russian)

Solovyev PP (1971) Lupine culture in increase of fertility of soils of the Nonchernozem zone of the USSR (methodical recommendations) (Культура люпина в повышении плодородия почв Нечерноземной зоны СССР). Moscow. Science Press. pp 31 (in Russian)

Summerell BA, Burgess LW (1989) Decomposition and chemical composition of cereal straw. Soil Biol Biochem 21(4):551–559. https://doi.org/10.1016/0038-0717(89)90129-6

Surmach GP (1976) Water erosion and its control (Водная эрозия и борьба с ней) Leningrad: Gidrometeoizdat. pp 254 (in Russian)

Trepachev EP (1999) Agrochemical aspects of biological nitrogen in modern agriculture (Агрохимические аспекты биологического азота в современном земледелии) Moscow. VIUA 1999 (in Russian)

Vadyunina AF, Korchagina ZA (1986) Methods of research agrophysical properties of soils (Методы исследования агрофизических свойств почв). Moscow. Agropromizdat. pp 416 (in Russian)

WRB (2006) World Reference Base for Soil Resources 2006, A Framework for International Classification, Correlation and Communication, FAO Rome, 2006, World Soil Resources Reports 103, p 145

Zaydelman FR (1991) Humid landscapes` ekologo-meliorative soil science (Эколого-мелиоративное почвоведение гумидных ландшафтов). Moscow. Agropromizdat Press. pp 320 ISBN: 5–10–000826–1 (in Russian)