Progress in Soil Science

Damien J. Field
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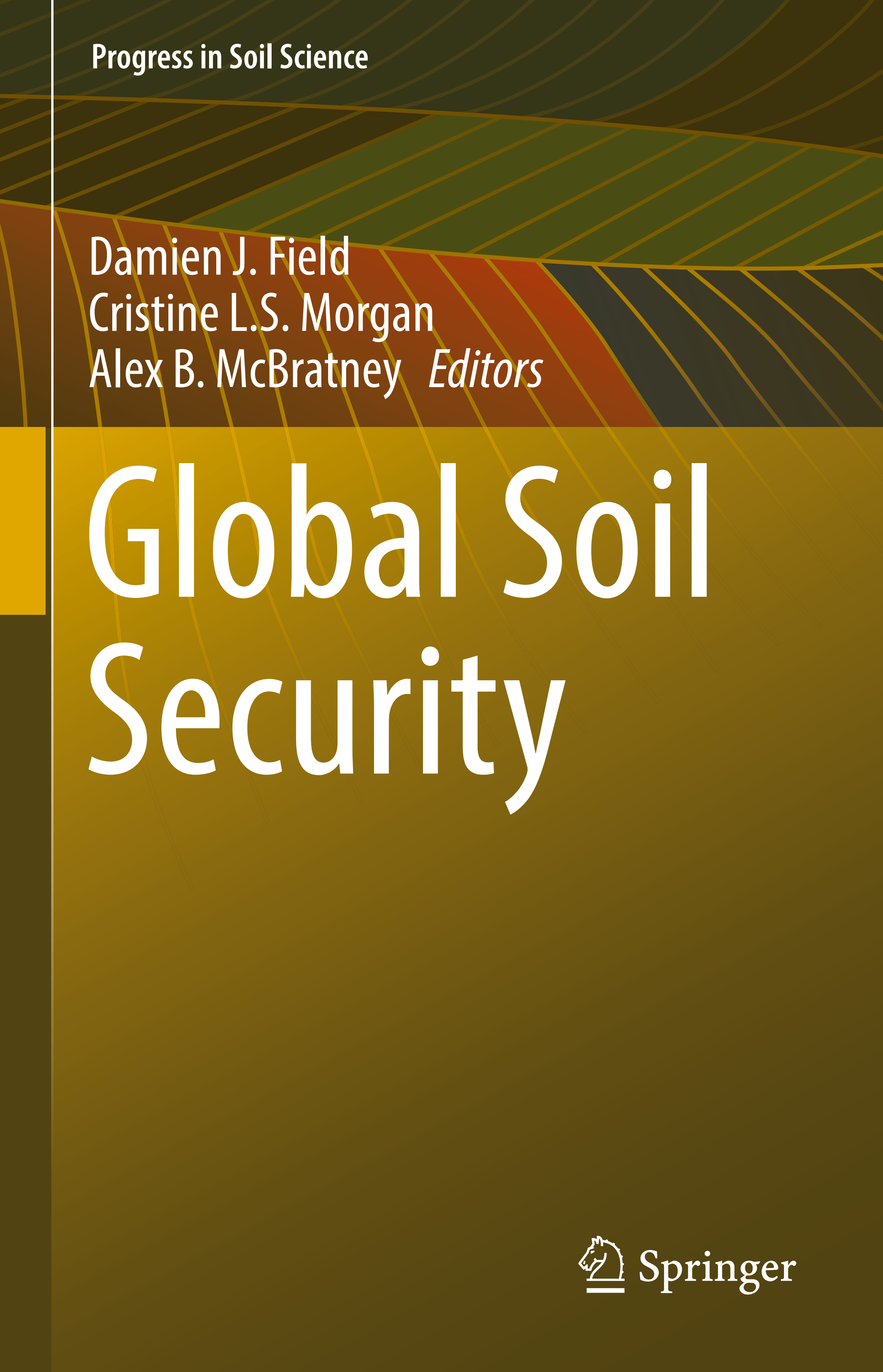
Global Soil Security



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Progress in Soil Science

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Aims and Scope

Progress in Soil Science series aims to publish books that contain novel approaches in soil science in its broadest sense – books should focus on true progress in a particular area of the soil science discipline. The scope of the series is to publish books that enhance the understanding of the functioning and diversity of soils in all parts of the globe. The series includes multidisciplinary approaches to soil studies and welcomes contributions of all soil science subdisciplines such as: soil genesis, geography and classification, soil chemistry, soil physics, soil biology, soil mineralogy, soil fertility and plant nutrition, soil and water conservation, pedometrics, digital soil mapping, proximal soil sensing, digital soil morphometrics, soils and land use change, global soil change, natural resources and the environment.

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Foreword

Food and water insecurity to 2050 is among the most formidable challenges facing much of the developing world in particular. Subsequent crises could include rising poverty levels, slowing growth and development and widespread social unrest. One of the greatest responsibilities and opportunities for the developed world in the twenty-first century is to help hungry and water-deficient populations, in part, by increasing food exports but, in particular, through the export of knowledge.

Global food and water security and other existential challenges, such as climate change mitigation, are almost totally dependent on our knowledge of what makes a healthy and productive soil, which in turn must be integrated with good hydrological, agronomical and vegetative management practices.

Time is of the essence, as China, India, sub-Saharan Africa and the Middle East are already experiencing severe soil and water problems. Fortunately, soil scientists and agronomists have many of the solutions, which we must share with the global community as an important contribution to future international stability.

To save our planet, we must save the soil.

Major General the Honourable Michael Jeffery
AC AO(Mil) CVO MC (Retd)
National Soil Advocate, Australia

Preface

Scientists, policy influencers, investors and citizens met at Texas A&M University in College Station, TX, from the 19th to the 21st of May 2015 to discuss the need for a new focus on soil security. Approximately 85 people from 14 countries and 40 institutions met to discuss the topic of soil security. The symposium was jointly organised by Texas A&M University, the University of Sydney, the US Studies Centre at the University of Sydney and the Soil Science Society of America and represents the International Union of Soil Sciences' contribution to the International Year of Soils. The symposium was sponsored by the OECD Co-operative Research Programme on Biological Resource Management for Sustainable Agricultural Systems, whose financial support made it possible for many of the invited speakers to participate in the conference. Additional sponsorship was provided by The Samuel Roberts Noble Foundation, the US Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Soil Survey Division, the Texas A&M AgriLife Research and Texas A&M University. Governmental bodies and organisations represented included the Australian Government, USDA, European Commission and INRES (Industrial Safety and Environmental Protection of France). Attendees participated in a frank and open discussion focused on each participant's perspective on how to achieve soil security.

Part of the rationale for soil security is the global drivers of food water and energy security and was timely, considering that 2015 was designated as the International Year of Soils by the United Nations and a report by the FAO on the *Status of the World's Soil Resources* highlighted the challenges confronting the world's soils (http://www.fao.org/fileadmin/user_upload/GSP/docs/PA_III/supporting_docs/SWSR_may15.pdf).

In response, soil security is recognised in similar terms to food and water security. It arises from the well-perceived global existential challenges although soil security itself has not hitherto been recognised. Chapters 1 and 2 elucidate these challenges and give the rationale and framework for a recognised soil-oriented response which are expanded in detail in subsequent chapters.

This book is broken into sections focused on each of the five dimensions of soil security with the first being capability. The idea of capability has had a long history in the evaluation and development of land. This evolved over time to be more specific to deal with particular qualities of soil for particular purposes. Most of these purposes were agricultural. In the 1990s, a new movement based on the concept of soil quality arose, and in some ways, it evolved without some of the ideas previously recognised in land and soil capability, i.e. that particular soil profiles have intrinsic capabilities and these vary markedly from soil to soil. In soil security, capability is recognised as the bio-physico-chemical ability of soil to perform a wide variety of functions more than simply biomass production.

Chapter 3 discusses these functions in detail and suggests ways of quantification, whereas Chap. 4 tries out the soil indicator and timescale differences between capability and the associated concept of condition. We see in Chap. 5 the importance of soil capability in land-surface modelling. In the USA, a number of the soil functions are quantified by a very large number of soil interpretations offering a framework for quantifying soil capability. This is described in detail in Chap. 6. There is a need for a uniform high-resolution data set for the whole world from which soil capability can be evaluated; Chap. 7 describes GlobalSoilMap which is designed for this purpose. Finally, in Chap. 8, the concept of capability is evaluated against previous studies and suggestions of new concepts are made.

In the next section, soil condition refers to the idea that environmental conditions and more predominately anthropogenic management have impact on how well a soil may function and may be considered largely synonymous with soil health. While soil capability refers to the genetic and pedogenic features of a soil to interact biophysically with its environment, condition refers to the fact that soil can be managed by people and this management can improve or degrade soil function. In modern history, the majority of social, political, scientific and agronomic efforts have focused on soil condition. Section C of this book addresses these components.

Chapter 9 merges the concepts of how society and the soil science discipline have valued soil and how concepts of soil care have varied in terminology and nuance of focus, but ultimately all concepts recognise awareness that agricultural practices and policy influence soil condition and ultimately soil function. A newly created programme for and concepts of valuing soil are found in Chap. 10 through the discussion of an initiative of the USA to promote management systems to improve soil. Chapter 11 develops a framework for linking the US Soil Survey concept of mapping by capability and cataloguing condition with respect to soil capability. Chapter 12 provides a discussion of soil-root microbiome interactions and how they are linked to both soil condition and initial capability.

Chapters 13, 14, 15 and 16 provide useful examples that reiterate the same theme of how important it is to first define or establish soil capability before evaluating or trying to improve soil condition. In the high plain region of Texas, the interactions between management and soil organic C and soil hydraulic function are illustrated (Chap. 13). In another example, further south, in the Yucatan Peninsula of Mexico, Chap. 14 shows how management does affect soil CO_2 efflux from soil, but only after the initial inorganic C concentrations are considered. Chapters 15 and 16 address biofuel production. Chapter 15 demonstrates that we can model the soil C and some N dynamics to infer or predict how biofuels may impact C and N cycles in soil, while Chap. 16 reinforces the importance of using many different species of plant to improve soil condition in intensive agricultural systems. It is clear from the examples provided and all discussions in these chapters on condition that soil capability and condition cannot be considered independently.

This is followed by what the value of soil to the economy and to society is. From a strictly economic perspective, one can assign value to soil through land values and agricultural commodity prices. However, perhaps the majority of the value of soil is hidden in the soil's ability to supply ecosystem services. Ecosystem services have a monetary value if built or human capital would be required to replace that service. However, the value of natural capital is difficult to define. The difficulty of assigning a value to soil ecosystem services and soil as natural capital is because this value changes with societal and economic priorities. At a macro-scale, natural capital of the world belongs to everyone. However, soil is managed at a very local scale and governed at regional and national scales. Soil natural capital supplies ecosystem services to social capital, built capital and human capital. It is through this interaction of capitals that the value of soil as a natural capital is defined. Section D wrestles with the rapidly evolving science of viewing soil and soil management from the economic perspective—soil as natural capital.

Chapter 17 shares an economic perspective of the challenges in securing soil in light of potential policy changes regarding climate change and biofuel policy in the USA. Growing biofuels may positively impact soil security through C sequestration, higher commodity value and conservation practices. Valuing soil through conservation practices and improving soil condition is also discussed. Chapter 18 provides details on how to value soil as a provider of ecosystem services in a farming perspective. An ecosystem approach to promoting farm investment in soil condition and soil value in general is a clear approach to achieving soil security in agroecosystems. In high-value crops, maximising soil ecosystem services to cycle nutrients and control pests has a clear economic value (Chap. 19). Chapter 20 takes a macro-approach to valuing soil as natural capital by integrating knowledge of soil function in global ecosystem service values. This approach is helpful in convincing policymakers of the ecosystem service value of soil. A quantitative approach to valuing soil condition is developed in Chap. 21. Taking action to prevent soil from degrading is shown to be less expensive than allowing the ecosystem function of soil to decline. Finally, a grass-roots approach to increasing soil value is discussed under the scope of social licensing in Chap. 22. Labelling agricultural products that are managed to specifically secure soil resources for society requires accreditation and a marketing strategy. Social licensing provides an alternative to policy for securing soil.

The section on connectivity is probably the least developed and recognised dimension in soil security. This dimension compliments placing a value on soil, i.e. its capital, and focuses on understanding how society as a whole is connected to soil. The most commonly identified groups contributing to this dimension are those involved in production, i.e. farmers and graziers. These are supported by *knowledge brokers* who provide advice on soil issues and ensure the extension of the latest soil knowledge and ongoing education. Reconnecting the broader community is essential to strengthen soil security, and this can be achieved by enabling consumers to connect the products they buy with the soil from which it is sourced, sharing their experience with soil through community (kitchen)gardens, contributing to the collection of soil data using crowd sourcing and taking time to absorb soil through art forms. Section D explores the opportunities to enhance connectivity with soil.

Chapter 23 explores a major initiative led by the Noble Foundation in the USA of a renaissance in soil to ensuring the soil's health. To achieve this, the foundation is committed to bring the right people together, researchers, farmers, industry and economist who can drive change and develop and promote the soil's health. The connection between soil and human health is further explored in Chap. 24, making a clear connection between the dimensions of soil security and the human health issues of providing food and exposure to contaminants, microbes and waste. Chapters 25 and 26 further explore soil's connection to human health with Chap. 25 focusing on the soil's function to protect humans by storing and recycle contaminants and Chap. 26 on soil being a sink of nutrients that contribute to human nutrition through food production. A philosophical look at the concept of cognizance grounded in integral ecology is elucidated in Chaps. 27 and 28, which in part allows the diagnosis of gaps between the values and beliefs people hold about soils and scientist's observations, data, maps and models of soils. Its application is illustrated in Chap. 29 with the investigation of soil and water security in Brazil. The opportunity to use regenerative cropping and grazing protocols to rejuvenate production and enhance ecosystem resilience is described in Chap. 30. To enable a scaling up of this approach will require a strengthening of the connections between the economic benefits and values of the community too. Aesthetics through art and getting your *hands dirty* in community gardens is explored in Chaps. 31 and 32, respectively. Both of these provide a means for the urban communities to re-engage with soil, by promoting a concept of care. Chapter 33 describes the importance of public policy and the influence of public opinion guiding the outcome, while Chap. 34 explores the concept of using the rock star as an advocate for soil. These chapters recognise that the importance of secular and nonsecular beliefs, national pride, heritage or economic prosperity will simultaneously galvanise public opinion.

The final section focuses on governance recognising that despite the proper management of the soil's condition in line with its capability, placing a proper value and improving society's connectivity with it, there is still the need for good governance and regulation. There have been a number of international initiatives to strengthen soil policy framework, with some of these explained in this section illustrating the codification dimension of soil security, albeit the agreement on national and international soil policies is still sporadic or given second priority. Therefore, the broadening of engagement in policy, governance and regulation is welcomed to secure soil through its codification.

This section starts with Chap. 35 reiterating the fundamental link between human existences and well-managed healthy soils. While the Soil Renaissance initiative is being developed in the USA, the gravity of this issue is demonstrated by the appointment in Australia of a national advocate for soil health. The sharing of soil knowledge through appropriate investment and coordinated government policies is called for in this chapter. Chapters 36, 37, 38 and 39 provide useful examples of how soil governance and policies are implemented in Brazil, the USA and Australia. They illustrate policy frameworks that have broadly adopted, what could be described as, a *carrot* or *stick* approach to promote good soil management. Chapter 40 introduces the idea of securitization which recognises that the articulation of the soil security concept indicates action must be taken and the form of securitization will depend on the uptake by policymakers. These chapters are complimented by Chap. 41 which summarises the integration of soil in policy at the international level. This chapter also calls for the need to develop some easily measurable and interpretable indicators that engage policymakers and are seen as relevant to society. Chapter 42 calls on soil science as a community to engage with stakeholders from other disciplines, policy and civil society to ensure soil is integrated along with other sustainable development issues such as food and water security, maintaining biodiversity and ecosystem protection. The final synthesis chapter, Chap. 43, explores how soil security could be achieved over the next two decades. This is clearly done by establishing specific and measurable goals for each of the dimensions of soil security, with working towards soil security that is identified as a goal in its own right.

The discussion of global soil security will continue with a focus of developing dialogue between land managers, multidisciplinary scientists and policymakers at subsequent global soil security symposia. A quantitative framework for assessing each of the dimensions will be developed. Those who wish to achieve global soil security will continue to increase awareness. This first book on global soil security includes most of the talks shared at the first symposium and facilitates continued conversations at all levels. Here we present 43 chapters relating the highlights of the presentations and discussions.

Conference presentations may be perused at the Soil Science Society of America website:

https://dl.sciencesocieties.org/publications/meetings/browse/sssa/2015GS

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Part I
Rationale for Soil Security

Chapter 1
Soil Security: A Rationale

Alex B. McBratney, Damien J. Field, Cristine L.S. Morgan, and Lorna E. Jarrett

Abstract The concept of soil security has strategic value in that it can serve to focus and guide the development of policies addressing the six global existential challenges, such that interventions for one challenge result in favourable effects on other challenges. Soil security arises from both top-down (global challenge) and bottom-up (societal value) considerations. We envision it as a homologous concept to those of food and water security. The major goal is to measure and manage the five dimensions of capability, condition, capital, connectivity and codification.

Keywords Soil security • Global existential challenge • Food security • Water security • Energy security • Climate change • Human health

1.1 What Is Soil Security?

We define soil security as the maintenance and improvement of the world's soil resource to produce food, fibre and fresh water, contribute to energy and climate sustainability and maintain the biodiversity and the overall protection of the ecosystem (Koch et al. 2013). This involves maintaining and optimising soil's structure and form; diversity of organisms; nutrient cycling capacity; ability to act as a substrate for plant growth; ability to regulate, store and filter fresh water; and capacity to sequester carbon dioxide from the atmosphere.

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1.2 Which Issues Does This Concept Intend to Address?

1.2.1 Global Existential Challenges: The Emerging Recognition of the Role of Soil

In order to achieve sustainable development for the world's population, six environmental existential challenges must be addressed. These are food, water and energy security, climate change abatement, biodiversity protection and human health. Soil plays a pivotal role in each of these: for example, the world's soil contains more than twice as much carbon as the atmosphere; 97 % of the world's food comes from agricultural soils; and over 98 % of terrestrial biodiversity is found within soil.

However, insights and advances in scientific understanding of the ecosystem services provided by soil over the past two decades have not been reflected in policymaking for sustainable development. For example, the Global Biodiversity Outlook (Secretariat of the Convention on Biological Diversity 2014) does not address biodiversity in soil. By neglecting the central importance of the role of soil, interventions and initiatives designed to address the other six existential challenges are at risk of failure. Therefore, it is essential that the role of soil is recognised and explicitly addressed in policies designed to meet all global existential challenges, because "a fully functioning soil lies at the heart of solving the big issues of food security, biodiversity, climate change and fresh water regulation, but to date there has been no easy way to communicate these linkages" (Koch et al. 2013 p. 4). The concept of soil security serves to make explicit the connections between soil and the other global existential challenges. It also provides, through the five dimensions of soil security, a framework for discussing and assessing the function of soil.

1.2.2 The World's Soils Are Under Threat

There is currently an unprecedented threat to world's soils through degradation. The only global initiative addressing soil degradation is the UN Convention to Combat Desertification. UNCCD has made an urgent call for a globally recognised, measurable target for measuring land degradation and desertification (LDD), in recognition of its contribution to biodiversity loss, climate change mitigation and alleviation of poverty, all of which have been targeted by Millennium Development Goals (MDGs). However, this focuses on arid and semiarid landscapes and therefore fails to address the full range of threats to the world's soil.

1.3 The Global Challenges and Their Connection to Soil

1.3.1 Food Security

Food security is defined as the situation "when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life" (FAO 2015a). The dimensions of food security include availability, access, quality, safety and use of food.

Food security is arguably the greatest of the six existential challenges. As of 2012, the FAO Committee of Food Security estimated that over one billion people – one in every seven of the world's population – may be suffering from food insecurity. There are projected to be over nine billion people on the planet by 2050; therefore, as well as addressing the one billion people currently suffering food insecurity, we face the challenge of securing food for a further two billion. UNCCD emphasises that global peace and political stability are dependent on food and water security.

Over 99 % of food energy intake comes from crops grown on soil; less than 0.3 % comes from aquatic sources. To date, efforts to ensure food security have involved improving crop yield and quality; reducing loss of productive land through degradation, pollution and urbanisation; and addressing the need for water supply and storage.

Global demand for food is expected to continue increasing for at least the next 40 years; ultimately we may need to produce twice as much food as we do now, while available agricultural land is likely to reduce through urbanisation and degradation (Godfray et al. 2010). Increasing the area of land under cultivation by clearing existing forests would result in substantial release of greenhouse gases, decrease in water quality in catchments through nutrient run-off and loss of biodiversity; threatening attempts to address other global existential threats.

However, while efforts to produce more food have the potential to threaten other aspects of sustainability, they may also work symbiotically. For example, management practices that increase soil organic carbon not only increase crop yields but also sequester carbon from the atmosphere at a low or negative monetary cost (Lal 2010). It is estimated that a 1 Mg C ha^{-1} increase in soil organic carbon could increase developing nations' food grain yields by 32 million Mg $year^{-1}$ and root crops by 9 million Mg $year^{-1}$. However, currently there is little direct experimental data to establish the relationship between soil organic carbon and crop yields.

Food production also faces a growing challenge of sourcing soil amendments such as phosphorus, which are required to maintain and increase agricultural soil fertility.

1.3.2 Water Security

Water differs from food and energy in that threats can arise not only the absence of water but also though its presence, for example, in the form of floods or tsunamis. Water security is “the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability” (UN-Water 2013). Three factors affect water security: the hydrogeologic environment which determines the amount, temporal variability and spatial distribution of water; the socio-economic environment; and future changes to the environment, such as climate change. Climate change is expected to make water security harder to achieve, both by reducing water availability where it is already scarce and by increasing variability (Grey and Sadoff 2007).

Water security is a significant and fast-growing challenge. More than one billion people lack adequate drinking water, and 90 % of infectious diseases in developing countries are transmitted through polluted water (Pimentel et al. 2004). Over 20 % of the world’s population lack safe drinking water, and half do not have adequate sanitation. In developing countries, 95 % of urban sewage is discharged untreated into surface waters, which are used further downstream for washing, bathing and drinking. This inadequate sanitation causes 12 million deaths each year. Even in developed countries such as the USA, up to 40 % of fresh water is unfit for consumption due to pathogen, pesticide and fertiliser contamination (Pimentel et al. 2004).

Agriculture currently uses 70 % of available fresh water. Therefore, the doubling of agricultural yields, needed to feed the world’s growing population, can only be achieved through more efficient use and management of water. Soil can store 2 % of the fresh water used by agriculture, but much of the water used by agriculture currently flows through soil and is not retained. Agricultural pesticides and fertilisers enter waterbodies through leaching and run-off, resulting in a decline in water quality.

“The soil functions of water retention, filtering and transforming compounds and nutrient cycling are significant contributors to the provision of water for human, biomass production and ecosystem needs” (McBratney et al. 2014, p. 205). In the environment, water resources exist as “blue water”, in rives, dams and aquifers, and as “green water”, namely, evapotranspiration. The hydrological functions of soil, including the partitioning of water fluxes into blue and green water, depend primarily on the amount and quality of soil organic carbon. Soil organic matter quality also controls the mobilisation of dissolved organic carbon, which affects the quality of water sources.

Recommended management practices have numerous and significant advantages for water security. Soil carbon sequestration increases efficiency in irrigation, decreases pollution through sedimentation, reduces non-point source pollution and declines in hypoxia of coastal waters (Lal 2010). Increasing soil organic matter can increase the water infiltration rate by up to 150 %, and intercropping can reduce runoff by up to 87 %. Shelterbelts can reduce evapotranspiration from crops by up to 20 % (Pimentel et al. 2004).

1.3.3 Energy Security

Energy security is "the continuous availability of energy in varied forms, in sufficient quantities, and at reasonable prices". Energy security implies limited exposure to disruptions of imported energy supplies and sufficient available resources, at reasonable prices, to meet demand (Khatib et al. 2000). In developing countries, many people depend on agricultural products such as wood, charcoal and crop residues, for fuel. This has adverse effects on health, due to indoor air pollution, and limits economic opportunities. Globally, three billion people rely on solid fuels for cooking, using inefficient fires and stoves. These produce not only indoor air pollution but also carbon emissions that contribute to climate change (Legros et al. 2009).

The challenge of energy security demonstrates that solving one global challenge can compromise others. In this case, the use of agricultural land for biofuel production takes agricultural land out of food production. Alternatively, less capable soil may be brought into production or native vegetation cleared in order to satisfy demand for biofuels. This is likely to compromise ecosystem services, reduce biodiversity, decrease water quality and result in the release of greenhouse gases.

According to Tilman et al. (2009), production of biofuels may lead to either positive or negative outcomes for climate change and food security, depending on how they are implemented. In order to realise positive outcomes, biofuel production must not compete with agriculture or natural vegetation. For example, biofuels based on perennial plants grown on abandoned, degraded agricultural land, can increase wildlife habitat, improve water quality and increase soil organic carbon. Biofuels may also be derived from crop residues, mixed cropping systems, wood residues and municipal wastes. In order to avoid negative outcomes, adequate legislation is also required.

1.3.4 Climate Change

Soil also has a part to play in mitigating against extreme climate events. For example, soil moisture content reduces wildfire risk, and soil that is able to store more water reduces flood risk (Lal 2004). The world's soil stores 2700 Pg of carbon: twice as much as the atmosphere (780 Pg) and biomass (575 Pg) combined. Soil's significance for the mitigation of climate change is also due to the fact that we can manage it directly in a way that is not possible with other carbon reservoirs. However, the amount of carbon stored in the world's soils has been falling, as a result of management practices such as tillage and drainage of wetland soils. Therefore, depending on management practices, soil can represent either an opportunity for carbon sequestration or a threat in the form of a flow of carbon into the atmosphere.

According to Lal (2010), recommended management practices have the potential to increase soil organic carbon by as much as 3 Pg C year^{-1} (3×10^9 tonnes C year^{-1}) globally; this corresponds to a reduction in atmospheric CO_2 of 50 ppm by 2100. Recommended management practices include afforestation of degraded soil, conversion of degraded cropland to pasture, zero-tillage and crop residue mulching, cover cropping and integration of biochar, compost or manure. These practices provide additional benefits because soil condition, and its ability to provide ecosystem services, is closely tied to the amount and quality of soil organic carbon in the root zone (Lal 2010). Therefore, by promoting a global increase in soil organic carbon, we can also address other existential challenges.

Soil also has a part to play in mitigating against extreme climate events. For example, soil moisture content reduces wildfire risk, and soil that's able to absorb water reduces flood risk.

1.3.5 Human Health

The challenge of human health is to improve life expectancy and quality of life. Soil is linked to human health primarily in three ways: nutrition, exposure to toxic or carcinogenic compounds in soil and disease prevention.

In order for food to be adequately nutritious, it must provide both sufficient macronutrients and micronutrients (trace elements). Trace elements are iron, manganese, nickel, zinc, copper, vanadium, cobalt, chromium, molybdenum, selenium, tin, iodine and fluorine. Food grown on depleted soils can be deficient in trace elements, for example, Keshan disease is caused by selenium-deficient soil, and goitre is caused by iodine-deficient soil. Selenium-deficient soil has also been implicated in the development of cancer and heart disease, and nutrient-poor glaciated soil in Northern Europe and the eastern USA correlates with rates of heart disease. Over three billion people are affected by micronutrient deficiencies.

Soil which contains high levels of toxic elements can also result in illness, for example, itai-itai disease, caused by high levels of cadmium (Oliver 1997). Carcinogenic compounds released from soil include radon gas and asbestos minerals. Trace elements are also toxic in excess concentrations, and the difference between essential and toxic concentrations is often very small. Soil pH and management practices affect trace element availability.

Soil also plays a role in disease prevention through the services it provides in recycling waste materials such as sewage sludge and filtering water that ultimately will be used for drinking, bathing and food preparation. As a soil amendment, sewage sludge increases soil organic carbon and nitrogen and enhances microbial activity. However, there is a limit to the quantity of sewage sludge that can be applied without reducing soil quality, and long-term use carries the risk of contamination with toxic elements. Pollution of groundwater by nitrates or dissolved organic carbon may also result (Roig et al. 2012). Sewage and animal manure contain large amounts of pathogens, and not enough is known about the fate of these following applications of biosolids to soil.

Agricultural practices may have impacts on human health. For example, the incidence of schistosomiasis is increasing worldwide, due to the construction of dams and irrigation canals that provide habitat for the parasite's intermediate host and bring humans into contact with infected water. Deforestation in parts of Africa has resulted in favourable breeding conditions for malaria-transmitting mosquitoes. Leaching and run-off of agricultural pesticides and fertilisers into water used for human consumption result in poisoning and death (Pimentel et al. 2004).

Human health and soil are discussed further in Chaps. 24 (Brevik et al.) and 25 (Carre et al.).

1.3.6 Biodiversity

Soil biodiversity is the variety of soil life, from genes to species to communities, and the variations in soil habitats, from micro aggregates to entire landscapes (Turbé et al. 2010). Over 25 % of the world's species are soil organisms; however, only 1 % of soil organism species have been identified (Lal 2006). The paucity of knowledge of soil biodiversity is a problem, because we do not know how much undiscovered biodiversity has already been lost. Because soil biodiversity is not visible in the way that above-ground biodiversity is, it is easy to under-recognise and undervalue it.

The ecosystem services provided by soil organisms are well understood. These include soil formation; decomposition; nutrient cycling, fixation and sequestration; and infiltration, purification and storage of water. Bacteria are responsible for the widest range of biogeochemical transformations. By contrast, invertebrates engineer the soil by mixing it and creating a matrix of burrows and pores that allow ingress of air and water, by adding substances such as silk or mucus and by incorporating organic matter and inoculating it with fungi. These processes are essential prerequisites for the biogeochemical transformations carried out by bacteria (Colloff 2011). Soil biodiversity therefore affects nutrient and water availability, soil structure and soil-borne disease – ultimately affecting other global challenges such as food and water security, climate change mitigation and human health. Solitary bees, by drilling burrows in compacted soil, greatly increase soil water recharge rates. Similarly, ant and termite activity has been shown to increase wheat yields (Colloff 2011). High levels of soil biodiversity also confer resilience against stress and disturbance and suppress disease (Brussaard et al. 2007).

Soil biodiversity is part of the natural capital of soil. The value of ecosystem services provided by soil biota may exceed 1.5 trillion US dollars per year. This includes recycling of 38 billion tonnes of organic wastes (over $760 billion), fixation of 100 Kg of nitrogen per hectare per year ($90 billion), bioremediation of polluted soil and water ($121 billion), control of agricultural pests ($160 billion) and pollination of crops ($200 billion) (Brussaard et al. 2007). Soil biodiversity also has value as a potential source of new pharmaceutical compounds; penicillin was first isolated from a soil fungus.

Threatening process for soil biodiversity includes habitat loss and fragmentation, as well as the disruptive effects of invasive species. However, we have insufficient knowledge of the size and mechanism of these effects. Management practices that enhance soil biodiversity include crop rotation, zero tillage, organic amendments and incorporation of natural elements into landscapes (Brussaard et al. 2007).

1.3.7 Summary

All six global existential challenges are connected to each other, through the underpinning role that soil plays in each. Interventions which address one challenge will inevitably affect one or more of the other challenges, and effects may be positive or negative. However, interventions which enhance the status of soil have been shown to have positive, synergistic effects on other challenges. Soil security is the common factor that must be addressed if these global challenges are to be successfully managed. The global challenges are also noble challenges – they are widely regarded as ethical issues, and there is a high level of political and social motivation to address them.

The global existential challenges constitute a "top-down" motivation for developing the concept of soil security. However, we also need to incorporate the "bottom-up" motivation, i.e. the ways in which humanity cares for and values soil. This leads to a set of dimensions for soil security that are socio-economic as well as biophysical.

1.4 Dimensions of Soil Security

In order to secure soil, we need to be able to assess both its current state and optimal biophysical state. These are soil *condition* and *capacity*, respectively. However, in order to determine the suitability of a soil for a particular purpose, we must also be able to assess the value placed on the soil by society, the actors who influence its use and how the use is regulated. These value-laden criteria are, respectively, *capital*, *connectivity* and *codification*.

The five dimensions of soil security are briefly summarised here and are discussed in detail in Chap. 2 following and expanded throughout the subsequent chapters.

1.4.1 Capability

This dimension recognises that different types of soil have different potential uses, as a consequence of their intrinsic biophysical characteristics, and is influenced by the discipline of land evaluation. By measuring capability, we seek to establish what functions a particular soil can perform. Measurement of soil capability requires a reference state defined by the soil's genoform.

1.4.2 Condition

Soil condition refers to the phenoform, i.e. the current state of the soil, and recognises that the ability of soil to perform functions may change as a result of management practices. If soil management practices are consistent with a soil's capability, then its condition will be "fit for purpose". In other words, the use to which a soil is put should match its capability (McBratney et al. 2014).

1.4.3 Capital

By placing a monetary value on an asset, we better able to secure it. Soil is part of *natural capital*, defined as "the stock of materials or information contained within an ecosystem" (Costanza 1997). Soil stocks include soil moisture, temperature, structure and organic and inorganic substances. The condition of soil stocks affects the ability of the soil to provide functions, known as ecosystem services. Ecosystem services can be defined as "the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly" (de Groot 1992). Soil also provides physical products, known as ecosystem goods. It is essential when valuing elements of soil capital that the full value of goods and services is accounted for. For example, an increase in soil organic carbon may be valued only as a greenhouse gas offset; however, it plays a crucial role in other soil functions such as infiltration and retention of water.

1.4.4 Connectivity

Ekbom (2008) pointed out that research on soil has been carried out within the disciplines of soil science and economics and that these strands need to be better integrated. When soil science research is limited to biophysical parameters, it fails to take account of the socio-economic implications of the fact that soil is owned and managed by farmers. Conversely, economic analyses ignore or oversimplify soil capital. By incorporating the dimension of soil connectivity into soil security, we seek to address these shortcomings.

Connectivity is concerned with the decision-making of the people who manage land. It acknowledges that the effects of soil management occur on an intergenerational scale and that different forms of land tenure affect the way that soil is used and cared for. It also acknowledges the need for knowledge about how best to care for soil and for this knowledge to be effectively communicated. Historically, this communication occurred linearly through technology transfer, but present-day communication transfer is complex, with information being obtained from multiple sources and multiple disciplines.

A second, relatively undeveloped aspect of connectivity seeks to determine how wider society understands and relates to soil. This is important because public knowledge and understanding will lead to increased public interest, concern and lobbying for measures to protect soil. We define the *societal footprint* of a soil as the sum of people who consume products from that soil. To enhance the security of a soil, its consumers need to be aware of their connection to it. New forms of media and communication have a part to play in facilitating this.

1.4.5 Codification

Codification acknowledges the need for, and role of, government policy and regulation in ensuring that soil is cared for. Effective policymaking involves the participation of all stakeholders and effective communication and translation of soil science knowledge, to generate practical solutions.

In recent decades, the need to protect soil has begun to be recognised in policymaking. Initiatives include the World Soil Charter (Food and Agriculture Organization 1982), the World Atlas of Desertification (United Nations Environment Programme 1992) and the World Soils Agenda (Hurni and Meyer 2002). These early initiatives focused on the biophysical issues of soil erosion and fertility. More recently, the Global Soil Partnership, launched in 2011, has a much needed broader focus that includes food security and climate change abatement (FAO 2015b).

1.5 Conclusions

The concept of soil security has strategic value in that it can serve to focus and guide the development of policies addressing the six global existential challenges, such that interventions for one challenge result in favourable effects on other challenges. It is timely in that while soil itself faces an unprecedented global threat, other global existential challenges, connected and underpinned by soil security, are the focus of international social and political attention.

The previous work on soil quality and soil health has focused on biophysical parameters to assess a soil's current condition. However, these concepts fail to include a reference state or capability for each soil. Securing soil also requires that society assigns full value to it and the goods and services it is able to produce. This in turn requires users of goods and services to understand their connection to soil and for appropriate policy and regulation to be in place as a safety net.

Soil security arises from both top-down (global challenge) and bottom-up (societal value) considerations. We envision it as a homologous concept to those of food and water security. The major goal is to measure and manage the five dimensions described. "If we can measure it, we can treasure it"; in other words, it is well established that in order for a good or service to be adequately recognised, valued and protected, it must be measurable.

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Chapter 2
Soil Security: Dimensions

Damien J. Field

Abstract Soil security is a concept that will make it possible to understand soil and its role in delivering ecosystem services and is used to quantify the soil resource by measuring it, mapping it, modelling it, managing it and forecasting its change. To achieve this will require a coming together of soil scientists, economists, social scientists and policy makers to discuss and contribute to the decision-making about soil. To frame this discussion requires a multidimensional approach whereby soil security acknowledges five dimensions of (1) capability, (2) condition, (3) capital, (4) connectivity and (5) codification. Each of these dimensions encompasses the social, economic and biophysical disciplines that contribute to providing good relevant soil knowledge, its use and integration into policy and legal frameworks. These dimensions can be used to assess the seven recognised functions that soil provides to society and are useful in characterising the threats to soil security.

Keywords Soil functions • Soil protection • Ecosystem services • Natural capital

2.1 Introduction

As described in Chap. 1, there are now six global existential challenges that have drawn the attention of the entire world. There is a common acceptance for the need to ensure global food, water and energy security. In doing so there is an understanding that biodiversity and ecosystem services have to be managed to avoid their decline (Godfray et al. 2010; Janzen et al. 2011). All of these challenges present risks to human, animal, plant and microbial health and are explored more fully in Chap. 35 (Jeffery and Achurch). Analysis of these challenges reveals that soil has a role in all of these, yet many exploratory models used to investigate these global challenges often only incorporate limited soil expertise (Bouma and McBratney 2013). The degradation of soil through erosion, fertility decline, acidification, salinity, compaction and soil carbon decline (Commission of the European Communities

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Table 2.1 The relationship of the six global challenges supported through the seven soil functions. The soil functions are italicised and numbered

Global challenges	Role of the soil functions
Food security	The quantity, quality and accessibility of food are affected by having soil that can produce an adequate *biomass* (1) through the soil being able to *store, filter and transform nutrients, substances and water* (2) and avoiding contamination
Water security	Soil contributes to clean water by *storing, filtering and transforming nutrients, substances and water* (2)
Energy security	The use of plants for energy is supported by soil's ability to produce *biomass* (1) linked with *storing, filtering and transforming nutrients, substances and water* (2) but may not be synergistic with food production and sustainable water use
Biodiversity	Soil has the largest *biodiversity pool, demonstrated through the diversity of habitats, species and genes* (3) enabling plant growth and recycling of waste and a source of products that benefit human and ecosystem health
Human health	In addition to the security of food and water and the potential resources that can be gained from maintaining a diverse gene pool in soil, human health is also supported through *the provision of physical and cultural environments for their activities* (4). Also, being an *archive of geological and archaeological heritage* (7) provides an opportunity for connecting with history or cultural identity, all of which contributes to well-being
Climate change	Soil *acts as a pool for organic carbon* (6), which contributes to the reduction of greenhouse gases. The use of soil as *a resource for raw materials* (5) is a concern as this removes a potential sink for carbon

2006) has significant consequences for agricultural productivity, provision of water and loss of biodiversity (Koch et al. 2013).

Following the definition provided in Chap. 1, soil security is focused on maintaining or improving the world's soil resource in response to the global challenges. In this definition, soil security is used in the same sense as security is used for food, water and energy (McBratney et al. 2014). Securing soil will involve recognising the agreed seven functions that soil provides as listed in Table 2.1 and listed in Chap. 3 (Bouma et al.). The role of soil in accumulating nutrients and water to secure our food, fibre and biofuel and for the provision of fresh water is recognised as two of the seven functions that soil provides. The function of the soil to store carbon and provide a habitat for the largest diversity of organisms needs to be protected to support environmental health, and as explored in Chap. 24 (Brevik et al.), the associated gene pool may provide an opportunity to advance pharmaceutical products to support human well-being. Supporting an environment for recreation and an archive of cultural heritage also needs to be observed, while the function of soil to provide materials for building may be seen as a threat (McBratney et al. 2014). The effect of maintaining or improving the ability of the soil functions for each global challenge needs to be assessed simultaneously, as the improvement of a soil function addressing one of the global challenges may have a negative impact on one or more of the others.

Recognised by the Food and Agriculture Organization of the United Nations, the knowledge of soil and the crucial role of the soil functions remain largely in the domain of soil science, and its consideration by other disciplines and decision makers and for policy is sporadic or of a secondary priority. Therefore, to frame this concept, a set of dimensions need to be established that articulates the function of soil and also makes soil security more inclusive, as has been done for food and water security, where the dimensions should account for the quantity, quality and accessibility of the soil (McBratney et al. 2014).

2.2 The Dimensions

As well as biophysical attributes, the global existential challenges inevitably have economic, social and policy aspects, which need to be addressed simultaneously (McBratney et al. 2014). This means that in addition to the use of scientific principles to assess soil, the decisions on soil and its management are also contextual and value driven (Alrøe and Kristensen 2002; Bouma et al. 2012; Schjønning et al. 2004), Therefore, this requires a multidisciplinary and multidimensional approach, and in doing so, the dimensions would explicitly distinguish the assessment of the optimal state of the soil, the current state of the soil and how the soil is effectively utilised (McBratney et al. 2014).

Two of the dimensions, capability and condition, focus on the biophysical aspects of soil, and these form the core business of soil science with a long history of research. While everybody's problem, but not the central focus of soil science, is the socio-economic concerns faced when soil is not secure. To address these soil security demands, there is a need to place a value on soil and its contribution to natural capital. To do this will also require an understanding of how people are connected with soil, and these along with the biophysical attributes will contribute to good policy to secure the soil against further degradation.

2.2.1 Capability and Condition

If we focus on food security, it is suggested that an increase of 50–70 % in production over the next 40 years is required while using the same area of land. This means we will have to produce more with less, including arable land, water and inputs, while adapting to climate change and maintaining biodiversity and other ecosystem services. To avoid further deterioration of the soil resource and optimise land management to maintain or even improve the soil condition compared to its natural ability will benefit from some assessment of the soil's suitability for a particular purpose and an ongoing management plan.

Capability refers to the ability for a soil to function and in particular asks the question 'what can this soil do?' As described by McBratney et al. (2014), this dimension is strongly influenced by a long history of work on land evaluation (FAO 1976), and this framework has resulted in well-defined land qualities on which the suitability for a particular use is classified (Bouma et al. 2012; iCannals et al. 2007), and this is fully explored in the work by McBratney et al. (2014).

Knowing the soil's capability will enable us to determine if the soil is at its full potential (a reference state) and if not, what is the potential to improve the soil in terms of the soil type, location and associated costs. To do this will require a set of soil indicators, and these need to be included in soil classification frameworks mapped across the landscape (Bouma et al. 1998; Rossiter 1996). The potential indicators and their utility are further explored in Chap. 4.

By objectively determining the soil's capability, we would also have a set of indicators that will enable determinations beyond its production potential to strategically include other ecosystem services such as nature reserves, water catchments and urban developments. Experts claim that ecosystem services contribute $125 trillion annually (see Chap. 20) and there is the opportunity to combine the soil capability with the costs of infrastructure and access. In this case capability provides the basis to quantify the soil resource across space and time that can be used for mapping, planning, modelling and forecasting.

As well as determining the capability of the soil, there is a need to assess the current condition of the soil which when referred to the soil's capability enables us to determine if the soil is being managed to its reference state (McBratney et al. 2014). Unlike capability, the condition of a soil is contemporary and is measured on a short-term management scale (McBratney et al. 2014). The use and management of the soil will result in changes to the soil condition, and if managed in a way that is consistent with its capability, its condition will be 'fit for purpose'.

The concepts of soil quality, soil health and soil protection are analogous to the dimension of condition and for the past 20 years have resulted in the development of a set of indicators to monitor that changes in the soil condition and have formed the basis assessment frameworks such as Soil Management Assessment Framework (SMAF), for soil quality score cards and kits (Andrews et al. 2004; Karlen et al. 2001). A distinguishing feature between quality and health is the focus on biological indicators by the latter, and the notion of soil protection is driven by the identification of threats to soil (Doran and Ziess 2000).

Assessing the soil's condition asks the more focused question of, 'Can this soil do this?', and in doing so the suitability of the soil for production, the assessment of changes over time and the management strategies that may be required are addressed (Schipper and Sparling 2000; Tugel et al. 2005; Wilson et al. 2008). Assessing changes in the soil's condition will also enable us to monitor soil threats such as erosion, acidification, sodicity and salinity, soil carbon decline and the emerging concern of subsoil constraints (Table 2.2) (McBratney et al. 2014). The allocation of water between human consumption and environmental and competing irrigation needs has also focused attention on the soil to be managed to store, transport and filter fresh water (Rockström et al. 2009).

Combining these two dimensions with science and farmer know-how along with properly invested technology will transform the production system. As an example,

Table 2.2 The threats to soil security

Dimension	Threat
Capability	Erosion, landslides and sealing by infrastructure
Condition	Contamination, organic matter decline, acidification, salinisation and floods
Capital	Inadequate value of the soil, its stock and supporting services, resulting in degradation (e.g. nutrient decline) and loss of regulating services (e.g. flood mitigation)
Connectivity	Inadequate knowledge and expertise in soil to provide reliable soil knowledge and an ever-increasing disconnected society
Codification	Incomplete and not properly integrated policy framework resulting in poorly designed legislation to service adequate legal securities

After McBratney et al. (2014)

simple approaches such as minimum tillage have addressed soil erosion, carbon storage and soil moisture (see Chaps. 14, 15, 16 and 23), but there is more to be done.

2.2.2 *Capital, Connectivity and Codification*

The least developed, yet equally important, dimensions of soil security are identified as capital, connectivity and codification. Placing a value on soil is accepted as a means to improve its security, and this is being addressed through frameworks such as ecosystem services. According to Robinson et al. (2009), placing a value on ‘things’ that contribute to human well-being avoids the neglect or omission of a resource or its contribution to the system in any decision-making process (McBratney et al. 2014). Thus, placing an inadequate value on soil can be considered one of the threats to its security (Table 2.2). Also known as natural capital, this is determined by knowing the compositional state of the soil, stocks, which mediate the functions that the soil provides contributing to the ecosystem service. The products derived from the ecosystem service by the soil are known as ecosystem goods (Costanza et al. 1997; Dominati et al. 2010; Robinson et al. 2012).

Valuing soil through its productivity and the other ecosystem services it provides requires a value to be placed on the soil stock and the goods that it produces, resulting in synergies that support both agricultural production and the surrounding ecosystem. Ecosystem services are derived from abiotic and biotic process and interactions, where ecosystem goods are concrete in nature, e.g. rocks, plants, soil and recreation. According to Brown et al. (2007), this is complicated depending on how practitioners in this area lump together or make a clear distinction between services and goods. This is an ongoing challenge for developing an account for soil (McBratney et al. 2012), and an example of how this is currently being achieved is given in Chap. 18 (Dominati et al.).

To support the farmer’s connectivity with soil will require having access to good soil information and knowledge and requires new ways of thinking about education and knowledge transfer and extension. One suggestion is capacity building through *knowledge brokers*, i.e. training those with good soil science knowledge and the social intelligence to see how this soil science knowledge can be used (Bouma et al. 2011). Engaging these knowledge brokers will also facilitate collaboration between researchers, educators and those who need good soil knowledge to support an environment where advice on soil can be collaboratively addressed (Stockmann et al. 2013). This will be underpinned by new approaches to education across the sector to incorporate teaching and learning experiences using problem-solving and a strong engagement with industry working on *real-world problems* (Field et al. 2010, 2011; Bouma and McBratney 2013) to connect the knowledge of soil science with the economic and value decisions being made by those who manage and write policy to secure soil.

Connectivity goes beyond those using soil for production and the ecosystem services it provides. To secure soil it is an imperative that society is able to reconnect with soil. Concepts, such as *terroir* relevant to viticulture, are an illustration where the wider society places a value on wine from particular soil, meaning the security of the soil is societally stronger (McBratney et al. 2014). There is the opportunity to expand this concept by developing systems that will enable the traceability of other products to the soil from which it is derived (see Chap. 22). The fashion of crowd-sourced data as a means to gather soil information needs to also be embraced by the soil science community as this illustrates how society know, interpret and value soil (Shelley et al. 2013). This along with traceability of the soil will contribute to those interested in developing a connection with soil to obtain a social licence (see Chap. 22).

It has been suggested, as a first step, there is the opportunity to identify one indicator which could be used to report the state of soil to the broader community. This approach is not endorsed by soil science, but since society is focused on carbon if a single indicator is warranted, the perhaps soil carbon should be adopted (see Chap. 41). This along with the support provided by knowledge brokers and the recognition of the soil services and goods provided to society lessens the threat to soil (Table 2.2).

Soil policies are often perceived as second tier or lower in international and national policy frameworks and are often trumped by the less explicit term *land*. Regarding codification the agreed national policy around soil is sporadic and may not be well developed in an integrated regulatory strategy. There have been a number of initiatives to give soil a stronger policy framework including the World Soil Charter in the 1980s, the United Nations Environmental Programme (UNEP) and World Atlas of Desertification and, more recently, the Food and Agriculture Organization's Global Soil Partnership (FAO 1982; UNEP 1997; Global Soil 2012). The continued use of soil science in framing policies internationally and nationally will need the good cooperation between soil scientists, lawyers and the bureaucracy (Napier 1998; Hannam 2007). A challenge for soil science is the willingness to accept policy is also built on decisions around the non-scientific principles of *better* or *worse* (Bouma et al. 2011) are constrained by economies and the value individuals put on soil, which needs to be facilitated by the knowledge brokers. Having society connect with soil and providing accessible soil capability and condition data

Table 2.3 Relationship of the dimensions with the soil's functions

Soil function	Dimensions
(i) Biomass production	Capability, condition
(ii) Storing, filtering and transforming water, nutrients and substances	Capital
(iii) Provisioning for habitat and gene pool	Capital
(iv) Cultural environment for mankind	Connectivity, capital
(v) A resource for building materials	Capital, condition
(vi) Acting as a carbon pool	Condition, capital
(vii) An archive for archaeological heritage	Condition, connectivity

will improve the opportunity for complete and integrated policy development to secure soil (Table 2.2).

2.3 Future Needs

If we consider the seven agreed soil functions, there already exists a strong alignment with the dimensions described here (Table 2.3). The capability and condition of the soil would be a major consideration for biomass production, while the ecosystem services provided by soil function (ii) are significantly influenced by capital. Providing a cultural environment would be influenced by how connected people are and the opportunity to store carbon is affected by value placed in it. The archaeological significance will be determined once again by the connectivity of society and the condition of the soil which may affect the long-term preservation. Exploring these connections further will require the development of risk-based soil security assessment and policy framework (McBratney et al. 2014). This will include an agreed method in which to assess the capability and condition of soil and in turn how this data can contribute to establishing the soil's capital and be included in accounts of ecosystems' goods and services. Efforts to widen the connectivity of soil and explore policy options when failure in one or more of the other dimensions results in soil insecurity are also warranted. This risk-based assessment needs to include the assessment of uncertainty for each and the combination of the dimensions and be expressed in a way that can be understood across the disciplines involved. Some of these issues are explored in the chapters in this book.

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Part II
Capability

Chapter 3
Soil Capability: Exploring the Functional Potentials of Soils

Johan Bouma, M.K. van Ittersum, J.J. Stoorvogel, N.H. Batjes, P. Droogers, and M.M. Pulleman

Abstract Capability, a term that has been well defined in welfare economics, can be applied to soil by defining the intrinsic capacity of a soil to contribute to ecosystem services, including biomass production. Seven soil functions are used to define capabilities, and combining different functions in storylines provides integrated expressions for capability considering the different functions. Applied to biomass production in a sustainable production system, potential production (Yp) is defined as a function of radiation, temperature, CO2 and plant physiology. Yp is independent of soil and provides an absolute point of reference. Yw represents water-limited yield, reflecting actual water regimes and assuming that soil fertility is adequate and pests and diseases don't occur. Ya represents actual yield. A soil capability index (SCI) is defined as SCI = (Ya/Yw) × 100 for a biomass production storyline for rainfed production systems. Some examples are presented. Using simulation modelling, Yp can be simulated for a given climate and Yw can be simulated for a given soil in a probabilistic manner using weather data for 30 years as a form of quantitative land evaluation. Ya can be measured. Not only capability, as such, is important, however, but also the way in which capability can be realized under practical conditions. Then, a management support system is needed to guide a farmer real

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time through the growing season, also taking into account long-term effects. Capability is defined for a given type of soil (the genoform), but sometimes management has had significant effects on soil properties, requiring a phenoform approach, as is illustrated.

Keywords Soil capability index (CPI) • Land evaluation • Soil functions • Potential yield • Water-limited yield

3.1 Introduction

The capability approach was introduced in welfare economics in the 1980s by the Nobel laureate Amartya Sen (Sen 1985), presenting a range of ideas that had been inadequately formulated in traditional welfare economics. The core focus is on what individuals are able to do, and the capability approach has later become a key factor in defining the UN Human Development Index, now a popular and widely quoted measure of human development capturing capabilities in health, education and income. What applies to humans applies to soils as living bodies in a landscape, which are subject to external forces with effects that are determined by inherent soil properties and capabilities. Sen (1985) identified five components for assessing capability, and each of them can be "translated" to fit soils:

(i) *the importance of real freedoms in the assessment of a person's advantage* translates into the need to take a fresh look at soils, independent of, but building on established opinions, schemes, codes and rules;
(ii) *individual differences in the ability to transform resources into valuable activities* translate into the need to recognize differences in potentials among soils. Each individual soil "has a characteristic story to tell". Soil Taxonomy (Soil Survey Staff 2010) provides names for individual soil types (soil series) that represent more than a combination of separate parameters;
(iii) *the multivariate nature of activities giving rise to happiness* translates into the different functions of soils (to be discussed later) that can individually or in combination result in healthy, vital soils, which in this context may qualify as a measure of happiness;
(iv) *a balance of materialistic and non-materialistic factors in evaluating human welfare* translates, again, in emphasis on the soil functions that not only emphasize physical, chemical and biological processes but also cultural and heritage values;
(v) *concern for the distribution of opportunities within society* translates into the need to not only focus on soils with the highest potentials but to also try to enhance opportunities for soils with inherent lower potentials. Moreover, some soils excel only in certain functions and not in others. This needs to be recognized.

These five components of soil capability will be considered when discussing capability, which places emphasis on functionality rather than on soil genesis that is the foundation of Soil Taxonomy (Soil Survey Staff 2010; World Reference Base 2014). Functionality can be well expressed by the seven soil functions, defined by EC (2006). Putting soils in a broad environmental and socio-economic context is crucial for future development of pedology (e.g. Bouma 2015a, b), and focusing on the contributions of soil functions to ecosystem services provides a necessary environmental perspective. Obviously, soil functions by themselves can't realize ecosystem services. Soils interact with functions of other disciplines such as agronomy, hydrology, climatology and ecology as they jointly formulate general ecosystem services. These are, in turn, related to the 17 UN Sustainable Development Goals (SDGs) that provide a socio-economic perspective. Six Dutch and Italian case studies recently illustrated logical links between soil functions, ecosystem services and SDGs (Bouma et al. 2015), and these links will not further be discussed here.

Emphasizing "what soils can do" (McBratney and Field 2015) implies attention for soil potentials. However, rather than discussing potentials as such, also ways to reach such potentials need to be explored to avoid a purely conceptual and sterile analysis without practical implications. The focus will be on individual types of soil, as defined by the soil series concept used in Soil Taxonomy (Soil Survey Staff 2010).

In summary, the objectives of this chapter are to define (1) soil potentials for a given soil based on analysing soil functions that are, in turn, linked to ecosystem services and SDGs, (2) how potentials can be reached and (3) a conceptual framework for the capability concept based on quantitative, reproducible criteria.

3.2 The Seven Soil Functions and Storylines

Seven soil functions have been defined by EC (2006):

1. Biomass production, including agriculture and forestry (relates to *food* and *energy* security)
2. Storing, filtering and transforming nutrients, substances and water (relates to clean *water* availability)
3. Biodiversity pool, such as habitats, species and genes (relates to *biodiversity* loss)
4. Physical and cultural environment for humans and human activities
5. Source of raw materials
6. Acting as a pool of organic carbon (relates to *climate* change)
7. Archive of geological and archaeological heritage

The seven soil functions cover five widely recognized major environmental issues, as indicated in italics. Functions 4, 5 and 7 set soils apart. They require a landscape approach, legislation and zoning to establish, for example, nature parks and geoparks. Extraction of raw materials, such as sands and peats, also requires enabling legislation in many countries. Criteria to judge functions 4 and 7 require expert judgements, while function 5 has a more economic character. The remaining functions 1, 2, 3 and 6 are often considered separately because the climate, hydrology and biodiversity research communities have separate identities and cultures (as has soil science). The functions are, however, strongly interrelated, and this can be well expressed by storylines that are also quite effective for communicating with citizens, stakeholders and policy makers. Examples are the following:

1. How can a sustainable production system (function 1) be developed where groundwater and soil quality are protected (function 2) and where biodiversity (function 3) and the organic carbon content (function 6) are increased or at least maintained?
2. How can the soil capacity to store, filter and transform nutrients, compounds and water (function 2) be maximized to allow development of sustainable production systems (function 1) with a relatively high biodiversity (function 3) and organic carbon content (function 6)?
3. How can land use be optimized to the effect that the soil biodiversity pool (function 3) in terms of habitats, species and genes makes a maximal contribution to soil functions 1, 2 and possibly 4 and 7?

In this chapter, attention will be focused on storyline 1, presented above, starting with function 1. Three steps are distinguished when implementing that storyline:

Step 1. What is potentially possible? The general land evaluation approach (FAO 1976, 2007) is empirical in character and needs to be quantified to face modern demands. Simulation modelling can express yields, trafficability and workability in terms of probabilities and risks, expressing effects of weather differences over an extended period of time. Also potential yields can be calculated that are independent from soil data, based on radiation, temperature and CO2. The focus here is on the use by land use planners and the regional level.

Step 2. How can the potential be reached? This has a short- and long-term dimension. The short term requires a management support approach leading the farmer through a given year with unknown weather conditions considering risks and indicating pitfalls and opportunities on the way. The long term relates to the requirement that soil quality is at least maintained over the years and preferably improved. The focus here is on the use by the farmer, and carbon management is an important element of management in this context.

Step 3. Resilience: When something goes wrong, e.g. when soil is inadvertently compacted, when fertility is severely depleted or when biocides are leaked, how resilient is the soil? Does it bounce back easily or is there lasting damage? The focus is on the use by both planners and farmers.

3.3 Functionality: The Phenoforms

Emphasizing functionality in the context of soil capability requires acknowledgement of the fact that soil conditions can differ considerably within a given soil series as a function of current and past management. This is not reflected in soil classification that quite correctly focuses on more permanent soil conditions and processes. To reflect the variability within soil types, Droogers and Bouma (1997) proposed the terms genoform for the genetic soil type and phenoforms reflecting effects of management. This is illustrated for a prime agricultural soil in the Netherlands with mapping code Mn25A (De Bakker 1979). The genoform, loamy, mixed, mesic Typic Fluvaquent (Soil Survey Staff 2010) and Haplic Fluvisol (WRB 2014), has developed into three phenoforms as a result of farm management: conventional arable farming, organic farming and permanent meadow (Fig. 3.1). Soil characteristics differ significantly within the soil type due to management (Table 3.1).

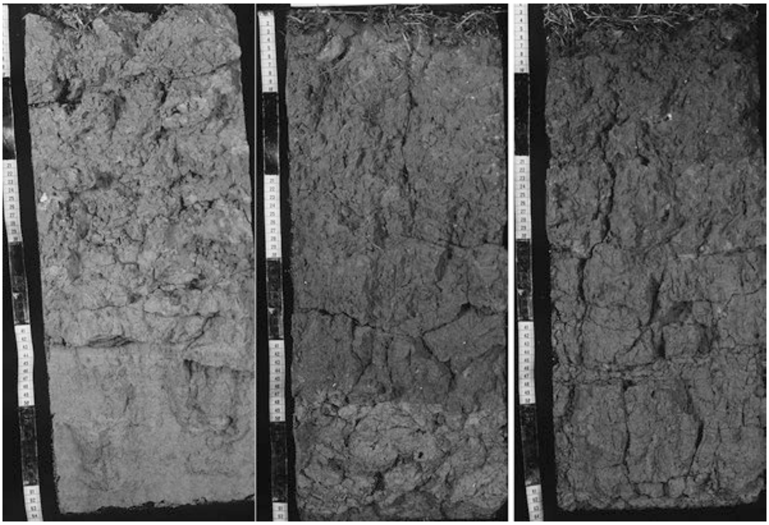

Fig. 3.1 The three phenoforms of the Typic Fluvisol in the Netherlands, from left to right: conventional arable farming (CONV), biological arable farming (BIO) and permanent meadow (PERM)

Table 3.1 Physical characteristics of the three phenoforms. Values for the three physical characteristics were significantly different at $p = 0.05$

Phenoform	Bulk density (Mg/m^3)		Organic matter (%)		Porosity (m^3/m^3)	
	Avg	Std	Avg	Std	Avg	Std
Bio	1.47	0.065	3.3	0.59	0.42	0.015
Conv	1.68	0.061	1.7	0.05	0.36	0.021
Perm	1.38	0.109	5.0	0.57	0.46	0.023

From Droogers et al. (1996)

Databases for soil series (i.e. genoforms) produce the range of measured soil characteristics, and these ranges are often rather large, some of them reflecting the effects of management. By distinguishing phenoforms of major soil series, these ranges can be restricted, and this is valuable to improve soil assessment. Pulleman et al. (2000) identified 40 sites on the soil map where the genoform Mn25A was found. The sites were sampled and soil organic matter content in the topsoil (SOM in %) was correlated to crop type (C=1, grass and C=0, arable) and management (M=1, organic and M=0, conventional) by regression:

$$\mathrm{SOM} = 20.7 + 29.7\mathrm{C}_1 + 7.5\mathrm{C}_2 + 7.5\mathrm{M}(\mathrm{r}^2 = 0.74)$$

where C_1 is the crop type 63–31 years ago, C_2 is the crop type 3–1 years ago and M is management type 7–3 years ago. Every genoform presents a unique equation, offering a good opportunity to estimate organic matter contents as a function of actual and past land use and management under the implicit assumption that the climate does not change significantly. Comparable results were obtained for a common sandy Dutch soil by Sonneveld et al. (2002).

3.4 What Is Potentially Possible? Quantitative Land Evaluation

Potential possibilities of any given soil are not only governed by soil properties but require consideration of the term “land” which is (somewhat abbreviated) defined as “an area of the Earth’s surface, the characteristics of which embrace all reasonably stable attributes of the biosphere including the atmosphere, soil, underlying geology, hydrology and biota and the effects of past and present human activities” (FAO 1976). Soil scientists should be aware of the fact that for outsiders, soil, land, dirt, earth and mud are synonyms, but putting soil in a broader ecological context by defining the term “land” is meaningful and justifies introduction of the term. It illustrates the importance of other scientific disciplines in defining “land evaluation” which describes “the fitness of a given type of land for a specific kind of land use” (FAO 1976). Traditional land evaluation by soil scientists uses soil characteristics to define different degrees of fitness, and this procedure is exclusively soil based, while fitness is also determined by many other disciplines, but it is also empirical, based on experience. This approach represented a breakthrough in the 1970s and is still valuable as it allows screening of regions, focusing attention on land where detailed analyses are meaningful, excluding, e.g. steep or stony areas or areas subject to flooding (e.g. Bonfante et al. 2015). But characterization of potentially suitable areas needs more quantitative, interdisciplinary approaches. While soil characterization and mapping have strongly and successfully developed during the last decades by geostatistics, remote, proximal and in situ sensors, electromagnetic non-invasive techniques, digital terrain modelling and GIS in general, development of land evaluation has been rather limited (e.g. Bouma et al. 2012). Quantitative models are needed to derive data that are potentially interesting to colleagues in hydrology, agronomy, climatology and ecology and to ever more educated stakeholders (e.g. Bouma 2015a, b).

Droogers et al. (1997) used the WAVE model (Van Clooster et al. 1994) to calculate productions of summer wheat for the three phenoforms, discussed above, using real weather data for a period of 30 years. A key element is the calculation of potential yield (Yp), which assumes that water and nutrients are in unlimited supply while pests and diseases don't occur or are fully controlled (Evans 1993; Van Ittersum and Rabbinge 1997; Van Ittersum et al. 2013). This value is location and crop specific and is defined by radiation level, temperature, CO2 and plant physiology and phenology. Realistic assumptions are made for sowing date and planting density as the cropping and farming system context in which production of a specific crop occurs is crucial. Yp is in theory soil independent and provides an absolute point of reference. Potential dry matter (DM) production is a function of the daily intercepted photosynthetically active radiation (PARi) by the canopy, under non-stressed conditions and with pests and diseases fully controlled, and the so-called radiation-use efficiency (RUE), expressed in grams of dry matter (DM) produced per megajoule of PAR intercepted. The seasonal dry matter production is then the summation of the daily values: $DM = \Sigma PARi \times RUE$ (Monteith 1977). The potential yield (Yp) is the product of dry matter production and the so-called harvest index (HI) which is the ratio of grain dry weight to crop dry weight (above ground) at physiological maturity ($Yp = DM \times HI$). The empirical value of the potential yield of specific crops can be derived from very well-managed experiments with ample water and nutrients and pests and diseases fully controlled.

Van Ittersum et al. (2013) define the "exploitable (potential) yield" as 80 % of Yp, which is more realistic in practice as a goal to be aiming at, as farmers do not know the weather in advance and cannot control all stresses and diseases for technical or economic reasons.

Next, water-limited yield (Yw) can also be calculated based on local water supply and again assuming that all the other growth factors are optimal. In its simplest form, Yw can be derived from Yp by multiplying it with the ratio of actual versus potential evapotranspiration. Generating 30 years of data allows presentation of results in terms of probabilities (Fig. 3.2). This is important information because farming is in essence a form of risk management and the curves of Fig. 3.2 allow risk assessment. Just providing average yields, even when including standard deviations, is much less attractive. The traditional system of land evaluation provided judgements in descriptive terms as degrees of "fitness for use". Now, judgements can be made by the land user or the politician who can select the level of risk he or she is comfortable with. Science should provide a choice not a judgement; see also Pielke (2007). The probability analysis was extended to trafficability and workability (Fig. 3.3). Workability was based on a threshold value for the soil moisture content corresponding to the lower plastic limit, defined by Atterberg and trafficability by measured penetrometer resistances (PR) as a function of the moisture content with a threshold PR of 0.7 Mpa (Droogers et al. 1996). Storyline 1 was

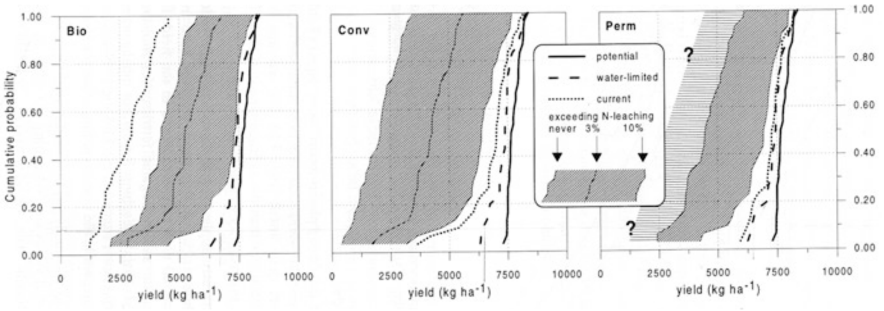

Fig. 3.2 Cumulative probabilities for simulated yields for three phenoforms, using 30 years of climate data (see text) (From Droogers and Bouma 1997)

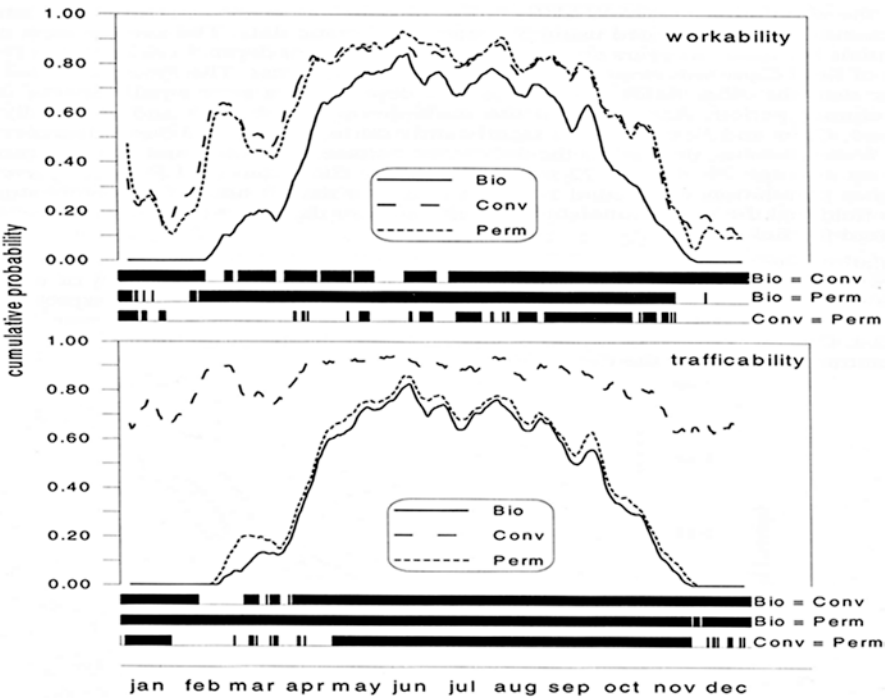

Fig. 3.3 Cumulative probabilities that workability and trafficability thresholds will be exceeded, as estimated by simulation of soil water regimes over a 30-year period (After Droogers et al 1996)

followed, also considered function 2, by running different fertilization scenarios for summer wheat aimed at defining rates corresponding with the probability that the environmental threshold of 50 mg nitrates/l in groundwater would be exceeded. Figure 3.2 shows that the curves are different for the three phenoforms. Due to N mineralization, the threshold is always exceeded (be it less than 3 % of the time), under permanent meadow. This approximate calculation procedure used the total calculated leached quantity of nitrates during a year and dissolved this in the precipitation surplus of that particular year, producing a single value above or below the threshold.

Van Ittersum et al. (2013) defined a "yield gap" (Yg) = Yp-Ya (actual yield) for irrigated crops and Yg = Yw-Ya for nonirrigated (rainfed) crops. The Global Yield Gap Atlas (www.yieldgap.org) provides examples for several continents and countries, showing that, for example, irrigated maize in Nebraska has (practically) reached the Yp level while rainfed wheat in Australia has reached only ca. 50 % of Yw. And, there is still a large Yg (often ca. 80 %) for rainfed maize in West Kenya. The yield gap analysis allows a focus on areas where the potential for production gains in the world is still significant.

The procedure of quantitative land evaluation by Droogers and Bouma (1997) for a given soil series focused on interrelated functions 1, 2, 6 and 3, the latter because higher organic matter contents are associated with lower soil disturbance and higher biodiversity. Thus, model runs for different soils allow comparisons in terms of their relative "fitness for a given type of land use" based on storyline 1. This is essential information for planning purposes, but it is less helpful for a farmer who faces every year a new growing season with as yet unknown weather conditions. Then, a management support system is needed to – in the context of this chapter – achieve the soil potential that has been estimated in the general land evaluation procedure.

3.5 How Can the Potential Be Reached? The Role of a Management Support System

Precision agriculture aims at providing the right quantity of nutrients, agrochemicals and water to plants as a function of space and time with the effect that, ideally, storyline1 is satisfied, because leaching of excess nutrients is avoided and costs are reduced (e.g. Stoorvogel et al. 2015). Note that 80 %Yp is also reached in many areas of the world following excessive fertilization, associated with environmental pollution which is avoided by applying the principles of precision agriculture. Then, obviously, storyline 1 does not apply because the system is not sustainable, which is a key element of storyline 1.

A study at the 150 ha van Bergeijk farm illustrates the procedure which was only possible because of the rapid developments in information technology (Van Alphen and Stoorvogel 2000, 2001, 2002; Bouma et al. 1999, 2002). The farm occurred on soil map unit Mn25A on the 1:50,000 soil map of the Netherlands, representing the genoform discussed above. But local variations in soil properties that are crucial for farming cannot be shown on this spatial scale. So a large number of soil observations were made, and simulation models were run for each observation focusing on aspects that were important for the particular production system being considered, including (i) water stress in a dry year and (ii) N stress, N leaching and total N at

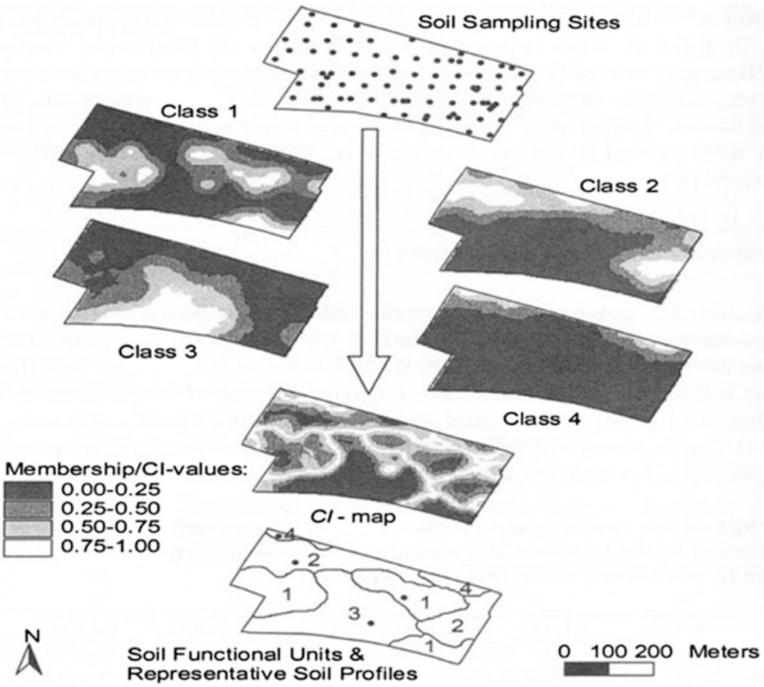

Fig. 3.4 Management units on a field of the van Bergeijk farm, determined by fuzzy clustering of point data for which simulations of key factors were made (see text) (After Van Alphen and Stoorvogel 2002)

harvest in a wet year. Maps of these four aspects were merged into one map with four management units using fuzzy clustering techniques (Fig. 3.4). The procedure followed for N management as the growing season progressed, using real-time modelling, is illustrated in Fig. 3.5. The amount of nitrogen in the root zone is calculated as daily uptake. Fertilization is recommended as soon as a threshold content is reached, avoiding complete depletion and damage to the crop. Recommended fertilizer quantities were based on available N in the soil and expected crop uptake during the remainder of the growing season. Fertilizer use was reduced by 35 % following this procedure as compared with the standard extension recommendation that is based on generalized data from climate and fertilization trials under a wide variety of conditions, creating a highly diffuse database.

Of course, actual soil management recommendations go beyond N fertilization. Bouma et al. (1999) reported recommendations for pesticide applications at the van Bergeijk farm, based on adsorption characteristics of various pesticides and their degradation properties. These data were valuable for the farmer because he could now apply relatively cheap pesticides on soils with a relatively high adsorptive capacity, while the more expensive chemicals could be reserved for the soils with a lower capacity. Again, financial gains were 35 % compared with the recommended procedure using the more expensive pesticide. The threshold values for workability

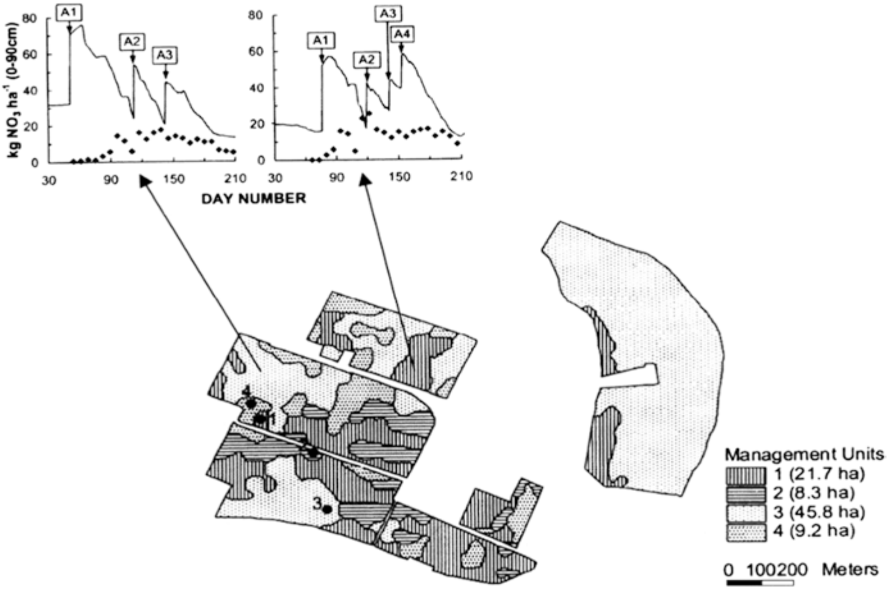

Fig. 3.5 N fertilizer applications (A numbers) for two management units as a function of real-time simulations of daily N uptake and storage of N in the root zone (After Van Alphen and Stoorvogel 2000)

and trafficability were also useful for actual management as soil traffic and tillage were avoided when the soil had moisture contents higher than the lower plastic limit. These moisture contents were simulated on a daily basis by the model. Presently, they can also be sensed in situ (e.g. Fares et al. 2013). Of course, nitrogen management and pesticide application are just two management measures. Application of proximal sensing techniques during the growing season can help to identify growth problems related to other factors in real time (e.g. Stoorvogel et al. 2015).

The van Bergeijk study was high-tech. But the principles of precision agriculture also apply in low-tech environments. African smallholder farmers, for example, often reserve application of the little amount of chemical fertilizer they can afford to areas in their fields close to their farm, because here waste products are usually deposited allowing a higher fertilizer response due to a higher soil organic matter content (e.g. Bouma et al. 2014; Giller et al. 2009; Tittonell and Giller 2012; Tittonell et al. 2005). Stoorvogel et al. (2004) reported an effective precision system on a banana farm in Costa Rica, and many other examples are available representing different degrees of technical detail.

Precision agriculture is focused on the short term, the next growing season. At the same time, management should also focus on the longer term, trying to preserve or improve the soil functions. Increasing the organic matter content of soil improves the soil functions by, e.g. manuring, incorporating cover crops or applying liquid or solid waste, and such measures need therefore to be considered as well when planning activities for the next growing season.

Precision agriculture, as applied in this case study, again follows storyline 1 as introduced above.

3.6 Resilience

Resilience addresses the dynamics and development of complex social-ecological systems (Folke et al. 2010). Three aspects are central: resilience, adaptability and transformability. Resilience in this context is the capacity of a social-ecological system to continually change and adapt yet remain within critical thresholds for performance criteria. Adaptability is part of resilience. It represents the capacity to adjust responses to changing external drivers and internal processes and thereby allow for development along the current trajectory (stability domain). Transformability is the capacity to cross thresholds into new development trajectories making use of crises as windows of opportunity for novelty and innovation and recombining sources of experience and knowledge to navigate social-ecological transitions.

So far, resilience has received relatively little attention in soil research. But accidents may happen, such as accidentally driving over wet soil causing compaction, unusual erosion following intense showers at a time a soil is unprotected or making errors by applying too much biocides. Problems can also be more long term, resulting from mismanagement leading to, e.g. nutrient depletion or inadequate return of organic matter to soil. How quickly can a soil recover? As this may take quite some time, it is difficult to see how short-term field experimentation can address this issue. The practical alternative is to try to use simulation techniques or, better, to observe and study changes in a certain soil type where mismanagement occurred at some time in the past. Returning to the field is a procedure also followed when distinguishing phenoforms. Anecdotal evidence was observed in Costa Rica, where relatively young andosols recovered rather quickly after being compacted during logging, while relatively old ultisols could not recover (e.g. Spaans et al. 1989). More attention is needed to characterize soil resilience as an important aspect of soil behaviour, possibly in the framework of a soil monitoring system (e.g. Arrouays et al. 2012; Batjes and van Wesemael 2015).

3.7 How to Best “frame” the Capability Concept?

A soil capability index (SCI) is proposed as an attractive means to “frame” the capability concept. Here, the focus is on storyline 1, which emphasizes sustainable production: SCI = (Ya/Yw) × 100. For irrigated crops (not considered here): SCI = (Ya/Yp) × 100. SCI is a dimensionless index, ranging between 0 and 100, allowing

Fig 3.6 Three genoforms used to illustrate the derivation of the soil capability index. From *left* to *right*: Ferric Luvisol, Orthic Acrisol and Orthic Ferralsol (see text)

comparisons among soils. Higher indexes indicate shorter trajectories towards reaching potential capabilities. Of course, the yield gap (Yg) also expresses such a trajectory in terms of crop yields in an agronomic context. The use of the soil-focused SCI is intended to attract the attention of soil scientists to the capability concept, emphasizing the particular contributions that soil science can make to reach soil capabilities. These contributions are bound to be major as they relate not only to soil moisture, air and temperature regimes but to fertilization and crop protection as well. Contributions need to be listed in the context of a management support system, as illustrated above.

As stated above, not only the SCI is important but also the way certain values are reached. Four soils were selected for illustration purposes, a Ferric Luvisol from Nigeria (Aw Köppen climate), a Haplic Acrisol from China (Cfa climate), a Haplic Ferralsol from Zambia (Aw climate) and a Haplic Fluvisol from the Netherlands (Cfb climate) (Fig. 3.6). Classifications are according to WRB (2014) and Peel et al. (2007). The Dutch soil is expressed by three phenoforms as discussed (Fig. 3.1). For the other soils, a hypothetical compacted phenoform and a water-eroded phenoform were considered (Table 3.2). Subsoil compaction was expressed by an assumed 50 % decrease of the infiltration rate and a reduced depth of rooting associated with a plough layer. Water erosion was expressed by an assumed topsoil loss of 30 cm with a concomitant decrease in infiltration rates and rootable depth, hence available water capacity. From a chemical point of view, for the Haplic Acrisol, erosion also resulted in acid layers coming closer to the soil surface, thus adversely affecting root growth of crops sensitive to Al toxicity. Results (Table 3.2) indicate that the

Table 3.2 The soil capability index (SCI) for estimated actual conditions (Ya) in four soil types as indicated

	Yp	Yw	SCI	SCI	SCI-Ya
	Mg/ha	Mg/ha	Erosion	Compaction	(Example)
Ferric Luvisol (Nigeria)	14	12	75	55	40
Haplic Acrisol (China)	8	7	40	85	60
Haplic Ferralsol (Zambia)	23	11	50	30	20
Haplic Fluvisol (Netherlands) Conv	6	6	nd	nd	100
Org	6	6	nd	nd	50
Perm	6	6	nd	nd	100

Values are also presented to indicate expected effects of erosion and compaction scenarios, as explained in text

Dutch Haplic Fluvisol has reached her potential, except for the organic farming phenoform where SCI= 50. This is due to only using organic manure and no chemical fertilizer and no chemical biocides.

Generally, yields of organic farms can reach 80 % of yields of conventional farms at single crop level (De Ponti et al. 2012), but this example illustrates that production, as such, does not cover the entire spectrum of societal concerns about modern agriculture. More importantly, emphasis on sustainable development while considering biomass production in storyline 1 implies that maximum production may not be a prime objective and that emphasizing the other soil functions may lead to lower production levels. The SCI, as defined here, allows such discussions.

Different Yp values for the locations of the other three soils show the effects of temperature and radiation on production. These are highest for the soils located in tropical Nigeria and Zambia. Yw values were calculated for a multiple cropping of C4 crops for which the number of growing seasons is determined by climate (Bouma et al. 1998). Yw, vis-à-vis Yp, is only markedly lower on the Haplic Ferralsol, reflecting that it occurs in a relatively dry climate.

Effects of erosion are strongest in the relatively nutrient poor and poorly structured Acrisol where toxic Al levels may come closer the surface upon topsoil loss. The effect of erosion is less clear for the Luvisol which has the highest natural fertility when compared to the Acrisol and Ferralsol. Effects of compaction are strong in all soils but relatively limited for the Haplic Acrisol with a low Yw and a low Yp due to climate conditions. The low SCI value for the compacted, originally well-structured Ferralsol is due to shallow rooting, which is deep in the uncompacted genoform. Ya shows the difference between actual conditions (based on assumed representative values) and Yw. The “road to be travelled” or the “yield gap closure” is longest for the Haplic Ferralsol where a relatively high Yw is quite attractive. With lower Yw values, the “road” may be shorter, but the goal to be reached is lower. Of course, when irrigation is available, 80 % of Yp can be reached. SCI values can indicate where potentials are highest, also when planning irrigation in water-scarce areas, realizing that long roads are not necessarily discouraging when

Yp and Yw values are relatively high. Of course, reasons for relatively low Ya have to be identified, and "management packages" need to be defined in terms of fertilization, biocide or biological controls and different crops or crop varieties and management practices. After decades of agronomic research, identifying "lighthouse" examples of successful farms becomes ever more possible and attractive to guide development. The UN Framework Convention on Climate Change (United Nations Framework Convention on Climate Change 2014) has successfully applied the "lighthouse" concept during the last 5 years.

Also, always identifying the type of soil, through classification according to an international system (e.g. Soil Survey Staff 2010; WRB 2014) that occurs, is important as "every soil has a different story to tell". This is often not done in agronomic research (e.g. Bouma et al. 2014; Hartemink 2015).

3.8 Conclusions

Soil capability, defining "what soils can do", requires emphasis on functionality and can therefore be based on interrelated soil functions, contributing to corresponding ecosystem services and SDGs. To make the soil capability concept attractive from an operational point of view, attention should also be paid to the gap between "what is"and "what can be", showing what needs to be done on the short term and the long term to close the gap.

Storylines are important to link different soil functions and avoid a separate disciplinary analysis of each of the functions which contributes less to defining soil capability in the context of sustainable development as compared with an integrated approach. Such an integrated storyline is presented in this chapter for function 1: biomass production. Other functions can, in principle, be evaluated in a comparable manner.

Models for quantitative land evaluation can be used to define *what is potentially possible* for a given soil series, defining capability, preferably using probability expressions allowing risk assessment based on multi-year simulations. Potential production (Yp) as a function of climate and plant physiology provides an absolute point of reference, independent of soil conditions. Water-limited yields (Yw) take into account effects of the local soil moisture regime but assume that nutrients are provided and pests and diseases don't occur. In reality, of course, many soils in the tropics and elsewhere are nutrient depleted or degraded, and pests and diseases do occur. That's why management support is needed to indicate how the gap between "what is" and "what can be" can be closed.

An attractive management support tool is precision agriculture, executed on the basis of real-time weather conditions to show *how potentials can be reached* in a given year and what needs to be done to get there. But actual management should also consider strategic long-term effects, maintaining or improving soil functions over longer periods of time. Aside from high-tech procedures, also low-tech variants of precision agriculture are successfully being used and may have the highest potential for the near future.

The proposed soil capability index (SCI) shows the gap between “what is” and “what can be” and defines the length of the road to be travelled, including advice what to do on the way. The term, originally proposed in the social sciences, relates well to soils as living bodies in a landscape being subjected to external forces. Interrelated soil functions play a key role in the process, and soil classification is important to define the object of attention.

Realizing soil capabilities in the real world is often quite complex because of, e.g. severe nutrient depletion and degradation, compaction, soil structure decline and loss of organic matter. But everywhere examples are to be found where creative farmers realize conditions that appeared at first to be impossible to achieve from a scientific point of view. The example of the UN Framework Convention on Climate Change (United Nations Framework Convention on Climate Change 2014) defining “lighthouses” where inspiring and transformational activities have occurred could be followed when further developing the soil capability concept.

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Chapter 4
Distinguishing Between Capability and Condition

Damien J. Field and T. Sanderson

Abstract Soil security is a concept that will make it possible to understand soil and its role in delivering ecosystem services and is used to quantify the soil resource. Of the five dimensions, capability and condition focus on the biophysical aspects of soil, and there is the potential to develop a data set of indicators to assess these two dimensions. The timescales of change and the ability to manage soils described by these dimensions will affect the choice of soil properties as indicators. Once established these indicators will be useful to users, managers and regulators of soil and the ongoing monitoring of changes in the soil's condition to avoid undesirable outcomes. This will involve understanding the soil's resilience to change both from a biophysical and socio-economic interpretation, i.e. focusing on the capability and its condition, respectively.

Keywords Minimum data sets • Resistance • Adaptability • Inertia • Opportunity • Possibility

4.1 Introduction

The concept of soil security has emerged in response to the global challenges that relate to increasing global populations, scarcity of water resources (Godfray et al. 2010; Rockström et al. 2009) and a need to maintain ecosystem health and maintain global biodiversity, and as described in Chap. 1 (McBratney et al.), all contribute to ongoing human health (Janzen et al. 2011). The continued loss of soil through erosion, acidification and salinity remains a concern globally (Koch et al. 2013). As described by Bouma and McBratney (2013), soil has a critical role to play and is linked through the seven functions that soil is known to provide, which are described in detail in Chap. 3 and are comprised of dimensions related to biophysical, economic and social considerations (McBratney et al. 2014). The five dimensions that

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frame soil security have been described in Chap. 2 (Field), and of these the two biophysical dimensions of *capability* and *condition* will be explored here.

To establish the capability and condition of a soil, a set of indicators will need to be established. These indicators should be clearly defined, and the scale at which they are useful should be considered (Karlen et al. 2001). The soil indicators also need to be aligned with the soil functions being considered and may not use the same soil properties for both dimensions. As well as establishing the indicators, the relationship between capability and condition to the soil's resilience needs to be further developed. Further developing this relationship will be useful when developing models to predict soil change (Tugel et al. 2005). While the two dimensions being discussed here focus on the biophysical nature of soil and its contribution, there is also an opportunity to consider how a socio-economic perspective of resilience will also engage with the dimensions of capability and condition.

4.2 Comparing Capability and Condition

Described in detail in Chap. 2 (Field), the dimension of *capability* is asking *what can this soil do?* which has many similarities to the concepts developed around land suitability that have been developing since the 1950s (FAO 1976; Bouma et al. 2012; iCannals et al. 2007; McBratney et al. 2014). In principle, knowing the soil capability will contribute to improved land management, enable land users to avoid land degradation and even quarantine areas of land that may serve a social value. As described in Chap. 2 (Field), capability also provides the basis to quantify the soil resource across space and time that can be used for mapping, planning, modelling and forecasting. McBratney et al. (2014) suggest that the identification of a reference state is required for this dimension, and based on the work by Droogers and Bouma (1997), this reference state may be described as a soil genoform. This is the identification of a local soil in its natural state and recognises what we know about soil and soil genesis (McBratney et al. 2014). There is also an acceptance that the long-term use of a soil, an extensive erosion and/or a catastrophic event would mean a soil can never return to its natural state (iCannals et al. 2007), and therefore using a combination of soil survey data, combined with the logic used in land evaluation, a local exemplar soil may be identified as the reference state (Bouma et al. 1998; Rossiter 1996; McBratney et al. 2014).

Complimenting capability assessing the soil's condition asks the question 'can the soil continue to do this?' This question focuses on the current state of the soil and considers its management on a short-term scale (McBratney et al. 2014). If this management of the soil's condition is done in a way that is consistent with the soil's capability, then its condition will be fit for purpose (McBratney et al. 2014). As described in Chap. 2 (Field), this dimension has a history linked with the development of the concepts of soil quality, soil health and soil protection (Andrews et al. 2004; Karlen et al. 2001; Doran and Ziess 2000). Primarily assessing the soil's condition will focus on monitoring changes over time, the development of management strategies that serve the intended use of the soil and guided by referring to the soil's capability, and establishing the soil threats that need to be overcome (Schipper and Sparling 2000; Tugel et al. 2005; Wilson et al. 2008; McBratney et al. 2014).

In combination these two dimensions will contribute to the development of a framework with a focus on the biophysical dimensions of soil. To determine the capability and condition will require a set of indicators, and in the case of capability, need to be incorporated into soil classification and/or land suitability frameworks (Bouma et al. 1998). Indicators for condition should be aligned with developing management strategies to improve the soil and used to establish the associated costs and in part affecting value of this use of the soil, i.e. its capital. Indicators for both dimensions need to be elucidated to establish the ability of the soil to resist degradation and understand how resilient the soil is to change. Understanding this will enable users of the soil to predict the long-term effect on the soil's condition and may be even permanent change in the soil's capability.

4.3 Potential Indicators of Capability and Condition

As noted by Karlen et al. (2001), the identification of appropriate indicators for each of the soil functions is best served by expert opinion from a wide spectrum of the community, including scientists, economists, soil scientists and stakeholders. The soil security concept encourages this level of engagement and should benefit this approach. There are many sources of data that could be collected to support this expert opinion, and statistical techniques such as principle component analysis are one of many ways data could be synthesised to related indicators to the relevant soil functions (Andrews et al. 2004). It has also been proposed that a minimum data set of soil physical, chemical and biological properties could be identified (Govaerts et al. 2006; Gregorich et al. 1994), in a similar way that has been done for soil quality and soil health, for both capability and condition.

For capability the soil's intrinsic properties that have developed over pedological timescales may be adopted as its indicators (McBratney et al. 2012). Table 4.1 suggests some possible soil properties that could be used to identify the soil capability. It is worth noting that these soil properties change over pedological timescales (Tugel et al. 2005) and are not readily changed through soil management. The use of texture, CEC, depth and stoniness and/or aggregation has long been associated with assessing the first two soil functions in Table 4.1, whereas the use of the other listed soil properties is still open to debate for the remaining five soil functions. For example, the need for building material (function 5) may require predominately sand, say for cement or low-activity clay for road bases, and therefore the texture and mineral types will determine the capability of the soil to support this. In contrast, the selection of soil properties to assess the condition is related to those which are quickly varying and manageable soil properties (Nortcliff 2002), for example, nutrient status for functions 1, 2 and 3 (Andrews et al. 2004; Karlen et al. 2001), the presence of soil carbon for function 6 (Stockmann et al. 2013) and a suitable pH that

Table 4.1 A list of potential indicators to measure capability and condition for each of the seven soil functions

Soil function	Condition	Capability
(i) Biomass production	Nutrients, pH, Exch. cations, bulk density, etc.	Texture, CEC, depth, stoniness
(ii) Storing, filtering and transforming water, nutrients, substances	Nutrients, pH, microbial activity, porosity, etc.	Texture, CEC, depth, aggregation
(iii) Provisioning for habitat and gene pool	Biodiversity, soil enzymes POM, etc.	Texture, CEC
(iv) Cultural environment for mankind	Strength, etc.	Texture, mineralogy, stability
(v) A resource for building materials	Linear extensibility	Texture, mineralogy, CEC
(vi) Acting as a carbon pool	Organic carbon, etc.	Texture, CEC, aggregation
(vii) An archive for archaeological heritage	pH, etc.	Texture, mineralogy

will not cause the deterioration of archaeological materials preserved in soil (Neff et al. 2005). Once agreed these indicators will enable us to know what the soil is capable of which will be useful to advise on government regulations, support stakeholders and their businesses (McBratney and Field 2015), and the ongoing monitoring of the indicators of the soil's condition to avoid any undesirable outcomes (Bouma et al. 2011).

4.4 Considerations of Resilience

Since the mid-1990s, there has been some consideration on resilience from a biophysical perspective, including for soil, focusing on the restoration process of soil after perturbation (Lal 1996; Kuan et al. 2007). This involves understanding the measuring soil indicators to assess the resilience, the rate of the change, and establishing the pathway to recovery or its loss (Lal 1993). This is illustrated for soil carbon in Fig. 4.1, where a change in management practice, such as change from grazing to continuous cropping, has resulted in a change in the soil carbon levels. The return to grazing may result in the return to the original carbon levels, whereas the adoption of minimum tillage and crop rotations may result in an increase in soil carbon but not to the original concentration (Fig. 4.1). The capability tells us that the soil can hold more carbon, but the management focusing on continuous cropping will result in a condition that will not achieve this. The difference between the original and this new equilibrium of carbon is interpreted through a process of flexibility and adaption, i.e. the rate at which the system can recover and who the system responds the degree of recovery, respectively (Tendall et al. 2015). Therefore, the

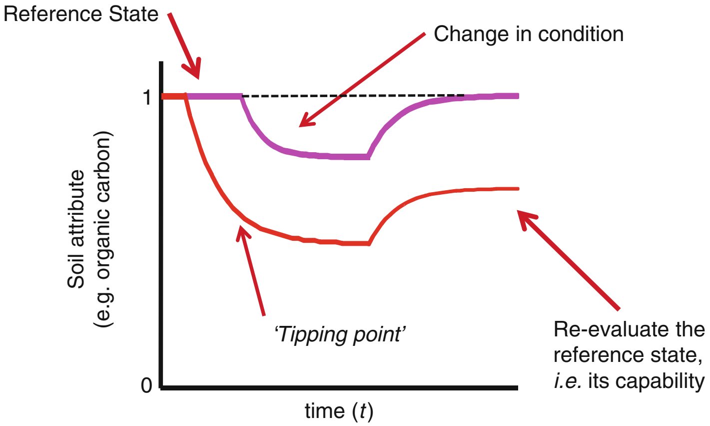

Fig. 4.1 Response of soil carbon to changes in management practices illustrating the resistance to change and the soil's resilience

capability is strongly aligned with the biophysical interpretations of resilience, but the choices made in relation to managing the soils condition, such as crop management, mean that the resilience of a system needs to also be viewed using a socio-economic understanding of resilience.

This view of resilience accepts that people significantly impact on the soil system as well, and they have expectations of the future in ways that the biophysical world cannot (Holling and Walker 2003). The presence of expectations in socio-economic systems means that resilience is related not just to the costs and benefits experienced in the current production regime, for example, wheat cropping, but is also related to the costs and benefits expected to attend the alternative production regimes, for example, livestock grazing pastures. In simple terms, in the present context, we are engaging with the question: what else could we be doing with the soil resources at our disposal? Given the fundamental questions of soil condition and capability outlined above, we can use the concept of socio-economic resilience to understand possible answers as an interaction between the socio-economic and biophysical worlds.

Taking the socio-economic perspective, soil condition presents us with a set of opportunities to utilise the resource for productive means. A resilient socio-economic production regime could impact positively or negatively upon the nature of opportunities conferred by soil condition over time. For example, poverty in subsistence farming systems exhibits strong socio-economic resilience but is also frequently associated with declining soil fertility over time (Hartemink 2003). The soil condition can in turn impact upon the resilience of socio-economic system through a variety of feedback mechanisms. In many cases subsistence farmers don't realise sufficient profits to justify reinvestment in the condition of their soils, which over time results in declining farm output. Lower farm outputs likely mean lower farm incomes, which reinforce the resilience of the poverty-dominated socio-economic regime.

The concept of soil capability establishes the possibilities of the system facing the land manager. The more limited the possibilities of the system, the more limited will be the range of management responses that can be made in response to changing conditions in related socio-economic systems. In economics the flexibility to respond to changing conditions is directly reflected in value, in this case the value of the soil itself. For example, a farmer who can take advantage of highly favourable commodity prices due to few soil capability constraints is wealthier than a comparable farmer whose soil capability constrains their response. The resilience of associated socio-economic regimes will be influenced by the nature of these capability constraints. The inability to flexibly respond to changing conditions in commodity markets, due to limited soil capability, suggests a socio-economic regime with potentially low resilience. Indeed, in cases of extreme soil capability constraints, there may be no socio-economic regime resilient enough to establish itself. In Australia, we call this kind of land national parks.

4.5 Future Needs

Establishing the difference between the dimensions of capability and condition illustrates that there is a need to investigate more fully the possible indicators that are relevant to evaluate these dimensions in relation to the soil functions. In doing so, it will be possible to compare the potential uses of the soil and monitor changes in the soil's condition and, in catastrophic events, changes to the soil's capability. Incorporating these into models, which evaluate the inertia, adaptability and resilience of the soil, both from a biophysical and socio-economic viewpoint, will enable the monitoring of soil change and avoid any undesirable outcomes.

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Chapter 5
Valuing of Soil Capability in Land Surface Modeling

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Abstract Land surface models (LSMs) simulate the mass and energy fluxes between the land surface and atmosphere and provide a critical link between hydrological and atmospheric models. In turn, hydrological and atmospheric models are being used to understand implications of policy changes on the global challenges of food, water, and energy security, as well as human health and biodiversity. These policy questions also address how solutions to these challenges might alter under drought and increased climate variability. Hence, LSMs have a broad base of users, for example, the Noah LSM has thousands of users, globally. Nonetheless, the Noah-MP LSM is using soil maps from the early 1990s and assuming vertically homogenous soil that is uniformly deep to 2 m. While it is known that soil water storage capacity and conductivity has a strong influence on energy fluxes, the disconnect is clear between knowledge of soil variability in the soil science community and land surface modeling activities in the atmospheric science community. An important step in securing the soil resource is acknowledging the role of soil in the global challenges. Soil provides a significant source of memory in the climate prediction system, so not having proper linkages and storages has the potential for significantly limiting model prediction accuracy. Currently, LSMs work well to predict climate; however, when policy makers ask the question of how climate variability alters food, water, and energy security, the scale of simulation must change, and answers from the scientific community are confined because soil science knowledge is not well represented in the accepted accounting system (the LSM). Ultimately, a better accounting of soil capability in the soil-plant-water-atmosphere

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exchanges of energy and mass is vital to soil security and addressing global challenges. In this chapter, we presented a case study that shows how soil information affected LSM's water and energy flux outputs in eastern Texas, USA.

Keywords Capability • Soil properties • Land surface modeling • Latent heat • Sensible heat

5.1 Introduction

Many disciplines of soil science have long valued the natural heterogeneity of soil. Soil properties can vary at depth in short distances of less than a few centimeters. Similarly, soil chemical and physical properties vary over landscapes at a hillslope scale (m) as well as across different geological depositions (km). This natural and mostly predictable variability also represents variability in soil capability or how well a soil can function to perform a given ecosystem service in the environment. Some soil functions are defined by the Soil Protection Strategy of the European Union, and include, biomass production, filtering nutrients, source of biodiversity, cultural environment, raw materials, carbon pool, and heritage. This chapter addresses how variations in soil capability alter our estimations of soil interacts in the biophysical environment. Particularly, this chapter addresses biophysical mechanisms of soil such as water capture and redistribution, energy capture and distribution, and the use of water and energy by plants growing in the soil. These soil biophysical processes are linked to global biophysical processes such as airflow and quality, hydrology cycles, and many other processes associated with energy and mass exchanges that are influenced by interactions between the soil surface, the vegetation, and the atmosphere.

Global existential challenges of society that depend on natural resources for survival include achieving food, water, and energy security, while maintaining human health and biodiversity in a climate that has increased weather variability (Chap. 1 McBratney et al. Chap. 2 Field). As part of the contribution of science to these challenges, simulation models are used to estimate how policy and management decisions might change global, regional, or local distributions of air quality, water quality and availability, nutrient availability and distribution, or energy fluxes. A significant component of these modeling activities includes the use of a land surface models (LSMs). LSMs simulate land surface interactions (mass and energy movement) and provide the boundary conditions as needed inputs for atmospheric models. For example, the Weather Research and Forecasting (WRF) model is a weather simulation model that is used to simulate mesoscale weather for scientific research and forecasting applications. An example of a research application of an LSM-coupled WRF simulation use might include using WRF (coupled with an atmospheric chemistry model) to predict how much ozone will accumulate over a city during the summer. A researcher might change conditions based on projected policy outcomes to see if the policy has any effect on ozone accumulation.

Ultimately, the goal in utilizing LSMs, multiscale atmospheric models, and any other coupled models is to simulate biophysical processes, to simulate mass and energy fluxes, to check that we understand the mechanisms and feedbacks associated with these processes, and to understand the consequences of changes in policy or land use. Soil properties are a key input for LSM modeling exercises, and because soil properties drive how water is partitioned between the atmosphere, plant, and groundwater, proper representation of soil system in the LSMs is crucial.

In current implementations of LSM models for the USA, two sources of soil information are used. First, the spatial position of soil is assigned for a given area. For example, a continuous grid of soil types has been created for the conterminous USA (CONUS-SOIL). This CONUS-SOIL map is gridded to 1 km, and it provides a spatial representation of soil particle classes (texture) and other soil properties for the soil surface and ten others depth to 2.5 m deep (Miller and White 1998). The second source of information is a look-up table that relates soil texture class to soil physical properties, including volumetric water content of soil at saturation, field capacity, permanent wilting point, and air dry; saturated hydraulic conductivity; and slope and intercept of a simple soil moisture release curve (Cosby et al. 1984, Chen and Dudhia 2001). These physical properties are used to solve for components of the hydrology cycle and to allow for the soil to store and provide water to plants during photosynthesis.

Though the CONUS-SOIL map is an excellent data source for how soil varies across the USA and soil scientists commonly use look-up tables of soil properties to simulate soil function regarding water movement, the use of soil knowledge in LSM modeling is incomplete. For example, Noah-MP LSM Niu et al. (2011) uses the surface soil texture mapped in CONUS-SOIL and assigns that surface texture class to the entire soil profile to 2 m deep. In other words, the default mode for running Noah-MP assumes that soil is uniform with depth and that all soil is 2 m deep. Additionally the soil look-up table that Noah-MP uses to assign each soil texture class to its physical properties has never been updated. The Soil Survey Division of the United States Department of Agriculture Natural Resource Conservation Service (NRCS) is continuously sampling soil across the USA and updating its soil databases. However the soil property look-up table that Noah-MP uses is very out of date. Previous work by Morgan and Kishné (2013) demonstrated that a simple update of the look-up table using contemporary soil databases, primarily provided by NRCS, significantly changed many soil property values in the Noah LSM look-up table. Morgan and Kishné (2013) hypothesized that these changes would result in significant changes in LSM simulation of surface simulations of water and energy fluxes. Particularly, they concluded that changes in estimates of soil moisture storage could significantly change processes like evapotranspiration. Evidence to this hypothesis is supported by Gochis et al. (2010), where limiting soil depth by the presence of bedrock significantly changed energy and water allocation in an LSM.

A key challenge to the soil science community is to engage with the LSM and atmospheric modeling community to improve the representation of soil properties for the purpose of developing better LSM simulations. The translation of the soil science knowledge about soil capability with the most updated and technologically enabled soil information is key to producing best estimates on how soil functions in the biophysical environment. The overall goal of this chapter is to provide an overview of how the representation of soil capability might be improved in LSMs as well as provide a simple illustration of the importance and effect of improving soil information in these types of models.

5.2 Experimental Overview

In this illustration, we show the effects of improving the look-up table that translates soil texture into soil physical properties and the effects of improving the three-dimensional spatial representation of soil variability. Improving spatial representation of and values of soil physical properties changes how the LSM simulates the water balance and surface energy fluxes. Particularly results of this illustration will show how partitioning of components of the water budget changes and how estimates of latent energy fluxes change. Latent and sensible heat partitioning is an important component of the energy balance at the Earth's surface that can be altered by soil processes and is key output of LSM simulations used by mesoscale weather models. At the Earth's surface, latent heat flux is the flux of heat associated with evaporation of water from the soil (or any surface) and transpiration of soil water through plant stomata. Sensible heat flux is the energy flux associated with changes in temperature at the Earth's surface.

A two-dimensional simulation for Noah-MP was run over a spatial domain in eastern Texas (Fig. 5.1). We used the CONUS-SOIL textural class dataset to evaluate the effect of change in soil parameter table and vertical heterogeneity on the water and energy flux outputs of the 2D Noah-MP model run. Three simulation scenarios were created to illustrate the effect of including better soil knowledge in the Noah-MP LSM. They are the following:

Scenario 1: **Default (or DHom)**. The Default scenario is created to illustrate business as usual LSM model simulation using Noah-MP. The soil property table is the default look-up table for the model, and the soil texture assignment is uniform with depth (homogenous) and assuming surface soil texture class mapped by CONUS-SOIL.

Scenario 2: **Revised (or RHom)**. The Revised scenario includes the soil property look-up table revised according to the database of soil properties in Texas and surrounding regions (Morgan and Kishné 2013). Soil texture assignments are the same as Scenario 1.

Scenario 3: **Revised Layered (or RHet)**. The third scenario includes best soil knowledge available, a revised look-up table, and using the CONUS-SOIL soil textural classes assigned as a function of depth, allowing soil texture to be heterogeneous with depth. In this scenario four layers were created from the CONUS-SOIL (0–0.1 m, 0.1–0.4 m, 0.4–1.0 m, and 1.0–2.0 m).

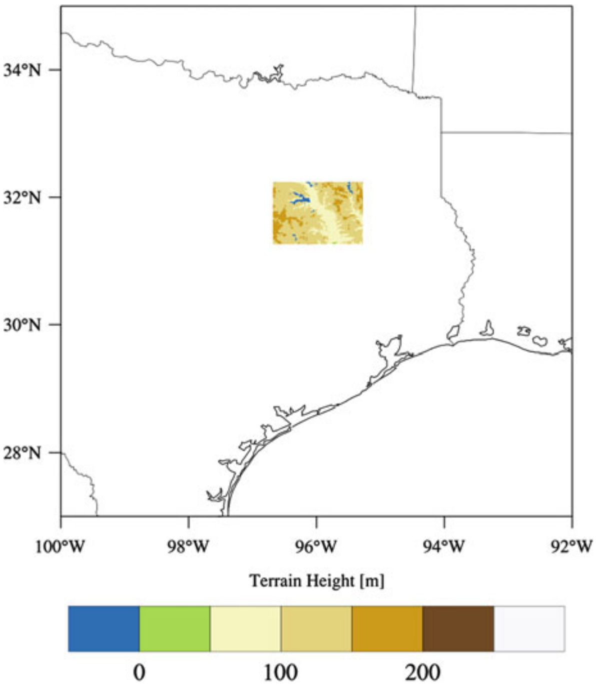

Fig. 5.1 East Texas study area

5.3 Results

Figure 5.2 shows the soil textural classes of the four soil layers for the test domain. Two textural classes, sandy loam and sand soil textures, account for 75 % of the total surface area, with each representing 47 % and 28 %, respectively. Clay texture covers 14 % of the area and is found mainly close to stream networks in the floodplains of the streams. Loam and clay loam textures collectively cover 10 % of the area. Soil texture generally becomes higher in clay with depth, changing the texture class and values of soil parameters used in the Noah-MP look-up table. Figure 5.3 shows the standard deviation of soil parameter values among the four soil layers (or depths). The largest standard deviations in the study area are found in locations where bedrock is reached before 2 m. As well, East Texas is full of soil with sandy surfaces and clayey subsurfaces, also causing a large degree in variation in soil properties with depth. Particularly, plant available water held by clayey soil is much higher than that of sandy soil affecting water availability for transpiration and direct evaporation.

In the study domain, the water budget components varied significantly from simulation to simulation depending on the soil information. The clearest differences in the three scenario results were in the partitioning between transpiration and evaporation (Fig. 5.4). The primary drivers of this difference were assigning a higher permanent wilting point value to the soil, particularly in the Revised Heterogeneous scenario, which created more water stress for plants and hence less transpiration. Direct evaporation was significantly greater for Revised Heterogeneous compared to other sce-

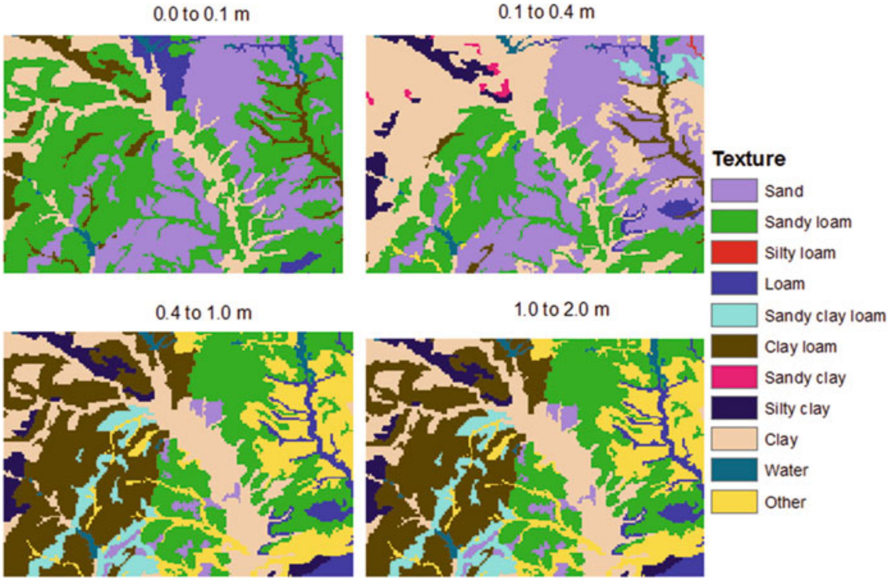

Fig. 5.2 Soil texture classes of the study domain for four soil depths

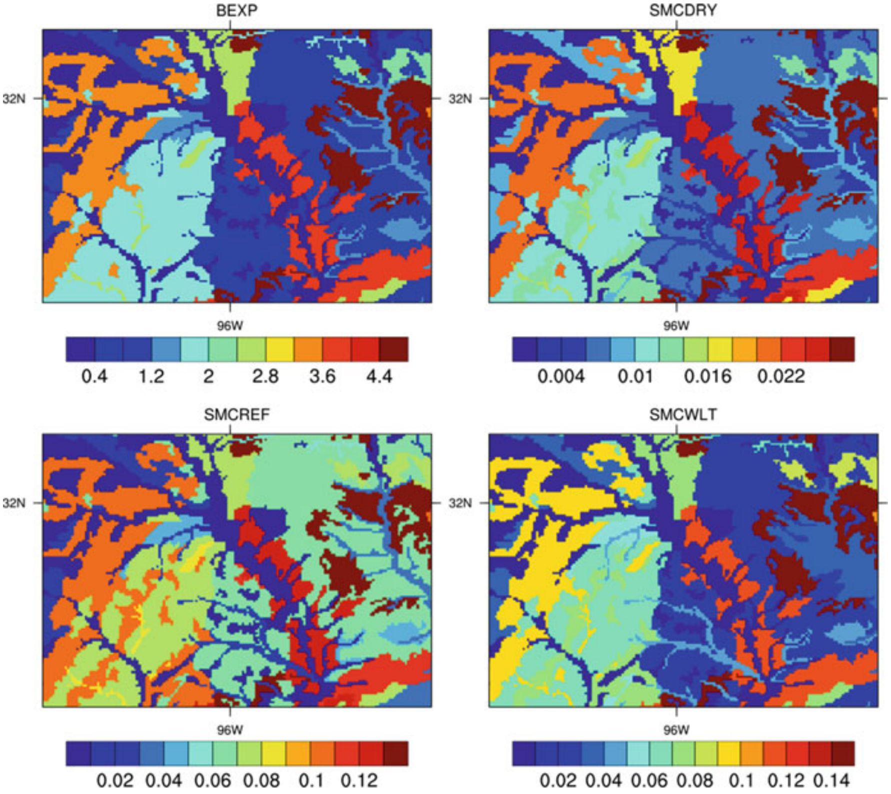

Fig. 5.3 Standard deviation of the four soil parameter values among the four soil layers. *Blue* colors indicate small standard deviations and *maroon* represents largest. The soil parameter values represented include the slope of the soil moisture retention line (BEXP), soil moisture at air dry (SMCDRY), soil moisture at field capacity (SMCREF), and soil moisture at permanent wilting point (SMCWLT)

narios because the soil water content for the top layer was also larger compared to the other scenarios. This could be because the lower layers are relatively finer and have lower conductivity letting the top layer to get wetter – i.e., less stress for evaporation.

Figure 5.5 illustrates how significantly different latent heat flux was among simulations varying only in their soil input. Total latent heat flux was the highest for the Revised Heterogeneous scenario followed by Revised Homogenous. The Default

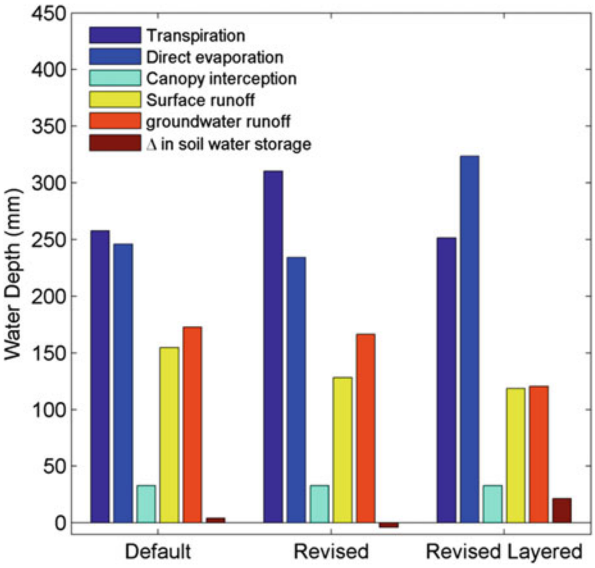

Fig. 5.4 Water budget components summarized for the two-dimensional space in Fig. 5.1. Default simulation represents Noah-MP output using default look-up table and homogenous soil. Revised represents results of the revised look-up table. And Revised Layered uses the revised table as well as heterogeneous soil texture classes with depth

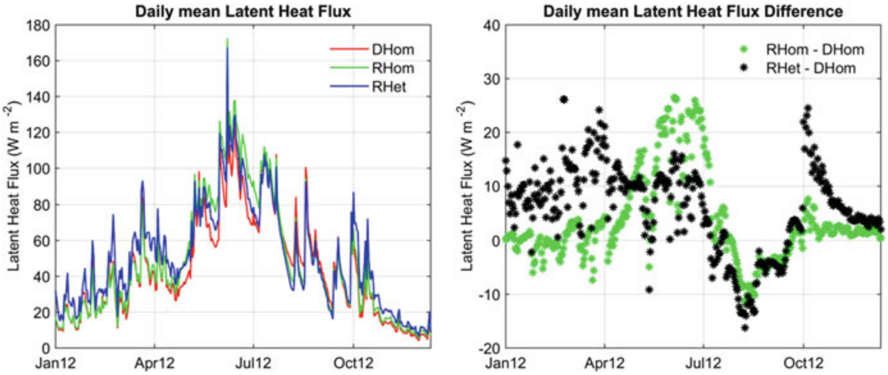

Fig. 5.5 Daily average simulation outputs of latent heat fluxes using default look-up table and homogenous soil profiles (DHom), revised look-up table and homogenous soil profiles (RHom), and revised look-up table and heterogeneous soil profiles (RHet) are shown at the *left*, and differences in latent heat fluxes between simulations that used RHom and DHom and RHet and DHom are shown at the *right*

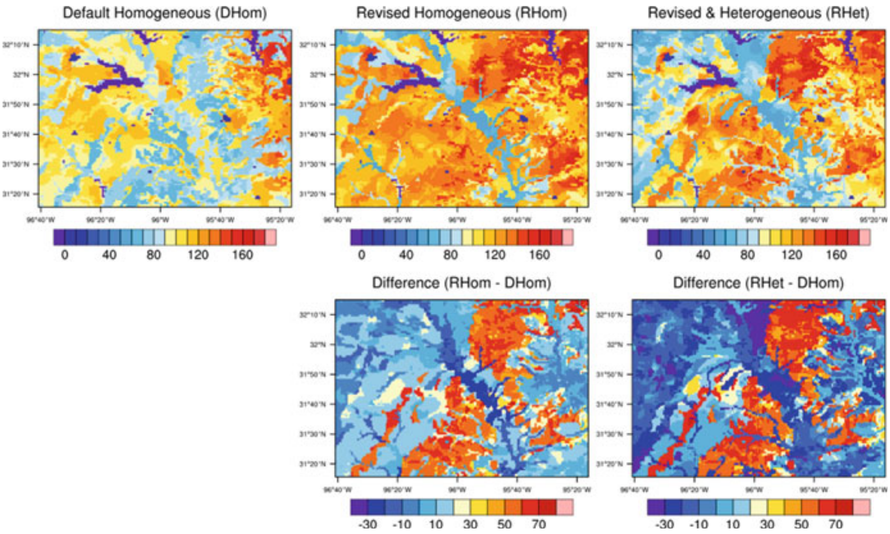

Fig. 5.6 Average latent heat flux in March 2012 simulated by Noah-MP using default look-up table and homogenous soil profiles (DHom), revised look-up table and homogenous soil profiles (RHom), and revised look-up table and heterogeneous soil profiles (RHet) (top 3 subplots) and the difference in latent heat flux between simulations that used RHom and DHom and RHet and DHom (lower 2 subplots)

scenario had the smallest latent heat flux. The total annual difference in latent heat flux between Revised Homogenous and Default was about 1190 W m^{-2}, which is equivalent to 42 mm of evapotranspiration. Whereas, the total annual difference between Revised Heterogeneous and Default was equivalent to 73 mm of evapotranspiration. The difference in latent heat between the Revised Heterogeneous and Default was primarily due to the difference in evaporation during the winter; whereas, the difference between Revised Homogenous and Default was due to transpiration.

Figure 5.6 illustrates the differences in latent heat flux for the month of June over the study area. From these figures, it is clear that the spatial variability in latent heat differences was significant. For example, the areal average difference in latent heat flux between Revised Heterogeneous and Default was +8.8 W m^{-2}. However, it ranged from a minimum of –54 W m^{-2} to a maximum of +87 W m^{-2} suggesting that both vertical and spatial heterogeneity of soil are crucial in determining latent heat fluxes.

5.4 Future Needs

This short illustration is an example of how current knowledge of how soil capability changes across the landscape and at depth is not included in a popular land surface model. But the incorporation of that knowledge results in significant differences in model output. By including knowledge of soil heterogeneity, simulated components of the water budget and energy partitioning change significantly.

Establishing the importance of spatial changes in soil capability is a critical need of soil security. Currently, the USA and other countries have maps of soil properties as well as databases of laboratory measurements of soil properties that can be made into improved look-up tables (Chap. 6 Levin et al.). Though these maps are available at different spatial scales, levels of complexity, and levels of specificity, it is necessary for the soil science community to not only make these data easily accessible to many users but also to communicate the importance of current soil knowledge and data to the larger biophysical/atmospheric modeling community. In our example, we used soil knowledge that is already available to the biophysical modeling community. However other crucial information that affects estimates of soil capability such as depth to bedrock is not easily accessible. Integration of soil capability criteria of policy-oriented models that assess effects that changes in the climate have on food and energy security, biodiversity loss, and water availability are a key challenge of soil security.

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Chapter 6
Soil Capability for the USA Now and into the Future

Maxine J. Levin, R. Dobos, S. Peaslee, D.W. Smith, and C. Seybold

Abstract Historically, the US National Cooperative Soil Survey used soil properties to define soil capability and function primarily for farm, forestry, and grazing land practices. The maps, which are consolidated into an official web-based database, are derived from a framework of land classification, combined soil properties (both estimated and measured), and land management classification. The mapping was originally conceived as a practical tool to provide farmers and community planners with information on the basic soil resource for economic gain. For more than 75 years, the Natural Resources Conservation Service (formerly the Soil Conservation Service) has used land capability classification as a tool for planning conservation measures and practices on farms so that the land could be used without serious deterioration from erosion or other causes. The land capability classification is one of innumerable methods of land classification based on broad interpretations of soil qualities and other site and climatic characteristics. Modern soil surveys have evolved to portray soil interpretations and soil capability both geospatially and with data analysis. As the functionality of the National Soil Survey Information System (NASIS) and Soil Survey Geographic System (SSURGO) increases, the Natural Resources Conservation Service (NRCS) is advancing its interpretation program nationally to address security issues within the context of soil capability beyond land use and land cover. Soil capability for any potential human use or ecosystem service must be assessed within the context of soil properties, either measured or estimated. Using soil security as a framework (including capability, condition, capital, connectivity, and codification), soil interpretations of the US National Cooperative Soil Survey database may be tailored to address the questions of sustainability and climate change at local, regional, and global scales and to facilitate the transfer of technology to other countries and related scientific disciplines.

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Keywords Land capability class • Soil capability • Soil resistance • Soil resilience • Soil vulnerability • Soil survey

6.1 Introduction

Soil properties delimit the capability of a soil to function in various capacities. Historically the US National Cooperative Soil Survey used soil properties to define soil capability and function primarily for farm, forestry, and grazing land practices. Since the 1960s and the Public Law 89–560, Soil Surveys for Resource Planning and Development (dated September 7, 1966) (US Department of Agriculture 2015) (this law clarified the legal authority for the soil survey program of the US Department of Agriculture by specifying that soil surveys are needed by "States and other public agencies in connection with community planning and resource development for protecting and improving the quality of the environment, meeting recreational needs, conserving land and water resources, providing for multiple uses of such resources, and controlling and reducing pollution from sediment and other pollutants in areas of rapidly changing uses...." (US Department of Agriculture 2015)), the US Soil Survey over the years has extended the concept of use to include community planning, urban uses, and ecosystem services.

The US National Cooperative Soil Survey started in the Weather Bureau (Agricultural Appropriation Act of 1896, dated March 2, 1895) (US Department of Agriculture 2015). This act authorized the "Investigation of the relation of soils to climate and organic life; for the investigation of the texture and composition of soils, in the field and laboratory…" by the Division of Agricultural Soils, Bureau of Weather. This act led to the first soil survey field operations during the summer of 1899 (US Department of Agriculture 2015). The modern soil survey has maps with soil boundaries and photos, descriptions, and tables of soil properties and features. Soil surveys are used by farmers, real estate agents, land use planners, engineers, and others who desire information about the soil resource. The maps consolidated into an official web-based database are derived from a framework of land classification, combined soil properties (both estimated and measured), and land management classification. The mapping was originally conceived as a practical tool to provide farmers and community planners with information on the basic soil resource for economic gain. The Dust Bowl disaster of the 1930s brought the need for consideration of the capability of the soil to sustain its productivity despite natural disaster of drought or flooding through sustainable management with the establishment of USDA Soil Conservation Service (now the USDA Natural Resources Conservation Service). The US Soil Survey evolved after the consolidation into the USDA Soil Conservation Service in 1952 as also a tool for conservation planning and soil protection and sustainability (Memorandum 1318 of the Secretary of Agriculture, dated October 14, 1952) (US Department of Agriculture 2015). All research activities of the SCS (now called NRCS), except those related to soil formation, soil geography, and laboratory analysis to aid in the proper classification and mapping of soils and for the basic principles of their behavior and change, were transferred to the Agricultural Research Service (Memorandum 1320, Supplement 4, dated November 2, 1953) (US Department of Agriculture 2015). This memorandum gave the SCS leadership responsibility for soil survey activities of the Department of Agriculture and federal leadership for the National Cooperative Soil Survey program.

6.2 Land Capability Class System

One of the first major tools developed to assist the farmer in analyzing land for farming and land management was the land capability class (LCC) system (Helms 1992) published in the Soil *Conservation Survey Handbook* of August 1939 under the name of E. A. Norton, who then headed the Physical Surveys Division. The system was developed somewhat earlier and the handbook represented the culmination of a team effort.

For over 75 years, the Soil Conservation Service (now NRCS) has used land capability classification as a planning tool in laying out conservation measures and practices on farms so as to farm the land without serious deterioration from erosion or other causes. The land capability classification is one of innumerable methods of land classification that can be based on broad interpretations of soil qualities and other factors of place. The originators of the system realized that classes of land were not permanent. Erosion, accumulation of salts, artificial drainage, new crops, farming methods, or supplies of irrigation water could call for reclassification of the area. The original soil surveyors did not necessarily see the system as permanent. They hoped "merely to establish a national basis of classification which would be good for a generation or two" (Helms 1992). In the field, technicians were to develop the tables with information to show where land should be placed in the capability classification based solely on physical characteristics. Then the SCS technicians, other state and federal agricultural agencies, and the local people were to develop tables showing the alternatives – cropping systems, practices, measures, and soil treatment – recommended for each class of land.

One reason SCS adopted the LCC for other uses was that it was the only source of soil interpretation the agency had. It was this difference in attitude and approach that had been a source of contention between Bennett and his SCS and Charles Kellogg's Division of Soil Surveys in the USDA's Bureau of Plant Industry, Soils, and Agricultural Engineering. The division and its predecessors had been carrying out soil surveys in cooperation with the land-grant universities since the late 1890s and the establishment of the US National Cooperative Soil Survey. But the funding was low, and only a small portion of the country had been surveyed when SCS started its soil conservation surveys on a much larger scale to farm planning. The attitude of the Division of Soil Surveys as explained by Charles Kellogg, its chief, was that the soil survey should be a comprehensive inventory of the soils' properties and characteristics. Then soil scientists made predictions of how one could expect soils to react under various uses – or "interpretations" as they were called. In Kellogg's view, by gearing the survey of soil properties to one purpose (in the case of SCS – farm planning), the survey could fail to meet other needs or interpretations and another survey would be necessary (Helms 1992).

The land-grant college association had long called for the merger of the two surveys under the US National Cooperative Soil Survey. Bennett's retirement made possible the merger of the two divisions into SCS with Kellogg as its head. Henceforth, there would be one soil survey. The merger also had profound implications for soil survey interpretations, including the land capability classification. It linked the main user agency, SCS, with the group making standard soil surveys (Helms 1992). As such it sped up the interpretation of soil surveys for various uses as they are used in soil surveys today. Land capability classes continue to be an important component of conservation planning and agronomic and land use modeling as an aggregate factor. The LCC is a separate data element in the US National Cooperative Soil Survey (Web Soil Survey distribution) database attached to the map units. Maps of LCC are available through the Web Soil Survey to field level and at the national level through gridded SSURGO database online (Figs. 6.1 and 6.2).

The current LCC includes eight classes of land designated by Roman numerals I through VIII. The first four classes are arable land – suitable for cropland – in which the limitations on their use and necessity of conservation measures and careful management increase from I through IV. The criteria for placing a given area in a particular class involve the landscape location, slope of the field, depth, texture, and reaction of the soil. The remaining four classes, V through VIII, are not to be used for cropland, but may have uses for pasture, range, woodland, grazing, wildlife,

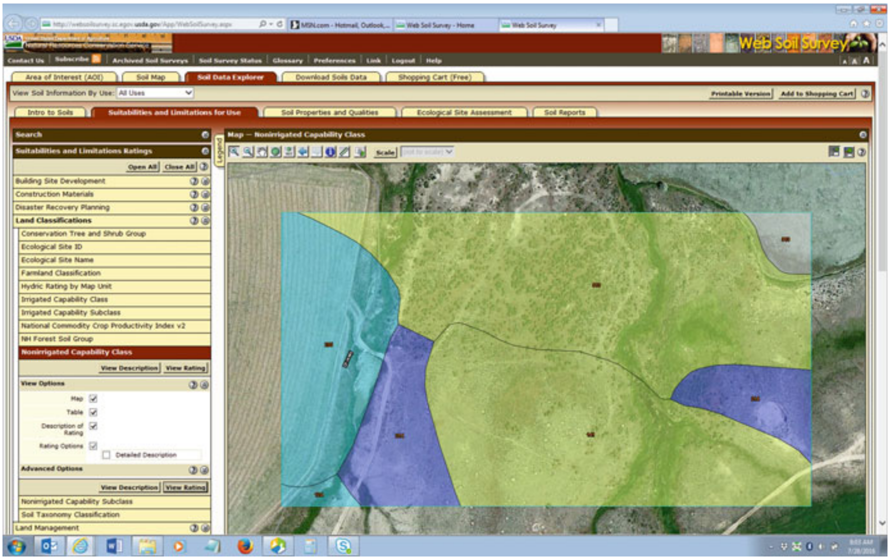


Fig. 6.1 Web Soil Survey (WSS) provides maps of land capability classes (LCC) through land analysis of soil characteristics. Land capability classification is subdivided into capability class and capability subclass if there are further limitations such as climate, erosion, wetness, or shallow soils

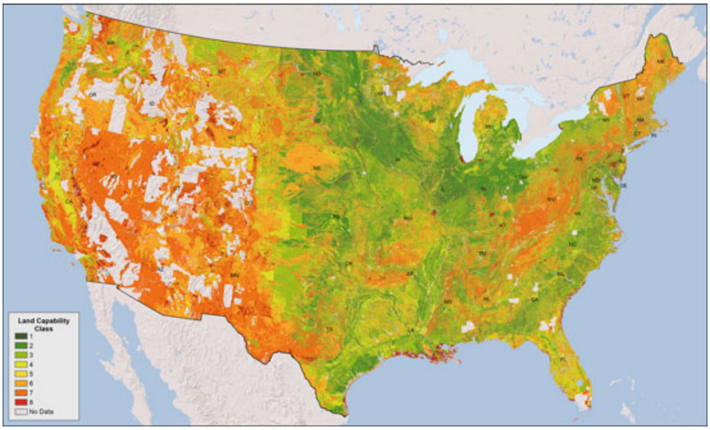


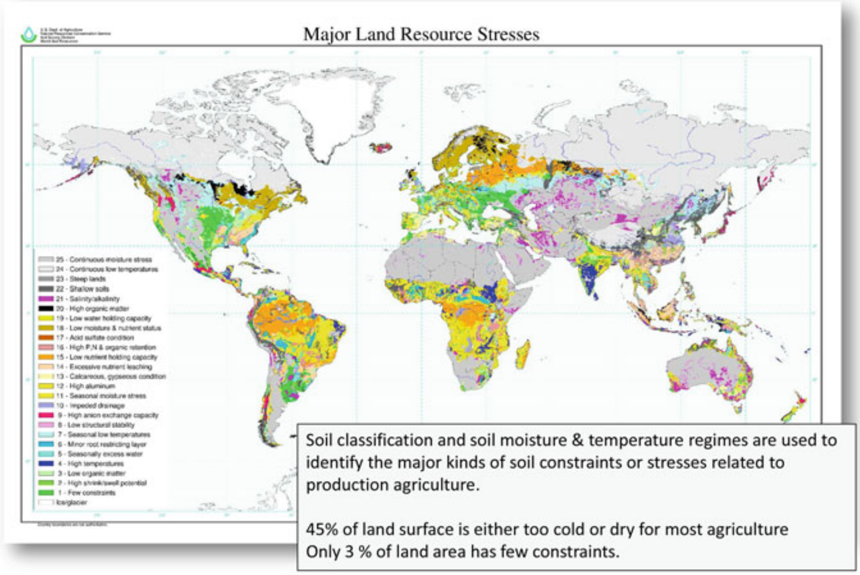
Fig. 6.2 Land capability class map of lower 48 states

recreation, and esthetic purposes. Within the broad classes are subclasses which signify special limitations such as (e) erosion, (w) excess wetness, (s) problems in the rooting zone, and (c) climatic limitations. Within the subclasses are the capability units which give some prediction of expected agricultural yields and indicate treatment needs. The capability units are groupings of soils that have common responses to pasture and crop plants under similar systems of farming. In choosing to designate classes not suited to continuous cultivation, the drafters of the legislation seized on classes VI through VIII and subclasses IIIe and IVe. The question for the policy and law makers is whether the land capability classes, especially IIIe and IVe, are accurate and the best method of identifying erodible land (Helms 1992).

6.3 Progress to Modern Soil Capability Maps

Eswaran et al. (2003) used the concept of land quality to refer to the capacity of land to sustain human needs, including food and fiber production as well as maintenance of ecological integrity over time. Land quality generally incorporates not only soil attributes but also those of climate, vegetation, and hydrology. It is important to distinguish between land quality and soil quality not only in terms of the unit that is being evaluated but also in terms of the functions of each and the relevant scale of evaluation. Land quality indicators not only enable assessment and monitoring of land quality; they can also be powerful tools for guiding the implementation of sustainable land management technologies just as land capability classes have done in the USA for conservation planning. Several maps were created based on LCC concepts but extended to worldwide land quality. Data from the FAO/UNESCO Soil Map of the World (FAO 1971–1981), digitally available in 1991, provided a global climate database, comprising data from about 25,000 stations (Science Staff 2004), and used a water balance model to compute long-term average soil moisture and temperature regimes consistent with the definitions of the USDA Soil Taxonomy (Soil Survey Staff 2015). The USDA NRCS World Soil Resources team converted the FAO soil classes to Soil Taxonomy, which incorporated soil moisture and temperature information in the soil name. Soil Taxonomy terms incorporate a wide variety of inherent soil properties, and these were used in combination with other land properties from the original FAO/UNESCO digital database to develop a spatially referenced database identifying 25 major land resource stresses. Based on the 25 major land resource stresses, inherent land quality maps were created aligned somewhat with the LCC concepts. Inherent land quality refers to the ability of land to perform its functions under natural conditions, influenced only by the intrinsic properties of the ecosystem and not significantly modified by land management (Figs. 6.3 and 6.4) (Eswaran et al. 2003).

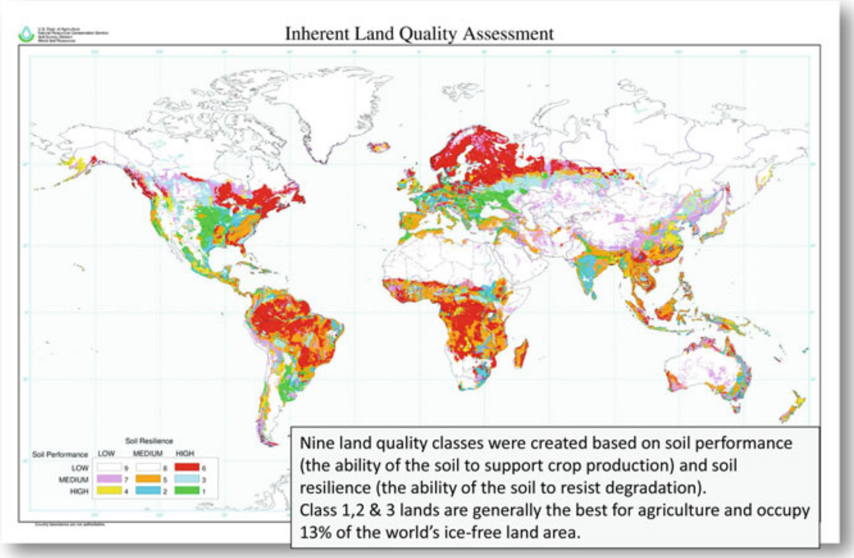
For sustainable land management and development, economic and tangible costs are involved in correcting or mitigating these stresses. The 25 stresses were ranked (in descending order) according to the estimated cost each would require to make the land suitable for sustainable grain production under rain-fed conditions (assuming that additional stresses would not limit agricultural use). They selected grain production as indicative of the capacity to provide major food and feed commodities to satisfy basic human needs. Forty-five percent of land surface is either too cold or dry for most agriculture. Only 3 % of land area has few constraints. For Inherent Land Quality Assessment (Fig. 6.4), nine land quality classes were created based on soil performance (the ability of the soil to support crop production) and soil resilience (the ability of the soil to resist degradation). The original 25 stresses,



Soil classification and soil moisture & temperature regimes are used to identify the major kinds of soil constraints or stresses related to production agriculture.

45% of land surface is either too cold or dry for most agriculture
Only 3 % of land area has few constraints.

Fig. 6.3 Major land resource stresses



Nine land quality classes were created based on soil performance (the ability of the soil to support crop production) and soil resilience (the ability of the soil to resist degradation).
Class 1,2 & 3 lands are generally the best for agriculture and occupy 13% of the world's ice-free land area.

Fig. 6.4 Inherent land quality assessment

along with qualitative assessments regarding land performance and resilience based on terms and conditions defined in the Soil Taxonomy, were used to define nine inherent land quality classes. Class 1, 2, and 3 lands are generally the best for agriculture and occupy 13 % of the world's ice-free land area (Eswaran et al. 2003).

6.4 Soil Interpretations in the US Soil Survey

Modern soil surveys have evolved to portray soil interpretations and soil capability both geospatially and with data analysis. With the functionality of the National Soil Survey Information system (NASIS) and Soil Survey Geographic System (SSURGO) maturing with the millennia, USDA NRCS has stepped up its interpretation program nationally to address security issues within the context of soil capability beyond land use/land cover. Soil capability for any potential human use or ecosystem service must be assessed within the context of soil properties, either measured or estimated. Soil needs to be managed to its capability by manipulating or maintaining condition. The thousands of soil series recognized in the USA offer the possibility of acting as reference states for the assessment of capability, to help monitor or reference the condition. See Table 6.1 for a list of properties of NASIS that affect soil capability and act as reference states for the assessment.

The hierarchy of property data used in models is at three levels. First, the characteristics of individual horizons are considered. These are properties such as pH in water or percentage of clay measured for a horizon. The second tier concerns the

Table 6.1 Properties that impact soil capability. This list is not exhaustive

Horizon properties	Profile properties	Site properties
pH in water	Depth to saturation	Slope gradient
Content of sand, silt, and clay	Depth to bedrock	Slope shape
Saturated hydraulic conductivity	Available water storage	Slope aspect
Electrical conductivity	Depth to a restrictive layer	Precipitation
Rock fragment content		Temperature
Matrix color		Day length
Organic carbon content		Surface stones
Unified class		Elevation
AASHTO class		Frost-free days
Bulk density		Parent material
1/3 bar water holding capacity		
15 bar water holding capacity		
Cation exchange capacity		

soil profile as an entity. These are items such as depth to a restrictive layer or root-zone available water storage. The third level consists of site features like slope gradient or flooding frequency. Some features that are thought of as soil properties, such as erodibility or steel corrosion, are the function of more basic soil properties, such as organic carbon content, soil moisture status class, or electrical conductivity. Some soil and site properties have strong temporal variation, such as temperature and depth to saturation. Site and climatic data are especially needed for ecologic soil capability assessments since a soil exists on a landscape within a climate (Soil Survey Staff 2015).

The array of site and soil properties that will influence a capability or function and the degree of impact is determined by a team of subject matter experts, university research, and local knowledge. The degree of impact has been indexed in many ways. It is called “sufficiency” by Kiniry et al. (1983), “indicator transformation” by Andrews et al. (2001), and “evaluation” by the Soil Survey Staff (2010a, b). In these systems, a score of 1 is assigned for the optimum value of a property for a particular function or capability and a score of 0 when that soil property does not support the use. Andrews et al. (2001) succinctly describe three general forms of the curves. The graph of response to some properties is like a bell-shaped curve having a midpoint optimum. The response of plant growth to soil pH is the classic example of this response style (Fig. 6.5). Others are a sigmoid curve with an upper asymptote, indicating more is better (Fig. 6.6). The plant growth to soil organic carbon relationship is of this form. Finally, a sigmoid curve having a lower asymptote showing less is better describes the plant response to electrical conductivity (Fig. 6.7) (Andrews et al. 2001). The relationships of soil properties to corn, small grains, and cotton yields that are given by Dobos et al. (2012) follow these basic trends.

Each individual soil property impacts the capability of a soil, and the relative importance of each can be codified in a system that rates the capability of a soil for

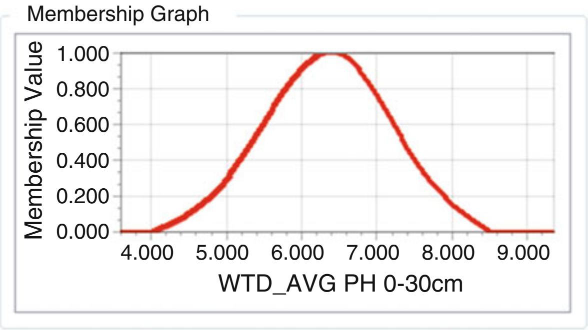


Fig. 6.5 Midpoint optimum

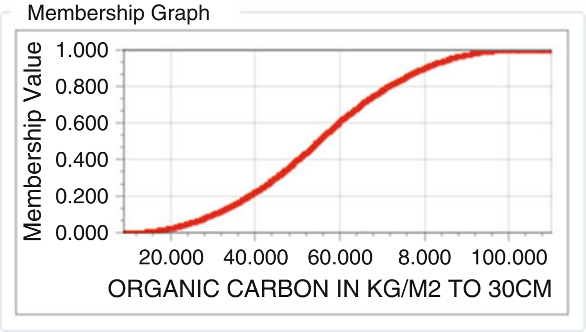


Fig. 6.6 More is better

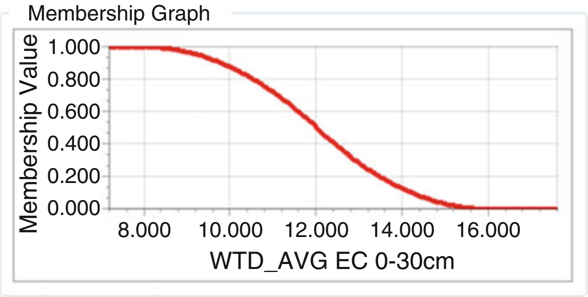


Fig. 6.7 Less is better

a use based on many soil, site, and climatic properties. The National Commodity Crop Productivity Index (NCCPI) of Dobos et al. (2012) arrays the capability of the soils of the USA in terms of their productivity for dryland crop production by using soil properties in this way (Fig. 6.8).

Soil capability can be predicted not only for human use but also as habitat for organisms, many useful, but some pathogenic, such as the causative fungus for the

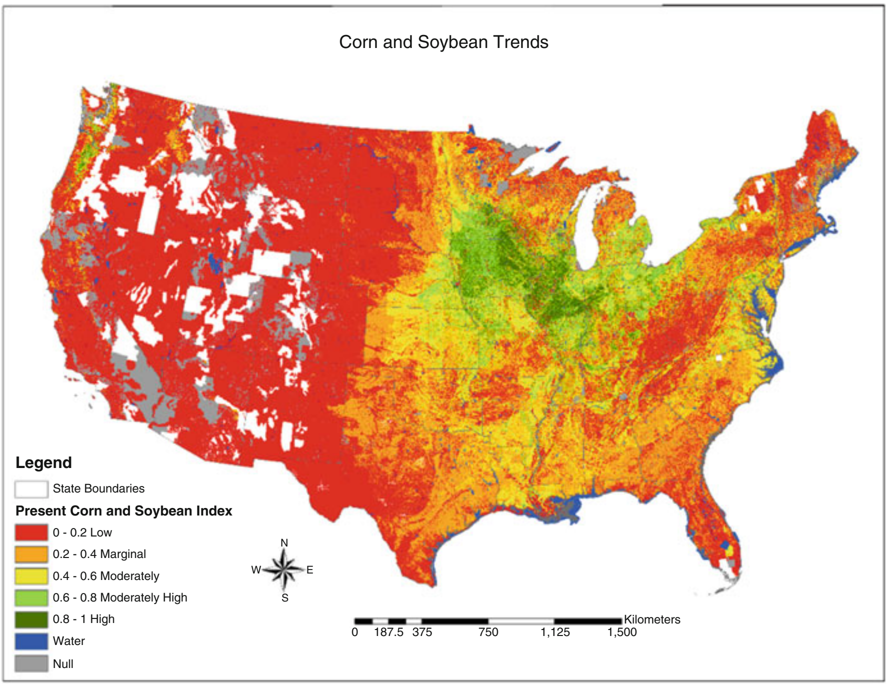


Fig. 6.8 NCCPI results showing relative productivity under the current climate

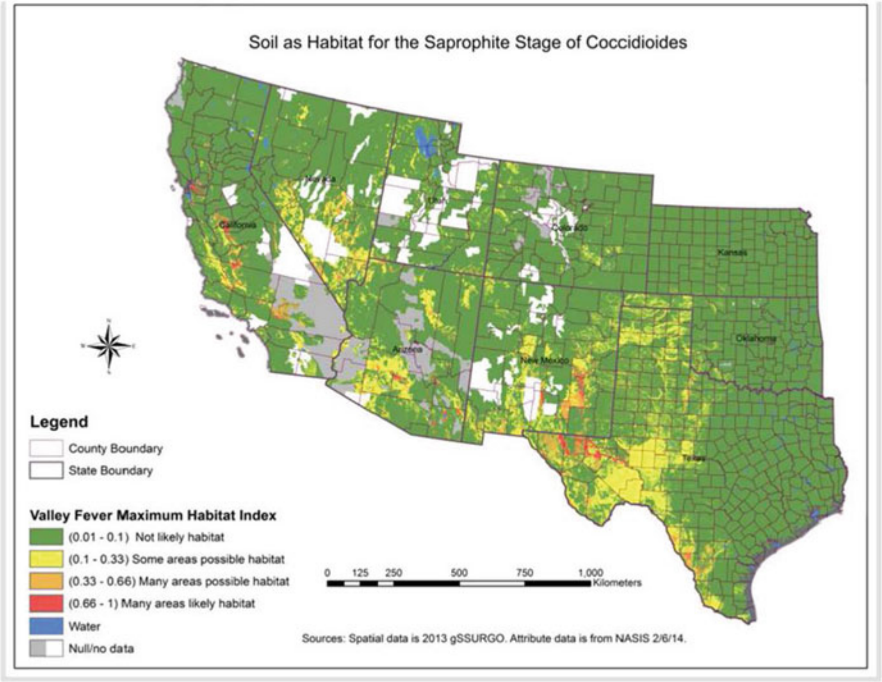
disease valley fever. This disease organism is endemic to the hot, dry southwestern USA (Kolivras et al. 2001). Areas where the soil is capable of supporting this organism have been identified by the Soil Survey Staff (2014) and are indicated in Fig. 6.9.

With detailed knowledge of the spatial distribution of soil properties and how they are related to the capability of soil for many functions and processes, a wide variety of interpretations germane to land use can be provided to the public for their planning. Soil properties are also used to predict the occurrence of chemical processes in soil that impact human use, the risk of the corrosion of steel in contact with soil being an important example (Fig. 6.10).

While much useful information can be deduced and mapped from soil classification systems like Soil Taxonomy or the World Reference Base, having actual soil properties to rate produces a map of much greater precision. It may be of some interest to note that using GIS and database techniques, the preferred way to rapidly examine soil survey data and its derivatives is cartographically.

The preceding discussion has examined how soil properties are used to predict capability for human food production, health, and infrastructure. Now let us look at how soil properties are used to indicate undesirable soil processes or capabilities that can be caused by the management.

USDA Natural Resources Conservation Service has been working on several indexes that measure soil capability. There are an increasing number of "vulnerabil-



Sources: Spatial data is 2013 gSSURGO. Attribute data is from NASIS 2/6/14.

Fig. 6.9 Predicted habitat map for the valley fever pathogen (*Coccidioides* spp.)

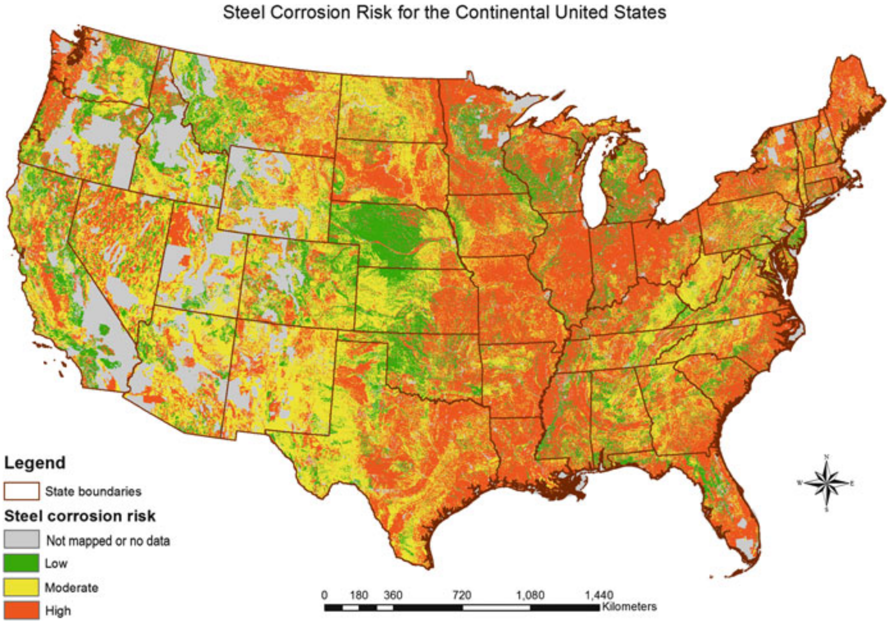


Fig. 6.10 Risk of steel corrosion in the continental USA

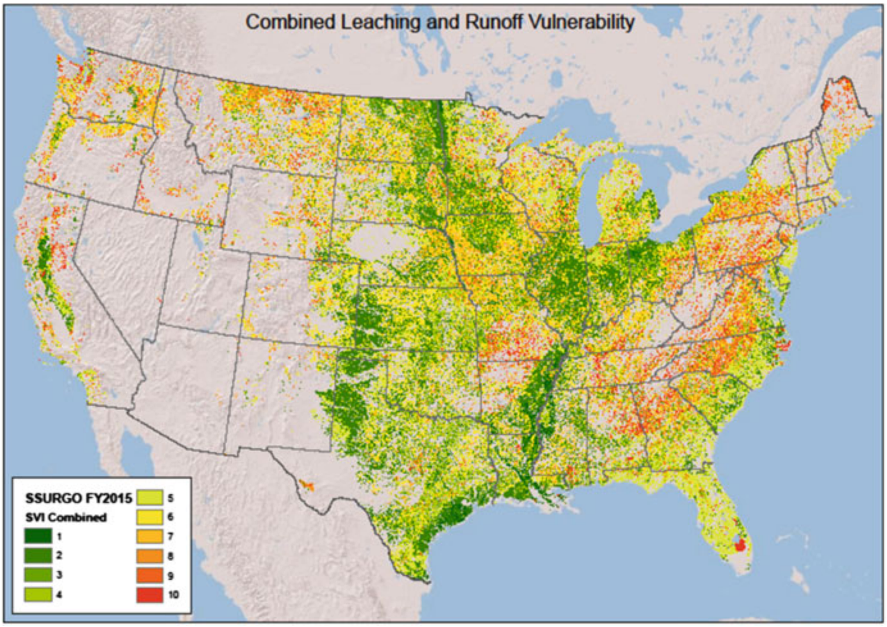


Fig. 6.11 Soil Vulnerability Index (SVI) combined leaching and runoff vulnerability

ity indices" (broadly defined) out there that have been or are being developed by numerous scientists and branches of USDA NRCS working in US Soil Survey database. The Soil Vulnerability Index (SVI) is a recent product still under development and review that broadly measures soil vulnerability for both runoff and nutrient leaching and categorizes the potential hazard in levels of high, medium, and low severity. There is also a combined map that compounds the vulnerability for both runoff and leaching into a single index (Fig. 6.11). The intent is to use the SVI as a rating to prioritize watersheds for targeting of limited funds for support and cost sharing of technical assistance. There is some interest in using the index at the field level but that is still under cautious consideration. The assumption is that targeted funds to the most vulnerable areas will have the most profound effect on outcomes for the cost. The SVI is also being tested at the watershed level by several Conservation Effects Assessment Program (CEAP) watersheds to consider sensitivity regionally in both leaching and runoff. The analysis considers land capability classes I–V as a broad separation to apply the SVI primarily to potentially productive agriculture, grazing, and forestlands.

Another model under development is a Fragile Soil Index which quantifies potential for soil resilience and soil *resistance* from the National Soil Survey database. Soil fragility defines how vulnerable a soil is to degradation (from a disturbance). Proposed indicators of soil fragility are as follows:

- Organic matter content – the greater the OM content, the less fragile the soil.

- Aggregate stability/structure characteristics – the greater the stability of aggregates, the less fragile the soil.
- Susceptibility to erosion/slope – the greater the slope, the more fragile the soil.
- Climate/aridity – the greater the aridity, the more fragile the soil.
- Biodiversity – the greater the biodiversity, the less fragile the soil.
- Rooting/soil depth – the greater the rooting depth, the less fragile the soil.
- Vegetation coverage – the greater the vegetation coverage, the less fragile the soil.

A response curve or scoring function (or group of curves) would need to be developed for each indicator. All of the above indicators would be assessed at one point in time and then combined into an index of soil fragility. The Fragile Soil Index could then be partitioned into groups for interpretation (e.g., non-fragile, slightly fragile, moderately fragile, and highly fragile). Soil fragility could be assessed over time to determine, for example, the impacts of climate change (the soil becomes more or less fragile) to develop a measure of soil resistance.

These are just two examples of several levels of consideration for soil capability that are being developed by staff with the USDA NRCS Soil Science and Resource Assessment Deputy Area. The information is going through validation and peer review for consistency and sensitivity to the questions being considered for its publication and use. Future efforts may be to transfer the tested interpretations and indexes to other soil property databases at various scales (local, national, and global) such as the global soil map to share information and processes efficiently in other parts of the world.

6.5 Conclusions

Soil capability has been the cornerstone of the US National Cooperative Soil Survey interpretation program. Approaches to soil capability have evolved in the USA as methodology of soil systems, and soil property databases have matured on a local, regional, and national scale. With the functionality of the National Soil Survey Information System (NASIS) and Soil Survey Geographic System (SSURGO) maturing with the millennia, USDA NRCS has stepped up its interpretation program nationally to address security issues within the context of soil capability beyond land use/land cover. Soil capability for any potential human use or ecosystem service must be assessed within the context of soil properties, either measured or estimated. Using soil security as a framework (capability, condition, capital, connectivity, codification), soil interpretations of the US National Cooperative Soil Survey database may be tailored to the questions of sustainability or climate change at local, regional, or global scale and the technology easily transferred to other countries or related science disciplines.

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Chapter 7
Quantifying Capability: GlobalSoilMap

Alex B. McBratney, Dominique Arrouays, and Lorna E. Jarrett

Abstract GlobalSoilMap is an initiative of the Digital Soil Mapping Working Groups of the International Union of Soil Sciences (IUSS, digitalsoilmapping.org. Available at http://digitalsoilmapping.org/. Accessed 22 Oct 2015). It aims to meet the needs of the modelling community, farmers, land managers, policy developers and decision-makers, by creating a fine resolution (100 × 100 m grid) quantitative digital soil map of the world, using state-of-the-art and emerging technologies such as remote sensing, data mining and spatial databases. The data will be stored in a freely available distributed system with a set of standards for Web services. The approach has three components: digital soil mapping, recommendations for soil management and providing service to end users (Sanchez et al. Science 325, 2009). The project originated in 2006 as an effort to address the unmet need for quantitative answers to questions about soil-related issues such as soil carbon sequestration, the impact of soil carbon on biomass production and the change in soil status over time. To address such questions requires information about stores and fluxes of water, carbon, nutrients and solutes, in other words, functional properties of soils. The most significant stocks and flows are water including run-off, leaching, waterlogging and water available to plants, nutrients, carbon, solutes and acidification. Access to information about soil properties reduces risks in decision-making, but in order to understand and manage these risks, estimates of uncertainties in soil properties are required. Therefore, all quantitative data in the GlobalSoilMap will have an associated uncertainty. The project is facilitated by the synthesis of pedology, which focuses on soil processes, and pedometrics, which focuses on quantitative analyses.

Keywords Digital soil map • Database • Soil functional properties • Legacy data • Pedotransfer function • Uncertainty • Capability

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7.1 Links to the Global Challenges

Global existential challenges such as food security and human nutrition can be addressed through assessment and improvement of agricultural efficiency and by addressing declining soil fertility. In regions vulnerable to the effects of climate change, soil information is needed in order to plan for future changes to land use. To mitigate against climate change, the most appropriate soil for carbon sequestration has to be located. All of these responses require that farmers, policymakers and scientists have accurate data on spatial and temporal variation in soil properties.

Sustainable land management requires three elements of knowledge. The first, namely, spatial variation in soil functional properties, is described above. GlobalSoilMap (Arrouays et al. 2014a, b) primarily addresses this element. The other two elements are the detection of change in function over time and the ability to predict the future state of soil. By providing a spatial framework, GlobalSoilMap can contribute to this element of knowledge, by facilitating the monitoring of change. Finally, it represents a source of data for computer modelling to address the third element.

By combining maps of soil properties with maps of socioeconomic data such as land use, farming systems, crop yields and poverty, it is possible to generate specific soil management recommendations. Agricultural extension workers and policymakers can use these in their efforts to reverse soil degradation and improve food security. Digital soil maps and management recommendations may also be used by research and modelling communities, farmer associations and environmental organisations, to address such issues as environmental degradation, climate change and threats to biodiversity.

7.2 Links to Dimensions of Soil Security

The five dimensions of soil security are capability, condition, capital, connectivity and codification. The GlobalSoilMap project will contribute each of these to some extent, to evaluating each of these for the world's soils.

The largest impact will be on the quantifying the capability of the world's soil by systematically assessing and quantifying spatial variation its functional properties. Capability describes the functions that a soil is able to perform, as a consequence of its intrinsic biophysical properties. The GlobalSoilMap will quantify key biophysical quantities that relate to soil functions.

The project will also contribute to evaluating condition and capital and, to a lesser extent, codification. Condition refers to the current functional state of the soil, which depends both on its capability and on historical management practices. Capital refers to the stock of materials and information, including physical structure and genetic information, contained in a soil. Physical stocks include soil moisture, organic and inorganic substances. Codification refers to the role played by government policy and regulation in ensuring that soil is appropriately and sustainably managed.

7.3 Conventional Soil Maps

Conventional paper polygon maps used qualitative sampling strategies. These were efficient but lacked statistical rigour. Classification of soil types formed the basis of these maps, summarising large quantities of morphological and analytical data and enabling extrapolation. However, the validity of assumptions underlying conventional survey methods, such as correlation between soil properties, spatial scales of their variation and the existence of sharp soil boundaries, is the subject of debate (Arrouays et al. 2014b).

In addition, polygon maps have a number of drawbacks:

- They do not provide information about temporal change; however such information is essential to decision-makers.
- They do not provide the functional information needed for quantitative studies.
- They imply the existence of abrupt spatial boundaries between soil properties.
- They provide highly summarised and condensed data, rather than detailed information.
- They exist at a specific scale that is not useful for all applications.
- The polygon model cannot be easily integrated with grid-based natural resource data such as satellite images.

Despite these limitations, polygon-based systems remain useful for a number of reasons and applications, and it is anticipated that polygon- and grid-based systems will play complementary roles in supporting and facilitating decision-making.

The first world soil map was created in 1980, by the FAO and UNESCO, using a single soil classification terminology (FAO-UNSECO 1974). However at a scale of 1:5 million, its resolution is too low to enable decisions to be made at field or catchment scales. The *Global Assessment of Human-Induced Soil Degradation* is highly cited but has extremely low resolution, at a scale of 1:50 million, and lacks quantitative information.

Higher resolution conventional soil maps, at a scale of 1:1 million or finer, exist for 109 countries and cover 31 % of the ice-free land area (Sanchez et al. 2009). Most of the available mapping was completed over two decades ago, using predigital methods.

7.4 From Paper Maps to Digital Maps

A digital soil map is a spatial database of soil properties (Sanchez et al. 2009). Spatial distribution of soil properties is determined through field sampling and analysis, and statistical methods are used to predict properties in areas between sample sites. These statistical methods also generate values for uncertainties in predictions. Digital soil mapping was first developed in the 1970s (Sanchez et al. 2009) and was enhanced in the 1980s by advances in remote sensing, computing, statistics and modelling, spatial information, global positioning systems and measurement systems and, more recently, by the Internet.

The Harmonised World Soil Database was developed in 2018 (FAO/IIASA/ISRIC/ISSCAS/JRC 2012), based on the Soil Map of the World, and despite its coarse spatial resolution (1 km), unquantified uncertainties and simple two-layer model, it has been widely used in modelling studies. This indicates that an improved global database is likely to be of great value.

In order to effectively overcome the limitations of existing maps, best meet the needs of users and represent a valuable return on time and money invested, the GlobalSoilMap project is guided by six principles:

- Achieving full global coverage, using the best available data
- Compatibility of spatial resolution with other global environmental data sets
- A focus on soil functional properties pertaining to stocks and flows of water, carbon and nutrients
- Estimates of uncertainties for all quantitative data
- The capacity for the system to be updated to meet future needs
- Data collection and use that respects national sovereignty (Arrouays et al. 2014b)

7.5 Creating Digital Soil Maps: A Summary of the Methods

Legacy data represents approximately 40 billion dollars of prior investment; however as described above, it has a number of limitations. These prevent it from being efficiently used in the wide variety of contexts and projects, from local to global scales, where accurate soil information is needed. Therefore the GlobalSoilMap project has been designed to make maximum use of the data contained in existing maps. The project will collate, integrate and harmonise these maps across spatial scales and in quantitative form. This requires consistent standards for the collection and analysis of data. It also requires that the information system can accommodate the variety in scale and underlying measurement parameters of the global legacy data. The global grid of soil functional properties resulting from the GlobalSoilMap project will be integrated with the Global Earth Observing System of Systems (GEOSS). The date of collection of legacy data will also be incorporated into the data set, enabling the creating of a world map of currency of available soil data.

In GlobalSoilMap, soil is mapped in a three-dimensional grid. The horizontal elements of the grid are a 3 arc sec by 3 arc sec geographic grid, matching the global Shuttle Radar Topography Missions DEM (digital elevation model) data set, but extended to the North and South poles. Covariates used to predict soil properties include the terrain data from NASA's SRTM (Arrouays et al. 2014b). In many parts of the world, these are the only available terrain data. For each soil property, estimates will be made both for points and for 100 m by 100 m blocks. The vertical component of the grid consists of six standard depths (0–5 cm, 5–15 cm, 15–30 cm, 30–60 cm, 60–100 cm and 100–200 cm.

Mathematical functions, particularly spline functions (Bishop et al. 1999), are used to generate data for each soil property, in each geographic grid cell, at each of the six standard depths. Procedures for sampling, measurement and estimation do not rely on the concept of a natural soil body such as a pedon, polypedon or horizon (Arrouays et al. 2014b). Spline or other mathematical functions are fitted to soil profile data, enabling estimates of soil properties to be generated for the six standard depths. These estimates can then be used to generate data of finer vertical resolution if required. Soil functional properties are estimated to a maximum depth of 2 m (Fig. 7.1).

This approach has a number of advantages. It overcomes the problems of multiple systems for naming and describing soil layers. It also facilitates efficient handling of quantitative queries. Finally, it is compatible with data models in related disciplines and is easily understood by non-soil scientists.

7.5.1 Minimum Data Set

A minimum data set has been determined in order to enable the most important soil functional properties to be calculated and is listed below. Each of these is either directly related to stocks and flows of water, carbon or nutrients or can be used to derive them using pedotransfer functions. Estimates of the properties, along with estimation of uncertainties and date of estimation, are required at each of the specified depths. At present, the selection and use of pedotransfer functions are the responsibility of individual nations (Arrouays et al. 2014b):

- Depth to rock (cm)
- Plant exploitable depth (cm)
- Organic carbon (g kg^{-1})
- pHx10
- Clay (g kg^{-1})
- Silt g kg^{-1}
- Sand (g kg^{-1})
- Coarse fragments >2 mm (m^3 m^{-3})
- ECEC ($mmol_c$ kg^{-1})
- Bulk density (Mg m^{-3})
- Bulk density of fine earth fraction <2 mm (Mg m^{-3})
- Available water capacity (mm – total over the depth range)
- Electrical conductivity (mS m^{-1})

Definitions and analytical methods for most of the properties correspond to ISO (International Standards Organisation) standards; however, the project uses the USDA Soil Survey Laboratory Methods Manual definitions for particle size (Burt 2004). Soil properties are translated to a standard method using guidance given in the Technical Specifications.

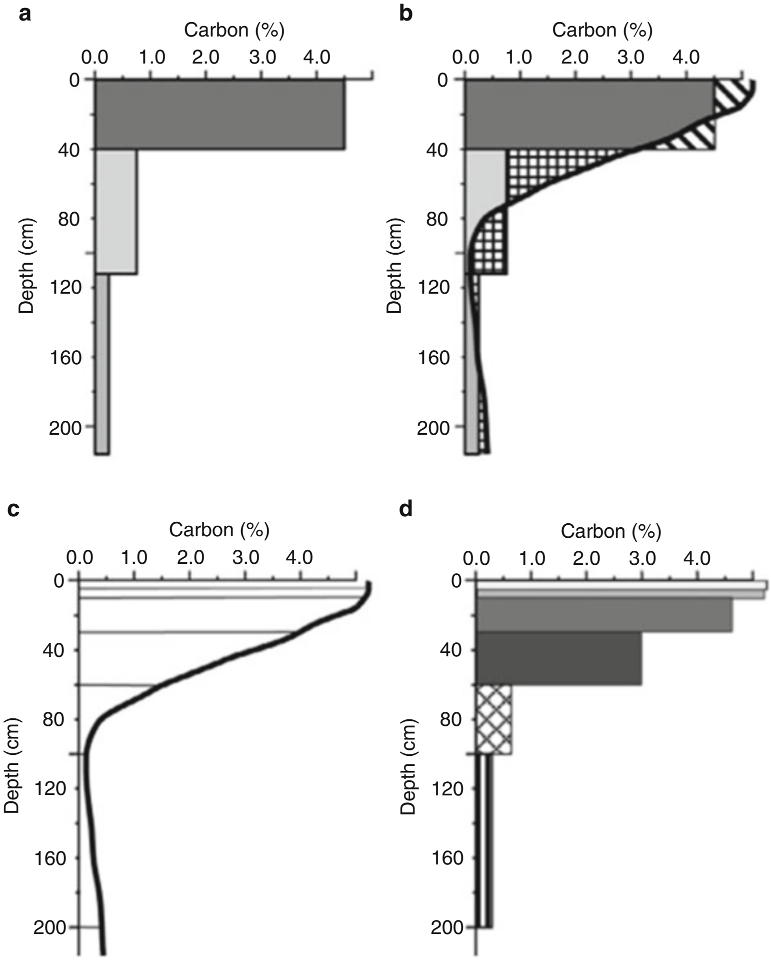

Fig. 7.1 Harmonising conventional horizon-based soil data using smoothing splines to standard depth increments are a key feature of the GlobalSoilMap legacy data approach

In addition to this minimum data set, individual countries may choose to generate data for other soil properties which are of particular relevance to their environment or systems of land use.

7.5.2 Estimating Soil Properties Using Legacy Data

A range of methods have been developed for estimating soil properties using either legacy data alone or a combination of legacy data and new data. These methods take account of the level of detail in soil maps, and whether or not soil point data is

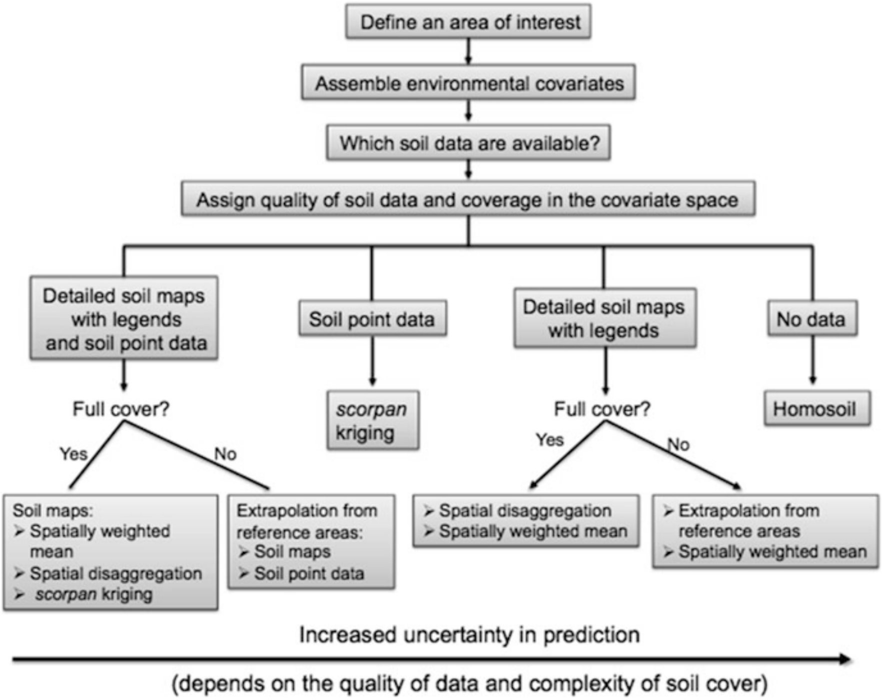

Fig. 7.2 Various approaches can be used depending on the availability of legacy data

available (Minasny and McBratney 2010) and are summarised in the decision tree shown in Fig. 7.2. In the last decade, rapid measurement technologies have emerged both for the laboratory and field (Viscarra Rossel et al. 2011); however research methods and standardised systems have yet to be established.

7.5.3 *Estimating Uncertainty*

As described previously, all quantitative data will have an associated estimate of uncertainty. GlobalSoilMap uses the 90 % prediction interval, which reports the range of values within which the true value is expected to occur 90 % of the time, with a 5 % probability of occurrence for each of the two tails. Brown (2004)'s framework for assessing and representing uncertainties has been followed.

Where sufficient point observations exist, there are two approaches to assessing uncertainty in digital soil maps. First, when statistical models are used to estimate soil properties, uncertainties are also generated as part of the model. Second, if non-statistical methods were used to generate the map, uncertainty can be estimated by comparing map predictions with independent observations of soil properties. Brus et al. (2011) describe methods for validating soil maps.

7.6 Administrative and Governance Issues

The administrative and institutional challenges of GlobalSoilMap are considerable. Governance is required to establish standards, maintain quality control and ensure that the project is completed on time and has the necessary ongoing support. For other disciplines such as climate and water, United Nations agencies fulfil this role. Governance structures are currently being developed through the UN FAO's Global Soil Partnership and its Intergovernmental Technical Panel on Soils (McKenzie 2014). However, it will take several years before the suitability of this institution as a governing body can be assessed.

Another challenge is that of ensuring that benefits flow to all project participants, to overcome the disincentive of the significant costs of delivering data into the global system. Partners will benefit from adoption of standards and associated time and cost savings, access to related tools such as farming and hydrologic models, training and mentoring associated with contacts in the international scientific and technical community, better decision-making and assurance that the best available data is used for international assessments of soil health.

7.7 Work to Date

The International Centre for Tropical Agriculture (CIAT) received $18 million from the Bill & Melinda Gates Foundation and the Alliance for a Green Revolution in Africa (AGRA), to create the Africa Soil Information Service (AfSIS). This has funded work in sub-Saharan Africa. Digital maps have been created for several regions worldwide. These include maps of particle size for Denmark, silt content for the Nabeul district in Tunisia, soil organic carbon for the USA, pH for Nigeria and available water capacity for Korea (Arrouays et al. 2014b).

The project will also foster collaboration between institutions in Canada, Mexico and the USA, to harmonise legacy soil survey data that were created for different spatial scales and under different taxonomic systems. This will result in a transnational data set of soil properties for these countries.

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Chapter 8
Testing the Links Between Soil Security, Sustainable Land Management Practices and Land Evaluation

Brian Murphy

Abstract A matrix based on the six global challenges identified for soil security (food security, water security, energy security, climate change abatement, human health, biodiversity protection) and the dimensions of soil security (capability, condition, capital, connectivity, codification) is proposed as a tool to demonstrate the links between soil security, sustainable land management and soil and land evaluation. The matrix was tested using a number of published systems of sustainable land management (SLM) practices and soil and land evaluation systems. This approach clearly validated the value and potential of the soil security concept in developing and promoting sustainable land management practices. However, it also identified several issues that need further discussion and consideration including the following: the need for a realignment of the definitions of capability and condition in the soil security concept; the recognition that soil capability cannot be assessed separately from land and site characteristics; the need for more emphasis on land management practices especially in the interaction with capability to produce the resultant soil condition; and clearer, more specific definitions of what is included under the dimensions of connectivity and codification.

Keywords Soil security • Sustainable land management • Land evaluation • Ecosystem services

8.1 Introduction

The pressure on land and soil resources has increased with the demand for food for a growing population and changing diets, climate change, higher energy costs for inputs such as fertilisers, water scarcity, risk of overgrazing and the competition for land between forestry, fuel, industry and urbanisation. It is estimated that the global

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demand for crop production will increase 100–110 % between 2005 and 2050 (Tilman et al. 2011). Associated with increased pressure on the land and soil resources is the threat of land degradation from processes such as nutrient decline, deforestation, desertification, soil organic matter decline, water and wind erosion, soil acidification, salinisation, surface sealing by urbanisation and soil contamination (FAO 2011; Jones et al. 2013; Nkonya et al. 2013). The competition for land for different uses such as forestry, urbanisation, infrastructure, industry and fuel has resulted in the intensification of land use which puts added pressure on the land and soil resources (Balmford et al. 2005; Tilman et al. 2011).

The development of sustainable land management (SLM) practices is essential to the effective management of the increased pressure on land and soil resources. SLM practices are defined as:

> *Management practices that protect the soil and enhance its performance for the production of goods and the provision of ecosystem services without degrading or impairing on- or off –site functions*. (Global Soil Partnership 2014)

More specifically, SLM practices include those that (World Bank 2008):

- Preserve and enhance the productivity of cropland, forest land and grazing land.
- Sustain productive forest land and forest reserves (potentially commercial and non-commercial).
- Maintain the integrity of watersheds for water supply and hydropower generation and water conservation.
- Maintain the ability of aquifers to serve the needs of farm and other activities.

Unsustainable land management practices are the main drivers of land degradation with impacts such as desertification, deforestation, lower agricultural productivity, loss of soil, changes in natural habitats and ecosystems, reduced ecosystem services and loss of biodiversity (FAO 1997; MA 2005; UNEP 2014).

The development of SLM practices has traditionally been largely based on biophysical criteria (FAO 1976; OEH 2012; USDA 2015). More recently it has been recognised that the development of effective SLM practices needs to include the environmental or biophysical, economic and social criteria (FAO 2007; Liniger et al. 2011). Matching land management to land capability is seen as a requirement for SLM practices (Liniger et al. 2011; OEH 2012; Gray et al. 2015). However, the land management practices also need to account for the economic and social constraints of any location or situation (World Bank 2008; FAO 2007; Liniger et al. 2011).

8.2 Soil Security Concept

Soil security is concerned "with the maintenance and improvement of the world's soil resource to produce food, fibre and freshwater, contribute to energy and climate sustainability, and maintain biodiversity and the overall protection of the ecosystem" (McBratney et al. 2014). Soil security identifies global challenges and a series of dimensions to the global challenges. Global challenges are food security, water security, energy security, climate change abatement, biodiversity protection and human health protection. The dimensions in relation to soil are capability, condition, capital value, connectivity and codification.

One advantage of soil security is that it emphasises the value of soils to society, as does the "soil capital" concept (Dominati et al. 2010), which is a change from the traditional approach of many soil evaluation systems that emphasised the limitations and negative aspects of soil and land degradation.

8.3 Assessment of SLM Publications Based on Soil Security

While the links of soil security to soil evaluation and assessment systems have been discussed in McBratney et al. (2014), there is a scope to expand on how soil security links to soil evaluation systems in more detail and how specific sustainable land management practices contribute to soil security. Furthermore, many of the soil evaluation schemes have valuable data and information on soil capability and soil condition. A matrix based on the six global challenges identified for soil security (food security, water security, energy security, climate change abatement, human health, biodiversity protection) and the dimensions of soil security (capability, condition, capital, connectivity, codification) is proposed as a tool to demonstrate the links between soil security and soil and land evaluation and to demonstrate the links between SLM practices and soil security.

Several land and soil evaluation systems and recommended sets of sustainable land management practices (Liniger et al. 2011; OEH 2012; Palm et al. 2007; Govers et al. 2013) are used to demonstrate the proposed matrix. The matrix identifies the global challenges and dimensions of soil security that are encompassed by the different land evaluation systems and publications on specific aspects of soil and land evaluation (Table 8.1). The degree of information and level of assessment for the dimensions for each of the global challenges are estimated in Table 8.1.

8.4 Results

8.4.1 Sustainable Land Management in Practice: WOCAT (Liniger et al. 2011)

The main objective of this publication is the development of land management practices that can be considered sustainable. The land management practices are intended to not just combat land degradation, but also to preserve ecosystem functions, ensuring food security, securing water resources within the land and

Table 8.1 Assessment of applicability of soil evaluation systems to soil security

	Capability	Condition	Capital	Connectivity	Codification
Liniger et al. (2011)					
Food security	**	**	***	*****	****
Water security	**	**	***	*****	****
Climate change abatement	**	**	**	****	****
Biodiversity protection	**	*	**	***	**
Energy security	*	*	*	*	*
Human health	*	*	*	**	*
OEH (2012)					
Food security	****	***	***	**	**
Water security	*	*	*	**	**
Climate change abatement	**	**	*	**	**
Biodiversity protection	*	*	–	–	–
Energy security	–	–	–	–	–
Human health	–	–	–	–	–
Palm et al. (2007)					
Food security	****	****	**	*	*
Water security	***	***	**	*	*
Climate change abatement	–	–	–	–	–
Biodiversity protection	*	*	*	*	*
Energy security	–	–	–	–	–
Human health	*	*	*	–	–

***** comprehensive detail, **** useful detail, *** general explanation only, ** introductory information, * brief mention, - not included.

addressing climate change issues of adaptation and mitigation and working towards maintaining biodiversity. The land management practices are to be fine-tuned for different climates, soil types and environments as well different economic and social conditions. The mapping of sustainable land management practices and their impacts provides a means of deciding where investment in sustainable land management practices is the most cost efficient and has the highest impact on site and off site. There is a strong emphasis on the rehabilitation of degraded land. The need for economic returns and a positive cost-benefit from land management practices can be considered a part of the capital value of soils, and the economic impacts of land management practices are critical to the successful adoption of sustainable land management practices. The WOCAT publication also identifies how land management practices impact on the regulating functions of ecosystem services such as flood control and regulation of water quality and quantity, combatting land degradation and disease control.

The impact of the land management practices on the cultural aspects of ecosystem services in relation to the community acceptability of practices, the capacity to adopt the practices and the impact on human well-being is considered. The setting up of policy, extension and legal frameworks for the implementation of sustainable land management practices relates to the connectivity and codification dimensions of soil security.

Overall, the WOCAT publication very much emphasises the land management practices and their implementation. Hence, it is strongest on the condition, connectivity and codification dimensions, with less specific detail on capability or on the actual identification of soil condition, except by linking condition and hence capability to specific land management practices. The land management practices advocated are those that are within capability.

8.4.2 Land and Soil Capability Assessment Scheme (OEH 2012)

The main objective of this system is the development of land management practices that result in land being used within its land and soil capability. Such practices can be considered sustainable. The main objective of the system is to prevent land degradation. The land and soil capability is assessed by a series of decision tables for the major land degradation processes, including water erosion, wind erosion, soil structure decline, acidification (agricultural), salinisation, waterlogging, shallow soils and rockiness, mass movement and acid sulphate soils. The system primarily considers the biophysical properties of the soil and the associated features of the land that can influence land degradation processes. These land features include climate (rainfall, temperature, rainfall erosivity, wind power), slope, rock outcrop and landform. The soil and land features are used in the different tables to assign a capability class from 1 to 8. The LSC assesses the degree of limitations and the likely impact of different land management practices (OEH 2012; Gray et al. 2015) with class 1 the highest capability and least limitations and class 8 the lowest capability with the most limitations to land management. The objective is that when land is managed within its capability, the impact of the land degradation processes is minimal and the land management practices can be considered sustainable.

Although the scheme is based largely on biophysical features of the land and soil, it has been incorporated into two key pieces of environmental legislation that control land management decisions in New South Wales. These are the Native Vegetation Act and the identification of strategic agricultural land to be protected for agricultural use. The land and soil capability scheme is only one of the inputs in these two pieces of legislation, but it is significant that it is included in the decision process. As well as the use in legislation, the scheme is widely used as a tool for understanding the limitations of land and soils at the regional level (Central West CMA 2008).

The scheme has strong links to the USDA land capability scheme (USDA 2015), and the two schemes have the same origins in the scheme originally proposed by Klingebiel and Montgomery (1961).

8.4.3 Soils: A Contemporary Perspective (SCP) (Palm et al. 2007)

The main objective of this system is the development of a framework for the contribution of the natural soil to ecosystem services. The SCP identifies two components in the capacity of the soils to provide ecosystem services. The first is the soil properties or soil constraints identified that determine the capacity of soils to provide ecosystem services. The second is the potential for soil degradation to cause changes in soil properties and processes leading to a reduction in ecosystem services. The changes in soil properties undermine the sustainability of many of the ecosystem services.

The SCP scheme considers the links between soil properties and a range of ecosystem services, especially those associated with food security and water security. There is minimal reference to the global challenges of energy security and climate change abatement. Some mention is made of biodiversity and human health is related to food security, because where there is malnutrition, people are more susceptible to diseases such as malaria and HIV. There is minimal mention of the issues that relate to the connectivity and codification dimensions of soil security.

8.5 Discussion on Implications for Soil Security

Applying the soil security concept to published soil and evaluation systems and publications on soil and land evaluation has raised some points for discussion.

8.5.1 Soil Capability v Land Capability

Does the capability refer to the “soil capability” alone and not the “land capability”? This is potentially a major source of confusion and difficult non-productive discussions in the field. When assessing the capability of an actual soil in the field, it is difficult to separate the “soil capability” and the “land capability”. In assessing the capability of a site, field or soil mapping unit, it is necessary to assess its capacity to provide ecosystem services as well as its stability and resilience to the effects of land management practices or its susceptibility to land degradation processes. To assess this capacity and the potential for land degradation, it is necessary to assess both soil properties and site features such as climate, rainfall erosivity, windiness and wind power, slope, concentration of flow, landform position, drainage, rock outcrop, etc. (Sanchez et al. 2003; Palm et al. 2007; Dominati et al. 2010; OEH 2012; USDA 2015). Therefore, it is logical to assess the overall land and soil capability, rather than just soil capability. Most policymakers and administrators and possibly many land managers would not accept easily the subtle difference between “soil capability” and “land capability”.

8.5.2 *Realignment of Concepts on Soil Capability and Soil Condition*

Attempts to apply the concepts of capability and condition presented in the paper on soil security (McBratney et al. 2014) proved difficult. Because of this a realignment of some of the concepts behind capability and condition is suggested. A more logical conceptual set of formulae is

$$\text{Soil condition} = \text{capability} \times \text{land management} \tag{8.1}$$

$$\text{Performance} = f(\text{soil condition}) \tag{8.2}$$

An important conclusion is that capability can be considered to have two components:

1. The stability and resilience of the soil condition to the effects of land management practices or the susceptibility to soil and land degradation (OEH 2012; Dent and Young 1981; Emery 1986; Sonter and Lawrie 2007; Gray et al. 2015).
2. The capacity to provide ecosystem services and the provision of food, water and fibre is a critical one of these – these services need to be evaluated and monitored for each specified land use (FAO 1976, 2007).

Similarly soil condition is based on the capacity of the soil to provide ecosystem services and its susceptibility to land degradation. In the assessment of soils, it is possible for a soil to have a low capacity to provide ecosystem services, but a low susceptibility to land degradation. Alternatively, soil may have a high capacity to provide ecosystem services but a high susceptibility to land degradation. The recognition of these two components of capability is exemplified in Palm et al. (2007) who present one table describing the relationships between provisioning ecosystem services, soil processes, soil properties and core soil determinants and the second table describing the types of soil degradation and causes and impacts on soil properties and processes.

8.5.3 *Land Management Is a Key Input*

One clear outcome of applying the soil security concept to a range of land evaluation systems is that land management practices drive the pressures on soils and land and there has to be an assessment of the sustainability of land management practices. As implied from Eq. (8.1), the soil condition that determines the effectiveness of the soils in providing ecosystem services, including the provision of food, water and fibre, is a product of the land and soil capability and the stresses and limitations imposed by land management practices. Where land management practices are effective in providing the ecosystem services required from soils and where land management practices do not cause deterioration in the soil condition, they can be considered sustainable. The identification of the land management practices and their sustainability is a key step in ensuring soil security.

Land management can have a range of effects on soil condition. While the potential for land management practices to cause land and soil degradation is well known (FAO 2011; OEH 2012; Nkonya et al. 2013; Gray et al. 2015), there is also the possibility that land management can improve soil condition by the addition of irrigation infrastructure, addition of nutrients or amelioration of natural soil limitations such as acidity and sodicity. Soils in a degraded condition can also be restored to differing degrees by management practices such as conservation agriculture, water ponding in scalded soils, liming of acidified soils and increasing soil organic matter levels (FAO 2000; Liniger et al. 2011; Read et al. 2012; Govers et al. 2013; Winterbottom et al. 2013; Lal 2015).

8.5.4 Economic Value of Ecosystem Services: Productivity

SLM practices have to be economically viable and hence produce a positive cost-benefit outcome (Liniger et al. 2011). Because of insufficient attention in soil security, therefore, it is necessary to add some estimate of the economic viability of SLM practices. The capacity of the soil to provide provisions of food, water, fibre and wood is a component in the assessment of the capital value of soils. The economic capital value of soils is determined by the provision or flow of other economic services as well (Dominati et al. 2010), but the provision of food, water and fibre is particularly crucial for food and water security.

8.5.5 Definitions of Connectivity and Codification

The definitions of connectivity and codification can be clarified to define exactly what actions and processes are considered to be included in these dimensions. Connectivity is concerned with whether a land manager has the attitude, beliefs and capacity to manage soil according to its capability. Having the capacity to manage the soil according to its capability requires sufficient knowledge, finance, labour and energy resources. Programmes to increase knowledge of land management practices can change attitudes and beliefs as well as provide the capacity to implement sustainable land management practices. Addressing limitations of finance, labour and energy may also be needed to implement SLM practices. To address these constraints, it may be necessary to consider aspects of codification.

Codification refers to the regulation and policy around the implementation of SLM practices to ensure soil security. Included are aspects such as land tenure mechanisms, mechanisms to provide finance, market structures for inputs including fertilisers and seeds, market structures for outputs such as grain and animal products, infrastructure and nature of technical support organisations, energy policy and the use of biofuels and environmental laws.

8.6 Conclusion

A matrix based on the six global challenges identified for soil security (food security, water security, energy security, climate change abatement, human health, biodiversity protection) and the dimensions of soil security (capability, condition, capital, connectivity, codification) is proposed as a tool to demonstrate the links between soil security and soil and land evaluation and to demonstrate the links between SLM practices and soil security. Several land and soil evaluation systems and recommended sets of sustainable land management practices (Liniger et al. 2011; OEH 2012; Palm et al. 2007; Govers et al. 2013) are used to demonstrate the proposed matrix.

This approach clearly validated the value and potential of the soil security concept in developing and promoting sustainable land management practices. However, it also identified several issues that need further discussion and consideration:

1. The need for a realignment of the definitions of capability and condition in the soil security concept.
2. Recognition that soil capability cannot be assessed separately from land and site characteristics and the term land and soil capability is perhaps appropriate.
3. More emphasis on land management practices would be beneficial, especially in the interaction with capability to produce the resultant soil condition.
4. Clearer, more specific definitions of what is included under connectivity and codification are warranted.

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Part III
Condition

Chapter 9
General Concepts of Valuing and Caring for Soil

Alex B. McBratney, Damien J. Field, and Lorna E. Jarrett

Abstract Beginning in the mid-twentieth century, concepts have arisen to define how society values and cares for soil. The earliest, soil conservation, focused narrowly on the causes and prevention of soil erosion. Other early concepts were land evaluation and capability and soil care. More recently, a large number of concepts have been proposed. These have a broader scope, reflecting increases in scientific understanding of soil and its interactions with other parts of the biosphere and with human society. They include soil function, soil quality, soil health, soil condition, soil change, soil resilience, soil ecosystem services and soil protection. However, none of these concepts includes the full range of ways in which society needs to value and care for soil, and some are vague in definition. The concept of soil security has five dimensions: capability, condition, capital, connectivity and codification (McBratney AB, Field DJ, Koch A et al., Geoderma 213:203–213, 2014). These recognise specific concepts of soil value and care.

Keywords Soil conservation • Land evaluation • Soil care • Soil function • Soil quality • Soil health • Soil condition • Soil change • Soil resilience • Soil ecosystem services • Soil protection

9.1 Introduction

Soil can be conceptualised in three ways: in terms of its biophysical attributes, as an object of scientific study and in societal terms, i.e. valuing and caring for soil for the benefit of humanity. This chapter focuses on the third approach: that of valuing and caring for soil. This idea has been proposed in the past, through the concepts of soil conservation, land evaluation and capability and soil care. More recently, a large number of related and interdependent concepts have been proposed and elaborated on.

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9.2 Early Concepts of Valuing and Caring for Soil

9.2.1 Soil Conservation

This concept arose in the first half of the twentieth century and focused on the problem of soil erosion on agricultural land. It is concerned with the physics and mechanism of soil erosion, the effects on soil of different forms of land use, methods for control of erosion and maintenance of productivity and economic issues pertaining to soil conservation (Bennett 1939; Kohnke and Bertrand 1959; Hudson 1972; Morgan 1986).

9.2.2 Land Evaluation and Capability

Rossiter (1996), who developed a classification system for land evaluation models, explained that land evaluation grew out of agricultural land capability classification in the 1960s. He described it as a tool for strategic land planning, predicting land performance in terms of expected benefits from and constraints to productive use and degradation that would be expected to occur under the use. Stewart (1968) defined land evaluation as "the assessment of the suitability of land for man's use in agriculture, forestry, engineering, hydrology, regional planning, recreation and warfare".

FAO (1985) defined land evaluation as "the selection of suitable land, and suitable cropping, irrigation and management alternatives that are physically and financially practicable and economically viable". Land evaluation provides information about the suitability of land for specific purposes, usually in the form of maps and reports. From the 1970s to the 1980s, the FAO developed a framework for land evaluation and created guidelines for land evaluation in dryland and irrigated agriculture, forestry, extensive grazing and steeplands. In the late 1980s and 1990s, quantitative methods emerged; these required considerable data. Most of these approaches to land evaluation were based on a soil science approach and did not take account of ecosystem, economic and societal factors (Rossiter 1996).

9.2.3 Soil Care

Soil care can be defined as selecting and implementing a system of soil and land use management that will improve and maintain its usefulness for any selected purpose, i.e. not only for agriculture but equally as an entity of the environment. Sustainable soil and land use requires a simultaneous application of socioeconomic concerns with sound environmental principles based on protecting the soil and biota (Yaalon 1996).

9.3 Present-Day Concepts

In the present day, a large number of concepts exist which describe the idea of valuing and caring for soil. These are described below.

9.3.1 Soil Function

"Soil function describes what the soil does" (Lal et al. (1997) p. 388). Various lists of soil functions have been described. These include providing a medium for plant growth and biological activity, regulating and partitioning water flow and storage in the environment and an environmental filter and buffer in the immobilisation and degradation of environmentally hazardous compounds (Larson and Pierce 1991). Harris et al. (1996) listed the following functions: nutrient relations, water relations, toxicant relations, pathogen relations, rooting relations, aesthetic relations and physical stability. According to NRCS East National Technology Support Center et al. (2011), soil functions are usually assessed using soil quality indicators, because they cannot be measured directly.

9.3.2 Soil Quality

A wide variety of definitions of soil quality have been proposed, all of which relate to soil function. Singer and Sojka (2002) explained the wide variety of definitions as due to the evolving nature of the concept. Soil quality has been defined as:

> The capacity of a soil to perform functions which sustain biological productivity and maintain environmental quality (p. 405). Soil quality is well correlated with soil organic carbon content. (Herrick and Wander 1997)
>
> The capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habituation. (Karlen et al. 1997, p. 6)
>
> The capacity of the soil to promote the growth of plants; protect watersheds by regulating the infiltration and partitioning of precipitation; and prevent water and air pollution by buffering potential pollutants such as agricultural chemicals, organic wastes and industrial chemicals. (National Research Council 1993)

Seybold et al. (1999) described two types of soil quality: *inherent soil quality*, determined by soil formation processes, and *dynamic soil quality*, the change in soil function, relative to a reference condition, due to management practices. These correspond to our definitions of *capability* and *condition*.

9.3.3 Soil Health

Soil health was defined by Doran (2002) as “the capacity of a living soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health”. This is almost identical to Karlen et al.’s (1997) definition of soil quality. Further, Doran explained that soil health can change over time due to natural events or land management practices. In this sense, it corresponds to the soil security definition of soil condition.

9.3.4 Soil Condition

An example of this concept is illustrated by a programme of monitoring, evaluating and reporting (MER) implemented by the NSW Natural Resources Commission in 2008, Australia. One of their targets was an improvement in soil condition by 2015, so baselines for soil condition were required. In the acknowledgement of the importance of many physical and chemical attributes and processes, eight key indicators were used to determine soil condition. These were sheet erosion, gully erosion, wind erosion, soil acidity, soil organic carbon, soil structure, soil salinity and acid sulphate soils. At each site, each of the eight indicators was evaluated against a reference condition and rated on a scale of 1–5, with 5 being at or better than reference condition and 1 being severely deteriorated against reference condition. The actual condition for each of the indicators, at each site, was derived from field data and modelling. Reference conditions were obtained through literature review and examination of soil at undisturbed sites. Finally, the eight ratings were combined to give an average soil condition rating for each site. This was expressed as a number from 1–1.9 (very poor), through 2.0–2.9 (poor), 3.0–3.9 (fair), 4.0–4.4 (good) to 4.5–5.0 (very good) (NSW Office of Environment and Heritage 2014). Examples of understanding soil condition in the USA are described in Chap. 8.

9.3.5 Soil Change

Tugel et al. (2005) defined soil change as “temporal variation in soil across various time scales at a specific location. Attributes of change include state variables (dynamic soil properties), reversibility, drivers, trends, rates, and pathways and functional interpretations include resistance, resilience, and early warning indicators”. Causes of change may be anthropogenic or natural. The concept emphasises the dynamic, evolving nature of soil, which to date has not been well accounted for in soil surveys. According to Robinson et al. (2012) soil change is a useful concept for conveying information about changes to soil that has relevance for political decision-making time scales and is an analogous field of study to climate change. This concept is central to the recent developments in the soil health initiative elaborated on in Chap. 8.

9.3.6 Soil Resilience

The concept of resilience began to be used in ecology in the 1960s. Lal (1993) defined it as “soil’s ability to restore its life support processes after being stressed”, while Herrick and Wander (1997) defined it as “the capacity of a soil to recover physical integrity after a disturbance”, i.e. any event which causes significant change from normal ecosystem functioning. Disturbances include fires, earthquakes, floods, landslides, high-intensity storms, logging, grazing, cropping, tillage and industrial development (Seybold et al. 1999). Resilience is therefore proportional to the rate of increase of soil function with time, following a disturbance (Herrick and Wander 1997). According to Seybold et al. (1999), soil resilience is a component of soil quality, and the resilience of a soil depends on the soil type, vegetation, climate, land use, scale and disturbance regime. Soil resilience can be assessed in three ways: directly measuring recovery after a disturbance, quantifying the integrity of recovery mechanisms after a disturbance or measuring properties that serve as indicators of recovery mechanisms.

Soil resilience has also been defined as the capacity to resist change due to a disturbance (Rozanov 1994). However, while Seybold et al. (1999) saw resistance as important, they considered it to be a distinct concept and clarified the difference as “During a disturbance, soil quality becomes a function of soil resistance. After a disturbance, soil quality becomes a function of soil resilience” (p. 227), and emphasised that both resistance and resilience are dependent on management practices. Soil resilience is an important concept due to the ubiquity of disturbance events. The relationship of soil resilience to the soil security dimensions of capability is further discussed in Chaps. 1 and 9 and condition in Chap. 9.

9.3.7 Soil Ecosystem Services

According to Robinson et al. (2012), the physical elements of the soil resource (minerals, carbon, water, air and their structural characteristics) constitute the soil stocks or soil natural capital. Processes act on these stocks, leading to flows and transformations of materials and energy. Soil ecosystem services result from these flows; these include carbon compounds in food and fibre, uptake of carbon in climate regulation, water regulation and filtration and the recycling of waste. Soil ecosystem services rely on soil natural capital, and for a system to be sustainable, it is essential that soil ecosystem services are not obtained in a way that reduces soil natural capital.

Daily (1997) defined ecosystem services as “the conditions and processes through which natural ecosystems and the species which make them up, sustain and fulfill human life” and classified soil ecosystem services as supporting, regulating, provisioning and cultural. Others have expanded on this framework, but no universally accepted version yet exists (Robinson et al. 2012). A soil ecosystem services framework needs to be developed that takes full account of the role of, and needs to conserve, soil natural capital.

9.3.8 Soil Protection

The concept of soil protection arose from the 6th Environmental Action Programme, published by the European Commission in 2001 (Blum et al. 2004). A need was identified to take a Europe-wide, systematic approach to the protection of soil. To achieve this, a communication entitled “Towards a Thematic Strategy for Soil Protection” was developed and ratified. This document focused on soil as distinct from land use and defined five functions of soil: production of biomass including food; storing, filtering and transforming; habitat and gene pool; physical and cultural environment; and source of raw materials. It identified eight threats to soil: erosion, decline in organic matter, contamination, sealing, compaction, decline in biodiversity, salinisation and floods/landslides. This systematic approach recognised that many areas of EU policy impact on soil and that knowledge of soil monitoring systems is incomplete in some countries and regions; therefore, there is a need for EU-wide monitoring and policy for soil protection.

Research working groups were established and based their results on a DPSIR approach (Blum et al. 2004): involving driving forces, which cause pressures, leading to a state, which gives rise to impacts, requiring responses. Main research goals, research clusters and priority areas were identified.

9.4 Discussion

In summary, a large number of concepts have been developed over the years to describe and define the idea of valuing and caring for soil. According to Robinson et al. (2012), soil quality, health and change are recently developed, emerging and evolving conceptual frameworks. The terms soil health and soil quality have been used interchangeably, to mean “fitness to support crop growth without becoming degraded or otherwise harming the environment” (Karlen et al. 1997, p. 6), which also equate soil health with dynamic, as opposed to inherent, soil quality. Doran (2002) also used the terms interchangeably, referring to “soil quality or health” (p. 121). According to Robinson et al. (2012), soil quality is a measure of soil natural capital, and soil change recognises that soil natural capital is not a fixed quantity.

Many of the concepts described above are relatively narrow in scope, sometimes vague, and generally focus on biophysical attributes of soil. In order to meet the global existential challenges, we need a broader concept that encompasses the economic, social and policy aspects of soil, which is clearly defined and which allows us to measure and quantify the degree to which soil is being valued and cared for. It is also important that this broader concept recognises the place of earlier concepts of caring for soil.

The concept of soil security, which has five dimensions, capability, condition, capital, connectivity and codification, is intended to meet this need. These dimensions recognise specific concepts of soil value and care. Because soil security integrates biophysical aspects with societal, policy and economic considerations, it is multidisciplinary in nature. In this section of the book, an understanding of the difference between capability and condition is warranted and is the opportunity to develop frameworks to action and illustrate these two biophysical dimensions.

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Chapter 10
Soil Health: Challenges and Opportunities

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Abstract In recent years, a broad stakeholder base within the agricultural sector and among the public has become aware of the critical importance of healthy soils, spurred by public awareness campaigns and workshops. As we continue to grapple with a changing climate and more extreme weather events, regenerating the health and proper functioning of our nation's, and indeed world's, soil resource will markedly improve the capacity of soil to maintain or increase yield and yield stability, lower input costs, and contribute to other ecosystem services. This is true not only for croplands but also for pastures and native rangelands, orchards, and forests. To aid in moving forward initiatives to help farmers and ranchers improve the soil resource base, the USDA Natural Resources Conservation Service (NRCS) has created a new Soil Health Division (SHD). Personnel distributed across the country will facilitate soil health technical training and education for stakeholders, work with partners to standardize soil health assessments, promote soil health management systems as part of the conservation planning process, and facilitate implementation and long-term adoption of soil health management systems on our nation's agricultural lands. The new division will leverage skills, resources, technology, and partnerships to achieve these goals.

Keywords NRCS Soil Health Division • Assessments • Management

10.1 Introduction

Widespread adoption of soil health management systems has the potential to make continental-scale, systemic improvements in environmental factors, farm resilience and productivity, as well as profitability. Concentrated efforts to improve soil health will thus provide significant return on the nation's conservation investment.

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10.2 Challenges: Making the Case for Soil Health

Our soils, and thus our society, face critical challenges. Our current population of 7 billion people is projected to increase to 9.1 billion by 2050 (Godfray et al. 2010). Our agricultural lands will need to produce more food, feed, and fiber in the next 50 years than in the previous 5000 years combined. Yet, over 20 million acres of active agricultural land were lost to development between 1982 and 2007 (U.S. Department of Agriculture 2015), we have not improved our nation's water quality (Dubrovsky et al. 2010), and available agricultural land is degrading.

During the last two centuries, our nation's agricultural soils have lost at least one-half of the vital soil rich in organic matter from converting prairies and forests to cultivated land (David et al. 2009; Jelinski and Kucharik 2009). Soil organic matter, often measured as soil organic carbon (SOC, about 58 % of organic matter is carbon), has been lost through microbial degradation as the plow has broken apart the soil structure that protects organic matter within aggregates or through excessive erosion via wind or water. Much of the country has lost up to two-thirds of the A-horizon (topsoil, Fig. 10.1), which is where the majority of plant roots, plant nutrients, and SOC are located, as well as most of the organisms that inhabit the soil. This not only impacts biological and physical soil functioning for in-field crop production but also significantly contributes to declining ecosystem services.

Temperature data from four international science institutions, NASA's Goddard Institute for Space Studies, NOAA National Climatic Data Center, U.K. Met Office Hadley Centre/Climatic Research Unit, and the Japanese Meteorological Agency, indicate a rapid warming worldwide over the last several decades (NASA 2016). The mean temperature across the USA has risen 1.1 °C (2 °F) since 1960 (Karl et al. 2009) and increases from 1.7 to 5.9 °C over global 1961–1990 mean temperatures that are projected by various emission scenarios. October 2015 was the warmest on record for the globe, with an average departure of 1.33 °C (2.39 °F) above the twentieth-century October average (136 years, 1880–2015) (National Oceanic and Atmospheric Administration 2016). In other words, the Earth is running a fever. Greenhouse gases that are the primary drivers of climate change have increased dramatically over the last 50 years. Agricultural practices affect emissions of several greenhouse gases, primarily CO_2, N_2O, and CH_4 (Johnson et al. 2011).

Climate-related changes impact US agriculture (Karl et al. 2009), particularly in degraded soils. Precipitation has increased about 5 % over the last five decades. Projections suggest northern regions will get wetter, with more heavy downpours, leading to increased water erosion from ground with insufficient cover. Crop yields may decline due to field operational and productivity impacts when excess water does not drain in a timely manner. Increased disease and pest pressures are anticipated as temperatures and CO_2 levels continue to rise. Drought and heat waves have increased significantly over the last 50 years. Southern areas, especially the southwest, are likely to get drier, resulting in increasing risk of drought-related crop loss and pressures on water resources for irrigation. Especially in degraded soils with low surface cover, low infiltration, and shallow active root zones, short- and

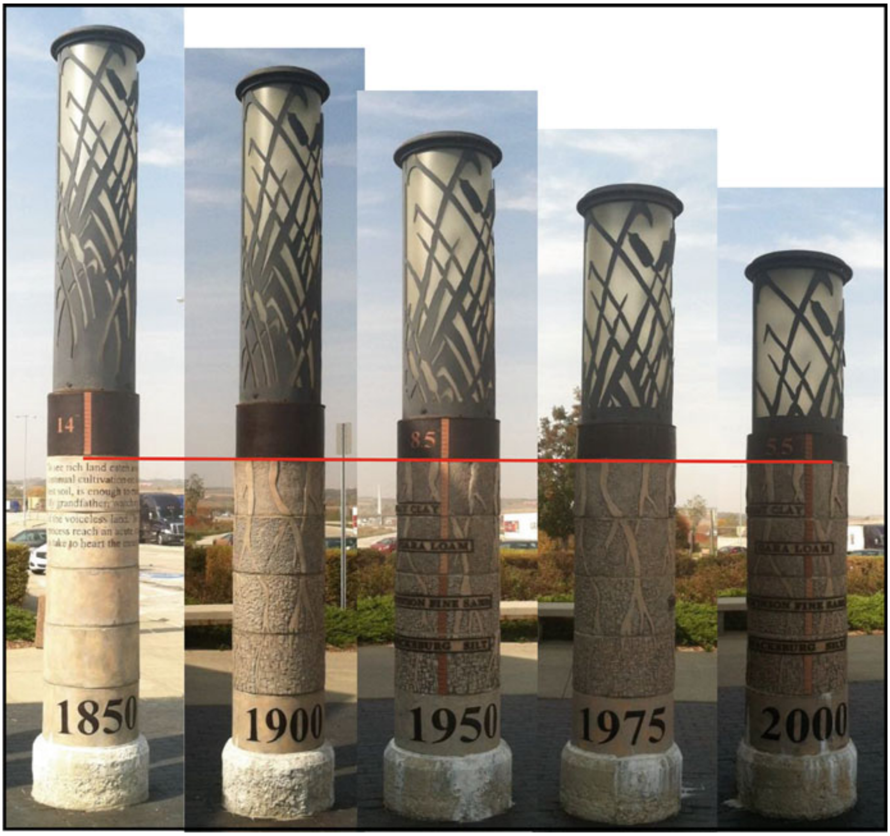

Fig. 10.1 Soil pillars representing the loss of the A-horizon from 1850 to 2000 in Iowa. Topsoil depth was 36 cm in 1850, and by 2000, 22 cm of topsoil had been lost. Pillars located at a rest area along I-80E, in Adair Co., IA, 41°29′46.2″N 94°33′42.7″W (Composite photo courtesy of Zamir Libohova, USDA-NRCS)

long-term water deficits and heat stress on growing crops result in yield instability and decreased yields.

Livestock production contributes to about 50 % of the nation's agricultural product output (National Agricultural Statistics Service 2014). Overgrazing and prolonged drought can both contribute to impaired rangeland health. Rangeland health assessments (Pellant et al. 2005), conducted periodically by the USDA-NRCS, include three attributes: soil and site stability (resilience to erosion by wind and water), surface hydrologic function (water partitioning), and biotic integrity (ability of the biotic community to support ecosystem services). While the assessment is not a soil health assessment, it integrates a number of soil health-related components. A significant proportion of private native rangelands, covering 17 western states, and areas of Louisiana and Florida, have become impaired over time (Fig. 10.2). Practices leading to the impairment are often historical. Management has improved

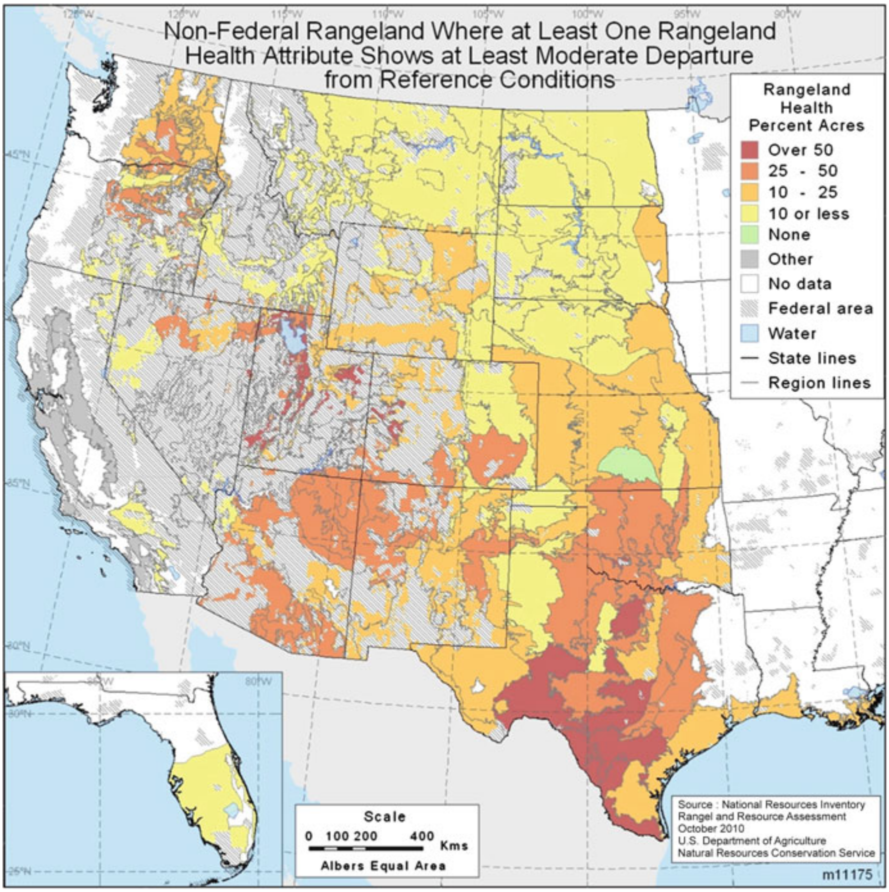

Fig. 10.2 2010 native rangeland assessment of nonfederal lands, indicating the percentage of land that had at least one rangeland health attribute showing at least a moderate variation from the localized reference conditions (Map from USDA-NRCS)

over time as the understanding of interactions among livestock, climate, and ecosystems has increased. However, in relatively fragile ecosystems with low average annual rainfall (e.g., <38 cm or 15 in.), recovery is slow, frequently decades long, and is challenged further by our changing climate. Forage quality generally declines with increasing concentrations of atmospheric CO_2, due to the impact on plant N and protein content (Hatfield et al. 2008). This and water stress reduce the land's ability to supply adequate livestock feed and regenerate soil function through belowground biomass production.

10.3 Opportunities: Moving Toward Healthier Soils

While the challenges are great, the work of scientists and land managers alike shows that there are tremendous opportunities to address these challenges. Through understanding how today's predominant soil management practices have caused our current situation, and implementing locally adapted soil health management systems that reverse these trends, farmers and ranchers have the opportunity to rebuild the health of our nation's soils.

10.3.1 Understanding Soil Health Degradation

Soil quality that, in concept, includes chemical, physical, and biological functioning and indicators came to the forefront of soil science research in the 1980s and 1990s (Doran et al. 1994; Gregorich et al. 1994; Larson and Pierce 1994). The term "soil quality" has been mostly replaced by "soil health," especially in communications among stakeholders beyond the scientific community, with the two terms generally used interchangeably. The transition to "soil health" has been largely influenced by a greater focus on the soil biotic community for soil functioning. Soil health refers to dynamic soil properties that can be altered by management, but must be assessed and managed with an understanding of underlying inherent soil property influences, such as soil taxonomic class, landscape position, mineralogy, and soil texture, as well as climate. Although there have been many definitions proposed for soil quality/health (Doran and Parkin 1994), the new USDA-NRCS Soil Health Division (SHD) defines soil health as "The continued capacity of the soil to function as a vital living ecosystem that sustains plants, animals, and humans."

A degraded soil is the result of a cascading downward spiral (Fig. 10.3) perpetuated by currently predominant soil management techniques. Intensive tillage, low crop diversity, and low soil cover and rooting lead to loss of SOC, resulting in a reduction in water (and wind)-stable macroaggregates (>250 μm) and reduced capacity to store and cycle nutrients, among many other impacts. Aggregates are the smallest unit of soil structure, where macroaggregation is affected by management through impacts on the ability of soil biota to rebuild and maintain that structure (microaggregation is controlled by inherent soil properties such as texture and mineralogy). When a high-intensity rainstorm hits a soil surface with weakened aggregates, those aggregates tend to break apart, leading to surface sealing and crusting. This in turn makes it difficult for germinating seeds to push through the surface and for water to infiltrate (Stott et al. 1999). Poor structure also leads to susceptibility of soil to compaction, either by field operations on excessively wet soil or overgrazing, leading to increased erosion by wind and water. This causes further loss of topsoil, organic matter, and nutrients, in addition to declining yields and other ecosystem services provided by soils. Some of the yield impacts of this loss can be made up by

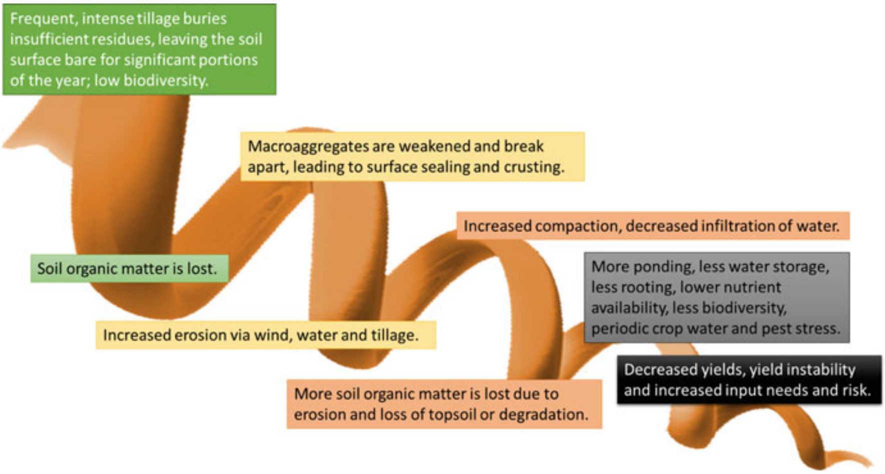

Fig. 10.3 Downward spiral leading to degraded soils and impaired yields. Implementing soil health management systems can reverse the trend (Modified from Magdoff and van Es 2009)

increased inputs (fertilizers, herbicides, etc.), which then generally results in decreased net profit, and can be associated with increased environmental impact (Magdoff and van Es 2009).

10.3.2 Assessing Soil Health Degradation

A step toward broadly reversing such impacts will be to make standardized comprehensive assessment of soil health degradation status available to producers. This can inform location-appropriate paths to better management by alleviating the most constraining biological and physical problems first. The suggested approach is similar to nutrient testing and management that is already successfully practiced, but would more comprehensively include monitoring and managing actionable soil processes beyond nutrient supply and important biological and physical influences on nutrient supply.

Several soil health assessments have been used successfully for varying purposes (Stott et al. 2010). The Soil Management Assessment Framework (SMAF) was developed by Andrews et al. (2004) and later modified (Stott et al. 2010; Wienhold et al. 2009). It has been used across the USA and internationally, largely by researchers and governmental agencies for landscape scale resource and impact assessment. The SMAF provides site-specific interpretations for soil health indicator results, using soil taxonomy as a foundation for the assessment to provide a contextual basis. For example, a measured soil organic carbon content of 1 % might be scored fairly high in an Ultisol in Georgia, but in an Iowa Mollisol, that content would be

Fig. 10.4 Soil health should be assessed within the context of soil taxonomic factors. Soils should be compared to like soils, or to the same soil or field over time. The photo on the left is a profile of a Mollisol, found throughout the Midwest, while the photo on the right is a profile of an Ultisol, found throughout the southeast. A 1.1 % soil organic carbon concentration would be considered near optimum for many Ultisols, while the same concentration in a Mollisol would be the cause for significant concern. (Photos from the USDA-NRCS)

considered low and cause for concern (Fig. 10.4). The SMAF allows the user to choose specific indicators depending on chosen goals, and indicator scoring curves can be added (Stott et al. 2010).

Since 2006 producers have been able to submit samples to the laboratory for Cornell's Comprehensive Assessment of Soil Health (Moebius-Clune et al. 2015). This assessment bases its approach for interpreting measured values on the SMAF, but includes additional measurements, and is specifically designed to inform producers on management decisions, similar to soil nutrient testing. Currently, it is calibrated for the northeastern USA, but there are plans to expand its capacity to regionally adjusted interpretations. It provides a color-coded interpretive report, explanation of identified biological and physical constraints (and a standard soil nutrient analysis), and management suggestions for alleviating constraints to soil functioning. Multiple other universities have started to adapt the above approach to local needs and capacity. Other private and public entities have made suites of indicators available that focus on biotic community assessment (e.g., phospholipid fatty acid analysis) or on biological contributions to nutrient availability (e.g., Soil Health Nutrient Tool). NRCS currently uses model-based proxies such as the Soil Conditioning Index (SCI) or the Soil Tillage Intensity Rating (STIR) to estimate management impact on soil health. The Soil Health Division, in collaboration with internal and external partners, will be evaluating publically available soil health assessments and frameworks to facilitate a nationally applicable, standardized approach and mechanisms for updating standards as the science advances, for comprehensive assessment of soil health that can inform soil health management planning and implementation.

10.3.3 Managing for Healthier Soils

Just as in the case with our own health, regaining soil health is not immediate. However, steps can be taken to improve conditions by implementing soil health management systems, which adapt mechanisms that build and maintain resilience in natural ecosystems. There are four guiding principles for annual crops: (1) minimize soil disturbance by reducing tillage; (2) maximize diversity of crops, animals, and amendments such as by adding crops to the rotation and integrating cover crops and/or livestock; (3) keep the soil covered as much of the time as possible, through surface-managed plant residues and/or plant canopies; and (4) maximize the amount of time during which living roots are actively growing in the system, either through crop intensification or cover crops. There are numerous studies that support these principles (Blanco-Canqui et al. 2015; Franzluebbers 2010; Karlen et al. 2014; Lal 2009; Lehman et al. 2015; Veum et al. 2015). These principles can be applied in pastures and rangelands, but through different management techniques. For example, timing grazing and reducing stocking rates appropriately to support local plant community productivity, placing water sources and fencing to encourage herds to utilize an entire field, and reducing congregating animals and overgrazing in specific areas within the field (Briske et al. 2008; Derner et al. 2006) will contribute to addressing all four principles above.

To properly address soil health issues on our nation's agricultural lands, production paradigms must first be shifted through training on and demonstration of new management systems and their benefits in diverse production systems. A comprehensive and knowledge-intensive approach is then needed. Each farm will benefit from assessing current soil health status, usually by field, to inform an individualized soil health management plan developed to guide each producer in adapting the above principles as is feasible for their particular situation. Differing identified soil health constraints, soil series, climate, management history, resource and equipment access, and goals of the individual farmer or rancher need to be considered during the development of a detailed plan.

There is a higher probability of success when adopting a soil health management system if implementation occurs in carefully designed stages. Transition steps need to (1) address soil constraints that may hamper full system implementation initially and (2) facilitate the producer's ability to try new knowledge-intensive techniques at a scale that introduces acceptable risk, to ensure it is working before adopting at larger scales. For example, soils that are frequently tilled may present challenges when converting to no-till due to existing poor surface soil structure and compaction. In such cases, limited/targeted tillage can be used to break up surface crusts to facilitate seed germination and water infiltration, but this is only a temporary fix, as surface crusts will reform with subsequent rainfall events. However, such targeted tillage can be combined with soil building practices such as cover cropping to regenerate the structure and biological activity needed for successfully reducing tillage in the longer term. Innovative producers, in collaboration with forward-looking researchers and public and private agricultural service providers, have been making progress in solving technical implementation challenges as they create improved management systems.

10.4 The USDA-NRCS Soil Health Division

In 2012, the USDA-NRCS launched a soil health campaign to "unlock the secrets in the soil" by providing trainings and workshops, educational materials, and web resources (USDA Natural Resources Conservation Service 2012) including innovative farmer and researcher case studies, running public awareness advertisements in major markets, and distributing soil health information kits to the public. In 2014, NRCS recognition of the long-term importance of regenerating our nation's soil health, and the increased stakeholder demand for soil health technical assistance, culminated in the initiation of the new Soil Health Division (SHD). As of December 2015, the new Division is almost fully staffed. Personnel are distributed throughout the USA to provide coverage in all regions of the country (Fig. 10.5). As team members have diverse strengths and specialties, they will be called upon to provide information, training, and assistance on projects of local to national scope both within and outside their primary coverage areas (in blue, Fig. 10.5) to strategically meet emerging needs.

The SHD's purpose is to increase NRCS capacity to incentivize and facilitate producers in broadly implementing science-based, effective, economically viable soil health management systems. The SHD will build partnerships and leverage expertise and resources within and outside of NRCS to drive broader change in management adapted to the soils, production systems, and climatic conditions of the nation's diverse agricultural lands. Partnerships with external public and private partners will, for example, leverage synergies with soil health-related efforts of other USDA agencies, other federal and state agencies, conservation districts, academic entities, and diverse nonprofit and industry partners, land owners, and managers, among others.

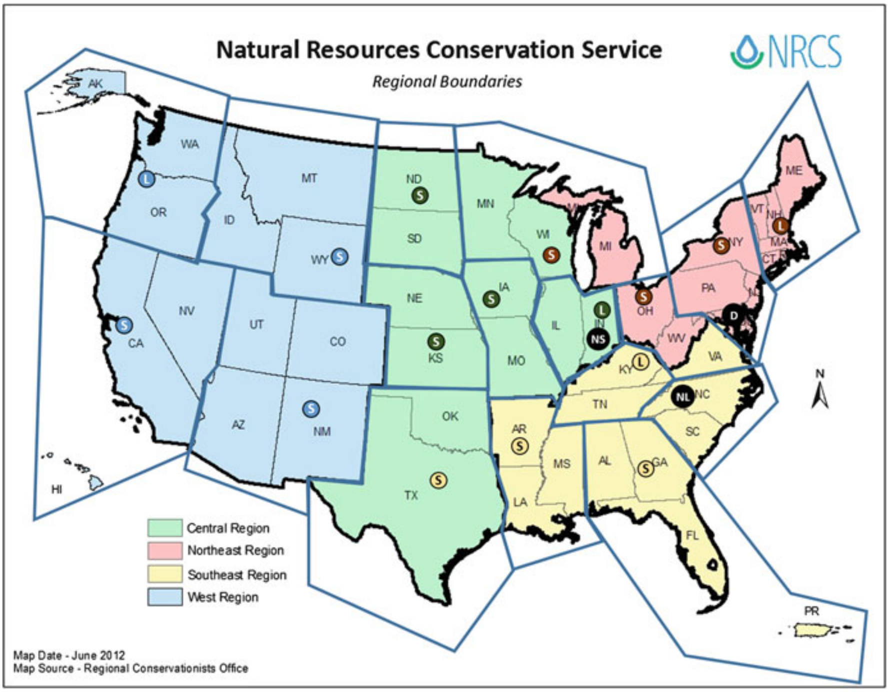

Fig. 10.5 Distribution of the Soil Health Division personnel. Symbols: *D* Director of the Soil Health Division, Washington, DC; *NS* National Soil Health Technical Specialist, West Lafayette, IN; *NL* National Soil Health Team Leader, Greensboro, NC; *L* Regional Team Leaders, Durham, NH for the northeast, Indianapolis, IN for central, Lexington, KY for southeast, and Portland OR for west; and *S* Soil Health Specialists (12, 3 in each region)

Key SHD goals include capacity building in soil health training, assessment, management planning, and implementation. The division will develop and provide advanced soil health technical training to diverse audiences, in particular to agricultural service providers and interested producers, to enable rapid adoption of critical concepts and technologies. The SHD is leading an effort with key partners to standardize soil health assessment methodologies to facilitate the availability and effective use of such assessments by producers. Soil health management planning will be developed, piloted, and integrated into NRCS conservation planning nationwide. The planning approach will enable local adaptation of the four soil health management principles to soil, production system, climatic, and operation conditions. Existing and new conservation practices will be packaged into soil health management systems, and capacity of field staff to provide technical and/or financial assistance for adaptive implementation of soil health management systems will be developed to stimulate long-term adoption.

10.5 Conclusions

Soil health management systems, once implemented, have the potential to markedly improve our soil resource, providing significant return on the nation's conservation investment. The USDA-NRCS Soil Health Division was created to facilitate implementation of science-based, effective, economically viable soil health management systems on the nation's agricultural lands. With changes in management, producers can achieve improvements in profits through better nutrient cycling, pest suppression, savings in energy and inputs, and enhanced water infiltration, storage, and drainage. Producers adopting soil health management systems will simultaneously address some of our most pressing regional and global challenges. They will improve water quality and availability, habitat for biodiversity, and rural economic vitality, while sequestering carbon, adapting to and mitigating climate change, and feeding a growing population.

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Chapter 11
Using Soil Survey to Assess and Predict Soil Condition and Change

Skye Wills, Candiss Williams, C. Seybold, Linda Scheffe, Zamir Libohova, David Hoover, Curtis Talbot, and Joel Brown

Abstract Soil survey organizes the landscape into units with common soil properties, characteristics, and classification. Soil survey units can be used to predict soil behavior and thus are useful for making management decisions and evaluating soil change. Traditionally, in the USA, soil survey mapping concepts have been developed with the dominant use of the landscape in mind. Current enhancement of soil survey includes documenting dynamic soil properties and soil change due to ecosystem management. Ecological sites are a concept used to describe "kinds of land" that have common potential kinds and amounts of vegetation and characteristic response to disturbance. In intensively managed (agronomic) systems, inputs (e.g., energy, fertilizer, irrigation water) can confound and homogenize vegetation indicators. In these situations, ecological site concepts, as constructed through state and transition models, can be differentiated based upon levels of soil function (indicated by dynamic soil properties) that occur as a result of the management (disturbance). Groupings and interpreting soil properties using an ecological site framework can serve as a useful tool for soil resource management and assessment and bring whole ecosystem insight into management decisions. Such organizational frameworks should provide information about both reference conditions and alternative management systems of soil functions or dynamic soil properties within an ecological site. Reference conditions might reflect either native or naturalized vegetation or the highest possible function that an ecological site could support. A framework for assessing soil condition in two ecological sites/soil types is examined. The capacity of each ecological site is different as indicated by soil carbon content and aggregate stability. This information allows for documentation of soil change (from reference to alternative states or management systems); it could also be used as a reference for soil health assessments and could be used to enhance soil survey with land use and management-specific information.

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Keywords Dynamic soil properties • Soil condition • Soil survey • Ecological sites

11.1 Introduction

Soil condition generally refers to the current status of a soil or soil system. Soil condition has been used to refer to soil's place in global environmental sustainability (Doran and Ziess 2000; Karlen et al. 2001; Wall et al. 2012). McBratney et al. (2014) acknowledge condition as one of the five dimensions of soil security; others are capability, capital, connectivity, and codification. They use condition to indicate the current status of the soil system which can be compared to a soil's capability (which can be thought of as an optimal or inherent reference state).

Currently, the US Department of Agriculture (USDA) is promoting soil health through policy, programs, and public outreach (U.S. Department of Agriculture Natural Resources Conservation Service 2016). The soil health initiative focuses on improving soil function through improved management systems (U.S. Department of Agriculture Natural Resources Conservation Service 2013). While these soil functions can be thought of as type of condition, this program does not explicitly use those terms. We propose using the terms of soil survey and ecological sites to frame soil health metrics in terms of condition relative to soil capacity or capability defined through reference condition or potential function. Reference condition and potential function are explicit quantifications of intrinsic, pedologic soil capability as referred to in the soil security framework (McBratney et al. 2012, 2014).

11.2 Background

11.2.1 Soil Health

Doran and Zeiss (2000) define soil health as the capacity of soil to function as a living system. They seem to be referring to the soil at a specific location's current capacity as opposed to the capacity as potential of a given soil type. The 2015 Wikipedia definition of soil health puts it in terms of status (analogous to condition) relative to its environmentally controlled ecosystem functions (analogous to capacity):

> **Soil health** is a state of a **soil** meeting its range of ecosystem functions as appropriate to its environment. **Soil Health** Testing is an assessment of this status. (Anonymous n.d.)

Soil health is an important concept for assessing soil change and soil management sustainability (Doran 2002). The holistic approach to soil health, including microorganisms interacting with soil structure, water movement, and nutrient cycling, is particularly important when soils are being managed to define, manage, and potentially improve ecosystem services (Abbot and Manning 2015; Lehman et al. 2015). While the soil health concept has been applied most widely to agronomic systems, it also has applications in urban gardening (Knight et al. 2013), rangeland (Damsma et al. 2015; Printz et al. 2014), and agroforestry (Bardgett et al. 2013). The Cornell Soil Health Test Assessment (Gugino et al. 2009) recommends measuring the following soil properties to indicate soil health: aggregate stability, available water capacity, hardness, organic matter, active carbon, potentially mineralizable nitrogen, root health, as well as standard soil test nutrients. These properties are then scored based on general concepts about what values function “better” (as adapted from the Soil Management Assessment Framework (SMAF) of Andrews et al. 2004).

11.2.2 Soil Survey

Soil survey organizes the landscape into units with common soil properties, characteristics, and classification (Soil Survey Division Staff 1993). De Bakker (1970) described two purposes of soil classification: (1) systematic organization and (2) practical application in terms of land use and management. Soil survey systematically organizes soil information by assigning conceptual soil type and landscape categories and then assigning those to mapping units. Map units group like areas and each kind of map unit is different from all other map units in some way (US Department of Agriculture, Natural Resources Conservation Service (NRCS); US Department of Agriculture Natural Resources Conservation Service 2015a).

To allow soil survey data to be used for land management, soil information (data and interpretations about types of soils) must be attributed or assigned to soil map units (delineations of soil boundaries applied to the physical world) that are made spatially explicit by polygons. Traditionally, in the USA, soil survey mapping concepts and soil properties have been developed and assigned with the dominant use of the landscape in mind including agriculture, military, forestry, and grazing uses (Brevik et al. 2016). In the USA, a high, representative value (RV) and low property value are assigned for various soil properties (texture, pH, rock fragments) for each map unit component (US Department of Agriculture 2015). It is assumed that the values will be representative of the dominant land use and conditions for a given soil survey area.

It has long been recognized that taxonomic soil survey units behave differently in response to different land management (Bouma 1994), and there is growing recognition that soil survey data must be collected and produced in ways that support environmental and resource management (Miller and Schaetzl 2014). Sonneveld et al. (2002) proposed differentiating soil map units and properties depending upon past land use. Tugel et al. (2008) formalized systematic measurement of “dynamic soil properties (DSPs)” as a part of US soil survey. They outline a way to capture and describe soil properties that vary with land use and vegetative communities. Current work involves incorporating the DSP collection into soil survey mapping and ecological inventory activities. To be successful, the information from DSP projects will need to be extrapolated based both upon soil survey units and current land management.

11.2.3 Soil Hierarchies: Soil Systems and Ecological Sites

A central premise of ecosystem science, including soil science or pedology, is that natural resources can be organized across broad geographic and climatic ranges. Bailey et al. (1985) proposed a regionalization of ecological mapping specifically to aid in information transfer or extrapolation, and Omernik (1987) published a map to understand regional patterns of terrestrial resources. The US Department of Agriculture (USDA) uses a similar set of criteria of climate, physiography, biology, and soils to separate the country into management regions according to Ag Handbook 296 (NRCS-USDA 2006).

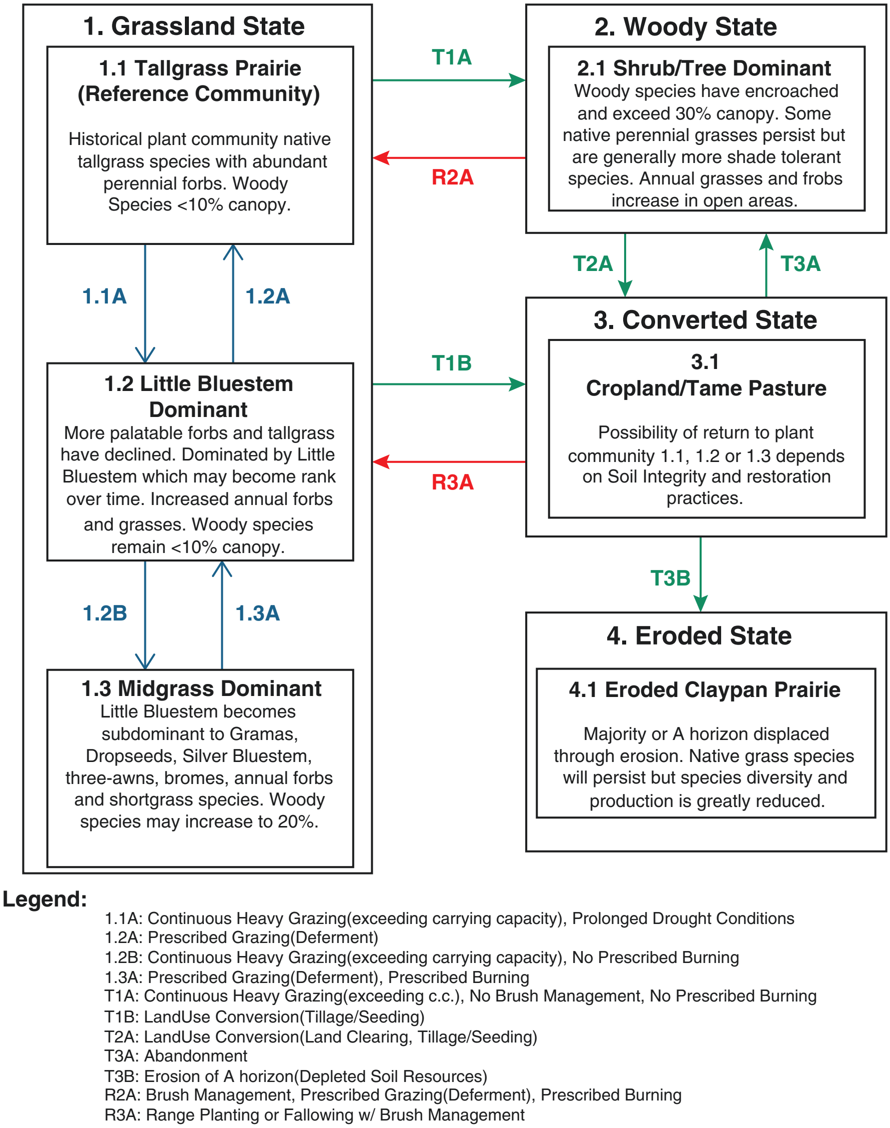
The USDA soil survey is currently organized by groups of Major Land Resource Areas (MLRAs), or MLRA regions, for the purposes of logistics and standardization (USDA 2015); it is expected that soil survey activities will be organized by MLRA. Conceptually, each MLRA can be described by a few characteristic catenas or repeating patterns of soils, what Huggett (1975) referred to as a soil system. The basic soil system unit is a three-dimensional body with multiple landscape elements. The soil system encompasses all environmental factors that closely interact in repeating and recognizable patterns including the conceptual ideas of soils, vegetation, geomorphology, and hydrology that are used for mapping in soil survey (Schoeneberger et al. 2014).

Within each soil system, there are typically a small number of individual units including soil types and ecological units with a limited range of variability in a predictable pattern. Soil survey focuses on creating soil map units that organize those patterns into spatial units and describing those map units with soil component information such as texture, thickness, and rock fragment content. Soil map units may contain soil components that are recognizably different but cannot be represented spatially. Soil map unit components can be grouped into useful constituents such as ecological sites. Ecological sites are a kind of land and can be considered an interpretation of site and soil potential – relevant at management scales (USDA-NRCS Natural Resources Conservation Service 2016).

The term "site" does not refer to a specific, individual location. It refers to groups of mapping units and it can be thought of as an interpretation or land classification. With the soil system diagram (or underlying conceptual models of soil property distribution), we can identify groups of soil that function in ecologically similar ways.

> An *ecological site* is a conceptual division of the landscape that is defined as a distinctive kind of land based on recurring soil, landform, geological, and climatic characteristics that differs from other kinds of land in its ability to produce distinctive kinds and amounts of vegetation, and in its ability to respond similarly to management actions and natural disturbances. (Caudle et al. 2013)

Ecological sites are differentiated based on edaphic criteria (including soil properties such as morphology, depth, texture, pH, etc.) that correlate to a reference condition or vegetative community that represents the historical complement of species that occupied that type of site (Bestelmeyer et al. 2010; Briske et al. 2008). The ecological dynamics of an ecological site can be described with a state and transition model (STM) (Fig. 11.1) (Bestelmeyer et al. 2003; Stringham et al. 2003)



1. Grassland State

1.1 Tallgrass Prairie (Reference Community)

Historical plant community native tallgrass species with abundant perennial forbs. Woody Species <10% canopy.

1.2 Little Bluestem Dominant

More palatable forbs and tallgrass have declined. Dominated by Little Bluestem which may become rank over time. Increased annual forbs and grasses. Woody species remain <10% canopy.

1.3 Midgrass Dominant

Little Bluestem becomes subdominant to Gramas, Dropseeds, Silver Bluestem, three-awns, bromes, annual forbs and shortgrass species. Woody species may increase to 20%.

2. Woody State

2.1 Shrub/Tree Dominant

Woody species have encroached and exceed 30% canopy. Some native perennial grasses persist but are generally more shade tolerant species. Annual grasses and frobs increase in open areas.

3. Converted State

3.1 Cropland/Tame Pasture

Possibility of return to plant community 1.1, 1.2 or 1.3 depends on Soil Integrity and restoration practices.

4. Eroded State

4.1 Eroded Claypan Prairie

Majority or A horizon displaced through erosion. Native grass species will persist but species diversity and production is greatly reduced.

Legend:

1.1A: Continuous Heavy Grazing(exceeding carrying capacity), Prolonged Drought Conditions
1.2A: Prescribed Grazing(Deferment)
1.2B: Continuous Heavy Grazing(exceeding carrying capacity), No Prescribed Burning
1.3A: Prescribed Grazing(Deferment), Prescribed Burning
T1A: Continuous Heavy Grazing(exceeding c.c.), No Brush Management, No Prescribed Burning
T1B: LandUse Conversion(Tillage/Seeding)
T2A: LandUse Conversion(Land Clearing, Tillage/Seeding)
T3A: Abandonment
T3B: Erosion of A horizon(Depleted Soil Resources)
R2A: Brush Management, Prescribed Grazing(Deferment), Prescribed Burning
R3A: Range Planting or Fallowing w/ Brush Management

Fig. 11.1 State and transition model for the Claypan Prairie ecological site (R080AY011OK). This model meets current standards of the US Department of Agriculture, Natural Resources Conservation Service, and is approved for distribution. The complete report is available at https://esis.sc.egov.usda.gov/ESDReport/fsReportPrt.aspx?id=R080AY011OK&rptLevel=general&approved=yes&repType=regular&scrns=&comm=. The figure includes states (*larger boxes* with one number), community phases (*smaller boxes* with two numbers), transitions, restoration pathways, and community pathways (as described in the legend) which describes the ecological dynamics of disturbances (both natural and anthropogenic) (Briske et al. 2005).

For each site, an STM represents multiple potential ecological states, vegetative communities that occur within those states, as well as the transitions and thresholds that occur between states (Bestelmeyer et al. 2010; Briske et al. 2008). The focus has been on vegetation, but dynamic soil properties can also be drivers and consequences of ecosystem change (Duniway et al. 2010) and can be used to indicate ecosystem functions (Herrick 2000).

While ecological sites and STMs are widely used in rangelands and gaining acceptance in other types of natural or naturalized vegetation, the concepts have not been widely applied to intensively managed systems. When cropland states are represented (as in the "Converted State" in the Claypan Prairie site, Fig. 11.1), the focus is often on the transitions to and from other states of perennial vegetation, not on dynamics and potentials within the state. The USDA-NRCS is committed to identifying and describing ecological sites and documenting ecological dynamics across all types of lands (NRCS n.d.). We propose that all lands be described with ecological site and STM tools based on a reference condition of native or naturalized vegetation to the best extent possible. Where an ecological site is commonly intensively managed across its extent, such as in pasture or crop land management, then additional information should be added about the soil dynamics under imposed land management categories.

The proposed dynamic soil properties (DSPs) model for Land Management Organizational Framework (LMOF) on intensively managed lands would supplement ecological site information for native and naturalized vegetation (Fig. 11.2). For any given soil function that can be represented by a DSP indicator such as soil organic carbon content or aggregate stability (Tugel et al. 2008), the range in characteristics of the natural vegetation should be summarized. The highest known value represents the known ecological potential. Additional groups of management system types (e.g., row crops, pasture) should be summarized in this same manner. Then within those summary boxes, the properties for individual management systems could be represented. This system provides a benchmark, similar to the ecological site-based reference condition used in rangeland health (Pellant et al. 2005) for the overall site, types of crops, and generalized management systems.

11.3 Using the Ecological Site Framework to Assess Soil Condition

11.3.1 Examples of Soil Condition Assessment

Two ecological sites with different parent materials and climates (and thus different soils and plant communities) are explored for this example. For each, a soil survey project was conducted according to the Soil Change Guide (Tugel et al. 2008)

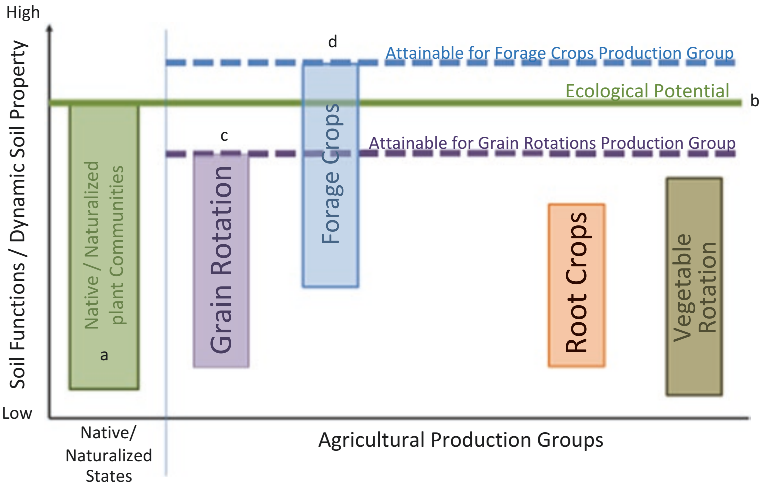


Fig. 11.2 Proposed Land Management Organizational Framework (LMOF) for using dynamic soil properties (DSPs) to assess soil condition against reference and management benchmarks: a) Range of DSP capability for native and naturalized states (inherent) is represented by a *box plot*; b) ecological potential is represented as a DSP value; c) alternative land management group (based on types of crops produced for market) ranges are represented by a *box*, with the maximum attainable represented by a single level; and d) potential is higher when inputs of energy and resources exceed those in naturalized systems (for instance, organic carbon levels might be high when irrigation and manure is added)

comparison study procedures. The objective of each project was to compare crop management systems to a reference state (Fig. 11.1). The sandy loam ecological site (R077CY036TX) is located in Southern High Plains MLRA (077C) and occurs on flat plains and playas with fine sandy loam Alfisols. The Claypan Prairie ecological site (R080AY011OK) in MLRA 080A-Central Rolling Red Prairies occurs on upland Mollisols with a loamy surface texture and finer (more clay) subsurface textures. These Mollisols have thick, dark surface horizons with high levels of organic carbon compared to the thinner, lower carbon surface horizons of the Alfisols. Both sites have rangeland reference plant communities. While the sandy loam site is dominated by mid and shortgrass prairie species, the Claypan Prairie site is dominated by tallgrass prairie species. Lists of soils and plant species for each site can be found online at the Ecological Site Description website (US Department of Agriculture, Natural Resources Conservation Service 2015b).

One soil was selected as representative of each ecological site. Representing the Claypan Prairie, the Kirkland soil series is a fine, mixed, superactive, thermic Udertic Paleustoll. The fine sandy loam component of the Amarillo soil, a fine-loamy, mixed, superactive, thermic Aridic Paleustalf, represents the sandy loam site (Soil Survey Staff 2015a). Both are benchmark soils because of their wide extent and are expected to be representative of the area (USDA 2015). For both projects, GIS techniques were used to locate map units expected to contain the target soil series components. Then the reference state (from the state and transition model) and two alternative conditions (common cropland management systems) were selected for evaluation. In the Claypan Prairie, both conventionally tilled and no-till wheat management systems were evaluated. In the sandy loam site, conventionally managed cotton fields and Conservation Reserve Program (CRP; FSA n.d.) fields were evaluated. Five locations were identified for each soil – management combination. At each location, a random point was used to anchor a 25 × 25 m plot with five pedons systematically placed throughout the plot in the arrangement described in the Soil Change Guide (Tugel et al. 2008). Soil samples were collected from each pedon at depth increment of 0–2 cm and by genetic horizon. All samples were analyzed at the Kellogg Soil Survey Laboratory (Burt 2004) and the data can be located in the National Cooperative Soil Survey Characterization Database (National Cooperative Soil Survey n.d.). In this example, we use the 0–2 cm samples for organic carbon, assumed in these samples to be equivalent to total carbon (4H2a1-3) and water-stable aggregates (3F1a1a) (Burt 2004). GIS analysis was done using ArcGIS (ESRI, Redlands, CA) with the National Soil Information System (NASIS) and Soil Survey Geographic (SSURGO) data sets (Soil Survey Staff 2015b), and graphs were made using the ggplot2 package in R (Wickham 2009).

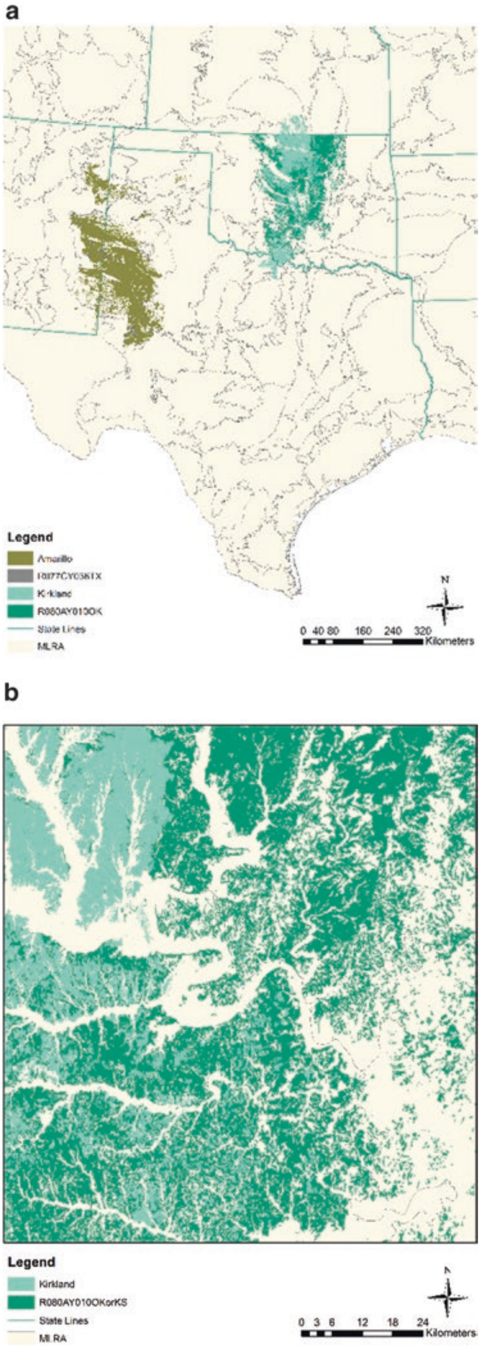
11.3.2 Results of Soil and Condition Comparisons

The GIS analysis shows that soil survey can be used to frame the inference of study results to soil and ecological site map units (Fig. 11.3). There was more organic carbon (Fig. 11.4a) and greater aggregate stability (Fig. 11.4b) in the reference state than in the alternative conditions. However, the levels in the reference state (which represents the capacity of each soil) were quite different. The Kirkland soil has more moisture and finer textures (more clay) which would be expected to lead to more accumulation of organic carbon (4.0 % vs. 2.6 %), and the combination of increased clay and organic carbon also improves the level of water-stable aggregates that might form (Kirkland, 71.2 %; Amarillo, 19.5 %) (Tisdall and Oades 1982).

As might be expected for two different ecological states, a different response to disturbance was observed. The conventionally tilled fields lost 32 % (Kirkland) and 15 % (Amarillo) soil carbon relative to the reference state; the Amarillo also lost less (14 %) water-stable aggregates relative to the reference condition than the Kirkland soil (19 %). The intermediate level of CRP and no-till conditions represent both previous disruptions due to agriculture; CRP is targeted toward soils/landscapes that are likely to have been eroded (FSA n.d.) and current moderate levels of disturbance. The values need to be monitored over time to ensure that they've reached a steady state. We expect that carbon inputs and storage would vary by climate and soil type (Conant et al. 2001).

Organic carbon and aggregate stability are two important indicators of soil health or soil quality. While improvements to both have been recommended as important

Fig. 11.3 SSURGO map units for a) the full extent of soils and ecological sites in this project and b) an area showing the Kirkland soil series map units and other map units in the Claypan Prairie ecological site that are expected to behave similarly. (**a**) Extent of example soils and ecological sites. (**b**) Landscape scale distribution of Kirkland soil and associate ecological site



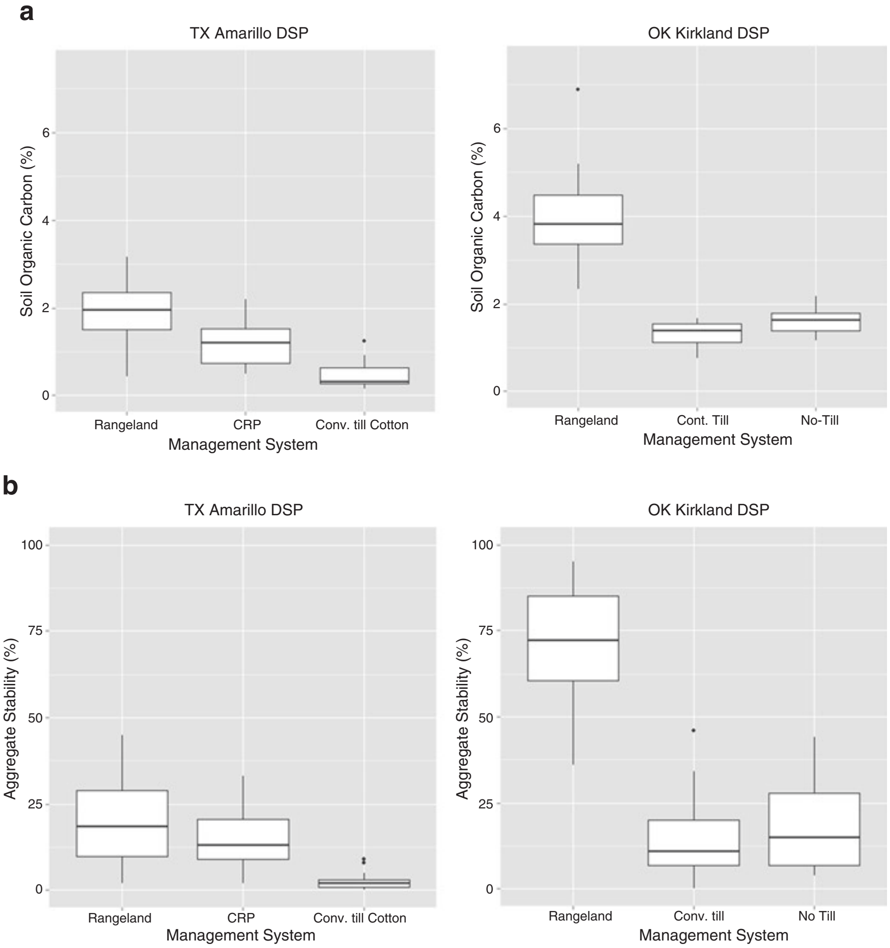


Fig. 11.4 Dynamic soil properties of 0–2 cm samples for (**a**) soil organic carbon (%) measured as total carbon and (**b**) water-stable aggregates (%) measured for two soils in two different ecological sites. *Box* plots represent the 25th and 75th percentiles

for soil quality for decades and the current soil health initiative recommends improving both, there are few systems that provide benchmark values. This expands on the scoring functions in the Cornell soil health test and the soil management assessment framework (Andrews et al. 2004) by providing expected soil property values for land use and management systems. The proposed Land Management Organizational Framework (LMOF) system organizes the information in relatable terms and units that can be used to assess soil condition based on a benchmark of soil capacity.

11.4 Summary

Groupings and interpretations of soil properties using an ecological site framework can serve as a useful tool for soil resource management and assessment and bring whole ecosystem insight into management decisions. Such organizational frameworks can provide information about both reference conditions and alternative management systems of soil functions or dynamic soil properties within an ecological site. Reference conditions might reflect either native or naturalized vegetation or the highest possible function that an ecological site could support (given the soils and climate). The organizational framework also includes information about expected soil functions or dynamic soil properties under various types of management systems that might be used. Once established, such a framework will allow for documentation of soil change, as well as assessments of soil health and function for individual sites, which can then be extrapolated to fields and landscapes using soil survey information.

In the example shown, the combination of the ecological site framework and dynamic soil property evaluation provides knowledge of the capacity of each soil (and potentially larger portions of the ecological/landscape hierarchy). It also provides information about expected soil properties after ecosystem disturbance. Both reference levels of soil carbon and aggregate stability and the levels observed under alternative management systems varied by ecological site. Future assessment of soil health management systems can be compared to these levels documented under conventional agricultural systems. The next phase of this work will use geographic spatial layers with ecological site and land use information to document current expected conditions, soil change time and space, and forecast future expectations of soil function. Soil survey enhanced with ecological site and dynamic soil property information provides information that can be used to make decisions related to soil security and soil health for field to continental scales.

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Chapter 12
Root-Microbe Interactions in Response to Soil Conditions

Anil Somenahally

Abstract Soil microbes are a substantial component of soils and are essential for many soil functions and capability. Many recent studies have confirmed the beneficial root-microbe associations for soil and plant health, including root growth, fitness, and stress tolerance of plants under different soil conditions. Roots and rhizosphere microbial communities are in flux with the environment; as a result, root-microbe interactions shift in response to soil conditions. Some soil conditions like moisture stress (transient soil condition) and acidity and alkalinity (inherent soil conditions) are common constraints for many beneficial root-microbe interactions. For example, during drought, the plant microbiome is significantly altered in many crops, and plants may select unique microbes to improve drought tolerance. Studies have shown that the phylogenetic and the physiological adaptations by some microbes in response to moisture stress can benefit plants. Soil constraints such as subsoil acidity and aluminum or salt toxicity can be detrimental to some plant-beneficial microbes like mycorrhizae. As a result, novel root-microbe interactions do occur most likely in subsoil, which may be critical for improving root fitness and soil health in the subsoil. There are opportunities to improve the root-microbe interactions through diversification of cropping systems and sustainable management practices. Further research is needed to clearly outline beneficial root-microbe interactions in response to soil conditions and fill knowledge gaps to effectively integrate belowground interactions with soil and crop management.

Keywords Plant-microbe • Acidity • Arsenic • Beneficial microbes

12.1 Importance of Root-Microbe Interactions

Soil microbes are an important component of soils and integral to soil capability and security. Microbes that are associated with plants are considered plant microbiome, which is the diverse microbial populations encompassing prokaryotes, fungi, and

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viruses associated with a plant and its habitat including the rhizosphere. Some microbes that are present within plant parts are termed endophytes and root endophytes are the microbes within roots. The plant microbiome, now considered a second genome of plants (Berendsen et al. 2012), can have both negative and positive effects on plant health and productivity. Soil microbes mediate many biogeochemical processes and plant physiological functions, as a result are key to managing soil fertility and nutrient use efficiency in plants. Soil microbes can alter soil nitrogen (N) and phosphorus (P) pools in soils by mediating key processes like nitrification, ammonification, denitrification, biological nitrogen fixation, P mineralization, and immobilization (Galloway et al. 2008). Microbial interactions can also improve plant fitness, nutrient supply through decomposition of organic matter, degradation of phytotoxic compounds, secretion of organic compounds such as siderophores and organic acids, and suppression of pathogens (Spence et al. 2014).

Many of the root functions like soil exploration for nutrients, nutrient release from soil minerals, and plant stress tolerance are intricately linked to soil microbes like arbuscular mycorrhizal fungi (AMF) (Rout and Southworth 2013). The AMF symbiosis is the most common of all the mycorrhizal fungi and has been identified in thousands of plants. With its extended and extensive hypha network, the mycorrhizal fungi can greatly expand the root's access to nutrients from greater volume and depths of soil (Jansa et al. 2003). Several studies do suggest that the mycorrhizal fungi can also promote mineral weathering and soil P solubilization. However, it has been noted that the bacteria may actually be responsible for P solubilization, which may eventually be transported by the mycorrhiza fungi to plant roots (Koele et al. 2009). As a result, root-fungi-bacteria associations may be key for efficiently acquiring soil P from the sparingly soluble sources and in soils with low P availability.

Root-microbe interactions are essential for improving root growth and fitness in subsoil, which is critical for drought tolerance in plants. According to recent scientific evidence, global climate change will likely produce droughts of increasing severity in many parts of the world. As such, soil moisture stress will continue to be a major production constraint globally. In response to this lingering problem, agriculture industry is implementing drought-tolerant crop varieties, most of them with deeper root systems. As noted in a recent paper, deep, steep, and cheap root systems could be a strategy to deal with the drought (Lynch 2013). Deep-rooted crops have been proven to be drought tolerant and have shown higher nutrient use efficiency. However, developing deep root networks can be metabolically expensive and in some cases improbable due to subsoil (E, B, and C horizons) constraints (Lynch and Wojciechowski 2015). Acidity, metal toxicity, salinity, hypoxia, and compactness are common subsoil constraints that can limit root growth and microbial communities. Aluminum and salt toxicities are the most widespread subsoil constraints, accounting for almost 36 % of the global cultivated area (Sumner 1999).

12.2 Microbial Communities Change in Response to Soil Conditions

Several biotic and abiotic soil factors can influence soil and root microbiome composition. Soil conditions like pH, hypoxia, carbon availability, compactness, and soil mineralogy can alter microbial diversity and root-microbe interactions (Heckman et al. 2009). Niche separation of microbial communities in response to local biogeochemical conditions has been observed in the rhizosphere of many plants. It was noted in one of our studies that the rice-rhizosphere compartments with microscale biogeochemical variations can have unique microbial communities (Somenahally et al. 2011). The Geochip-based functional gene analysis of the rice-rhizosphere bacterial community demonstrated major shifts in metabolic capabilities of many metal cycling processes (genes), which was in response to microscale oxygen gradients and iron oxide precipitation (Fig. 12.1) (Somenahally et al. 2015). These differences in the metabolic functions of microbial community can greatly affect the biogeochemistry of toxic metals like arsenic and their bioavailability at the root-soil interface.

Root-microbe interactions are impacted by many soil constraints such as acidity, compactness, and hypoxia. Aluminum affects root apex development and growth of most microbes is affected below pH 4.5, when free trivalent Al concentrations increase. One of the common tolerance mechanisms by plants is through exudation of organic acids, as some carboxylic acid groups of organic acids can readily chelate Al. For example, maize can activate anion transporter in the plasma membrane to exude organic acids and phenolic compounds when Al levels are higher (Krill et al.

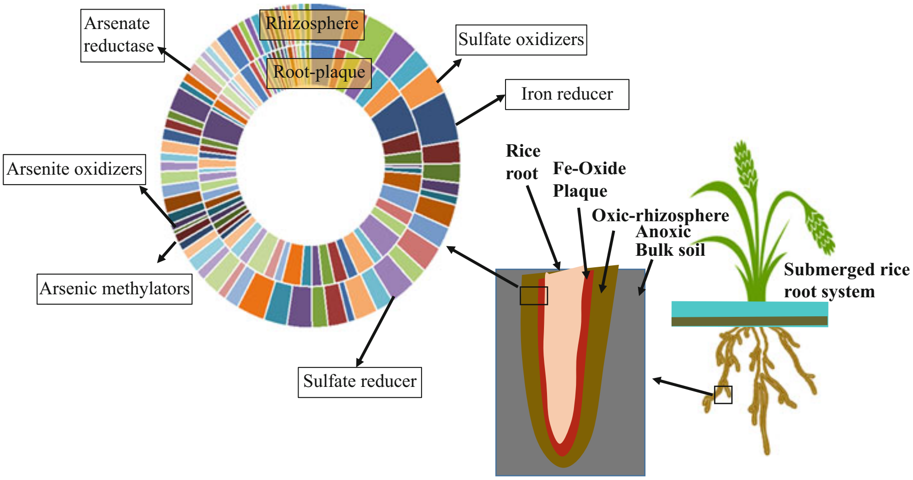

Fig. 12.1 Geochip-based bacterial functional gene abundance (relative abundance of markers) in rice-rhizosphere compartments (iron oxide-rich root plaque and adjacent rhizosphere). Only a selected group of metal transformation genes are identified

2010). However, most of the studies on evaluating plants for acid tolerance did not include microbes while assessing for organic acids. Similar to plants, some microbes exude organic anions such as citrate and malate to chelate Al and minimize its toxicity. Such mechanisms in the rhizosphere may benefit plant roots and promote Al tolerance in plants at much lower metabolic cost to them (Kelly et al. 2005). Microbes may also alter the metabolic pathways to tolerate Al toxicity and induce organic acid production to chelate Al, such as oxalate (Hamel and Appanna 2003). In *Pseudomonas fluorescence*, malate dehydrogenase and pyruvate carboxylase were upregulated to produce oxaloacetate at a greater rate when Al was present. Apart from organic acids, some microbes may also utilize hydroxyl, carboxyl, and phosphate groups to complex aluminum and exopolysaccharides in some of the rhizobia strains (Ferreira et al. 2012). Anaerobic microbial communities have also been found to remove Al as precipitates, such as sulfate reducers (Martins et al. 2012). Plants may also produce several signaling compounds such as jasmonic acid and salicylic acid in response to biotic and abiotic stresses, which may promote microbial abundance and root-microbe interactions to improve Al tolerance (Kniskern et al. 2007). Whether any cryptic root-microbe interactions exist to mutually benefit from these tolerance mechanisms is not clearly known.

As such, microbial biomass and substrate pools generally decrease by depth, but active microbial life exists in deeper soil horizons. In subsoil, novel plant-beneficial microbes do occur most likely, as commonly observed symbionts (in rhizosphere of surface soil) like AMF do not flourish at greater soil depths (Higo et al. 2013), and studies have noted decreased fungal to bacterial ratios by depth and decrease in general diversity of AM fungi with soil depth (Stone et al. 2014). One reason could be the low abundance of plant roots, which is essential for mycorrhiza proliferation. Perhaps, increasing root biomass in subsoil can increase root-associated fungi and plant-microbe interactions in deeper soil. Some evidence suggests that the subsoil microbial composition is mostly different from the surface soil, even though less abundant (Richter and Markewitz 1995). Unique root-microbe interactions can occur in subsurface soil in response to soil conditions, as soil horizon-specific changes in taxonomic and functional diversity of microbes have been observed (Uroz et al. 2013). Some evidence suggests that the subsoil microbial metabolic capabilities and energy generation processes must adapt to lower substrate and oxygen levels (Hartmann et al. 2009). We noticed in an ongoing experiment that the rhizosphere and the root endophytes of cowpea plants were significantly different between the surface and the acidic subsurface layer with high Al concentrations (Fig. 12.2) (Somenahally and Leonard 2015). The root endophytes appeared to be a subset of the rhizosphere community, but demonstrated a distinct profile. These results suggest that the roots may recruit soil condition-specific endophytes, and it needs to be investigated whether microbial metabolic capabilities also change in response to soil conditions.

Actinobacteria spp. usually increase with depth in the rhizosphere, as they are a metabolically versatile group of organisms that degrade high molecular weight components of SOM including lignin and cellulose (McCarthy and Williams 1992). Another prominent group noted to increase in deeper soils are archaeal groups, like

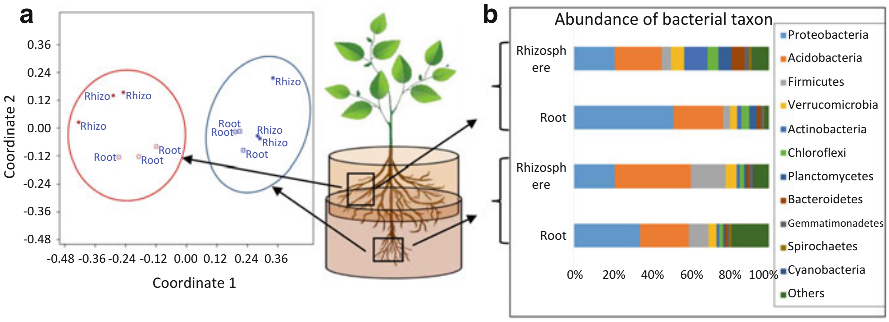

Fig. 12.2 (**a**) Non-metric multidimension scaling (NMDS) analysis of Bray-Curtis distances of bacterial OTUs from cowpea rhizosphere and root endophytes, showing the community structure differences at 7 weeks after planting, from surface and acidic subsoil of cowpea rhizosphere. (**b**) Relative abundance of bacterial taxon of root and rhizosphere

Crenarchaeota (Eilers et al. 2012); as a result archaea to bacteria ratios generally increase with the soil depth. Most archaea are free living and are not known to form plant associations (Eilers et al. 2012). Archaea are not usually found in the rhizosphere and only a few of the archaea have been found among root endophytes (Ferreira et al. 2012), but it needs to be determined whether the same is true in subsoil rhizosphere. Although archaea are well suited for extreme conditions and they seem to be dominant in acidic soils, not much is known about the root-archaea interactions. It needs to be also determined whether any plant-beneficial archaea occur in soils and whether they have any beneficial role in conditions that are not favorable for bacterial and fungal proliferation

12.3 Improving Root-Microbe Interactions

Studies have clearly demonstrated that some root-microbe interactions can improve plant productivity and soil health, but the challenge has been to manipulate microbes to produce desired results. However, it is generally accepted that soil organic carbon can increase microbial diversity and that the declining trends in soil carbon pools can diminish many beneficial microbes and limit the root-microbe interactions. This is especially true for root-microbe interactions in the subsoil with additional limitations for roots and microbial growth. Some management practices to increase soil organic carbon produced positive results by improving AM associations in wheat, which attenuated Al toxicity to some extent (Seguel et al. 2013). The AM fungi associations have also been noted to increase plant nutrient uptake from acid soils (Borie and Rubio 1999). However, the challenge has been to improve such associations in the subsoil, which generally supports less diversity of mycorrhizae. One strategy can be including deep-rooted cover crops to increase active root growth and carbon substrate additions to subsoil. Many plants produce explicit rhizodeposits to recruit different consortia of microbes in response to soil conditions. Depending on the subsoil conditions, cropping systems must be developed based on belowground interactions to improve subsoil health. For example, acid tolerant plants may be able to grow roots more efficiently into the acidic subsoil and can increase subsoil microbial diversity. Some of the plants are known to produce higher concentrations of root exudates and can tolerate soil acidity and alkalinity, however the exudates concentrations and composition can vary between legumes and grassess, and as a result the root associated microbial populations can also change (Vranova et al. 2013).

It is well established that crop rotations with cover crops provide many soil and ecosystem services, compared to a mono-crop system (Snapp et al. 2005). There is considerable evidence to support that the cover crops increase AMF fungi, as cropping systems with cover crops provide active roots most of the season, which can increase AMF survival and proliferation (White and Weil 2010). Additionally, cover crops can increase soil organic status, moisture balance, and nutrient cycling and may have some legacy effects on microbial communities of subsequent crops. Cover crops with higher belowground productivity can develop effective root-microbe interactions, although many beneficial associations are not yet clearly outlined.

Recent developments in genomics have greatly enhanced our understanding of soil biology, and opened new avenues for tapping root-microbe interactions for improving soil and plant health. However, a much further understanding of the many beneficial interactions is essential to develop sustainable management adaptations and technologies based on root-microbe interactions. Future research must focus on how rhizodeposit composition modulates soil microbiome structure and consequential root-microbe interactions and responses. Cropping systems and management practices based on belowground interactions can greatly enhance crop productivity and soil health, but further studies are essential to gain mechanistic understanding of the root-microbe manifestations among cropping systems and identify most effective combination of crops and soil management. Understanding subsoil root-microbe interactions of cover crops and their legacy effects in crop rotations is also essential to make informed decisions on cover crop species for rotation and improve soil health and capability.

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Chapter 13
Securing Our Soil in Intensive Monoculture Cropping Systems

Katie L. Lewis, Paul DeLaune, and Wayne Keeling

Abstract Adoption of reduced tillage and no-till cotton is one of the most rapidly growing conservation areas in the United States. As conservation tillage expands in use, understanding the impact of transitioning to such systems on nutrient cycling and soil compaction and the soil's overall health becomes paramount. Our objective was to measure the impact of long-term conservation tillage systems in cotton production systems on soil chemical, physical, and biological properties. The Soil Health Tool developed by USDA-ARS was used to measure biological properties of soil samples taken to a depth of 15 cm. Soil physical properties measured included bulk density, soil strength using penetrometers (cone index values), and infiltration. Soil cores were taken to a depth of 90 cm and segmented for analysis of soil chemical properties. Soil carbon was higher in the upper 10 cm for systems that had been in no-till for more than 10 years. We also observed that carbon sequestration was higher in systems that incorporated crop rotation, particularly wheat, versus a continuous cotton system. Among locations through the Southern High Plains of Texas, infiltration rates were generally greater in conservation tillage systems than adjacent conventional tillage systems.

Keywords Soil health • Compaction • Cover crops • Conservation tillage • Soil organic carbon • Cropping system

13.1 Introduction

The primary goal of agricultural production is to provide the world's population with food, fiber, and fuel. As global population and the demand for food grow and nonrenewable resources become more limited, the agricultural industry, and more specifically producers, will be challenged to increase crop yields with less resources

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(e.g., land, water, and nutrients) while maintaining soil productivity, practicing environmental stewardship, and sustaining the economic viability of farm operations (Godfray et al. 2010). Implementing conservation practices such as crop rotations, cover crops, and reduced tillage may not only improve soil health but also optimize inputs and maximize nutrient and water use efficiencies.

Although continuous cotton may be the most economic cropping system for farmers in the Rolling Plains and Southern High Plains of Texas, continuation of this practice will likely exacerbate longer-term problems involving reduced productive capacity of soils; thus, rotations with other cash crops or the use of cover crops combined with conservation tillage must be implemented. For this reason, adoption of reduced tillage and no-till cotton is one of the most rapidly growing conservation tools in the United States.

Soil compaction has been reported to reduce cotton yields in the southeastern United States; however, little information exists within the top cotton-producing state of Texas. Cotton has been found to be particularly susceptible to soil compaction with Raper et al. (2007) indicating significant yield reductions as a result of excessive vehicle traffic or naturally occurring conditions. No-till soils are often susceptible to compaction due to field equipment traffic and the lack of soil disturbance. In contrast, some studies have reported that soils under long-term no-till systems can be less susceptible to compaction than plowed soils due to no-till-induced increases in soil organic carbon (Thomas et al. 1996; Blanco-Canqui et al. 2009, 2010).

Cover crops have been shown to reduce the effects of soil compaction, increase infiltration, and increase water holding capacity of the soil, primarily due to increased soil organic matter (SOM). It has also been hypothesized that increasing SOM in the soil profile enables the soil to better support vehicle traffic. Nutrient stratification, particularly P and to a lesser extent K, is also a concern in conservation tillage systems. Therefore, an evaluation of the impact of cropping systems on soil physical, chemical, and biological properties is warranted to better understand potential effects on cotton production within the Texas Rolling Plains and Southern Plains.

13.2 Materials and Methods

Two research locations were selected to meet the objective. One location consisting of an Abilene clay loam was at the Texas A&M AgriLife Chillicothe Research Station. Tillage treatments at Chillicothe included conventional tillage, no-till, no-till with a terminated wheat cover crop, and strip-till. No-till treatments have been in place since 2007, whereas strip-till was implemented in 2011. The second location consisting of an Amarillo fine sandy loam was at the AG-CARES farm in Lamesa, TX. Treatments at Lamesa included conventional tillage and no-till with a terminated rye cover crop, with no-till being implemented since 1998.

Soil samples were taken from each site in 2013 and 2014. Cores were taken to a depth of 90 cm and segmented into 0–10, 10–20 and 20–30, 30–60, and 60–90 cm samples. Soil samples were sent to the Texas A&M AgriLife Extension Service Soil, Water, and Forage Laboratory in College Station, TX, for analysis of nitrate-N (NO_3^-–N), total N, total C, organic C, Mehlich III P, and extractable K, Ca, Mg, S, Na, Fe, Zn, Mn, and Cu. Additional samples were collected (15 cm depth) prior to planting cover crops in 2014 and were analyzed using the Soil Health Tool (ver. 4.4) developed by Rick Haney (USDA-ARS, Temple, TX).

Sites were visited during the growing season (June/July) to evaluate soil physical properties. Measured properties included soil bulk density, soil resistance using a penetrometer, and infiltration using a single ring infiltrometer. One inch of water was placed within a 24.4-cm ring, and the time of infiltration was recorded. Immediately thereafter, the procedure was repeated. In dry conditions, the second reading may provide a more accurate reading, while in wet conditions, the second reading can be less accurate if field capacity has been reached. In most cases, readings were taken under very dry conditions.

13.3 Results and Discussion

13.3.1 Soil Chemical Properties

Our main focus was nutrient stratification and carbon sequestration. We did not see evidence of significant phosphorus stratification as a result of long-term conservation tillage at Lamesa or Chillicothe (results not presented). At Chillicothe, concentrations of soil carbon did not differ significantly (Table 13.1). It was expected that no-till with a cover crop would have the greatest C levels; however, this was not observed. Similarly, Abreu et al. (2011) noted no impact on organic C when a monocrop system was used in low rainfall areas (Western OK). In contrast, organic C levels were 40 % higher in the upper 10 cm at Lamesa where no-till had been implemented for 15 years (Table 13.2). The increase in C was evident to a depth of 60 cm.

Table 13.1 Organic carbon concentrations in the soil profile at the Texas A&M AgriLife Chillicothe Research Station from plots under conservation tillage since 2008

	Conventional till	Strip-till	No-till	No-till/cover crop
Depth (cm)	Organic C (mg kg^{-1})			
0–10	8476	7242	6972	8346
10–20	6472	6155	5743	5872
20–30	6103	6002	5838	5684
30–60	5688	6375	5297	5275
60–90	6516	6848	4534	4404

Table 13.2 Organic carbon concentrations in the soil profile at the AG-CARES farm in Lamesa, TX from plots under no-till for 17 years

	Conventional till	No-till
Depth (cm)	Organic C (mg kg^{-1})	
0–10	1540	2595
10–20	1421	1577
20–30	1407	1525
30–60	1738	1925
60–90	1449	1475

Table 13.3 Effects of management practices on soil organic C and N, plant-available nutrients, and soil nutrient value and health at the AG-CARES farm in Lamesa, TX

			Plant-available nutrients					
Cropping system	Organic C[1]	Organic N	NO_3^-–N	N[2]	P_2O_5	K_2O	Nutrient value[3]	Soil health[4]
	mg kg^{-1}		kg ha^{-1}				\$ ha^{-1}	
Conventional	100	13.6 b[5]	2.1 b	10.7 b	68	370 b	83.32 b	3.09 b
No-till, rye cover	128	16.7 a	6.6 a	17.8 a	96	509 a	116.17 a	4.07 a
P-value	0.077	0.005	0.004	0.026	0.077	0.0003	0.001	0.006

[1] Organic C and Organic N: amount of organic C and organic N extracted with water

[2] N: calculated as NH_4^+–N + 70 % of NO_3^-–N + (microbially active C*organic N*4)

[3] Nutrient Value: value in dollars per acre of nutrients currently in the soil

[4] Soil Health: calculated to include a weighted contribution of microbial activity and water-extractable organic C and N

[5] Within columns, means with the same letters are not significantly different at $\alpha = 0.05$

Soil Health Tool. Water-extractable organic C, and plant available phosphorus (P_2O_5) were generally greater with the no-till, rye cover crop system (128 mg kg^{-1} and 96 kg ha^{-1}, respectively) compared to the conventional till (100 mg kg^{-1} and 68 kg ha^{-1}, respectively; Table 13.3). Water-extractable organic N, total plant available N [as NH_4^+–N + 70 % of NO_3^-–N + (microbially active C*organic N*4)], and NO_3^-–N were greater in the no-till, rye cover system (16.7 mg kg^{-1}, 17.8 kg ha^{-1}, and 6.6 kg ha^{-1}, respectively) compared to conventional cotton (13.6 mg kg^{-1}, 10.7 kg ha^{-1}, and 2.1 kg ha^{-1}, respectively). Approximately 140 kg more K_2O per hectare was present in the no-till, rye cover compared to conventional. Calculated using the Soil Health Tool and based on dollars per acre of nutrients currently in the soil, the no-till, rye cover crop system resulted in greater nutrient value (\$116.17 per hectare) than conventional cotton (\$83.32 per hectare). Soil health ratings were also greater for the no-till, rye cover crop system. These results suggest that implementing no-till, cover cropping systems may improve the health and value of soil; however, accomplishing this will be a long-term process.

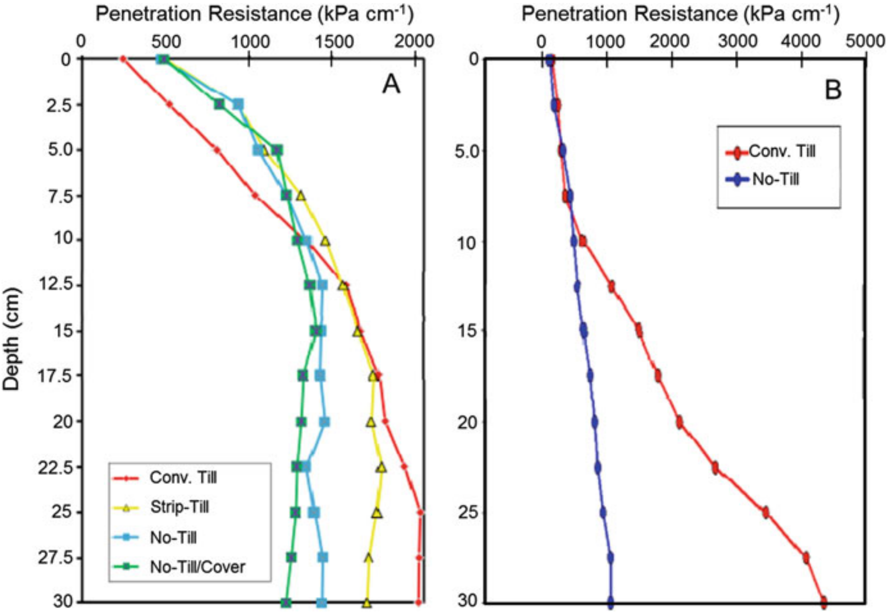

Fig. 13.1 Soil penetration resistance as measured by penetrometer at (**a**) the Chillicothe Research Station and (**b**) the AG-CARES farm in Lamesa

13.3.2 Soil Physical Properties

In general, bulk density did not significantly differ among treatments at Chillicothe and Lamesa. However, surface bulk density at the surface was lower at each site when measurements were taken shortly after a tillage event. When a precipitation or irrigation event was recorded prior to measurement, bulk density measurements were not significantly different at the surface (data not shown). Penetrometer data indicated a tillage effect at each location. At Chillicothe, no-till and no-till with a terminated cover crop treatments indicated reduced resistance compared with conventional tillage and strip-till beginning at a depth of about 13 cm (Fig. 13.1a). Conventional tillage generally consists of disking at a 15-cm depth. Hence, the change in resistance is evidence of a plow pan. Similar results were observed at Lamesa, where resistance became significantly lower beginning at the 13–15 cm depth (Fig. 13.1b). These data suggest that plow pans can be reversed over time with no-till.

Infiltration rates are presented in Fig. 13.2. Although no differences in soil organic C were observed at Chillicothe, infiltration rates indicated a response to conservation tillage. No-till with a terminated wheat cover crop resulted in significantly higher infiltration rates compared with all other treatments (Fig. 13.2a). At Lamesa, no-till with a terminated rye cover crop resulted in significantly greater

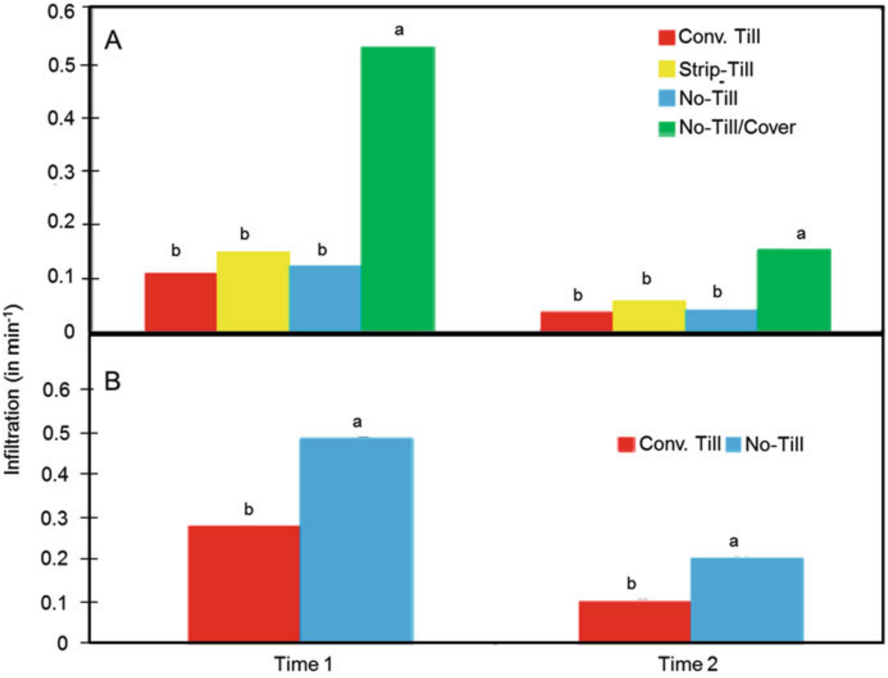

Fig. 13.2 Infiltration rates for two consecutively timed trials using single ring infiltrometers at (**a**) the Chillicothe Research Station and (**b**) the AG-CARES farm in Lamesa

infiltration rates compared to conventionally tilled plots (Fig. 13.2b). These results indicate that long-term conservation tillage systems have the capability to capture and store moisture more efficiently than conventionally tilled systems.

13.4 Conclusion

Long-term conservation tillage systems have the capability to sequester C, improve soil structure, decrease soil resistance, improve water infiltration rates, and enhance the nutrient value and overall condition of the soil. In semi-arid environments, soil C is very difficult to build up and may take multiple years to see improvements (>10 years). Increased soil C levels were observed where no-till had been implemented for 17 years but not in the location where no-till had been implemented less than 10 years. Soil resistance measurements indicated plow plans were alleviated and infiltration rates were increased under no-till conditions.

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Chapter 14
Soil Organic Carbon Stocks and Soil Respiration in Tropical Secondary Forests in Southern Mexico

Deb Raj Aryal, Bernardus Hendricus Joseph De Jong, Jorge Mendoza-Vega, Susana Ochoa-Gaona, and Ligia Esparza-Olguín

Abstract The soil CO_2 efflux is recognized as one of the largest fluxes in the global carbon cycle, and small changes in the magnitude of soil respiration could have a large consequence on the concentration of CO_2 in the atmosphere. In this study, we analyzed the soil organic carbon (SOC) stocks and CO_2 efflux from soil respiration in a tropical secondary forest succession grown after abandonment of swidden agriculture in Southern Mexico. The study was conducted in a chronosequence of semi-evergreen tropical secondary and primary forests in the southern part of Yucatan Peninsula, Mexico. We collected soil samples (up to 30 cm depth) from 32 carbon monitoring plots and analyzed these for physical and chemical soil properties. Soil respiration measurements were carried out by using PP systems EGM-4 (an infrared gas analyzer). Analysis of variance (ANOVA), correlation, and regression was performed to test differences between forest age groups as the independent variable and soil respiration, organic as well as inorganic carbon in soil. Contrary to the hypothesis, SOC in the mineral soil horizon did not increase with forest age. Soil CO_2 efflux did not correlate to soil organic carbon, it rather correlated to carbonate concentration in the soil. Higher CO_2 efflux in carbonate rich soils can be explained probably by the faster decomposition but the slower ultimate mixing of organic matter in mineral soils of carbonate origin. However, it needs further investigation in separating soil CO_2 efflux into autotrophic, heterotrophic, and abiotic fluxes to better understand the role of carbonate soils in atmospheric CO_2 exchange.

Keywords CO_2 efflux • Forest age • Calcareous soil • Yucatan Peninsula

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14.1 Introduction

A large portion of tropical landscapes and their soils are in the continuous process of change because of activities like swidden cultivation, livestock farming, and subsequent abandonment of productive activities (Brown and Lugo 1990; Marín-Spiotta et al. 2008).

Slash and burn agriculture is a common farming practice in Southern Mexico where farmers chop down the primary or secondary forests, burn the dry biomass, and prepare the land for their milpa (Fig. 14.1). Milpa is a multiple cropping system with corn beans and cucurbits. After a few years of cultivation, farmers abandon the land for forest regrowth and recovery of soil fertility. Forest structure, species composition, and functioning of those secondary forests grown after abandonment of agriculture and grasslands are different from original primary forests and take a long time to recover to pre-disturbed conditions (DeWalt et al. 2003; Dupuy et al. 2012). The changes have strong implications for carbon capture and emission cycles in these disturbed ecosystems. Reports suggest that live and dead biomass carbon dynamics vary in different stages of secondary forest growth (Aryal et al. 2014; Fonseca et al. 2011). Some authors mention that soil organic carbon in these secondary forests can also change due to variation in the disturbance intensity and time of recovery of the secondary vegetation (Lu et al. 2002; Werner 1984). The changes in soil properties in successional forests vary among regions and have not been well understood. Soil organic carbon and other nutrient concentrations also vary, due to alterations in nutrient flow arisen from changing productivity and decomposition of organic matter (Marín-Spiotta et al. 2008; Vitousek and Reiners 1975). Soil organic carbon content relates to the efflux of carbon dioxide (CO_2) from soil respiration (Raich and Tufekciogul 2000; Singh and Gupta 1977). In addition, CO_2 efflux has some relations to the inorganic carbon content, especially in soils of calcareous origin (Chen et al. 2014; Thomas et al. 2014).

The soil CO_2 efflux is recognized as one of the largest fluxes in the global carbon cycle, and small changes in the magnitude of soil respiration could have large

Fig. 14.1 Farmers of Southern Mexico slash the forest and burn it (*left*) to prepare land for milpa (*right*) (Photo: D. R. Aryal)

consequences on the concentration of CO_2 in the atmosphere (Schlesinger and Andrews 2000). Large amounts of inorganic carbon have been accumulated in the form of soil carbonates in different regions of the world over a long period of time. Carbonate carbon in the earth's soil is one of the large carbon pools, which ranges from 750 to 950 Pg C (Lal et al. 1999; Schlesinger and Bernhardt 2013). Few studies have considered the importance of abiotic carbon flows from dissolution of carbonates in calcareous soil. Dissolution of carbonates in the soil can have significant contribution to soil CO_2 efflux. However, studies have given less attention to abiotic exchange of CO_2 between soil and the atmosphere, which at a large scale, might have a significant role in the global carbon cycle and in climate change feedbacks (Chen et al. 2014). In this study, we tested the following two hypotheses: (i) Soil organic carbon of soil varies among different stages of forest recovery after land abandonment; (ii) soil respiration (CO_2 efflux) is related to soil organic and/or inorganic carbon content. The study was carried out in the Yucatan Peninsula in Southeastern Mexico, which is dominated by soils of karstic origin.

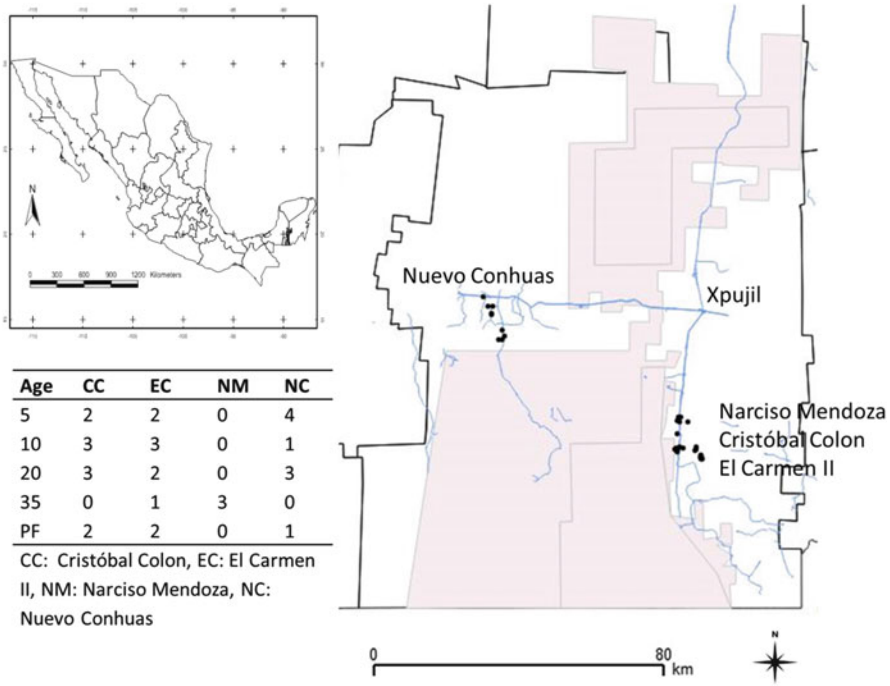
14.2 Methods

14.2.1 Study Site

The study was conducted in a chronosequence of semievergreen tropical forests, recovering after slash and burn agriculture in four communities: El Carmen II, Cristóbal Colon, Narcizo Mendoza, and Nuevo Conhuas of Calakmul, Campeche, all situated in the southern part of the Yucatan Peninsula, Mexico (Fig. 14.2). The region is characterized by a subhumid tropical climate with an average precipitation of 1000–1500 mm per year (with major portions of the rainfall from July to October) and mean annual temperature of 22–26 °C (García Gil et al. 2002). Rendzic Leptosols formed over the karstic parent material are the dominating soil types (Bautista et al. 2011). The collection of soil sample and the experiments of soil respiration were carried out in 32 experimental plots, distributed in a chronosequence of forest recovery (Fig. 14.2).

14.2.2 Soil Sampling and Analysis

Soil samples were collected at four random points in each experimental plot separately for three depth classes: 0–10 cm, 10–20 cm, and 20–30 cm, using a soil auger with a cylinder of 5 cm diameter and 10 cm height. In some points, soil samples could only be collected to the depth of the calcareous rock. Forest floor litter layers were removed before sampling. Samples from the same depth classes were then mixed to generate plot level composite samples. Three composite samples from



Age	CC	EC	NM	NC
5	2	2	0	4
10	3	3	0	1
20	3	2	0	3
35	0	1	3	0
PF	2	2	0	1

CC: Cristóbal Colon, EC: El Carmen II, NM: Narciso Mendoza, NC: Nuevo Conhuas

Fig. 14.2 Study site and distribution of experimental plots. *Shaded* area in the map represents the Calakmul biosphere reserve. The *table* on the lower left side represents the distribution of the experimental plots among age gradients and communities

each plot were then transported to laboratory for analysis. Soil bulk density was estimated by oven drying (105 °C to constant weight) using parallel samples collected at each point using a cylinder with 196.4 cm^3 volume. Coarse rock (>2 mm) and all the root fragments were separated before weighing the dry soil mass. Rock and root volume were subtracted from the total volume for bulk density calculations.

All composite soil samples were analyzed for total carbon (%) using a Shimadzu A500 total carbon analyzer and total nitrogen (%) by semimicro Kjeldahl method (Bremner and Mulvaney 1982). Available phosphorus (ppm) was analyzed by Olsen's method of extraction with sodium bicarbonate (Olsen 1954) and exchangeable potassium (cmoles kg^{-1}) by atomic absorption spectrophotometry (David 1960). Calcium carbonate content ($CaCO_3$ %) was analyzed by neutralization with 0.5 M HCl and titration with 0.25 N NaOH following Daeva method (Etchevers Barra 1992). Soil organic carbon (SOC) was estimated by subtracting carbonate-based carbon from total carbon. Cation exchange capacity (CEC) was analyzed by base extraction method (Schollenberger and Simon 1945). Soil pH was analyzed by potentiometric measurement method (Bates 1964). Soil texture was analyzed following the Bouyoucos method to determine the percentage of sand, silt, and clay (Bouyoucos 1935).

14.2.3 Soil Respiration Measurement

PP Systems Environmental Gas Monitor (EGM-4) was used to measure the soil CO_2 efflux in different months representing three distinct seasons: June–Oct (“summer” rains), Nov–Jan (“winter” rains), and Feb–May (dry season) between 2012 and 2013. The EGM-4 is a nondispersive, infrared gas analyzer with a chamber which can readily measure the instantaneous flux of CO_2 from the soil surface (Mills et al. 2011; PP Systems 2010).

Twelve measurements were made randomly within each sampling plot during daytime. Soil respiration data from different points were averaged to obtain plot level data of each respective measurement. The data from different sampling seasons were again averaged to obtain a plot level mean efflux (g CO_2 m^{-2} h^{-1}) that represent the whole period of measurement. The soil CO_2 efflux is the sum of plant root respiration, mycorrhiza fungi and other root-associated microbes (autotrophic), soil organic matter decomposition (heterotrophic), and carbonate dissolution (abiotic). We considered the total soil CO_2 efflux value in our analysis because we didn’t have the equipment to separate those fluxes.

14.2.4 Data Analysis

All the data were checked for normality and transformed if necessary to meet the ANOVA assumptions. Soil properties and soil carbon stocks data were analyzed using factorial ANOVA to test the effect of forest age and soil depth. Tukey HSD post hoc tests were carried out to detect the significant differences ($\alpha = 0.05$) between forest age categories and soil depth classes. Back transformed data are presented in the results for those cases where transformation was required. Soil respiration data were analyzed using repeated measures ANOVA to check the effect of forest age and sampling season. Multiple regression and correlation analysis were performed to evaluate the relationships between soil respiration and independent variables like forest age, soil organic carbon, and calcium carbonate concentrations.

14.3 Results

14.3.1 Physical and Chemical Properties of Soil

Soil properties like pH, CEC, texture, and bulk density did not differ significantly among forest age categories, but some of them differ among soil depth classes (Table 14.1). Average pH value ranged from 7.5 ± 0.3 to 7.9 ± 0.3 indicating the presence of alkaline soils in the region. Average CEC value ranged from 64 ± 16 to

Table 14.1 Physical and chemical properties of soil at different stages of forest growth

Soil properties at three depth intervals	Mean ± 95 % confidence interval				
	5 years SF	10 years SF	20 years SF	35 years SF	PF
Soil pH					
0–10 cm	7.8 ± 0.1^{Aa}	7.5 ± 0.4^{Aa}	7.5 ± 0.3^{Aa}	7.5 ± 0.3^{Aa}	7.6 ± 0.3^{Aa}
10–20 cm	7.8 ± 0.2^{Aa}	7.5 ± 0.5^{Aa}	7.6 ± 0.4^{Aa}	7.5 ± 0.5^{Aa}	7.8 ± 0.3^{Aa}
20–30 cm	7.8 ± 0.2^{Aa}	7.5 ± 0.5^{Aa}	7.5 ± 0.5^{Aa}	7.5 ± 0.6^{Aa}	7.9 ± 0.3^{Aa}
Cation exchange capacity cmoles kg^{-1}					
0–10 cm	79.6 ± 9.4^{Aa}	76.2 ± 16.7^{Aa}	78.7 ± 8.1^{Aa}	64.2 ± 16.7^{Aa}	83.6 ± 11.1^{Aa}
10–20 cm	79.1 ± 6.8^{Aa}	72.1 ± 12.1^{Aa}	79.3 ± 10.3^{A}a	70.5 ± 13.4^{Aa}	72.4 ± 12.3^{Aa}
20–30 cm	73.6 ± 8.4^{Aa}	74.2 ± 10.9^{Aa}	82.8 ± 18.8^{Aa}	68.2 ± 20.1^{Aa}	61.0 ± 12.6^{Aa}
Sand %					
0–10 cm	31.5 ± 3.0^{Aa}	27.5 ± 5.7^{Aa}	32.7 ± 7.6^{Aa}	29.9 ± 3.3^{Aa}	37.0 ± 7.4^{Aa}
10–20 cm	24.0 ± 3.8^{Aa}	23.8 ± 5.6^{Aa}	27.1 ± 6.8^{Aa}	24.4 ± 5.0^{Aa}	35.4 ± 9.1^{Aa}
20–30 cm	19.6 ± 2.5^{Aa}	20.0 ± 3.8^{Aa}	16.7 ± 1.4^{Ab}	21.9 ± 3.1^{Aa}	25.2 ± 5.8^{Aa}
Silt %					
0–10 cm	14.7 ± 1.4^{Aa}	13.5 ± 3.5^{Aa}	15.3 ± 2.4^{Aa}	15.1 ± 6.0^{Aa}	15.9 ± 2.0^{Aa}
10–20 cm	13.4 ± 2.2^{Aa}	11.5 ± 3.2^{Aa}	18.1 ± 12.7^{Aa}	14.6 ± 4.4^{Aa}	9.9 ± 5.3^{Aa}
20–30 cm	11.5 ± 2.6^{Aa}	10.0 ± 3.5^{Aa}	20.6 ± 14.0^{Aa}	12.6 ± 9.9^{Aa}	15.3 ± 4.7^{Aa}
Clay %					
0–10 cm	53.8 ± 3.9^{Aa}	59.0 ± 8.4^{Aa}	52.0 ± 7.7^{Aa}	55.0 ± 8.3^{Aa}	47.0 ± 8.7^{Aa}
10–20 cm	62.5 ± 3.2^{Aa}	64.8 ± 7.9^{Aa}	54.8 ± 16.0^{Aa}	61.0 ± 7.8^{Aa}	54.6 ± 9.0^{Aa}
20–30 cm	69.8 ± 3.6^{Aa}	70.6 ± 7.0^{Aa}	62.6 ± 13.4^{Aa}	65.5 ± 12.2^{Aa}	59.5 ± 6.6^{Aa}
Bulk density g cm^{-3}					
0–10 cm	0.6 ± 0.0^{Aa}	0.6 ± 0.1^{Aa}	0.6 ± 0.0^{Aa}	0.6 ± 0.0^{Aa}	0.6 ± 0.0^{Aa}
10–20 cm	0.7 ± 0.1^{Aa}	0.7 ± 0.1^{Aab}	0.7 ± 0.1^{Aab}	0.7 ± 0.1^{Aa}	0.7 ± 0.0^{Aa}
20–30 cm	0.9 ± 0.1^{Ab}	0.8 ± 0.0^{Ab}	0.8 ± 0.1^{Ab}	0.7 ± 0.1^{Aa}	1.0 ± 0.1^{Ab}

Different uppercase letters in the superscripts show significant differences among forest age categories, and lowercase letters denote significant differences among depth classes ($\alpha = 0.05$)
SF secondary forests, *PF* primary forests

84 ± 11 cmoles kg^{-1}. Both soil pH and CEC did not show any difference between depth classes. Most soils from all depth classes were considered as clay and sandy clay by texture classification. Clay percentage ranged from 47 % to 71 %, while sand and silt proportion ranged from 20 % to 37 % and 10 % to 21 %, respectively. We found significant differences in bulk density between soil depth classes, and it ranged from 0.6 to 1.0 g cm^{-3}. Soils from upper horizons showed lower bulk densities compared to deeper layer soils (Table 14.1).

Although it seemed that there was a slight increase in total soil carbon with forest age, we did not find any statistically significant differences between forest age categories (Table 14.2). Total carbon concentration in the soil ranged from 2.2 ± 0.6 % to 9.5 ± 2.1 %. We found significantly higher carbon concentration in the soils of

Table 14.2 Concentrations of soil carbon, nitrogen, phosphorus, potassium, and calcium carbonate at different stages of forest growth in three depth classes

Soil nutrients and depth class	Mean ± 95 % confidence interval				
	5 years SF	10 years SF	20 years SF	35 years SF	PF
Total carbon %					
0–10 cm	7.2 ± 0.8^{Aa}	6.7 ± 0.8^{Aa}	8.2 ± 1.6^{Aa}	8.7 ± 1.3^{Aa}	9.5 ± 2.1^{Aa}
10–20 cm	4.8 ± 0.5^{Aab}	4.5 ± 0.9^{Aab}	4.3 ± 1.3^{Ab}	4.8 ± 0.4^{Ab}	5.7 ± 1.4^{Ab}
20–30 cm	3.3 ± 0.6^{Ab}	2.9 ± 0.7^{Ab}	2.2 ± 0.6^{Ab}	2.7 ± 0.2^{Ab}	3.2 ± 0.7^{Ab}
Total nitrogen %					
0–10 cm	0.6 ± 0.1^{Aa}	0.5 ± 0.1^{Aa}	0.7 ± 0.2^{Aa}	0.6 ± 0.0^{Aa}	0.7 ± 0.2^{Aa}
10–20 cm	0.4 ± 0.1^{Aab}	0.4 ± 0.1^{Aab}	0.4 ± 0.1^{Aab}	0.4 ± 0.0^{Aab}	0.4 ± 0.1^{Aab}
20–30 cm	0.3 ± 0.1^{Ab}	0.3 ± 0.1^{Ab}	0.2 ± 0.1^{Ab}	0.2 ± 0.1^{Ab}	0.3 ± 0.1^{Ab}
Available phosphorus ppm					
0–10 cm	2.6 ± 1.2^{Aa}	3.2 ± 1.8^{Aa}	2.7 ± 1.6^{Aa}	3.9 ± 1.7^{Aa}	2.6 ± 2.7^{Aa}
10–20 cm	1.6 ± 0.7^{Aa}	1.9 ± 1.5^{Aa}	1.7 ± 1.9^{Aa}	3.0 ± 1.1^{Aa}	2.7 ± 1.2^{Aa}
20–30 cm	0.6 ± 0.3^{Aa}	0.8 ± 0.7^{Aa}	1.9 ± 1.8^{Aa}	2.3 ± 2.1^{Aa}	1.6 ± 1.6^{Aa}
Exchangeable potassium cmoles kg^{-1}					
0–10 cm	2.1 ± 0.3^{Aa}	1.6 ± 0.4^{Aa}	2.1 ± 0.6^{Aa}	1.0 ± 0.2^{Aa}	1.7 ± 0.4^{Aa}
10–20 cm	1.7 ± 0.4^{Aa}	1.3 ± 0.5^{Aa}	1.7 ± 0.4^{Aab}	1.1 ± 0.2^{Aa}	1.3 ± 0.3^{Aa}
20–30 cm	1.6 ± 0.4^{Aa}	1.0 ± 0.4^{Aa}	0.9 ± 0.3^{Ab}	0.8 ± 0.4^{Aa}	0.9 ± 0.3^{Aa}
$CaCO_3$ %					
0–10 cm	12.4 ± 4.3^{Aa}	14.2 ± 6.5^{Aa}	13.4 ± 3.7^{Aa}	12.3 ± 6.3^{Aa}	17.0 ± 5.5^{Aa}
10–20 cm	11.5 ± 4.7^{Aa}	12.8 ± 6.2^{Aa}	13.6 ± 5.4^{Aa}	11.3 ± 6.7^{Aa}	18.7 ± 6.2^{Aa}
20–30 cm	12.9 ± 5.0^{Aa}	15.4 ± 6.0^{Aa}	17.3 ± 6.3^{Aa}	11.2 ± 6.5^{Aa}	20.2 ± 6.3^{Aa}

Different uppercase letters in the superscripts show significant differences among forest age categories, and lowercase letters denote significant differences among depth classes ($\alpha = 0.05$)
SF secondary forests, *PF* primary forests

upper horizon (0–10 cm depth) compared to deeper horizons. The average carbon in the soils of 0–10 cm layer was found to be 100–190 % higher compared to the soils of 20–30 cm depth class indicating that carbon accumulation is highly concentrated in upper shallow soil horizons. Total nitrogen concentration in the soil ranged from 0.2 ± 0.1 % to 0.7 ± 0.2 %, and it also decreased with soil depth. Available phosphorus in the soil ranged from 0.6 to 3.9 ppm and did not differ with forest age and soil depth. Exchangeable potassium was found in the range of 0.9–2.1 cmoles kg^{-1}. The difference between depth classes was observed only in secondary forest of 20 years. We found high concentrations of calcium carbonate in the soils of all depth classes and age categories that ranged from 11 % to 20 % (Table 14.2). Carbonate-based inorganic carbon constituted 15–28 % of the total carbon in the soils of 0–10 cm depth, but it constituted 47–94 % of total carbon in the soils of 20–30 cm (Fig. 14.3).

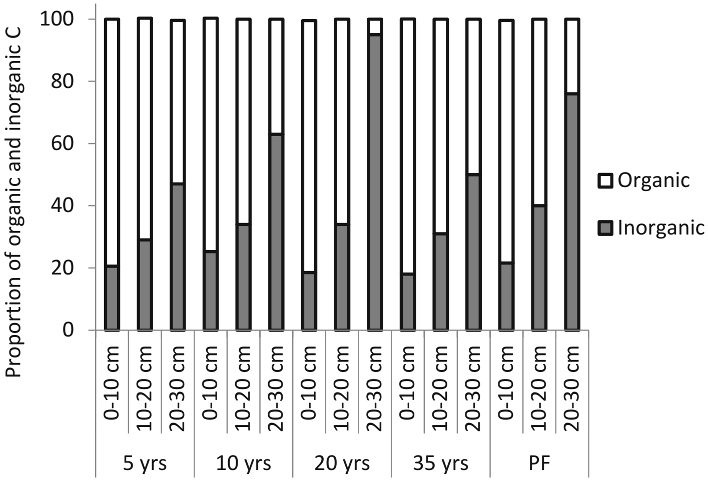


Fig. 14.3 Proportion of organic and inorganic carbon (expressed in % of total carbon) at three depth classes among different phases of forest growth

14.3.2 Soil Respiration

The average soil respiration rates ranged from 0.8 ± 0.1 to 2.3 ± 0.2 g m^{-2} h^{-1} with the highest value observed in mature forest during summer rainy season and the lowest in a 20-year-old secondary forest during dry season (Fig. 14.4). We found significant differences between sampling seasons within all age groups. Soil respiration was higher in the summer rainy season followed by winter rainy season, and the dry season showed the lowest rate of soil CO_2 efflux. When we compare the fluxes between the forest age categories, mature forests and secondary forests of 35 years showed significant differences with other secondary forests only during the winter rainy season (Fig. 14.4). Dry season soil CO_2 efflux did not show any significant difference between forest age categories. Stepwise multiple regression analysis showed that forest age and soil organic carbon concentration are not significant predictors of soil respiration (Fig. 14.5a, b), while calcium carbonate concentration in the soil was positively correlated to soil respiration ($r = 0.48$, $\alpha < 0.05$) (Fig. 14.5c). We found a negative correlation between $CaCO_3$ concentration and organic carbon content in the soil (Fig. 14.5d).

14.4 Discussion

Better understanding of soil carbon reservoirs and soil CO_2 flux balance has significant implications for climate change adaptation, one of the important soil functions (McBratney et al. 2014). Soil respiration is one of the important fluxes of CO_2 from

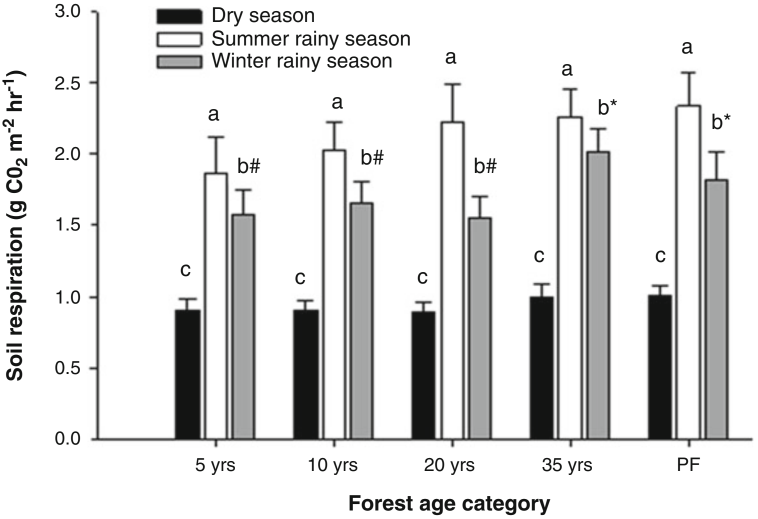


Fig. 14.4 Average soil respiration (g CO_2 m^{-2} h^{-1}) measured in three distinct seasons in secondary (5, 10, 20, and 35 years old) and primary forests (PF). *Error bars* represent 95 % confidence interval. Different *letters* over the *vertical bars* indicate significant differences among flux monitoring seasons, and different *symbols* indicate significant differences among forest age categories

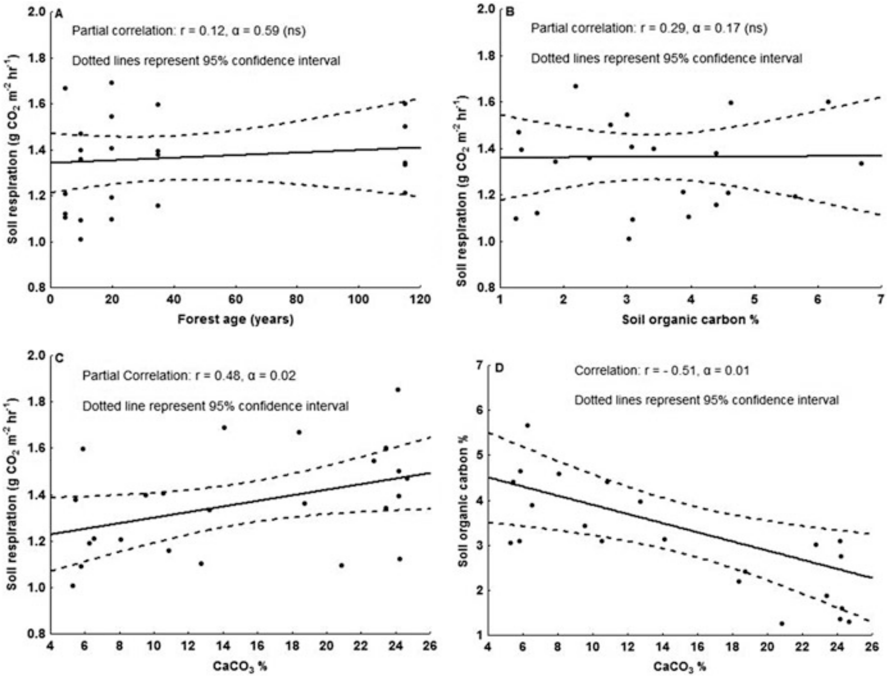


Fig. 14.5 Relationship between soil respiration and (**a**) forest age, (**b**) soil organic carbon, and (**c**) calcium carbonate. (**d**) Correlation between calcium carbonate and soil organic carbon

the soil to the atmosphere with a huge potential to exacerbate climate change if rates of decomposition and mineralization of soil organic and/or inorganic carbon are altered (Raich and Tufekciogul 2000; Singh and Gupta 1977). It has been reported that soil respiration rates are dependent on various factors like temperature, precipitation, soil, vegetation, and substrate availability (Schlesinger and Andrews 2000). The results of our study showed that soil respiration in mature forests and older secondary forests was higher than younger secondary forests which can be explained by the difference in microclimate created by the growth of vegetation (Raich and Schlesinger 1992). Dry soil condition slows down microbial activity and mineralization process which resulted lower soil CO_2 efflux in dry season compared to wet rainy seasons in our study (Muhr et al. 2008). Although soil respiration is highly variable, our estimates of soil respiration rates are found within the reported range in tropical ecosystems (Bae et al. 2013; Davidson et al. 2000; Raich and Schlesinger 1992).

Contrary to the hypothesis, soil respiration did not relate to soil organic carbon content. Soil respiration was rather related significantly to $CaCO_3$ concentration in the soil which can be explained by high rates of carbonate dissolution during wet seasons in tropical calcareous soils. This implies that changing precipitation regimes and temperature can alter the velocity of soil CO_2 efflux from tropical karstic soils to the atmosphere with a significant feedback to increasing atmospheric CO_2. The positive correlation between soil respiration and $CaCO_3$ concentration demonstrates that carbonate dissolution can be one of the principal sources of variation in soil CO_2 efflux in calcareous soil (Chen et al. 2014; Oades 1988; Stevenson and Verburg 2006). This contradicts with some of the earlier statement of higher soil respiration in soils with more organic carbon (Baldock 2007; Schmidt et al. 2012).

However, further investigation is required to partition CO_2 efflux from root respiration, organic matter decomposition, and inorganic carbon emission. It has been reported that calcareous soils not only emit CO_2 but can also capture carbon (Chen et al. 2014). Negative relationship between organic carbon and $CaCO_3$ content in soil can probably be explained by the fact that an alkaline environment can favor the conversion of organic carbon to carbonates as reported in some earlier studies (Thomas et al. 2014). However, both carbon absorption and emission by calcareous soils should be studied deeper in the future.

Unexpectedly, soil properties, soil carbon, and other soil nutrient concentrations did not change with forest age, but this is not uncommon in tropical forest succession (Feldpausch et al. 2004). It can be considered as one of the advantages of traditional swidden cultivation practices, applied by Mayan farmers in the region, where soil manipulation is low compared to mechanized farming systems. However, increasing cycles of cultivation and fallow rotation can reduce the speed of carbon sequestration of these secondary forests (Aryal et al. 2014). Soils from upper horizons are normally richer in soil nutrients than deeper soils, but bulk density was lower in upper horizons because of the presence of more organic material. High soil pH and calcium carbonate content are related to the dominance of alkaline soil in the region, showing the importance of studying in more detail the carbon efflux from inorganic sources.

14.5 Conclusion

Physical and chemical properties of soil did not change during succession of secondary forests grown after abandonment of slash and burn agriculture nor do they differ from original primary forests in the Yucatan Peninsula, Mexico. However, it is important to consider the results of earlier studies which reported the lower rate of biomass accumulation in intensely cultivated lands. Higher soil respiration in calcareous soils needs further investigation through partitioning techniques to separate soil CO_2 efflux from autotrophic, heterotrophic, and abiotic sources. Establishing a system of continuous flux measurements for longer period of time is recommended to reduce the level of uncertainty of our estimates.

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Chapter 15
Simulating Impacts of Bioenergy *Sorghum* Residue Return on Soil Organic Carbon and Greenhouse Gas Emissions Using the DAYCENT Model

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Abstract Different residue management practices can affect carbon (C) allocation and thus soil C and nitrogen (N) turnover. A biogeochemical model, DAYCENT, was used to simulate the effects of bioenergy *Sorghum* [*Sorghum bicolor* (L.) Moench] residue return on soil temperature and water content, soil organic carbon (SOC), and greenhouse gas (GHG) [carbon dioxide (CO_2) and nitrous oxide (N_2O)] emissions under bioenergy *Sorghum* production. Coefficient of determination (r^2) was used to test model performance. Coefficients of determination between the observed and simulated soil temperature, soil water content, SOC, and annual CO_2 and N_2O emissions were 0.94, 0.81, 0.75, 0.97, and 0.0057, respectively, indicating that the DAYCENT model captured the major patterns of soil environmental factors and C turnover but was less

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accurate in estimating N_2O emissions. Compared with the simulated control (0 % residue return), the simulated 50 % residue return treatment had 7.77 %, 15.12 %, and 1.25 % greater SOC, annual CO_2, and N_2O emissions, respectively, averaged over 2 years' data (2010 and 2011). Similar patterns in the simulated outputs were also observed in our field trials, with percentages being 4.52 %, 15.98 %, and 12.89 %, respectively. The model also successfully reflected the daily GHG flux variation affected by treatments, management practices, and seasonal changes except for missing some high growing season fluxes. In addition, annual variations in the simulated outputs were comparable with field observations except the N_2O emissions in the 50 % residue return treatment. Our study indicated that DAYCENT reasonably simulated the main effects of residue return on soil C turnover but underestimated N_2O emissions.

Keywords Bioenergy *Sorghum* • Soil organic carbon • Greenhouse gases • DAYCENT

15.1 Introduction

Bioenergy *Sorghum* has been promoted as a next-generation biofuel crop due to its features of high biomass yield and nutrient and water use efficiency. Biomass yields of bioenergy *Sorghum* have been reported to range from 8.0 to 60.0 Mg ha^{-1} depending on management practices and environmental conditions (Hao et al. 2014; Olson et al. 2012; Wight et al. 2012). Compared with grain *Sorghum*, forage *Sorghum*, or corn (*Zea mays* L.), higher biomass yields have been observed in bioenergy *Sorghum* systems, which also performed better than switchgrass (*Panicum virgatum* L.) and *Miscanthus* (*Miscanthus* × giganteus) during their establishment years (Gill et al. 2014; Propheter et al. 2010; Rocateli et al. 2012). Compared with other *Sorghum* types and corn, bioenergy *Sorghum* exhibited higher N use efficiency, which was comparable to sugarcane (*Saccharum officinarum*) and *Miscanthus* (Olson et al. 2013). The C4 photosynthetic pathway increases bioenergy *Sorghum's* adaption to hot dry environments, increasing its water use efficiency and drought tolerance.

Agricultural residues increase SOC sequestration through enhanced aggregate formation. Higher SOC as well as improved soil aggregation have been reported at different residue return rates in various cropping systems (Malhi and Lemke 2007; Osborne et al. 2014; Saffigna et al. 1989). Residue return, however, lowers the amount of available feedstock and may increase soil microbial activity and GHG emissions, thereby offsetting benefits associated with biofuel production (Baker et al. 2014; Jin et al. 2014; Saffigna et al. 1989). Previous studies have focused on corn stover and cereal residues for biofuel production and their environmental impacts, with minimum return rates being proposed for corn stover to establish sustainable harvest criteria (Johnson et al. 2014; Karlen and Johnson 2014). However, information is lacking on impacts of bioenergy *Sorghum* residue return on the soil environment, SOC, and GHG emissions. Sustainable harvest rates need to be estimated in order to balance biofuel feedstock production, soil quality, and environmental health.

DAYCENT is a process-based biogeochemical model used to simulate soil environmental factors such as soil temperature and water fluxes, plant and soil C and nutrient dynamics, and GHG fluxes (Parton et al. 1998) and has been effective in many traditional agricultural systems (Chang et al. 2013; Del Grosso et al. 2008). Few bioenergy crop production systems have been modeled to date. Corn, switchgrass, *Miscanthus*, soybean [*Glycine max* (L.) Merr.], alfalfa (*Medicago sativa*), and hybrid poplar (*Populus* sp.) production systems have been simulated by DAYCENT, with observed crop yield, soil C, and N_2O emission data compared with simulated results (Adler et al. 2007; Chamberlain et al. 2011; Davis et al. 2010). The objective of this study was to parameterize and validate DAYCENT performance in simulating soil temperature and water content, SOC, and CO_2 and N_2O emissions in a bioenergy *Sorghum* production system with variable biomass (residue) returns.

15.2 Material and Methods

15.2.1 Site Description and Experimental Design

The field study associated with this research was established at the Texas A&M AgriLife Research Farm near College Station, TX (30°32′15″N, 96°25′37″W), in 2008. The region has a mean annual temperature of 20 °C and annual precipitation of 1017 mm. Soil at the site is classified as a Weswood silty clay loam (fine, mixed, thermic Udifluventic Ustochrept) consisting of 100, 560, and 340 g kg^{-1} of sand, silt, and clay, respectively, in the top 15 cm, as well as a mean bulk density of 1.36 g cm^{-3} in the top 20 cm. The soil has a pH of 8.2 (1:2 soil/water) and initial SOC was 8.0 g kg^{-1} in the top 15 cm. The field was previously in a cotton (*Gossypium hirsutum* L.) and corn rotation.

The study used a randomized complete block design to study effects of bioenergy *Sorghum* residue return: 0 or 50 % of *Sorghum* biomass yield return at harvest with each treatment replicated three times. Plots were 9.14-m long by 4.08-m wide, with four, 1.02-m rows. The bioenergy *Sorghum* planted annually at a seeding rate of 160,000 seed ha^{-1} was "4-Ever Green," a photoperiod-sensitive, one-cross hybrid with high biomass yield and low lodging potential (Walter Moss Seed Co, Waco, Texas, USA). A nitrogen rate of 336 kg ha^{-1} as urea was side-dress applied 15-cm deep in 2008, with 280 kg ha^{-1} applied annually thereafter. Each year, conventional disk tillage to a depth of 15–20 cm was conducted after harvest and prior to planting. Furrow irrigation was applied only as needed to prevent severe water stress. Specific field operation dates and irrigation amounts can be found in Table 15.1. Since data for 2010 and 2011 were used in this simulation, related field activities and irrigation amounts for these 2 years are shown. Additional detailed field setup and operation information was reported by Wight et al. (2012) and Storlien et al. (2014).

Table 15.1 Field operation dates and irrigation amounts at College Station, Texas

Operation	2010	Amount	2011	Amount
Preplant herbicide application	17th March		2nd March	
Soil sampling	17th March		14th March	
Preplant cultivation	17th March		24th March	
Planting	13th April		25th March	
Fertilization	22nd May		5th May	
Inter-row cultivation	22nd May		5th May	
Irrigation	31st May	11 cm	12th April	11 cm
	–		9th May	9 cm
	–		14th July	11 cm
	–		4th August	11 cm
Harvest	7th October		1st September	
Bedding	12th October		5th September	

15.2.2 Field Observations

Soil temperature was measured hourly by type T thermocouples at 10-cm depth near gas sampling collars within each plot (Storlien et al. 2014). Soil volumetric water content was determined every 6 h by time domain reflectometry at 15-cm depth in the vicinity of the temperature sensors. Both temperature and moisture data were collected within the field with a CR1000 data logger (Campbell Scientific, Inc., Logan, UT), with hourly data for each sensor aggregated into daily values.

Composite soil samples from each experimental unit were collected from three 4-cm i.d. soil cores in March each year at depth increments of 0–5, 5–15, 15–30, 30–60, and 60–90 cm and oven dried at 105 °C for 7 days. However, only SOC data at the 0–20 cm depth was used to compare with DAYCENT output due to the model limitation. Soil organic C content for 0–20 cm was computed by accumulating SOC contents from 0-5, 5-15, and 15-20 cm using SOC concentrations and bulk densities from 0-5, 5-15, and 15-30 cm. Soil organic C was measured using an Elementar Americas Inc., VarioMAX CN analyzer (Mt. Laurel, NJ, USA).

Soil GHG (CO_2, N_2O) fluxes were measured by integrating a Li-Cor 20-cm survey chamber (model 8100-103, Li-Cor Inc., Lincoln, NE) with an INNOVA 1412 photoacoustic gas analyzer (Innova AirTech Instruments A/S, Denmark) (Storlien et al. 2014). Soil collars were installed near the middle of each plot to a depth of approximately 12 cm no less than 24 h before the initial gas sampling for each growing or fallow season and remained in place throughout the entire phase. Soil gas measurements were performed approximately weekly through the growing season and less intensively during the fallow period. More detailed observation and measurement information was included in previous publications (Storlien et al. 2014; Wight et al. 2012).

Table 15.2 Site parameters for DAYCENT

Site parameters	Unit	Value
Field capacity	Volumetric	0.2907
Wilting point	Volumetric	0.0578
Damping factor for calculating soil temperature	–	0.005
N_2/N_2O ratio adjustment coefficient	–	1.0
Proportion of nitrified N that is lost as N_2O	–	0.9
Maximum daily nitrification amount	g Nm^{-2}	0.7
Fraction of new net mineralization that goes to NO_3	–	0.8

15.2.3 Model Description and Modification

The DAYCENT model runs on a daily time step, and the key drivers include maximum and minimum daily air temperature, daily precipitation, soil properties, land management, and crop characteristics. The model simulation requires initializing the model based on the native ecosystem type at the site and using the best available information about land management during agricultural use.

Weather data from 1952 to 2012 at College Station Easterwood Field Climate Station used to drive model simulations for this study were derived from the National Oceanic and Atmospheric Administration website (National Oceanic and Atmospheric Administration n.d.). Soil properties were described previously in Site Description and Experimental Design. Land management is given in Table 15.1, and other important site-specific parameter modifications are presented in Table 15.2.

The model was started with a 5000-year equilibrium simulation to obtain the native grassland SOC level, followed by a baseline simulation accompanied by agriculture initialization after the 1830s with increasing fertilization according to the land use change described by the Burleson County Soil Survey (U.S. Department of Agriculture Natural Resources Conservation Service n.d.). Given the planting history before our field experiment, cotton and corn were chosen to run the baseline simulations, and default parameterizations for these two crops were adopted. Soil organic C contents were adapted from Potter and Derner (2006) as well as field observations before the study was initiated.

Before biomass *Sorghum* production simulation was initiated, cultivation and crop parameters were modified accordingly. Cropping and cultivation practices were parameterized based on the field management schedule (Table 15.1). Field cultivators and tandem disk, Row cultivator, and Field cultivators and tandem disk functions in DAYCENT were applied to represent preplanting cultivation, inter-row cultivation, and bedding, respectively, in the study.

Other than climate, site, and management parameterization, each crop to be simulated should have a set of specific parameters representing its own characteristics. Carbon partitioning between shoots and roots, C:N ratio and lignin concentration in biomass of the crop compartments, and coefficients affecting plant growth and senescence were modified through other study results, our own measurements, and default values before simulation (Rocateli et al. 2012; Rooney et al. 2007). Key relevant parameters are included in Table 15.3. Lignin concentrations of shoots and roots were

Table 15.3 Crop parameters for DAYCENT

Parameter	Definition	Value	Default
PRDX(1)	Coefficient for calculating potential production	0.625	0.5
PPDF(1)	Optimum temperature for production	35	30
PPDF(2)	Maximum temperature for production	50	45
FRTC(2)	Fraction of C allocated to roots in mature plants	0.3	0.1
CKMRSPMX(2)	Maximum fraction of juvenile live fine root C that goes to maintenance respiration for crops	1.0	0.5
CKMRSPMX(3)	Maximum fraction of mature live fine root C that goes to maintenance respiration for crops	1.0	0.5
CGRESP(2)	Maximum fraction of juvenile fine root live C that goes to growth respiration for crops	1.0	0.5
CGRESP(3)	Maximum fraction of mature fine root live C that goes to growth respiration for crops	1.0	0.5

set to 8 % and 6–10 %, respectively. Ranges of C:N ratios for shoots and roots were set to 20–90 and 40–60, respectively. Data of soil temperature, soil water content, SOC, and daily CO_2 and N_2O fluxes in control treatment (0 % residue return) were used for model calibration, and data in 50 % residue return were used for model validation.

15.2.4 Statistical Analyses

Statistical analyses were completed using the PROC GLIMMIX procedure of SAS 9.3 (Institute Inc. 2013). The 2-year combined data set was analyzed to test year and residue return effects for SOC and GHG annual emissions. Measurements with different residue return rates in the same year were compared first, followed by the measurement comparisons in different years with the same return rate. Return rate and year were taken as fixed factors and block as a random factor. Mean separation was at $P < 0.05$ level using Tukey's test. Linear regression analyses were used to compare measured vs. modeled soil temperature, soil water content, SOC, and annual GHG emissions, with coefficient of determinations (r^2) computed.

15.3 Results and Discussion

15.3.1 Soil Temperature and Soil Water Content

Crop residues have the capability of increasing soil water content and mitigating soil temperature fluctuations. The 50 % residue return treatment increased soil water content by 23.13 % during the 2011 growing season and decreased soil temperature by 0.73 % across the 2010 and 2011 growing seasons (Figs. 15.1 and 15.2).

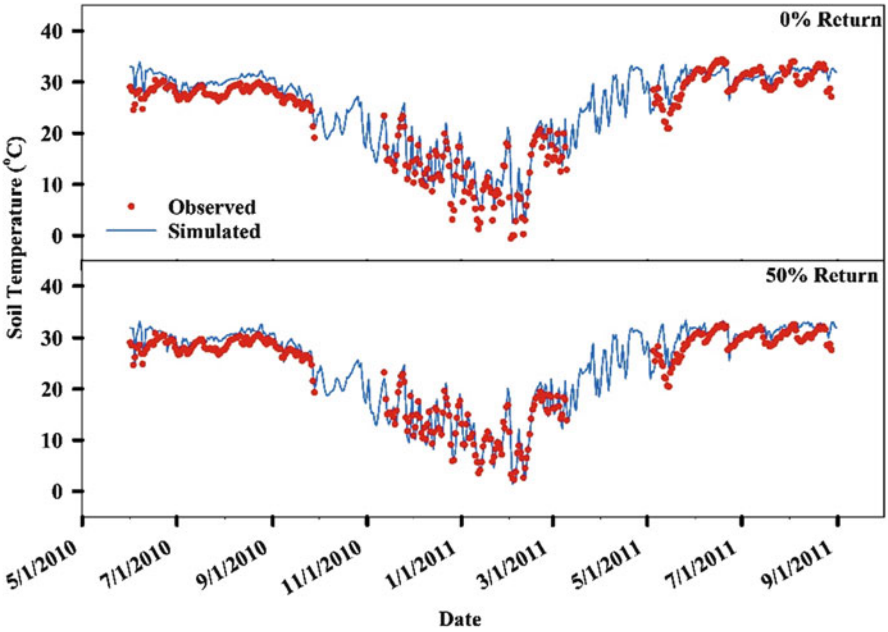

Fig. 15.1 Observed and simulated soil temperature under different residue returns from the beginning of 2010 growing season through the end of 2011 growing season

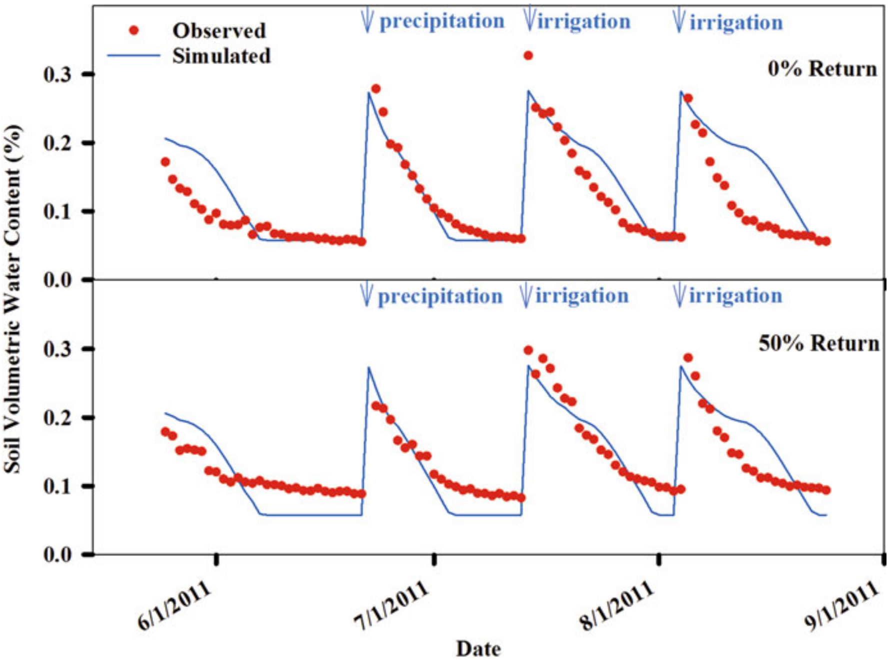

Fig. 15.2 Observed and simulated soil water content under different residue returns during the 2011 growing season

Soil moisture dynamics and soil temperature profiles are major drivers of C flows and nutrient cycles in the DAYCENT model, thus potentially affecting plant growth and trace gas fluxes. Across the different return rates, r^2 values between observed and simulated soil temperature and soil water content were 0.94 and 0.81, respectively, indicating that the model could adequately capture the patterns of soil temperature and water fluxes for the residue return treatments. However, the simulated control (0 % residue return) and the simulated 50 % residue return treatment showed little difference in soil water content and temperature if taken separately (Figs. 15.1 and 15.2), implying that DAYCENT might underestimate the effects of residues in water-holding capacity and temperature flux mitigation.

The reason little difference in soil water content between 0 % and 50 % residue returns was observed for the simulated output could possibly be associated with decreased bare soil evaporation in the 50 % return treatment being offset by increased transpiration and intercepted water loss. Better model performance might be achieved by taking into account increased water holding capacity and reduced evaporation by litter, which was returned biomass in this study. The soil temperature submodel in DAYCENT is a function of air temperature and plant biomass (Parton et al. 1998). Smaller live biomass difference between the two return rates from the simulated output than for field observations or a less sensitive temperature mitigation coefficient for litter effect in the submodel could be reasons for similar simulated soil temperatures between the two residue return rates.

15.3.2 Soil Organic Carbon

Residue return increased SOC in both years (Fig. 15.3). Soil organic C with 50 % residue return was 7.77 % greater than that under the control across both years. Similar results have been reported by other studies (Malhi and Lemke 2007; Powell and Hons 1991; Saffigna et al. 1989). For example, Saffigna et al. (1989) reported that SOC in the surface layer was 8 % greater in the *Sorghum* residue-retained than in the residue-removed treatment. Powell and Hons (1991) reported that removing all *Sorghum* stover significantly decreased SOC.

Compared with 2010, SOC in 2011 was greater regardless of residue return, indicating that root biomass and root exudates may contribute to a significant increase in SOC. Our result was consistent with those reported by others (Johnson et al. 2006; Menichetti et al. 2015; Zhao et al. 2014) who reported that belowground C inputs play a critical role in building and maintaining SOC.

Simulated SOC increased as bioenergy *Sorghum* residue return increased in both years. Modeled SOC in 2011 was higher than that in 2010, regardless of the rate of residue return. Residue return and temporal effects on SOC were favorably modeled with an r^2 value of 0.75. The DAYCENT model has previously been shown by numerous studies to be effective at modeling SOC dynamics for conventional crops (Del Grosso et al. 2002; Smith et al. 2012). In this study, the results simulated by DAYCENT matched well with the observed changes in SOC for both different

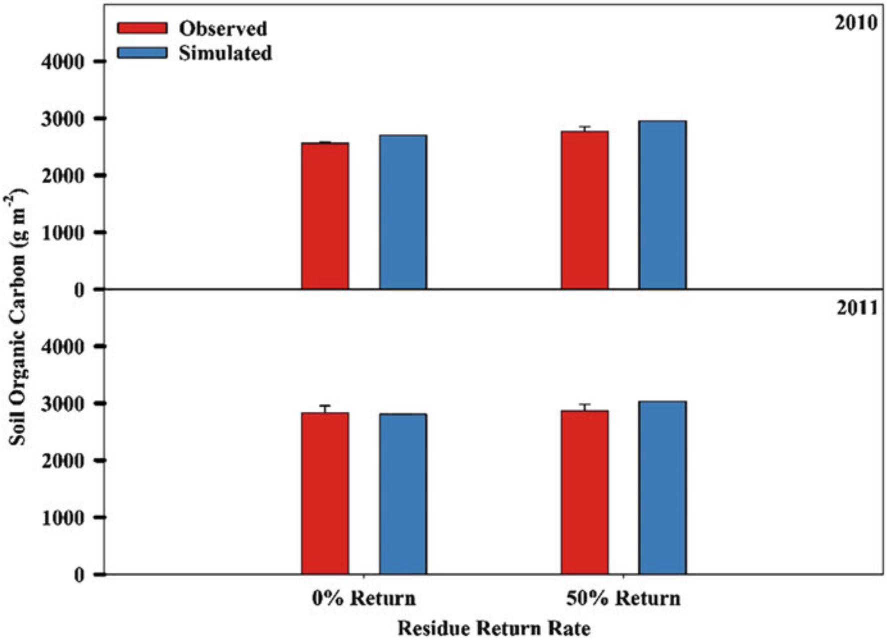

Fig. 15.3 Observed and simulated soil organic C at 0–20 cm depth under different residue returns in 2010 and 2011

residue return rates and years. Campbell et al. (2014) also reported similar effects of differential residue removal on SOC.

15.3.3 Carbon Dioxide (CO_2)

During most gas sampling events, higher daily CO_2 fluxes were observed for 50 % compared with 0 % residue return, though differences weren't always significant (Fig. 15.4). Compared with the 2010 growing season, higher daily CO_2 fluxes occurred during the 2011 growing season for both return rates. Average measured soil temperatures for June, July, and August 2011 vs. 2010 were +1.4, +1.2, and −0.4 °C, respectively, for 2011. Daily peak fluxes were observed after irrigation, precipitation, and fertilization when soil moisture was relatively high (Fig. 15.4).

Higher cumulative CO_2 emission for the 50 % residue return treatment was found when combined across years, though results were not significantly different compared with 0 % residue return in either year (data not shown). Compared with 2010, higher annual CO_2 losses were measured in 2011 for both return rates, indicating that conditions in 2011 were more favorable for decomposition. Jin et al. (2014) summarized static chamber estimates of GHG emissions from nine corn production systems under various crop residue and tillage management practices across the US

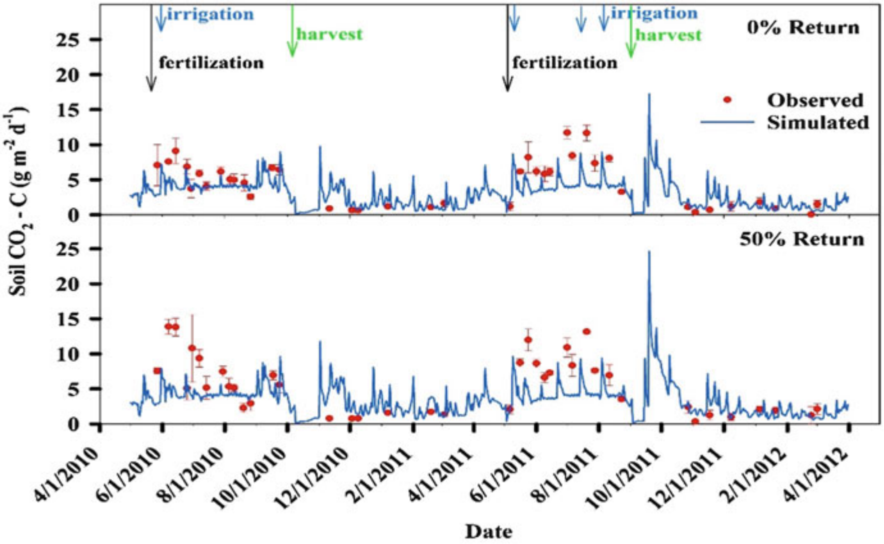

Fig. 15.4 Observed and simulated CO_2 – C fluxes under different residue returns during growing seasons and fallows in 2010 and 2011

Corn Belt and found that stover harvest generally reduced total soil CO_2 emissions by 4 %. Baker et al. (2014) summarized automated continuous chamber CO_2 data collected between spring 2010 and spring 2012 for three levels of stover harvest and found that CO_2 loss from plots with complete stover removal was lower than from plots with zero removal.

Similar daily flux patterns generally existed in the measured and simulated results (Fig. 15.4), though annual cumulative CO_2 emissions were underestimated by the model. Like observed results, modeled outputs also indicated that 50 % residue return increased CO_2 emissions in both years and showed higher CO_2 emissions in 2011 than in 2010 for both residue returns. DAYCENT performed very well in simulating annual cumulative CO_2 emissions with an r^2 value of 0.97.

15.3.4 Nitrous Oxide (N_2O)

Fluxes of N_2O were highly variable compared with CO_2, especially in 2011 when more irrigation was required because of the hot dry conditions (Storlien et al. 2014) (Fig. 15.5). During 2010, daily N_2O fluxes were mostly higher with the 50 % residue return treatment, while in 2011, the situation was the opposite, with 0 % residue return exhibiting more high daily N_2O fluxes, maybe due to more frequent water addition. Higher and more variable daily N_2O fluxes were observed for the 2011 compared to the 2010 growing season for both return rates. Peak daily N_2O fluxes

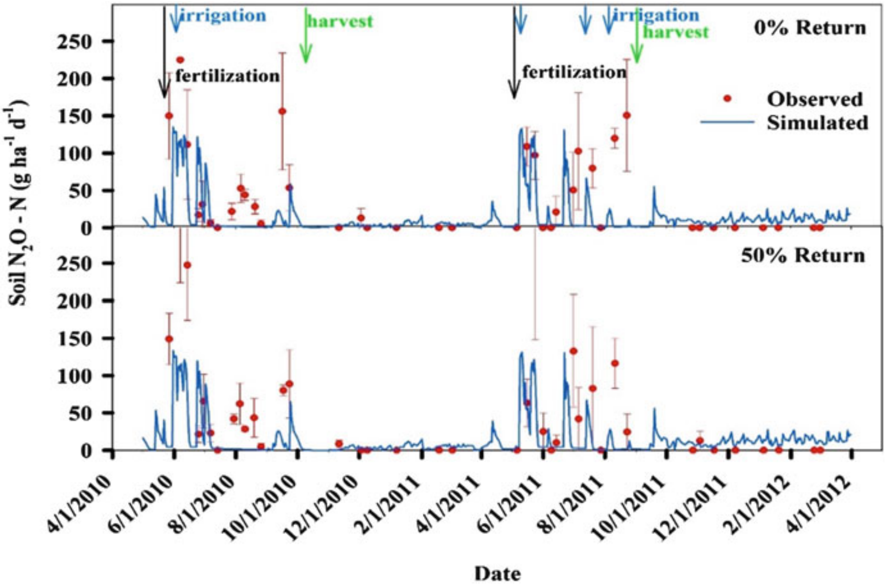

Fig. 15.5 Observed and simulated N_2O – N fluxes under different residue returns during growing seasons and fallows in 2010 and 2011

were generally observed following fertilization and water addition from irrigation and precipitation (Fig. 15.5).

Annual cumulative N_2O emissions showed the same pattern as daily N_2O fluxes, with 50 % residue return having greater annual cumulative emission in 2010 and 0 % residue return having higher annual cumulative emission in 2011, and no significant difference was found in either case (data not shown). When averaged over 2 years, higher N_2O loss was measured with 50 % compared with 0 % residue return, though the difference was not significant. This effect might be associated with enhanced microbial activity and C and N cycling due to the additional organic matter added. Annual cumulative N_2O emission was higher in 2011 than in 2010 for control treatment (0 % residue return), but the reverse pattern was found for 50 % residue return treatment.

Similar to the simulated annual cumulative CO_2 emissions, lower annual cumulative N_2O losses were produced by the model. Simulated daily N_2O fluxes underestimated the observed results during the growing seasons, while overestimating fluxes during the fallow periods. Simulated results also showed higher N_2O emissions with the return of 50 % of the aboveground biomass after harvest. DAYCENT, however, did not accurately simulate annual N_2O losses ($r^2 = 0.0057$).

Due to both the transience and the magnitude of N_2O flux changes across growing and fallow seasons, continuously measured N_2O data would be of great value for comparison against DAYCENT model results, especially after rainfall or irrigation and N fertilization. Continuous monitoring would provide better information for simulating the magnitude and timing of peak flux events as well as more accurately estimating annual emissions. When using DAYCENT to evaluate N_2O emissions from different production practices, care should be taken not to underestimate emissions in systems of potentially high flux (Campbell et al. 2014). Trace gas fluxes can also only be modeled well on the premise of accurate simulation of nutrient uptake and mineralization and soil water and temperature dynamics (Parton et al. 1998).

15.4 Conclusions

The DAYCENT model simulated soil temperature, soil water content, SOC, and CO_2 very well, with corresponding r^2 values of 0.94, 0.81, 0.75, and 0.97, but was much less accurate in estimating N_2O emissions ($r^2 = 0.0057$). For both greenhouse gases, DAYCENT produced lower annual cumulative emissions than measured, especially for N_2O. These biases should be considered when DAYCENT is used as a decision support tool for recommending sustainable *Sorghum* stover removal practices for bioenergy production.

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Chapter 16
Cover Crops for Enriching Soil Carbon and Nitrogen Under Bioenergy *Sorghum*

Upendra M. Sainju, H.P. Singh, and B.P. Singh

Abstract Soil carbon (C) and nitrogen (N) can be enriched with cover crops under agronomic crops, but little is known about their enrichment under bioenergy crops. Legume (hairy vetch [*Vicia villosa* Roth]), nonlegume (rye [*Secale cereale* L.]), a mixture of legume and nonlegume (hairy vetch and rye), and a control with no cover crop were grown in the winter to evaluate their effects on soil organic C (SOC), total N (STN), and nitrate-N (NO_3-N) contents under bioenergy *Sorghum* from 2010 to 2013. Cover crop biomass and C and N contents were greater with vetch/rye mixture than rye and the control. The SOC at 5–15 and 15–30 cm was greater with vetch/rye than other treatments under forage *Sorghum* and at 0–5 cm and 5–15 cm was greater with vetch/rye and vetch than rye or the control under sweet *Sorghum*. The STN at 5–15 cm was greater with vetch/rye and the control than rye under forage *Sorghum* and at 0–5 and 5–15 cm was greater with vetch/rye and rye than the control under sweet *Sorghum*. Both SOC and STN at all depths increased linearly from 2010 to 2013, regardless of cover crops and *Sorghum* species. The NO_3-N content at all depths varied with cover crops from 2011 to 2013. Bicultural cover crops, such as hairy vetch/rye mixture, have greater potential to sequester C and N than monocultures, such as hairy vetch and rye, or no cover crop due to greater crop residue returned to the soil under bioenergy *Sorghum* where aboveground biomass is harvested for bioenergy or feedstock.

Keywords Available nitrogen • Bioenergy crop • Carbon storage • Cover crop • Nitrogen storage • Soil organic matter

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16.1 Bioenergy *Sorghum*

Increased demand of fossil fuels for energy and their negative effect on environmental quality necessitate that alternative sources of energy, such as bioenergy, be developed (USDOE 2007). *Sorghum* crops, such as forage and sweet *Sorghum*, can be used for bioenergy production because of their relatively higher biomass yields compared with other bioenergy crops (Pacala and Solocolow 2004; USDOE 2007; Blanco-Canqui 2010). Utilization of biomass from such crops can either produce ethanol or generate electricity that can substantially reduce the use of fossil fuel and the amount of petroleum imported from foreign countries (Adler et al. 2007). Some of the benefits of using such crops are that they can be easily grown in marginal lands where cash crops cannot be grown, require less water than most other crops, and are drought tolerant (Pacala and Solocolow 2004; Ragauskas et al. 2006; USDOE 2007). Sweet *Sorghum* has the additional benefit of using both its juice and bagasse for ethanol production (Gnansounou et al. 2005).

Continuous removal of aboveground biomass for bioenergy can result in adverse effect on soil and environmental quality (Blanco-Canqui 2010). Because crop residues serve as C and N inputs to the soil, their removal from the soil can reduce soil organic matter which is a key factor for maintaining long-term soil fertility (Blanco-Canqui and Lal 2007; Blanco-Canqui 2010; Sainju 2014). This also indirectly affects environmental quality by reducing the potential of soil to sequester atmospheric CO_2 (Blanco-Canqui and Lal 2007). Agricultural soils, being depleted of large amounts of organic C and N due to cultivation, have significant potentials to sequester atmospheric CO_2 as well as to reduce N losses primarily through leaching, thereby increasing soil C and N storage (Lal and Kimble 1997; Paustian et al. 1997). There is a paucity of information about how bioenergy crop residue removal can affect soil C and N storage and N leaching (Blanco-Canqui and Lal 2007; Blanco-Canqui 2010).

16.2 Cover Crop

Cover crops have been grown successfully in regions with mild winter to provide vegetative cover for reducing soil erosion. Cover crops are usually grown in the fall after the harvest of summer cash crops and have many benefits for sustaining crop yields and improving soil and water quality. Winter cover crops use soil residual N that may otherwise leach into groundwater after crop harvest in the fall, thereby reducing soil profile NO_3-N content and N leaching (Meisinger et al. 1991; McCracken et al. 1994; Sainju et al. 1999). Depending on the species, cover crops can maintain or increase soil organic C (SOC) and total N (STN) concentrations by providing additional crop residue which increases C and N inputs to the soil (Hargrove 1986; Kuo et al. 1997a, b; Sainju et al. 2000). Legume cover crops can fix atmospheric N, thereby reducing N fertilization rates for summer crops (Hargrove 1986; Meisinger et al. 1991; Kuo et al. 1997a, b). While increased biomass C returned to the soil may increase soil C sequestration, increased biomass N may increase both soil N sequestration and available N that can increase succeeding crop yields (McVay et al. 1989; Kuo et al. 1997a, b). Other benefits of cover crops include increased soil aggregation and water infiltration capacity (McVay et al. 1989; Roberson et al. 1991), improved water holding capacity (Smith et al. 1987), reduced soil erosion (Frye et al. 1985; Langdale et al. 1991), and increased root growth of summer crops (Sainju et al. 2001) compared with no cover crop.

Legume cover crops can supply N to succeeding crops and increase yields compared with nonlegumes or no cover crop (Hargrove 1986; Clark et al. 1994; Kuo et al. 1997b). In contrast, nonlegume cover crops can be effective in increasing soil organic matter by supplying C through increased biomass production (Kuo et al. 1997a, b; Sainju et al. 2000) compared with legumes or no cover crop. Nonlegumes can also reduce NO_3-N leaching from the soil profile better than legumes or no cover crop do (Meisinger et al. 1991; McCracken et al. 1994). Since none of the cover crops are effective enough to provide most of these benefits, i.e., to supply N, sustain crop yields, increase soil organic matter, and reduce N leaching, a mixture of legume and nonlegume cover crops would be ideal to supply both C and N inputs in adequate amounts that helps to improve soil and water quality by increasing organic matter content and reducing N leaching compared with legumes and increase crop yields compared with nonlegumes.

Cover crop biomass and C and N contents can vary among species. In our experiment, cover crop biomass and C content, averaged across 4 years, were greater with vetch/rye mixture than rye and the control with weeds under forage *Sorghum* (Fig. 16.1). Under sweet *Sorghum*, cover crop biomass and C content were greater with vetch/rye mixture than vetch, rye, and the control. Cover crop N content was greater with vetch and vetch/rye mixture than rye and the control under forage *Sorghum* and greater with vetch/rye than other cover crops under sweet *Sorghum*. Sainju et al. (2005) also found that biomass yield and C content varied with cover crops, but N content was greater with hairy vetch than rye due to higher N concentration. The hairy vetch/rye biculture had similar or greater biomass yield and C and N contents than hairy vetch or rye alone. This could have resulted from:

1. N being transferred from hairy vetch to rye, thereby increasing biomass yield and N concentration of rye in biculture than in monoculture (Ta and Faris 1987; Russelle and Hargrove 1989; Ranells and Wagger 1996);
2. higher seeding rates of hairy vetch and rye mixture used in biculture than in monocultures, thereby increasing biomass yield because of reduced interspecies competition (Clark et al. 1994);
3. non-dominative growth habits of hairy vetch and rye in biculture, such as the upright growth habit of rye providing an excellent scaffold for the viney growth habit of hairy vetch to grow upward, thereby intercepting a greater percentage of light and reducing the growth competition between the two species (Ranells and Wagger 1996; Kuo and Jellum 2002); and
4. similar biomass yields and C and N concentrations of rye and hairy vetch in biculture as found in monocultures (Sainju et al. 2005).

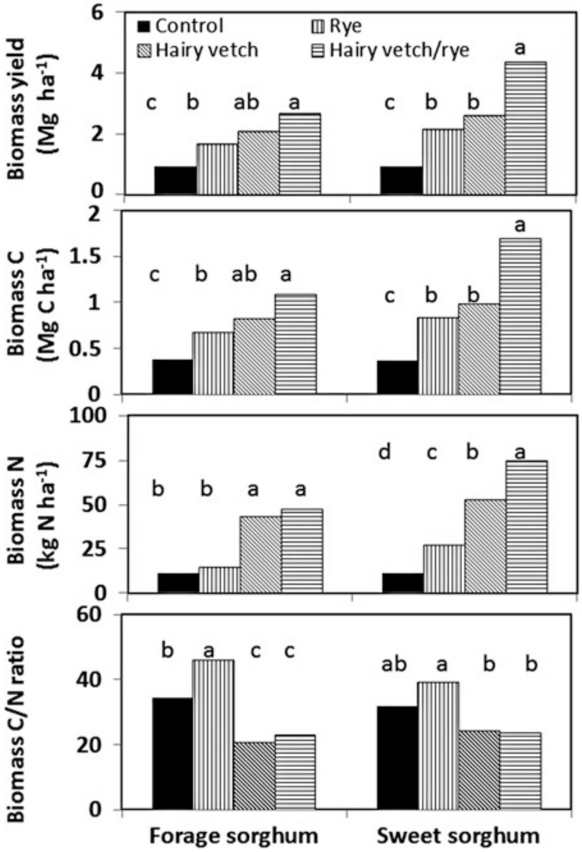


Fig. 16.1 Cover crop biomass yield, C and N contents, and C/N ratio averaged across 3 years under forage and sweet sorghum. *Bars* followed by different letters at the *top* are significantly different

Greater biomass yield and N content in hairy vetch + rye biculture than in monocultures have also been reported by several other researchers (Clark et al. 1994; Ranells and Wagger 1996; Vaughan and Evanylo 1998; Kuo and Jellum 2002).

The N content or C/N ratio of cover crops is a principal determinant factor for soil N availability, regardless of placement of their residues in the soil (Hargrove 1986; Smith et al. 1987; Ranells and Wagger 1996). As C/N ratio of plant residues increases above 25:1, potential for N immobilization in the soil increases (Allison 1966). In contrast, as N content of plant residue increases or C/N ratio decreases, initial soil N mineralization potential and N mineralization rate increase (Frankenberger and Abdelmagid 1985; Kuo and Sainju 1998), and the crossover time for net N mineralization decreases (Kuo and Sainju 1998). Therefore, one of the management options to increase N content or reduce C/N ratio of nonlegume cover crops is to mix them with legume cover crops as bicultural treatments, because nonlegume cover crops, such as rye, typically have low N content or high C/N ratio, thereby having little effects on soil N availability and crop yields (Clark et al. 1994; Ranells and Wagger 1996; Kuo and Jellum 2002). In our experiment, the C/N ratio was greater with rye than other cover crops under forage *Sorghum* and greater with rye than vetch and vetch/rye mixture under sweet *Sorghum* (Fig. 16.1). Because C/N ratio was below 25:1 with vetch and vetch/rye mixture both under forage and sweet *Sorghum*, the potential for N immobilization was lower with these cover crops. Studies have shown that including hairy vetch or crimson clover (*Trifolium incarnatum* L.) with rye in biculture increased N content or decreased C/N ratio of rye, thereby reducing the potential for N immobilization from rye residue (Sullivan et al. 1991; Ranells and Wagger 1996; Vaughan and Evanylo 1998). Ranells and Wagger (1996) observed that as N concentration in rye increased from monoculture to biculture with hairy vetch, the C/N ratio decreased from 42 to 16. As a result, more N was released from hairy vetch and rye biculture residue in the soil than from rye residue alone. Therefore, legume-nonlegume biculture can reduce the C/N ratio of nonlegume cover crops and increase the potential for soil N mineralization and availability for succeeding crops.

16.3 Soil Organic Carbon

Increased above- and belowground (root) crop biomass residue returned to the soil can increase SOC (McVay et al. 1989; Kuo et al. 1997a; Sainju et al. 2000). In our experiment, averaged SOC at 5–15 cm across 4 years was greater with vetch/rye mixture than vetch and the control under forage *Sorghum* (Fig. 16.2). At 15–30 cm, SOC was greater with vetch/rye and the control than rye. Under sweet *Sorghum*, SOC at 0–5 cm was greater with vetch/rye than the control, but at 5–15 cm was greater with vetch and the control than vetch/rye. Except for the SOC at 5–15 cm under sweet *Sorghum*, the greater SOC at other depths with vetch/rye than other cover crops likely resulted from increased above- and belowground biomass and C input (Fig. 16.1), considering that belowground biomass is proportional to aboveground biomass (Kuo et al. 1997a; Sainju et al. 2005). A direct relationship exists between C input rates and SOC, regardless of tillage practices (Larson et al. 1972; Lal et al. 1980; Rasmussen et al. 1980). Although hairy vetch can increase SOC compared with the control (McVay et al. 1989; Kuo et al. 1997a; Sainju et al. 2000), the result can be even more pronounced with hairy vetch/rye biculture due to greater amount of above- and belowground biomass residue returned to the soil (Sainju et al. 2006).

Averaged across cover crops and years, SOC was greater under sweet than forage *Sorghum* (Fig. 16.2). Increased above- and belowground biomass may have increased SOC under sweet than forage *Sorghum*. Average aboveground biomass yield of sweet *Sorghum* across 3 years was 16.0 Mg ha^{-1} compared with 12.2 Mg ha^{-1} for forage *Sorghum*. The fact that hairy vetch increased SOC more under sweet than forage *Sorghum* was probably related to increased growth response with N supply. It may be possible that sweet *Sorghum* responded more to N supply from hairy vetch for grain, brix, and sugar content as well as belowground biomass in addition to stover yield compared with stover and belowground biomass yields in forage *Sorghum*.

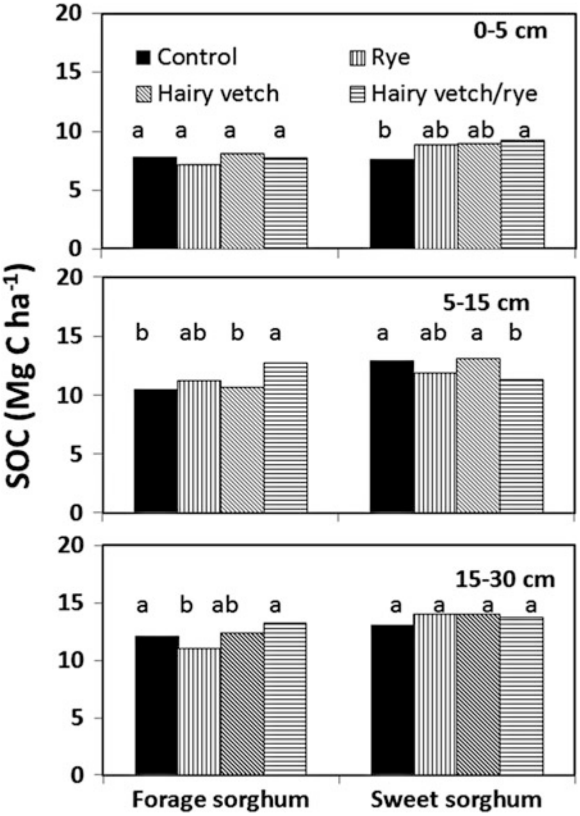


Fig. 16.2 Soil organic carbon (*SOC*) at 0–5, 5–15, and 15–30 cm depths averaged across 4 years as affected by cover crops under forage and sweet sorghum. *Bars* followed by different letters at the *top* are significantly different

Regardless of cover crops and *Sorghum* species, SOC at all depths increased linearly from 2010 to 2013 (Fig. 16.3). The SOC increased from 0.52 Mg C ha^{-1} year^{-1} at 0–5 cm to 1.42 Mg C ha^{-1} year^{-1} at 15–30 cm. Carbon sequestration rate increased with the depth due to increased soil bulk density and thickness of the soil layer, although SOC concentration was higher in the surface layer (12.39, 8.94, and 5.03 g C kg^{-1} at 0–5, 5–15, and 15–20 cm, respectively). Bioenergy crops can sequester C at 0–3 Mg C ha^{-1} year^{-1} at 0–5 cm (Lemus and Lal 2005). Our C sequestration rates were similar to or higher than the rates of 0.3–0.5 Mg C ha^{-1} year^{-1} at 0–30 cm under bioenergy crops reported by several researchers (Anderson-Teixeiera et al. 2009; Blanco-Canqui and Lal 2009).

16.4 Soil Total Nitrogen

As with SOC, greater STN with vetch/rye than other cover crops under forage and sweet *Sorghum* in our experiment appeared to be a result of increased N inputs from above- and belowground biomass (Fig. 16.1). Averaged across 4 years, STN at

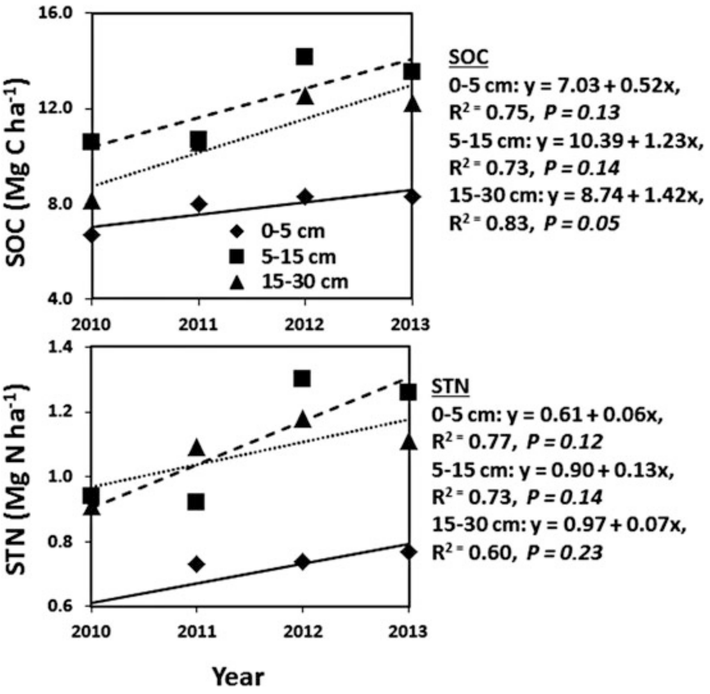
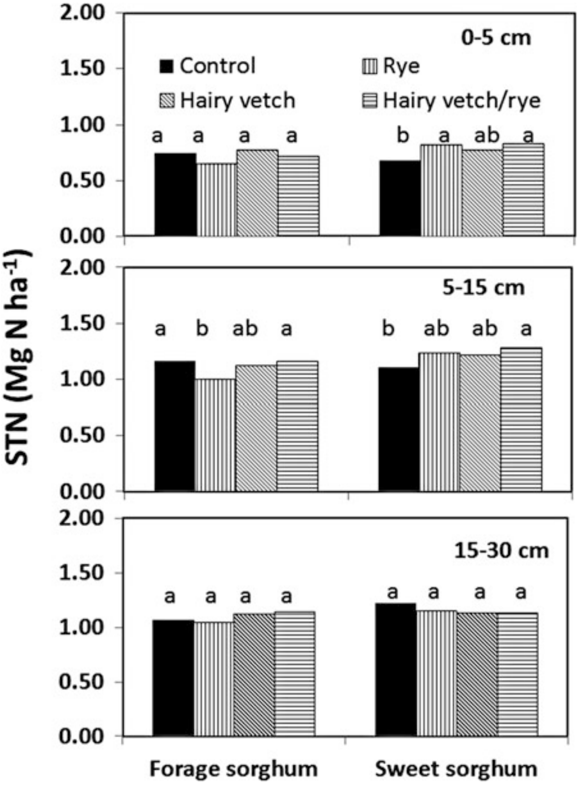


Fig. 16.3 Relationships between soil organic C (*SOC*) and total N (*STN*) at 0–5, 5–15, and 15–30 cm depths and year averaged across cover crops and bioenergy sorghum species

0–5 cm was greater with vetch than rye under forage *Sorghum* and greater with vetch/rye and rye than the control under sweet *Sorghum* (Fig. 16.4). At 5–15 cm, STN was greater with vetch/rye and the control than rye under forage *Sorghum* and greater with vetch/rye than the control under sweet *Sorghum*. Averaged across cover crops and years, STN at 5–15 cm was greater with sweet than forage *Sorghum*. At 15–30 cm, STN was not different among treatments and averaged 1.13 Mg N ha^{-1}.

Sainju and Singh (2008) similarly found greater STN under hairy vetch/rye biculture than rye or no cover crop under cotton and *Sorghum*. They reported that total crop residue N returned to the soil from above- and belowground biomass was two to three times greater with hairy vetch/rye than rye and the control. They, however, observed no difference in STN between hairy vetch and hairy vetch/rye due to increased N supplied by hairy vetch residue as a result of its higher tissue N concentration. Similarly, greater STN under sweet than forage *Sorghum* can be related to higher above- and belowground biomass N. The SOC/STN ratio was not influenced by treatment and year and averaged 10.9, 11.0, and 10.4 at 0–5, 5–15, and 15–30 cm, respectively. Because of similar STN between hairy vetch and hairy vetch + rye mixture, hairy vetch can be replaced by hairy vetch + rye mixture to maintain soil N storage (Sainju et al. 2000), if hairy vetch increases N leaching compared with rye (Meisinger et al. 1991; McCracken et al. 1994).

Fig. 16.4 Soil total nitrogen (*STN*) at 0–5, 5–15, and 15–30 cm depths averaged across 4 years as affected by cover crops under forage and sweet sorghum. *Bars* followed by different letters at the *top* are significantly different



The STN increased linearly at all depths from 2010 to 2013, regardless of cover crops and *Sorghum* species (Fig. 16.3), a case similar to that observed for SOC. The STN increased from 0.06 Mg N ha^{-1} year^{-1} at 0–5 cm to 0.13 Mg N ha^{-1} year^{-1} at 5–15 cm. Continuous accumulation of N from belowground biomass of *Sorghum* and from above- and belowground biomass of cover crops over years likely increased STN from 2010 to 2013. Sainju and Singh (2008) reported N storage rates from 73 to 314 kg N ha^{-1} year^{-1} at 0–120 cm over 4 years due to increased crop residue N returned to the soil from cover crop, cotton, and *Sorghum* residue in central Georgia. Greater soil N storage will lead to sustained crop production and improved soil, water, and air quality by increasing soil organic matter and reducing N leaching and N_2O emissions, a potent greenhouse gas that contributes to global warming (Meisinger et al. 1991; McCracken et al. 1994; Sainju and Singh 2008).

16.5 Soil Nitrate-Nitrogen

Cover crops have been increasingly used to reduce N leaching by scavenging residual N in the soil after fall crop harvest and to increase N supply for succeeding summer crops. As a result, N fertilization rates can be either reduced or eliminated, especially with legume cover crops, in order to reduce the cost of N fertilization. The effectiveness of cover crops in reducing N leaching and increasing N supply depends on the species. Studies have shown that nonlegume cover crops, such as rye and annual ryegrass (*Lolium multiflorum* L.), were more effective in reducing soil residual N (Kuo et al. 1995; Vyn et al. 1999) and N leaching (McCracken et al. 1994; Bergstrom and Kirchmann 2004) than legumes, such as hairy vetch, or the non-cover cropped treatment. Sainju and Singh (1997), in a review of literature, concluded that nonlegumes reduced N leaching by 29–94 % compared with −6 to 48 % for legumes. The effectiveness of cover crops in reducing soil residual N depends on their ability to establish rapidly in the fall and to extend their root system (Kuo et al. 1997b; Sainju et al. 1998). Nonlegumes, such as rye and annual ryegrass, have extensive root systems and remove more N from the soil than legumes or the non-cover cropped treatment do (Kuo et al. 1997b; Sainju et al. 1998). In contrast, legumes increased soil mineral N content and crop N uptake compared with nonlegumes (Vyn et al. 1999; Bergstrom and Kirchmann 2004). A mixture of legume and nonlegume cover crops could be an ideal treatment to sustain both soil mineral N content and succeeding crop N uptake and reduce N leaching compared with either of the species alone.

Differences in N supplied by cover crops and N uptake by *Sorghum* species resulted in variations in soil NO_3-N content among cover crops and years in our experiment (Fig. 16.5). Averaged across *Sorghum* species, NO_3-N content at 5–15 cm was greater with vetch/rye than rye in 2011 but was greater with rye than vetch/rye and the control in 2012. Compared with other cover crops, NO_3-N content at 15–30 cm was greater with vetch/rye in 2011 but lower with the control in 2012. At 0–5 cm, NO_3-N content was not influenced by treatment and year and averaged 6.8 kg NO_3-N ha^{-1}.

Increased N uptake during the year with near normal precipitation appeared to lower NO_3-N content at 5–15 cm with rye than other cover crops in 2011. When precipitation was lower in 2012 (841 mm) than other years (981–1809 mm), reduced growth of rye probably resulted in lower N removal, thereby increasing soil NO_3-N content at 5–15 cm with rye. Vetch/rye reduced NO_3-N content by increasing N uptake in that year. Similar results occurred for NO_3-N content at 15–30 cm, except that increased N supplied by vetch and vetch/rye (Fig. 16.1) appeared to increase NO_3-N content in 2012. Sainju et al. (2007) found that, although hairy vetch/rye biculture supplied N similar to or greater than hairy vetch alone, rye in the biculture immobilized part of soil NO_3-N, thereby resulting in NO_3-N content with hairy vetch/rye intermediate to that between hairy vetch and rye, a case similar to that observed in our study. They suggested that, because of increased NO_3-N concentration with soil depth, hairy vetch may increase the potential for N leaching compared with other treatments. Several researchers (Vaughan and Evanylo 1998; Kuo and Jellum 2002) also found that soil mineral N concentration was higher with hairy vetch + rye mixture than with rye but lower than with hairy vetch.

Averaged across treatments, NO_3-N content at all depths declined from 2011 to 2013 (Fig. 16.5). Nitrogen supplied by hairy vetch may have increased NO_3-N content in 2011. Increased N uptake by *Sorghum* and/or N losses through leaching, however, may have reduced NO_3-N content from 2011 to 2013. Aboveground

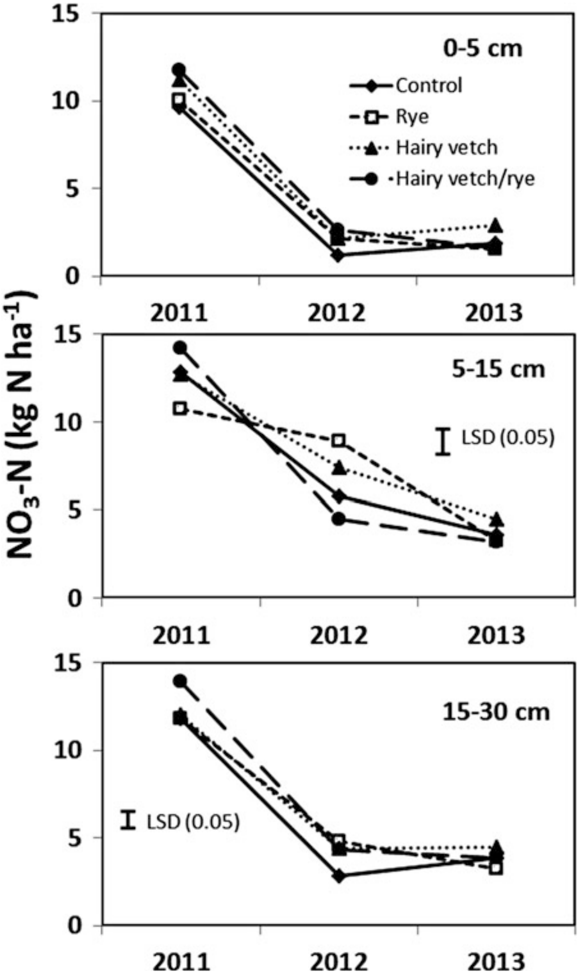


Fig. 16.5 Soil NO_3-N content at 0–5, 5–15, and 15–30 cm depths from 2011 to 2013 averaged across sorghum species as affected by cover crops. LSD (0.05) is the least significant difference among treatments at $P = 0.05$

biomass yield increased from 4.5 Mg ha^{-1} for forage *Sorghum* in 2011 to 18.8 Mg ha^{-1} for sweet *Sorghum* in 2012, which may have increased N uptake and therefore reduced soil NO_3-N content. Also above average precipitation in 2013 (1809 mm compared with the normal precipitation of 1212 mm) may have increased N leaching, thereby reducing soil NO_3-N content in that year.

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Part IV
Capital

Chapter 17
Economics, Energy, Climate Change, and Soil Security

Bruce A. McCarl

Abstract The Global Soil Security Symposium for which this chapter was developed was part of an effort to both improve and recognize the role of soils as they contribute to society with some speakers stating a goal of improving overall soil condition and health and the recognition of the capital value of soil. Such an effort naturally will face challenges. This chapter addresses from an economic point of view challenges that are likely to arrive from societal efforts to increase biofuels and from the ongoing and projected effects of climate change. In addition, the chapter covers some economic material regarding soil valuation in relation to management practices.

Keywords Bioenergy • Soil implications • Climate change • Adaptation • Mitigation • Carbon markets

17.1 Energy/Bioenergy Implications for Soils

There are a number of ways that energy-related developments may raise challenges to improve or maintain soil condition. In particular there are energy actions that influence soil characteristics.[1] This involves carbon balance, organic matter, nitrous oxide emissions, erosion, water retention, nutrient holding, and many other things that could be mentioned (Chaps. 15 and 16). The energy developments with soil implications discussed here are:

- Soil implications of the RFS2 in terms of land use shifts plus farming at the intensive and extensive margins
- Soil implications of bioenergy-related cellulosic ethanol production initiatives including both the use of energy crops and crop residues like corn stover
- Soil implications of strategies to use marginal lands for the production of energy

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[1] By characteristics I mean the totality of physical, chemical, biological, and ecological attributes of soil.

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- Soil implications of higher energy prices due to carbon taxes
- Soil implications when using biochar – a by-product from energy production via fast and slow pyrolysis

17.1.1 Effect of RFS2

Under the 2005 US energy act, there was a requirement that the USA produce a minimum amount of renewable fuel. This has been called the Renewable Fuel Standard (RFS). In 2007 the requirements were revised upward and that requirement is commonly called RFS2. In conjunction with the EPA, I have been examining the economic and environmental implications of agriculture producing large amounts of bioenergy feedstock. In recent analyses in the context of US agriculture, we find this will (Beach and McCarl 2010):

- Induce substantial increases in crop prices both domestically and internationally
- Increase cropping a little bringing in lands from the pasture, forest, or CRP
- Increase corn and cellulosic feedstock acreage substantially
- Increase fertilizer and other chemical use
- Increase irrigation but decrease use of reduced tillage

Additionally Bruce Babcock at Iowa State shows using both the US and global data sets that this reduces the gap between planted and harvested and increases double cropping (Babcock and Iqbal 2014).

Such developments put pressure on the use of grasslands and forest lands for feedstocks or replacement of diverted commodities (see Searchinger et al. (2008), Miyake et al. (2012), or Wright and Wimberly (2013) or the general treatment in Murray et al. (2004) for discussion).

17.1.2 Expanding Cellulosic Through Energy Crops and Residues

Cellulosic ethanol is required in large volumes under RFS2. The agriculturally based feedstocks for cellulosic ethanol are generally of several types: (a) energy crops in the form of perennial grasses (e.g., switchgrass, *Miscanthus*), (b) short rotation woody crops (e.g., poplar, willow), (c) some annuals (e.g., energy *Sorghum*), (d) crop residues (e.g., corn stover), (e) forest products (e.g., logs), and (f) processing by-products (e.g., milling residues). Generally all of these have soil implications via several pathways. First, the energy and short rotation crops need land and will either crowd out conventional crops or cause the use of lands that were not previously cropped as discussed under marginal lands below. Second, the energy and short rotation crops often involve less soil disturbance and can increase sequestration (Agostini et al. 2015), but the extent depends on the prior land use with it being a loss if substantial sequestration is displaced in establishing the energy and short rotation crops, for example, if long-standing forest is displaced (Fargione et al. 2008). Third, they may increase erosion relative to the previous land use depending on previous land use cover type. Fourth, fertilizer use is generally low but again resultant net emissions depend on comparison with previous land use. Fifth, removal of residues can decrease soil carbon content (Jin et al. 2014; Vanhala et al. 2013; Chap. 16 Upendra et al.).

17.1.3 Using Marginal Lands

Many people, including a National Academy of Sciences (NAS) report (Ramage et al. 2009), have been saying crops like switchgrass and *Miscanthus* can be grown on marginal lands. That NAS report said 400 million tons could be grown "… in a sustainable manner [where] growing and harvesting of cellulosic biomass would incur minimal or even reduce adverse environmental effects such as erosion, excessive water use, and nutrient runoff" (p. 12) (I was a reviewer and thought this was naïve at best). We looked into the effects of the requirements for cellulosic ethanol under the RFS2 with and without production on marginal lands in particular land classified as cropland pasture (Shiva 2014). We found about 10 million hectares of marginal land would be used and that this would reduce commodity prices. But we found several other things. First, net greenhouse gas net emissions were increased due to a reduction in soil sequestration plus more emissions from cropping operations and fertilization. Second, erosion increased as did chemical runoff. We also found under a carbon price most of the feedstock from the marginal lands went into electricity and the food price reduction did not occur as the cellulosic feedstock production largely occurred on conventional lands. Under this carbon price, greenhouse gasses were decreased due to the high carbon efficiency of burning the feedstock rather than converting to ethanol.

17.1.4 Energy Tax and Tillage Intensity

Years ago we saw a lot of interest in carbon pricing. But despite some cases where carbon markets are occurring, we find agriculture both is largely exempted as a capped sector other than on fuels used and is often excluded as an offset sector (Murray 2015). Today we will likely see the effects of carbon programs on energy costs before we see full agricultural involvement in a market. We looked at the effects of this and found it greatly stimulated lower intensity forms of tillage and if biofuels were exempted from the tax production of cellulosic feedstocks (Schneider and McCarl 2005).

17.1.5 Bringing in Biochar

A few years ago I was asked to do a biochar analysis by an international group. I looked at the benefits in a corn stover removal context considering estimates of soil C loss due to stover removal, nutrients to replace that lost with stover removal, available removal per acre, assembly and hauling cost, energy and biochar yields via fast and slow pyrolysis, energy fate, biochar fate – to agriculture or charcoal – biochar hauling and application cost, biochar retention rate, nutrient- and water-applied reductions under biochar, yield enhancements, and greenhouse gasses across the spectrum (McCarl et al. 2009; Shackley et al. 2014). What did we find – biochar was a money loser unless there was a large carbon price and also needed a high cost on the energy (it did make sense in Taiwan for potatoes on set-aside land where the produced energy value was much higher (Kung 2010). The more I looked into this the less comfortable I became about global assumptions with major doubts about the yield enhancement and char retention rates I was being given. I think today's literature shows many cases where it does not increase yields and may decrease them (Jeffery et al. 2011; Crane-Droesch et al. 2013).

17.2 Climate Change Issues

There are a number of ways that climate change-related developments may raise challenges to improve or maintain soil condition and health:

- Soil-related effects of a warming world and associated changes in precipitation, extreme events, and other climate attributes. There are both direct and indirect aspects of this.
- Soil-related effects of actions to adapt to climate change.
- Soil-related effects of climate change mitigation efforts in terms of sequestration enhancement and more general greenhouse gas emission control.

17.2.1 Climate Effects

Much has been written on climate change effects on agriculture. Warmer conditions have effects on soil microbes and organic matter although the response is complex and depends on moisture (Davidson and Janssens 2006; Sierra et al. 2015). Climate change also is likely to shift zones suitable for crops with a poleward shift observed and expected (Reilly et al. 2003) plus some areas are projected to have substantially reduced productivity (Reilly et al. 2003). Additionally technological progress is likely to slow down with a need for additional investment in locations to maintain current production (Villavicencio et al. 2013). Finally soil moisture is projected to be reduced in many areas (IPCC 2013). Collectively these forces imply a changing demand for land in cropping and will have soil implications.

17.2.2 Soil's Role in a Carbon Market

Climate change effects and its possible damages have led many to suggest pursuing mitigation of net greenhouse gas emissions through sequestration enhancement and emission control. A commonly advocated means for doing this has involved greenhouse gas markets which have broadly been called carbon markets. There, farmers could sell carbon offsets. Over the years there has been much written about agricultural participation in such a market (McCarl and Schneider 2000; Smith et al. 2007a, b). From the soil side this has involved strategies such as changing practices to increase soil carbon, improving fertilization management, and changing land use from cropping to grasslands and forest. Over the years economists have looked at this from a number of viewpoints and found:

- There are large issues of permanence, additionality, uncertainty, leakage, and transaction costs that have inhibited agricultural participation (Smith et al. 2007a; Post et al. 2009).
- At low carbon prices tillage changes make sense but only in certain areas, while at high prices land moves into biofuels and trees. Generally there is a small role for nitrogen management (McCarl and Schneider 2001; Lee et al. 2005).
- In terms of fertilization nitrification inhibitors may be attractive (Ogle et al. 2015).
- Carbon markets can cause vegetation and tillage changes that yield substantial soil retention and water quality gains (Pattanayak et al. 2005).
- Carbon in soils accumulates to a point of a new equilibrium and is reversed if practices are intensified (West and Six 2007). This renders cases of soil sequestration worth considerably less than other permanent practices like methane destruction with estimates of the tonnage sequestered value being less than one-half the carbon price (Kim et al. 2008).

At the moment such markets are not very accommodating of agricultural sales (Murray 2015) and may not be requiring new approaches (Lewandrowski and Zook 2015).

Nevertheless, carbon markets or other carbon storage promotion means hold out implications for soils influencing land use, tillage methods, and fertilization among other items.

17.2.3 Adaptation and Land Use Change

Climate change is likely to have substantial effects in the next 25 years regardless of efforts on climate change mitigation. In particular, the IPCC future projections (IPCC 2013) are summarized in Fig. 17.1 (which is reproduced from McCarl 2015) where the figure shows temperature change under alternative mitigation scenarios (called RCPs). IPCC (2014) formed alternative futures based on these as represented by the vertical lines and arrows that appear in the figure.

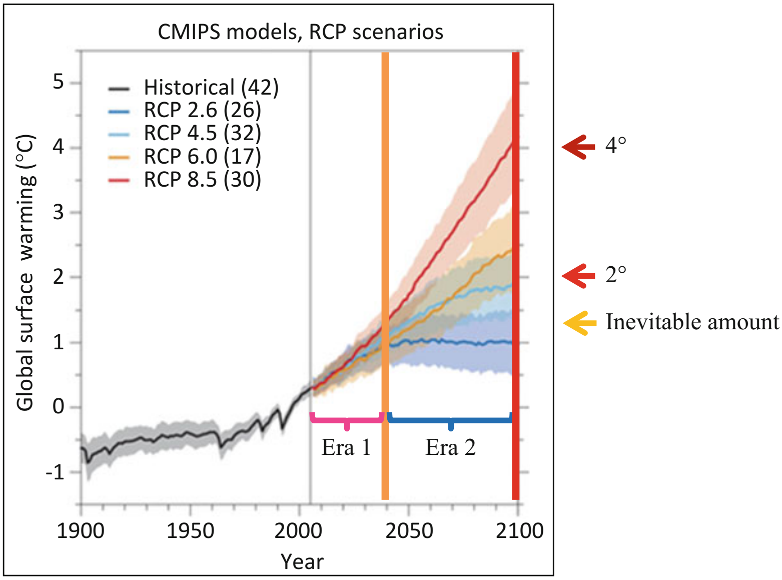

Fig. 17.1 IPCC graph of future temperature change under alternative emission scenarios adapted from Knutti and Sedláček (2013) with the vertical lines, arrows, and era markings added for exposition by McCarl (2015)

Following IPCC (2014) and McCarl (2015), two eras of climate change are portrayed in Fig. 17.1 – Era 1, between now and 2040, and Era 2, between 2040 and 2100. During era 1, the next 25 years, climate change follows one basic path regardless of mitigation effort with the amount of warming essentially the same across all the RCP emission scenarios at about 1 °C for 2040. Agriculture will likely confront this inevitable amount of temperature change and must prepare/adapt for it. Beyond that the emission scenario results diverge depending on mitigation effort. Neglecting the unrealistic RCP2.6 case, the era 2 cases show a temperature change spanning between 2 and 4 °C. Thus, the adaptation challenge is: How can agriculture prepare itself for a 1 °C change in the next 25 years and 2–4 °C degrees by the end of the century?

Given the inevitability of substantial amount of climate change, adaptation options will almost certainly have to be taken (Rose 2015; McCarl 2015). Soils will undoubtedly be impacted. Adaptations can involve many actions. Drawing out soil-related ones from IPCC (2014 chapters 14 and 17) and McCarl (2015), famers can alter:

- Crop and livestock mix including latitude and elevation where, for example, we have seen corn moving north and west in the USA (by 172 miles as estimated in Attavanich et al. (2011) which is an update of Reilly et al. 2003). This has resulted in concerns on land being broken out from wetlands in the USA (Rashford et al. 2015).

- Crop management changing planting and harvesting dates as growing seasons have increased with earlier planting or later harvesting with earlier planting usually resulting in improved yield (Sacks and Kucharik 2011). In addition, longer growing seasons also allow for additional double cropping (Seifert and Lobell 2015).
- Land use between cropping and grassland where hotter temperatures tend to move lands from cropping to grass in warm areas and vice versa in cool areas (Mu et al. 2013).
- Direct capital investments in infrastructure (e.g., irrigation, roads).
- Technology development through research (e.g., development of crop varieties).

17.3 Turning to Economics

Now as an economist there are a couple of soil value aspects that have been addressed that are meritorious of brief comment.

17.3.1 Value of Soil

During the symposium material was presented on the global value of all soil services. Typically economists don't look at such values as we do not make decisions on whether or not to have soil, but rather we act more on the margin-making decisions on whether or not to retain or improve a given amount of soil at a specific location. Such decisions involve, for example, given a parcel of land whether to use soil erosion-reducing practices, whether to preserve prime farm land, and whether to reverse soil degradation, i.e., improve soil condition. The soil value in these cases is a marginal one and I believe it is useful to establish such values. I have been involved in several such studies which I briefly review below.

Years ago we were trying to value the use of soil-preserving practices and looked at the shift in the net present value of future earnings in Eastern Oregon wheat production when we retained rather than lost potentially eroded soil (Hanrahan 1986; Hanrahan et al. 1986). Here we found that the retention of the eroded soil was worth very little. Why? The soil we studied was deep and the marginal effects of the lost soil on production volume and cost were quite small. This would be different on a shallow soil where productivity was being substantially lost and/or expensive additional inputs would be needed. Perhaps inclusion of other ecosystem services would make a difference, but these are nonmarket goods and are hard to value. This does point out a potential need in soil valuation, and that is to value soil retention in a case where erosion does substantially reduce the production capability of a parcel of land or to value the restoration of low-productivity land.

We next addressed how much it cost to have the eroded soil running off into the environment. Here we looked in the Willamette Valley at the cost of dealing with erosion and found major costs in water treatment for cities, ditch maintenance, reservoir sedimentation, and ship channel dredging (Moore and McCarl 1987). We repeated the municipal part of this in Texas and found major costs (Dearmont et al. 1998).

After these two experiences, I wrote a book for the World Bank of how to appraise soil conservation implications in the context of project design (McCarl 1983) which deals with approaches like extra cost added by erosion, replacement of services from other sources, and many other approaches.

17.3.2 Promise of Reduced Tillage

Reduced tillage has been advocated as a farm profit increasing strategy by soil scientists for many years. In the late 1970s, one of my students looked into the use of no-till and found it did not make economic sense in terms of average incomes plus was risk increasing certainly in the first 5 years (Klemme 1985). Now years later it seems to me it is routinely used for cases where, for example, moisture management is imperative or we have glyphosate resistance permitting pesticide application to reduce weed infestations or when energy and aquifer depletion cost savings from reduced irrigation pumping are large among other cases. We may need incentives to widen adoption in cases where the societal benefits of adoption make such an action desirable. However, one must be careful in looking at these societal benefits as other practices that could be enhanced with the incentive monies may also have substantial benefits (Elbakidze and McCarl 2007). I have also been repeatedly told that farmers did not want to sell but rather lease promises to use soil-retaining practices as they are concerned about their ability to sustain the practice (Bennett 2002).

17.4 So What Do We See from These Ramblings?

Energy and climate change do have consequences for soils and soil condition and health, some positive and some negative. For example, on the energy side moving energy production into marginal lands can worsen erosion and runoff as can intensification moves to produce more crops and energy feedstocks. Similarly on the climate side effects may cause some lands to move into grasslands from cropping, adaptation may result in breaking out current grass and wetlands, and carbon markets may stimulate moves to increase sequestration and organic matter. All of this has complex implications which need to be factored into decisions or goals to greatly enhance soil health.

Additionally actions that enhance soil condition and health and the long-run value of the soil resource to society are not always better for a farmer's short-run profits and may need subsidies to be adopted. For example, there are certainly cases involving no-till, biochar, and perhaps adding organic material that fall into this class.

Overall, climate change and energy needs, along with population and income growth, are forces that will challenge our ability to simultaneously produce healthier soils, food, fuel, and climate mitigation. Technology must continue a strong advance if all are to be accommodated.

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Chapter 18
Understanding Soils' Contribution to Ecosystem Services Provision to Inform Farm System Analysis

Estelle Dominati, A. Mackay, and J. Rendel

Abstract Amongst our natural resources, soils are often forgotten and poorly represented in resource management decision-making processes. Increasing global concerns about soil degradation combined with the ever-growing demands for the finite land resource demonstrate that the time is rapidly arriving when land evaluation needs to include consideration of all the ecosystem services provided to humans by a combination of land type, climate, land use and management practices. The feasibility of using an ecosystems approach to address this gap in land evaluation procedure and provide better soil security is explored here.

The concepts of natural capital and ecosystem services at the heart of the ecosystems approach align very closely with the dimensions of soil security. Using an ecosystems approach to assess farm investments in either ecological infrastructure (e.g. soil conservation) or built infrastructure (e.g. irrigation) provides the basis for obtaining new insights into the impacts of those investments on the provision of services alongside environmental outcomes.

An expansion of land evaluation to include multiple ecosystem services needs to include the quantification of the contribution of soils to the provision of multiple services under a specific use, considerations of natural resources use efficiency, considerations of ecological boundaries and considerations of multiple outcomes (economic, environmental, social and cultural) desired by the community.

An ecosystems approach to farm investment and farm system design enables links to be made between soil capability and the ecological boundaries within which the agroecosystem needs to operate, soil condition under a use, performance in the provision of services and environmental outcomes, which allows the multifunctionality of land resources to be taken into account in decision-making.

Keywords Natural capital • Ecosystem services • Agroecosystem • Farm system • Multifunctional land evaluation • Outcomes

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18.1 Introduction

Amongst our natural resources, soils are often forgotten and poorly represented in resource management decision-making processes, even though they are a non-renewable resource at the base of the health of most terrestrial ecosystems. Increasing global concerns about soil degradation combined with the ever-growing demands for the finite land resource demonstrate that the time is rapidly arriving when land evaluation must go beyond an assessment of just land suitability for primary production, which is driving much of the current conservation on soil security (McBratney et al. 2014). Future land evaluation needs to include consideration of all the ecosystem services provided to humans by a combination of land type, climate, land use and management practices. In this chapter, we explore the feasibility of using an ecosystems approach to address this gap in land evaluation procedure. Examples are presented that illustrate the potential utility of the approach to farm system design, resource management and policy development.

18.2 The Ecosystems Approach

A rapidly emerging multidisciplinary approach to assess the multifunctionality of natural resources, including soils, is the ecosystems approach. The approach is based on the concepts of natural capital and ecosystem services. Natural capital is defined as the "stocks of natural assets that yield a flow of ecosystem goods or services into the future" (Costanza and Daly 1992). The notion of natural capital comes from trying to frame the contribution of natural resources alongside manufactured capital (factories, buildings, tools), human capital (labour, skills) and social capital (education, culture, knowledge) to the economy (Costanza and Daly 1992). Ecosystem services are defined as "the benefits people obtain from ecosystems" (MEA 2005).

The ecosystems approach has its origins in ecological economics, recognising that the economy is a subsystem of the ecological system. Ecological economics argues that natural resources are finite and that sustainable economic activity needs to be performed within the biophysical limits of the natural environment (Rockstrom et al. 2009). Natural resources scarcity is nowadays the limiting factor to economic development and wellbeing (Braat and de Groot 2012). Moreover, the environment has limited capacity to assimilate the waste products of economic activity without deleterious feedbacks, like CO_2 emissions.

The ideas captured in the concepts of natural capital and ecosystem services align very closely with the five dimensions of soil security or five Cs, as defined by McBratney et al. (2014) (Fig. 18.1):

- Capital: defining soils as natural capital, described by capability and condition, enables the consideration of the value of soils through their contribution to the provision of ecosystem services when under a use.

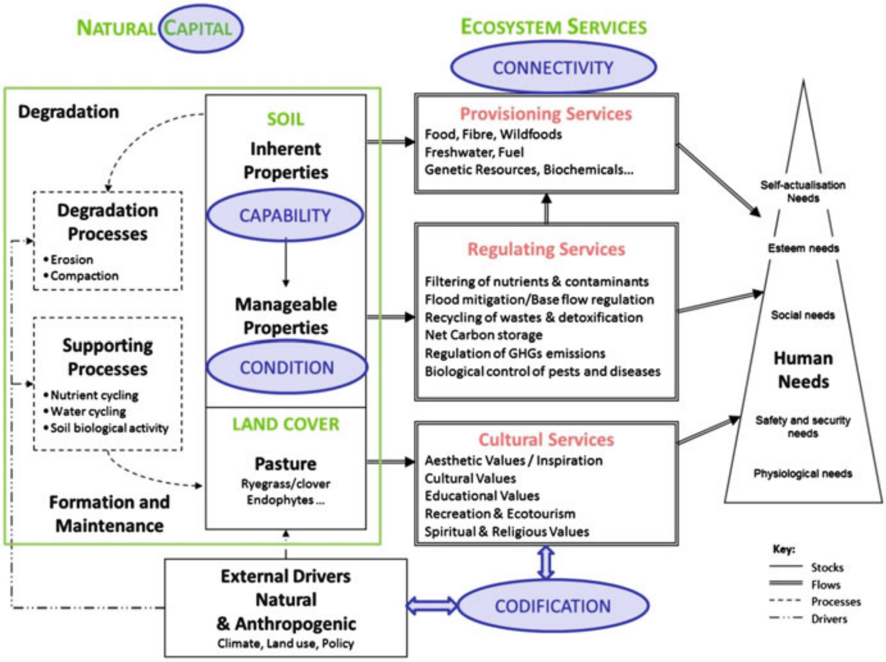

Fig. 18.1 Adapted natural capital and ecosystem services framework (Dominati et al. 2010) and links to soil security dimensions

- Capability: the inherent properties of soil natural capital stocks (Dominati et al. 2010) inform the intrinsic capacity of a soil to function and contribute to ecosystem services provision under a use.
- Condition: the manageable properties of soil natural capital stocks (Dominati et al. 2010) are the results of modification by human activities through land use and management practices and inform the current state of the soil. Moreover, the impacts of a change in soil condition can be tracked by following changes to the provision of all ecosystem services.
- Connectivity: by definition ecosystem services describe the benefits people obtain from natural resources, with the different types of services describing the different types of connections between resources and beneficiaries, direct, indirect or sociocultural.
- Codification: the ecosystems approach enables the multifunctionality of land resources to be taken into account in decision-making and can help evaluating the impacts of policy frameworks on the integrity of natural capital stocks such as soils and thereby on the provision of different ecosystem services.

18.3 Ecosystems Approach, Farm Investments and Sustainability

Ecological economists believe that sustainable economic activity is based on sustainable income coming from the use of both renewable natural capital (RNC) and non-renewable natural capital (NNC) (Costanza and Daly 1992). To keep income constant, total capital stocks need to be sustained; however, as land use intensity increases, pressure can often result in a depletion of the NNC. This will be reflected in an associated decline in the flow of services and income. To keep income constant in this situation, total natural capital needs to be maintained, by increasing the investment in renewable natural capital (Costanza and Daly 1992). Monitoring of the flow of services from the NNC and associated RNC on-farm over time offers a robust framework for assessing soil security at that scale, by providing a basis for quantifying if current uses are sustaining or degrading the underlying resource (Fig. 18.1). This framework enables thresholds or boundary conditions (Rockstrom et al. 2009) to be defined on natural capital stocks, for land use to operate within, to ensure sustainability and the provision of minimum levels of services. Further the framework provides the basis for obtaining new insights into the return on investments into additional capital, built or RNC, often addressing an inherent weakness in, for example, soil capability (improve soil drainage) or to increase flows of one specific service (fertiliser use to improve yield), with little understanding of the impact on the provision of other ecosystem services. Below we provide some examples.

18.3.1 Investment in Ecological Infrastructure: Soil Conservation in Hill Country

Dominati et al. (2014) quantified and valued the provision of ecosystem services from a sheep and beef grazed pasture before and after landslides, in the Hawke's Bay region in New Zealand. They examined the recovery of the soil after a shallow mass movement erosion event and how that then affected the provision of services. The influence of wide-spaced soil conservation trees on soil condition and thereby services provision was also assessed. The combined value of the provisioning and regulating ecosystem services provided by an uneroded pasture on steep land for a typical sheep and beef farm was \$3717/ha/year (Fig. 18.2). This value dropped by 64 % following a single shallow mass movement event (Fig. 18.2). Twenty years after the erosion event and after soil and pasture recovery, the ecosystem services only recovered up to 61 % (in dollar value) of uneroded levels (Fig. 18.2). In sharp contrast, the same uneroded land planted with 15-year-old conservation trees to reduce erosion risk provided additional ecosystem services (+23 % in dollar value) from the similar unprotected and uneroded landscape (Fig. 18.2) (Dominati et al. 2014).

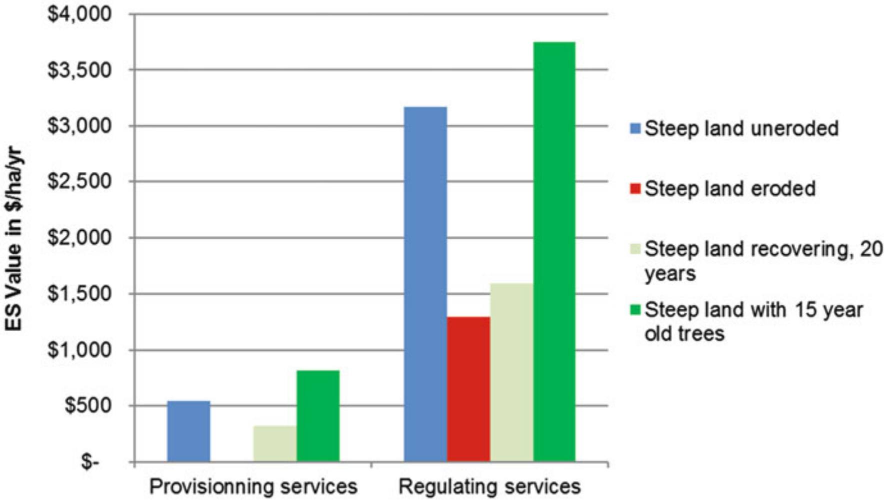

Fig. 18.2 Economic value (NZD/ha/year) of ecosystem services provided by pasture grazed by sheep and cattle on uneroded steep land, steep land immediately after a shallow landslide and following 20 years of recovery and steep land planted with 15-year-old wide-spaced trees (Modified from Dominati et al. 2014)

An investment analysis of soil conservation practices was undertaken. Four scenarios were considered for the cost-benefit analysis (Fig. 18.3) where harvesting of timber at some future date and the value of all ecosystem services have or have not been included. From a strictly farm financial point of view, planting conservation trees isn't profitable for farmers, unless the trees are harvested for timber after 20 years, and low discount rates (<5 %) are used (Fig. 18.3). However, when the value of ecosystem services beyond food and timber, including regulating services, is included in the analysis, the net present value (NPV) of the investment is greatly positive over a range of discount rates (0–10 %) (Fig. 18.3) (Dominati et al. 2014). Inclusion of all the benefits an investment in soil conservation offers in reducing the risk of erosion provides a more complete picture of the value of the investment and importantly the value of the soil resource when kept intact, secure and able to function.

18.3.2 Investment in Built Infrastructure: Irrigation for Dairy

Many of the on-farm built infrastructure investments to lift production often address inherent weaknesses in the farm's natural capital stocks. For example, if water is a constraint to plant growth in soils with a limited water holding capacity, due to its texture class or physical condition or in a climate zone with a seasonal deficit, an investment in irrigation water immediately removes that NNC limitation.

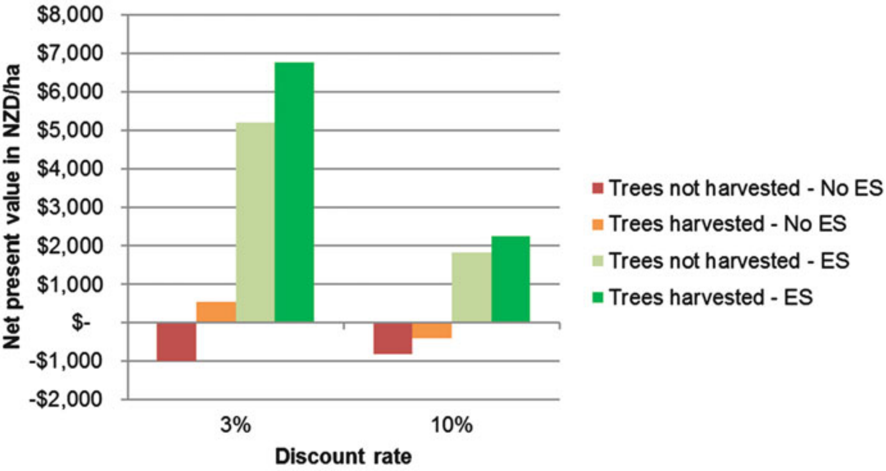

Fig. 18.3 Net present value (NPV; NZD/ha) of the flow of ecosystem services over 20 years for four different scenarios at two discount rates

Dominati and Mackay (2015) explored the links between changes in soil condition and changes to the provision of ecosystem services beyond the provision of food from a dairy-grazed system following the introduction of additional available water through investment in irrigation infrastructure. The changes in the flow of services, beyond food quantity and quality, including the support for human infrastructures and farm animals, freshwater availability, flood and drought mitigation, filtering of nutrients and contaminants, decomposition of wastes, net carbon storage, greenhouse gas regulation and regulation of pests and diseases, were quantified using soil and pasture data collected from irrigated and rain-fed pastures over several years, as well as by modelling those pastoral systems using the Overseer® nutrient budgets (2016). Neoclassical valuation techniques such as market prices, provision and replacement costs and defensive expenditure were then used to determine the economic value of both provisioning and regulating services provided by the agroecosystems.

An investment in irrigation infrastructure on a 250 ha dairy farm on the sand country in the Manawatu enabled milking cow stocking rate to be lifted from 2.5 to 3/ha, milk production increased from 875 to 1200 kgMS/ha/year, while modelled N losses increased from 33 to 61 kgN/ha/year. Introduction of water through irrigation modified soil condition and thereby the provision of ecosystem services from the agroecosystem, increasing the value of services by almost $2400/ha/year from $5288 to $7678/ha/year.

The analysis of an investment in irrigation revealed a positive net present value (NPV) over 10 years, when the analysis was limited to the increase in the flow of provisioning (e.g. food production) services (Fig. 18.4). When the costs of mitigating the additional losses to the environment (N, P and N_2O losses) associated with the introduction of irrigation were included in the analysis, the NPV of the irrigation

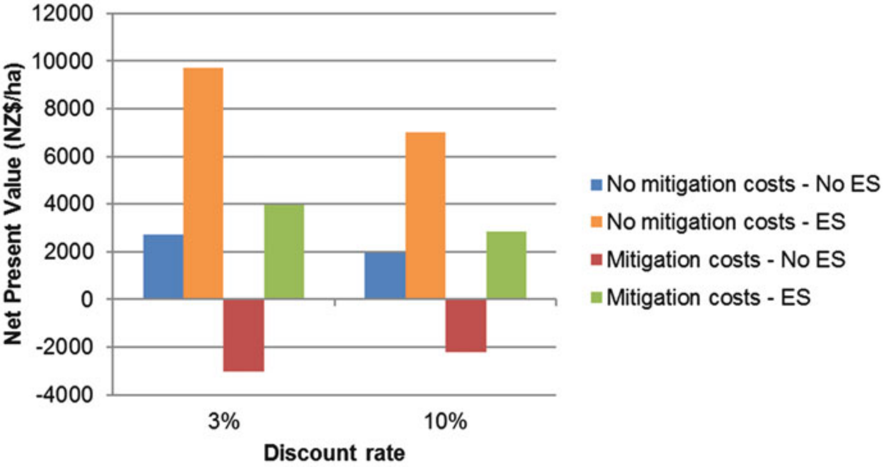

Fig. 18.4 Net present value (NZ$/ha) over 10 years of the flow of ecosystem services for the four scenarios considered, for two discount rates

investment became negative. Adding the economic value of all the ecosystem services (i.e. regulating in addition to provisioning) to the analysis returned a positive NPV, even with the inclusion of the mitigation costs (Fig. 18.4).

Once again, this study shows the links between change in soil condition and change in ecosystem services provision. It also shows that even when soil condition is improved by management, the ecosystem services provision needs to be considered alongside environmental outcomes and ecological boundaries.

18.4 Ecosystems Approach and Outcomes Delivery

Two new trends emerging from land evaluation frameworks globally are the recognition of the wider functions and ecosystem services provided by landscapes and the need for stakeholders' participation to determine desired economic, environmental, social and cultural outcomes to inform the land evaluation process. In order to recognise the whole range of services provided by landscapes, new land suitability frameworks should incorporate indicators specifically developed to inform capability for multiple functions. Furthermore, until land use, management intensity and level of inputs are specified within any evaluation framework, the actual land condition and therefore performance in services delivery and sustainability of the matched combination of land type, land use and land management cannot be assessed nor the impacts of that use on receiving environments (Fig. 18.5). Decisions on farm which impact beyond the farm boundary also need to be included in any integrated assessment framework. The current environmental challenges faced around the world are partly due to a failure to recognise soil contribution to two critical principles:

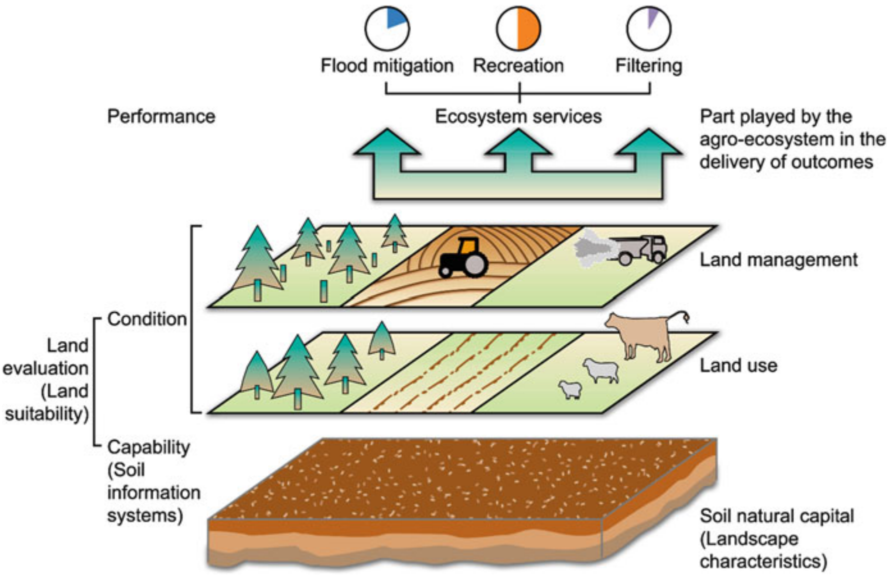

Fig. 18.5 Relationships between the land evaluation, ecosystem services provision and performance towards outcomes delivery

ecosystems have a predetermined capacity to function (capability), and receiving environments have a finite capacity to assimilate losses from agroecosystems (nutrients, GHGs). The latter should be informing the former and used as a trigger for mitigation.

The expansion of land evaluation to include multiple ecosystem services would include in the assessment the quantification of the contribution of soils to multiple ecosystem services under a specific use, considerations of the efficiency of the use of the natural resources, considerations of natural ecosystems' boundaries and considerations of multiple outcomes (i.e. economic, environmental, social and cultural) desired by the community. Moreover, adding an ecosystem services approach to land evaluation enables the supply of services to be directly linked to the performance of a combination of land type/land use and management intensity to deliver specific outcomes, as identified by stakeholders. If outcomes are the goal, measures of ecosystem services provide more quantitative information on the performance of the system to deliver towards that goal (Fig. 18.5).

18.5 Future of Farm System Modelling and Analysis

Farms are more often than not an assemblage of multiple landscapes that include a mix of topographies and range of different natural capitals such as soil types, both of which influence pasture and crop production, and importantly these land units show different responses to inputs and practices. Today's intensive agricultural systems are the product of successfully combining and using built capital, alongside the diversity of natural resources (e.g. soil, land, water) in the production of food and fibre for profit. In the future, analysis of the farm system will need to be extended to include the implication of decision-making on not just food and fibre production but all the services that our farm systems provide. While not a formal process, it must be acknowledged that this already occurs tacitly to some extent, in that farmers do recognise some other services and sometimes choose not to push productive potential. Building an ecosystem service approach into the land evaluation framework provides a basis for recording, quantifying and including ecosystem services in the analysis. It also offers a method for separating out and assessing the contribution from both the natural and built capital to the farm system and the delivery of the services.

The ecosystems approach creates the ability to define "ecological boundaries" within which resources should be managed to ensure the preservation of natural capital stocks (e.g. soil condition) and thereby the sustainable delivery of ecosystem services from our landscapes. The concept of adding ecological boundaries (Rockstrom et al. 2009), within which land use must operate, moves the analysis from managing land to managing a landscape from which the community seeks multiple outcomes. While some of these boundaries will be defined by the landowner at the farm scale (related to sustaining the quality of natural capital stocks, such as soil quality), some will be defined at the catchment scale related to desired community (thresholds on nutrient losses, sediment) and consumer (practice and produce quality) outcomes, and some will be defined at the global scale (GHGs emissions to air). The ability to define and include ecological boundaries within which resources should be managed will be a capability that farm system models will require into the future to meet the needs of producers, resource managers and policy agents.

Emerging farm system models and analytical capabilities can help in putting these ideas on the ground. Integrated Farm Optimisation and Resource Allocation Model (INFORM) is a new generation farm system model that advances the use of linear programming in farm system modelling and decision-making by departing from the use of whole farm and average data, to integrate independently obtained biological data from specific land management units (LMU) within a farm system (Rendel et al. 2013, 2015). Land management units are defined as areas of the farm having similar natural resources and management practices. This allows the responses to inputs or constraints to be isolated to that unit on the farm, as part of an optimisation routine, aiming to maximise farm profit. The optimisation routine uses this information to identify the mix of production enterprises and management regimes that maximises profit for the business. This also creates the capacity to estimate the expected returns from specific on-farm investments targeted at specific LMUs for the whole farm business. A major advantage of the approach is that it provides a picture of the contribution each part of the farm makes, e.g. where the livestock are located on the farm during the year. The use of specific biophysical data for each LMU (pasture growth rates, N response, pasture utilisation) to optimise the farm system assumes that there is sound resource information available for the farm operations from a whole farm plan.

The linear programming equations formed by INFORM can be divided into a single objective and a number of constraints. These constraints or boundary conditions can be placed on individual LMUs. This provides a vehicle for exploring the influence of ecological boundaries on the farm system. As indicated some of these boundaries will be defined by the landowner at the farm scale (related to sustaining the quality of natural capital stocks or to specific farm performance objectives), and some informed from wider scales (e.g. thresholds on nutrient losses). The ability to optimise the farm system within defined boundaries is an emerging analytical capability requirement for industry in a future world where there will be limits on their environmental footprint. This represents a step change over the current approach which first explores economic outcome (EBIDTA) and then tries to mitigate for specific emissions (e.g. N, P, GHG). Web search and discussions with various experts revealed that different tools already exist to look at multiple outcomes based on scenarios at different scales, but none exist that look at optimising farming system design within ecological system boundaries.

18.6 Conclusion

The utility of an ecosystems approach to ground the soil security concept and its five dimensions was discussed in this chapter. The concepts of natural capital and ecosystem services fit well with the five dimensions of soil security. An ecosystems approach to farm investment and farm system design enables links to be made between soil capability and the ecological boundaries of the agroecosystem, soil condition under a use, performance in the provision of ecosystem services (connectivity) and environmental outcomes, which allows the multifunctionality of land resources to be taken into account in decision-making (codification).

Emerging farm systems analytical capability allow landowners and decision-makers to better relate land resources condition to ecosystem services and environmental outcomes over time which gives life to the concept of soil security.

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Chapter 19
The Dollars and Cents of Soil Health

Charles M. Benbrook

Abstract Soil health is driven by a fluid and dynamic set of factors, many of which arise from above- and below-ground biodiversity and population dynamics. Unless soil depth, nutrients, water, or warmth/sunlight are dramatically limiting, plant health arises from interactions occurring at the root-soil-microorganism interface. In most cases, healthy soils make it far easier to grow healthy plants, while poor soil health makes it more difficult and costly to bring a crop to harvest. Accordingly, the ability to support healthy and profitable crop production is the core attribute of a healthy soil, and slippage in that ability is a direct consequence of declining soil health.

Soil and plant health, management skill, and net farm income are almost always intrinsically linked, especially in the medium to long term. The most significant, soil-health driven economic impacts on net returns per acre typically occur where high-value specialty crops (e.g., tomatoes, peppers, strawberries, celery) are grown and can vary from several hundred to $10,000 or more per acre. In the Pacific Northwest, astute soil-health investments and management can add or subtract several hundred to $2000 or more in profits per acre per year when replanting apple orchards, and also it is critical when converting rough, never-farmed dry land to irrigated vegetable production systems. In the Midwest, success in attaining and sustaining healthy soil can increase annual profits by an estimated $75–$145 per acre.

Keywords Soil health • Organic matter • Soil microbial biocontrol • Economic value soil

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19.1 The Soil Health Continuum

On any given field, crop production and profitability are determined by how skillfully farm managers take advantage of existing soil quality, along with the solar radiation and rainfall (and/or irrigation water) available to nourish a crop. Over several years, management decisions will trigger usually small, incremental changes in soil quality, while changes in soil health can occur more rapidly but also prove more fleeting.

Often, soil-health changes have their roots in shifting pest pressure and population dynamics. Such changes can be brought about because of the emergence of resistant populations, the establishment of a new, invasive species, or the loss of a previously effective pesticide.

Soil health exists along a continuum and is both cropping-system dependent and dynamic. Sometimes soil health alters the speed of water intake and water holding capacity, thereby changing yield outcomes. Likewise, macro- or micronutrient deficiencies, excesses, or imbalances linked to soil health, or big shifts in pH, can also drive profit margins up or down.

It is useful to analyze the typical impact of soil health on the performance and profitability of farming systems in three zones along the soil-health continuum:

- The “limited” zone where a problem or problems grounded in soil health are reducing yields and/or increasing costs relative to other nearby farmers producing a similar crop mix on similar soils
- The “moderate” zone in which soil health does not appear to be triggering any added costs or constraining yields compared to average conditions and cropping system performance in an area
- The “high” zone where enhancements in soil health make possible higher yields in years with ample rainfall; reduce the reduction in yield in dry years; increase N use efficiency, thereby lowering fertilizer costs; and, avoid significant pest-related costs or crop damage

Depending on the cropping system, location, and degree of differences in soil health, average expected net economic returns per acre on a typical field in the “high” zone might be 20–30 % higher, compared to a field in the “limited” zone. Differences in net returns along the soil-health continuum are typically greater in the case of high-value specialty crops, as well as when the performance of a soil in the top 10 % of fields along the continuum is compared to one in the bottom 10 %.

On a given field, soil health may be “moderate” or “limited” in support of the production of certain crops, but “high” if used to produce some other crop, or forages, trees, or vines. For example, raw land with sandy soils that is converted to intensive, irrigated production in the Columbia Basin requires significant compost, animal manure, and other soil-amendment inputs to produce commercially acceptable yields. Sometimes, significant quantities of viable weed seeds are brought onto such fields in improperly finished compost or raw animal manure. As a result, soil health on such fields would be seriously limited in the production of carrots, because of the limited options and high cost of weed management, but might well support a profitable potato or corn silage crop.

This is an example of why soil health is situation dependent. The crop to be grown in the next production cycle; the recent crop rotational pattern, whether a cover crop was planted or crop residues removed the season before; recent soil-amendment applications; and, several other factors *all* play a role in determining the ability of soil to grow a profitable crop in the next production cycle.

Intrinsic, physical, and chemical soil quality characteristics on a given piece of land, like soil type, pH, slope, and bulk density, tend to change slowly, if at all. Routine farm management decisions can either negatively or positively impact soil health, in turn altering crop production, input costs, and net farm income.

Farmers tend to be most acutely aware of changes in soil health when production problems, higher costs, or both undercut per acre profits. These circumstances also increase the odds that farmers will reassess long-standing practices and pencil out changes in management likely to address the underlying cause or causes of soil-health problems.

While slipping yields and profits are bound to attract the attention of farm managers, owners, and bankers, improvements in soil health are infrequently given credit when yields and gross income do better than typically expected.

19.2 Soil-Health and Pest Management Case Studies

In any given year, specialty crop growers must navigate through multiple sources of uncertainty and manage multiple risks that can drive net farm income dramatically up or down. In several years out of 10, specialty crop profit per acre is several thousand dollars lower or higher than projected, and often for reasons at least partially beyond the control of the grower.

While farmers cannot control the weather nor predict demand-supply dynamics, they are responsible for crafting responses to biotic stressors like weeds, nematodes, plant viruses, and recurring insects, any of which can significantly reduce yields and/or crop quality or drive pesticide costs sharply upward.

Over the long term, growers that respond cost-effectively to unforeseen, exogenous stresses in their production fields will make more money than growers who delay responses, respond inappropriately (e.g., adding N when pH, or a micronutrient imbalance is the issue), or overrespond by, for example, replanting a field when other options could have saved a crop.

The following case studies place into perspective the sizable economic consequences that can follow slippage in soil health or accompany sustained enhancement of soil health.

19.2.1 Orange Production in South Australia

Citrus growers in the Riverland-Sunraysia region of Southern Australia have suffered serious losses in fruit quality from Kelly's citrus thrips (KCT), *Pezothrips kellyanus* (Bagnall), feeding from the early 1990s (Crisp 2014). This insect causes scurfing of the surface of citrus and bleaching of the rind, reducing by 20–40 % the packout of export-quality, high-dollar fruit, as well as making some fruit unmarketable.

Depending on weather and population dynamics, one to five applications of organophosphate (OP) insecticides have been used over the last two decades in an effort to control KCT, but efficacy has slipped incrementally as the level of resistance in target populations rose. The industry recognized it was on an insecticide treadmill that would leave no producer standing.

Scientists led by Dr. Peter Crisp at the South Australia Research and Development Institute convinced growers to try a new approach grounded in the biology of KCTs. Composted soil amendments made from animal manures, grape mark, and other plant materials were applied at commercially common rates ranging from 40 kg/ha of animal manure to 200 kg/ha of composted green wastes plus animal manure, to increase soil carbon levels, one proven tactic to support progress along the soil-health continuum.

Emergence of KCTs was reduced more than 50 % in the plots treated with soil amendments in 2006 (Crisp 2014). Other results were dramatic and sustained and included:

- Higher soil moisture levels in treated plots for at least 6 years post application.
- Increased populations of a variety of fungivorous and detritivorous arthropods.
- Twofold to almost sixfold increases in predatory mite levels in the top 2.5 cm of soil.
- Plant-available nitrogen (total Kjeldahl % N) was three to six times higher.
- The percent soil carbon at 0–5 cm rose from 2.8 % to over 7 % and as high as 21.3 % in the 200 cubic meter/ha treatment with grape mark.
- Soil carbon increases in the 5–15 cm layer were about one-half of those in the top 0–5 cm layer.
- Increases in yield averaging over 20 %, and as high as 60 %, persisted for up to 4 years (end of study).
- Fruit size and density (i.e., soluble solids) increased.

Crisp and colleagues reported an estimated 5:1 return over the cost of the soil-amendment treatment. The direct economic benefits of the soil-amendment treatments included an average annual (Crisp et al. 2013):

- Reduction of around two OP sprays annually, at an average cost of approximately \$75–\$100 (US \$\$) per hectare for the active ingredient and application
- Substantial reductions in fertilizer and other pest management costs over the useful life of the soil-amendment treatment, after taking into account the cost of the treatment

- Increased gross income on the order of \$1800 per hectare, given the expected ~20 % average increase in marketable fruit, increased packout of export-quality fruit, and average, pretreatment gross income from sale of citrus fruit of about \$9000/ha
- Unquantified environmental footprint benefits arising from lessened OP use and improved water quality and nutrient cycling in the soil

Accordingly, the total, annual economic benefits can be roughly estimated to be ~\$2000 (US \$\$) per hectare (\$810/acre) in a typical year. In years when weather conditions worsen KCT pressure or place trees under moisture stress, the benefits would likely be at least 2-X higher. In years with exceptional well-timed rains and low pest pressure, the benefits/ha would likely be 50–75 % lower.

19.2.2 Vegetables in Florida

In South Florida's fresh market tomato and pepper production systems, gross income per acre generally ranges from \$20,000 (US \$) to \$25,000 per acre. Production costs vary between \$15,000 and \$22,000 per acre in "typical" years. Two factors, above all else, can dramatically alter end-of-the-season net economic outcomes:

- Market price levels and demand when the early season and main crop comes in, as well as whether harvest operations can be prolonged until late in the season when prices typically rise sharply
- Costs and efficacy of control of soil-borne pathogens and especially nematodes that can increase costs by hundreds of dollars per acre and reduce yields by 15–50 % or more

For many years, Florida vegetable growers and their IPM consultants avoided nematode feeding damage in high-value crops by fumigating with methyl bromide and/or chloropicrin. In 2004, 81 % of Florida's 42,000 acres of fresh market tomatoes were treated with both methyl bromide (69 lb active ingredient/acre) and chloropicrin (151 lb/acre), for a total of over 7.5 million pounds of active ingredients (USDA-NASS 2005).

Efforts to reduce agricultural emissions of greenhouse gasses were incorporated in the Montreal protocols, resulting in a negotiated phase-out of methyl bromide use in agriculture. Fumigant use on FLA tomatoes fell to 48 % of acres surveyed in 2006, with a combination of fumigants including dibromochloropropane (1,2-D), metam sodium, and chloropicrin. Reliance fell further in 2010 to 38 % of surveyed acres treated with 1.5 million pounds of a variety of fumigants, an 80 % drop since 2004.

Concern over airborne exposures to farm and field workers, and rural neighbors, led the Florida Department of Agriculture to further tighten already-strict limits on fumigant use. As a result, only about 20 % of tomato acres are now treated with a fumigant, opening up a biological vacuum nematodes have sometimes exploited.

Most Florida vegetable growers are no longer confident they can afford to spray their way through nematode problems, because the chemical tools are either too expensive, only partially effective, or pose unacceptable risks. Just as the case with Kelly's citrus thrips in Australia, the most promising management solution is building soil health and microbial activity to the point where nematode populations are usually kept below damage thresholds.

Microbial biocontrol can be elegant, safe, and profitable when everything falls into place, but efficacy is dependent on a host of factors not under the farmer's control. As a result, farmers moving toward prevention-based, biointensive integrated pest management (IPM) solutions need a broader toolkit of tactics, practices, and inputs to draw upon quickly when nematode populations threaten to spike, despite a promising degree of microbial biocontrol.

Many growers are now nurturing soil and plant health as their primary line of defense and managing biological interactions in ways that target nematodes when and where they are vulnerable. Fortunately, highly selective bio-insecticides are also now available that target a major nematode weakness – their chitin-based outer skins.

Over evolutionary time in the never-ending quest for a solid meal and survival, many microorganisms have evolved the ability to emit enzymes that decompose the chitin-based shells of a variety of organisms from the land (e.g., nematodes) and sea (e.g., crabs, other shellfish). A number of commercial bio-insecticides on the market contain mixtures of enzymes that break down chitin. "Rootgard" is among them and is currently being used by several Florida vegetable growers.

The soil in tomato and pepper fields treated with Rootgard becomes decidedly *unhealthy* to nematodes, but healthier for plants and people. The economic benefits can be impressive. Farmers that forego a traditional soil fumigant application save between $350 and $500 per acre in direct costs and unknown but no doubt significant indirect costs.

Operations applying 200–300 lb per acre of chitin-based products incur costs between $200 and $300 per acre. The yield and crop quality benefits vary across seasons, mostly as a function of population levels and how well applications are timed. Nematode damage can cost a grower up to $10,000/acre in lost production and crop quality, plus control costs. Those who rise to the nematode challenge can increase profits by a comparable margin as a result of:

- Harvesting higher yields
- Reducing the percentage of fruit that does not meet top quality-grade standards
- Keeping plants healthy and productive longer, allowing the grower to carry out a late-season picking when market prices are typically much higher
- Reducing season-long pest management expenditures

Florida vegetable producers who have invested management effort in building healthier soils are able to tap into soil microbial biocontrol as a first and primary nematode line of defense. When such prevention-based systems can be supplemented, as needed, with a cost-effective chitin-inhibiter product, the risks accompanying prevention-based IPM are diminished and average, long-term returns to improvements in soil health will rise.

19.3 Modeling the Impacts of Soil Health on Farming System Economic Performance

Soil quality is intrinsically bounded by the current state of the soil resource on a given farm field – soil depth and composition, organic matter content, nutrient levels, balances in micro- and macronutrient levels, microbial biodiversity, degree of compaction, topography, and available water.

Changes in most soil quality parameters occur slowly, if at all, except in certain circumstances. Unusually high rates of soil erosion will sometimes reduce rooting depth toward or below critical thresholds. Application of a broad-spectrum fumigant will dramatically reduce microbial biodiversity and may shift microbial community structure.

Soil health is a major factor determining the degree to which the productive potential of a given field is taken advantage of fully during a given growing season. Slipping soil health erodes the productive capacity of soils, regardless of their quality, and enhanced soil health will help close the gap between a soil's productive potential and actual outcomes.

Changes in soil health occur over several time frames in multiple dimensions. It is useful to group factors altering soil health into three temporal categories:

- Short-term impacts occurring over a 1- to 3-year time frame
- Medium-term changes that arise over 3–10 years
- Long-term impacts that take 10 or more years to bring about measurable changes in farming system performance

Changes in soil health can alter several soil functional characteristics and as a result also impact farming system performance. Soil health can shift the absolute levels of plant-available micro- and macronutrients, as well as balance across nutrients, with positive, neutral, or negative consequences. Soil health can alter the capacity of soil to take in and hold water, as well as the ability to suppress or otherwise avoid damaging levels of soil-borne pathogens. The presence of weeds, insects, or pathogens that have become resistant to previously effective control measures can erode soil health and farm profits, by driving up pest management costs and/or undermining efficacy.

On most actively farmed fields around the world, soil health is usually improving in some ways and degrading in others. At the end of each production year, the actual economic performance of the farming system, in contrast to the recent past or anticipated performance, is the indictor farmers most closely monitor in judging whether they have a problem rooted in soil health. Unfortunately, high prices, unusually favorable weather, or inputs can sometimes mask incremental erosion in soil health.

The Soil Renaissance Project (SRP), which has evolved into the Soil Health Institute (SHI) (Farm Foundation et al. 2015), recognize that soil health will advance only to the degree that building, or sustaining, high levels of soil health is widely recognized by producers and land managers as a *necessary condition* in order to maximize farm profits per acre. For this reason, the SRP/SHI research agenda will strive to develop the tools and datasets needed to map the linkages between soil health and profitability.

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Chapter 20
The Value of Soil's Contributions to Ecosystem Services

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Abstract As a contribution to the 2015 Global Soil Security Conference, we estimated the value of ecosystem service contributions by soil. The general purpose of this estimate was to give soil a value with respect to natural capital, to compare that value to other values recognised in the global economy and to start a conversation among soil scientists and economist about the value of soil. In particular, we want to incite a conversation about the value of soil beyond that discussed using commodity prices. The simple estimate of the value ecosystem services from soil is approximately 11.4 trillion USD, which compares to the 2015 gross domestic product of the USA at 15 trillion USD. The original source used for this estimate has been updated. In general the updated values of global ecosystem service are now at 2.7 times the original, which likely increases our estimate by a similar multiplier. The concept of estimating a value for global ecosystem services is criticised by many economists. However, understanding the change in the value of soil for ecosystems services provision because of changes in soil management and use gives a valuation that is critical for policy decisions regarding soil security.

Keywords Natural capital • Ecosystem services • Environmental economics • Soil natural capital

20.1 Introduction

In order to secure an asset, it is important to obtain an estimate of its value and the value of benefits that flow from it. Otherwise the asset's value may fail to be fully considered in decision-making. In the case of natural capital and the ecosystem services, such failure may jeopardise human sustainable development (Costanza et al. 1997). Calculating a monetary value for the services provided by natural

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systems is one option and a significant challenge; however, it is useful in communicating the importance of ecosystems to human society to policymakers, guiding decision-making about conservation, restoration or land-use performance and sustainability and evaluating the effectiveness of environmental policies (de Groot et al. 2012; Howarth and Farber 2002). As discussed in Chap. 1, one of the five dimensions of soil security, namely, soil capital, addresses the need for humanity to value the contributions to ecosystem services provision of the world's soils.

20.2 Theorising Ecosystem Services

Ecosystem services and natural capital are related concepts. In Costanza et al.'s (1997) framework "Ecosystem services consist of flows of materials, energy, and information from natural capital stocks which combine with manufactured and human capital services to produce human welfare". Ecosystem goods include seafood, forage, timber, biomass fuels, natural fibres, pharmaceuticals, genetic resources and industrial products and their precursors (Daily 1997). Ecosystem services include pollination; storage, retention and purification of water; recycling of wastes; biological control of pests; climate regulation; extreme events mitigation; and cultural or recreational uses (Costanza et al. 1997; Dominati et al. 2010). Most authors refer to both goods and services arising from ecosystem functions as ecosystem services. The concept of ecosystem goods and services is an anthropocentric one, because it depends on the presence of humans using the materials, energy and information (de Groot et al. 2002).

Costanza and Daly (1992; in Dominati et al. 2010) defined natural capital as "a stock of natural assets yielding a flow of either natural resources or ecosystem services". For example, soil natural capital includes the physical elements of soil: minerals, carbon, air and water (Robinson et al. 2012). Soil natural capital also includes structure, composition and ecosystem diversity, because to deliver services, ecosystems must function as whole systems. Soil natural capital can be characterised by soil physical, chemical and biological properties under a specific land use and management. A given soil type has different contributions to the delivery of ecosystem services under one land use compared to another. Soil classification systems therefore provide a basis for determining the natural capital of soil (Dominati et al. 2010).

In the literature, the terms *ecosystem services*, *ecosystem functions* and *ecosystem processes* have not been used consistently; therefore, care must be taken to ensure that analogous concepts are being compared. De Groot (1992) produced one of the first systems for classifying ecosystem services. De Groot et al. (2002) used the term ecosystem *functions*, which they described as giving rise to a large number of ecosystem *services*. They defined ecosystem functions as "the capacity of natural processes and components to provide goods and services that satisfy human needs" (p. 394). This is analogous to Daily's (1997) definition of ecosystem services: "the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life. They maintain biodiversity and the production of ecosystem goods". De Groot et al. (2002) produced a classification system that included all of Costanza et al.'s (1997) 17 ecosystem services, plus an additional 6 (soil retention, nursery function, medicinal resources, ornamental resources, aesthetic information, spiritual/historic information and science/education). De Groot et al. (2002) referred to these as ecosystem *functions*. However, despite this change in terminology, they clearly refer to the same concepts as Costanza et al.'s (1997) list of 17 ecosystem *services* (Table 20.1).

Ecosystem processes (referred to by some authors as ecosystem functions) are distinct from ecosystem services. Ecosystem processes are the properties or processes of ecosystems, for example, soil formation processes, retention and storage of water, habitat and regulation of populations. Humans indirectly derive goods and services from these; therefore, ecosystem services refer to any benefit that humans directly derive from ecosystem functions.

De Groot et al. (2002) clarified that some ecosystem processes support other processes and that rather than providing ecosystem services directly, these processes contribute to the health and functioning of ecosystems and hence their ability to provide services. Failure to recognise this fact can lead to double accounting, when estimating the value of ecosystem services. According to Dominati et al. (2010), the supporting processes of soil are nutrient cycling, water cycling and biological activity. These processes drive soil formation and soil properties under a use, thus determining soil natural capital condition. Soil processes in turn may be influenced by external drivers such as climate (a natural driver) or farming practices (an anthropogenic driver).

Costanza et al. (1997) and de Groot et al. (2002) agreed that only renewable goods and services should be considered. For example, this excludes non-renewable resources such as fossil fuels. De Groot et al. (2002) also excluded renewable energy sources such as wind power, which cannot be attributed to a single ecosystem.

20.3 Valuing the World's Ecosystem Services

Since the 1960s, efforts have been made to estimate the value of services provided by various forms of natural capital. To date, over 1700 studies have been published (de Groot et al. 2012). Costanza et al. (1997) synthesised findings of over 100 previous studies to derive a first approximation of the total value of the world's ecosystem services. In 2014, Costanza updated this estimate using 2011 estimates of biome area and costs (Costanza et al. 2014). The evaluation presented here is based on the 1997 publication. The majority of studies used by Costanza et al. (1997) estimate "willingness to pay" in order to assign a monetary value to ecosystem services, including those not currently recognised by markets. To achieve this, the authors evaluated the contribution to 17 ecosystem services, for each of 16 biomes. Table 20.2 shows Costanza et al.'s (1997) biomes.

Table 20.1 Ecosystem services to which soil contributes value, which are derived from the categories developed by Costanza et al. (1997) and de Groot et al. (2002)

Ecosystem functions (de Groot et al. 2002)/ Ecosystem services (Costanza et al. 1997)	Ecosystem processes/ components (de Groot et al. 2002)/Ecosystem functions (Costanza et al. 1997)	Examples (Costanza et al. 1997) of goods and services (de Groot et al. 2002)
Gas regulation	Ecosystem contributions to biogeochemical cycles, e.g. O_2/CO_2 balance	UVB protection Good air quality
Climate regulation	Regulation of temperature, precipitation, etc., through topography, vegetation type, albedo, etc.	Maintenance of climate
Disturbance prevention	Capacitance and dampening influence on natural hazards by ecosystem structure	Storm protection by coral reefs Flood protection by wetlands Protection of human structures
Water regulation	Regulation of runoff and river discharge under normal conditions	Drainage and natural irrigation, transport medium
Water supply	Filtering by vegetation and soil biota. Retention and storage of freshwater in lakes, rivers and aquifers	Provision of water for consumption, e.g. drinking, industry, irrigation
Nutrient regulation	Storage and recycling of nutrients	Maintenance of soil health and ecosystem productivity
Waste treatment	Storage and recycling of organic and inorganic human wastes	Pollution control/detoxification Filtration of dust.
Biological control	Control of populations through trophic-dynamic relations	Pest and disease control[b] Reduction in crop damage
Food	Production of edible biomass (distinct from agriculture)	Wild-harvested fish, bushmeat, game, plants, birds' nests Small scale subsistence farming/ aquaculture
Raw materials	Production of nonedible biomass	Timber, fuel wood, animal skins, animal fodder, latex, gums, waxes, tannins, dyes
Genetic resources	Genetic material and evolutionary processes	Improvement of cultivar productivity, resistance to pathogens or pests, adaptation to environment, etc.
Recreation	Recreational uses of landscapes	Outdoor sports, ecotourism
Cultural[a]	Non-commercial uses of landscapes	Aesthetic, artistic, spiritual, educational or scientific applications

[a] de Groot et al. categorised cultural/artistic, aesthetic, spiritual, scientific/educational functions as separate ecosystem functions, while Costanza et al. (1997) grouped them together

[b] Natural ecosystems control >95 % of potential crop pests and carriers of human disease (in de Groot et al. 2002)

Table 20.2 Ecosystems used in Costanza et al. (1997) study. We classified urban ecosystems as non-soil based because a large proportion of these ecosystems have sealed surfaces

Terrestrial biomes		Aquatic biomes
Soil-based	Non-soil based	
Tropical forest	Lakes/rivers	Open ocean
Temperate/boreal forest	Ice/rock	Estuarine
Grasslands/rangelands	Urban	Seagrass/algae beds
Swamps/floodplains		Coral reefs
Cropland		Shelf
Tundra		
Tidal marsh/mangroves		
Desert		

To obtain a monetary value for Earth's ecosystem services, Costanza et al. (1997) estimated the value per unit area of each ecosystem service, for each of the ecosystem types. This was calculated using one of the following methods, in order of preference:

1. The sum of the producer and consumer surplus
2. The net rent (producer surplus)
3. Price multiplied by quantity

The value per unit area was multiplied by the area of each ecosystem type, to obtain the total value of each ecosystem service for each ecosystem. These were summed to obtain global total values. Their aggregate total of $33 trillion (in 1994 prices) corresponded closely with the findings of two previous studies that they were able to identify.

In 2014, Costanza et al. (2014) used the same methods with updated data to re-estimate the value of the total global ecosystem services. The updated value was estimated at $125 trillion year^{-1} (assuming updated unit values and changes to biome areas) in 2007. From this, the estimated loss of eco-services from 1997 to 2011 due to land-use change was $4.3–20.2 trillion year^{-1}, depending on which unit values are used. Ultimately the result of the updated work by Costanza suggests that the value if ecosystem services, in total, grew by 2.7 times.

20.4 Ecosystem Services Attributable to Soil

Clearly, a proportion of the ecosystem services provided by terrestrial ecosystems are attributable to the physical, chemical and biological properties and processes of soil, as the provision of ecosystem services comes from the combination of below- and above-ground natural capital stocks and ecosystem functioning. Dominati et al. (2010) reviewed the literature on soil contribution to ecosystem services provision and identified six key roles performed by soil in the provision of ecosystem services:

- Fertility, i.e. delivery of nutrients to plants through soil nutrient cycles
- Filtering, purifying and storing water, for uptake by plants and for flood mitigation
- Structural support for plants, animals and human infrastructure
- Carbon sequestration and regulation of greenhouse gases
- Contribution to biodiversity through the provision of habitat
- Source of raw materials such as peat, sand and clay

However, as Dominati et al. (2010) note, this list neglects the recreational and cultural services provided by soil, such as aesthetic and religious experiences, burial sites and the storage and preparation of food. Howarth and Farber (2002) emphasised the importance of accounting for goods such as leisure and social relationships. Dominati et al. (2014a) therefore derived a set of ecosystem services to which soils have critical contributions. These are:

- Provision of food, wood and fibre
- Provision of raw materials
- Provision of physical support
- Flood mitigation
- Filtering of nutrients and contaminants
- Carbon storage and greenhouse gas regulation
- Detoxification and recycling of wastes
- Regulation of pests and disease populations

This list corresponds closely to the one we derived from Costanza et al.'s (1997) work. Dominati et al.'s (2014a) list does not explicitly address soil's contribution to water supply, erosion control and genetic resources, although the authors explicitly link soil biodiversity to the following ecosystem services: provision of nutrients, filtering of nutrients and contaminants, detoxification, greenhouse gas regulation and pest/disease control.

20.5 Quantifying Soil's Contribution to the Provision of Ecosystem Services

The data in Table 20.3 is derived from Costanza et al.'s (1997) valuation of the world's ecosystem services, adjusted to 2015 value of USD. As can be seen from Table 20.3, our estimated total annual value of soil contribution to ecosystem services is $11.38 trillion. Table 20.4 compares this value with 2015 values for GDP and some agricultural commodities.

Table 20.3 Annual value of soil ecosystem services

Ecosystem function	Ecosystem service	Value (billion USD $year^{-1}$)	Proportion contributed by Soil	Value of proportion contributed by soil (Billion USD $year^{-1}$)
Regulation functions	Gas regulation	2119	0.1	212
	Climate regulation	1081	0.1	108
	Disturbance regulation	2811	0	0
	Water regulation	1762	0.2	352
	Water supply	2673	0.1	267
	Erosion control	910	0.5	455
	Soil formation	84	1	84
	Nutrient cycling	26,979	0.3	8094
	Waste treatment	3598	0.05	180
	Pollination	185	0	0
	Biological control	659	0	0
Habitat functions	Habitat/refuge	196	0.05	10
Production functions	Food production	2190	0.5	1095
	Raw materials	1139	0.02	23
	Genetic resources	125	0.2	25
Information functions	Recreation	1288	0	0
	Cultural	4764	0.1	476
	Total	*52,563*		*11,381*

Data sources Costanza et al. (1997), de Groot et al. (2002)

Table 20.4 Comparison of soil ecosystem services with other monetary values

Quantity	Value	Comparison with value of soil ecosystem services
US GDP	\$17 trillion	1.5 times larger
World GDP	\$77 trillion	6.8 times larger
World wheat	\$0.18 trillion	63 times smaller
World corn	\$0.14 trillion	81 times smaller
World cotton	\$0.08 trillion	142 times smaller

20.6 Average Values of Soil Natural Capital and Ecosystem Services per Unit Area

According to Costanza et al. (2014), the total global area occupied by soil (see Table 20.2) is 13,131 million hectares, i.e. 1.31×10^8 km^2. Dividing our estimated value of the world's soil ecosystem services by the world's total soil area, we obtain an average value of soil ecosystem services of:

- \$86,700 $(km^2)^{-1}$ $year^{-1}$
- \$867 ha^{-1} $year^{-1}$
- \$351 ac^{-1} $year^{-1}$

The relationship between natural capital and ecosystem services allows us to derive a value for the natural capital of the world's soil. Assuming that ecosystems and soils are non-degraded in the future and the flow of ecosystem services continues in perpetuity, using a 3.5 % discount rate (Kula and Evans 2011), this implies that the capital value of the world's soil stock is equal to \$325 trillion, or $\$3.25 \times 10^{14}$.

Dividing our estimated value of the world's soil natural capital by the world's total soil area, we obtain an average value of soil natural capital of:

- \$2.47 million km^{-2}
- \$24,700 ha^{-1}
- \$9996 acre^{-1}

20.7 Discussion

No standardised definition of ecosystem services yet exists; this is a significant obstacle to be faced when attempting to quantify the value of ecosystem services (Dominati et al. 2014a). Our estimate of the value of soil's contribution to ecosystem services provision is based on the work of Costanza et al. (1997, 2014), who were not able to source valuation studies for some biomes and ecosystem services. Also, the authors emphasised that "willingness to pay" estimates would probably be higher if societies were environmentally sustainable and socially fair and if individuals better understood their connection to ecosystems. As a result, the authors acknowledge that their figures most likely underestimate the full value of Earth's ecosystem services. Our estimate of the value of soil's contribution to ecosystem services must therefore also be considered a minimum value. Costanza et al. (1997) also pointed out that with land and ecosystems degradation, ecosystem services are becoming more "scarce" in future and their value is likely to rise. This would further increase the value of soil as critical natural capital (Ekins et al. 2003) contributing to ecosystem services. Howarth and Farber (2002) analysed the theoretical underpinnings of Costanza et al.'s (1997) work, concluding that the methodology was conceptually sound and represents a logical way of extending national accounting to include nonmarket environmental goods and services.

Valuing ecosystem services should not be seen as a substitute for other methods of achieving human welfare. However, it is an important component of a multifaceted approach. Further, all decision-making involves valuation, whether explicit or implicit. A significant proportion of the value of ecosystem services is not recognised by the monetary economy. In fact, people are often not aware that they are benefitting from ecosystem services, for example, in the provision of clean air and water (Costanza et al. 1997). Thus, current macroeconomic indicators, which do not capture the value of ecosystem services, neglect both the benefits of these services and the costs of reducing their value, through depletion of natural capital (Howarth and Farber 2002). Efforts to assign monetary value are therefore likely to help decision-makers avoid approving developments whose social costs are far greater than their anticipated benefits and to make best use of limited conservation and restoration funds (Costanza et al. 1997; de Groot et al. 2012; Howarth and Farber 2002).

De Groot et al. (2002, 2012) emphasised that valuing ecosystem services does not imply that they should be treated as tradable private commodities, rather that they should be seen as non-tradable public goods. Therefore, their over-exploitation represents a loss for the poor and for future generations.

It is important to bear in mind that the ability of a soil to contribute ecosystem services is dependent on its condition. This in turn depends on the way in which the soil is used. Therefore, if soil condition changes as a consequence of a change in use, then the value of ecosystem services provided by the soil would also change as demonstrated in (Dominati et al. 2014b).

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Chapter 21
Economics of Land Degradation to Estimate Capital Value of Soil in Eurasia

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Abstract Among the dimensions of soil security, capital occupies a special place because it depends on numerous factors that are not necessarily related to soil, such as regional economic development, current dynamics of food markets, social stability, and many others. However, the capital also depends on soil capacity and conditions that are threatened by land and soil degradation. Economics of land degradation is one of the useful approaches that help in quantifying the relation between soil and capital. We used the approach for a preliminary quantification of the impact of land degradation in Northern Eurasia (Russia and neighboring countries) on the loss of profit due to the decline in agricultural production and in ecosystem services. The approximate loss on the national level exceeds 1.9 % of annual gross domestic product, and the mean ratio of the cost of action to the cost of inaction in the country is 18 %. However, we also show that the credibility of the results is low yet due to methodological difficulties and recommend the improvement of the approach for the regional conditions.

Keywords Sustainable land management • Land-use and land-cover change • Land abandonment • Ecosystem services

21.1 Introduction

The recently proposed concept of soils security provides a holistic view on soils and their place in the environment and society (Koch et al. 2013; McBratney et al. 2014). According to this concept, there are five dimensions of soil security: capability, condition, capital, connectivity, and codification (Chap. 2). Among these dimensions that are discussed in detail in the present volume, the capital has a special

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place: capability and condition are intrinsic soil characteristics, connectivity and codification are related to the external perception of soils, and capital has a dual nature. On the one hand, soil is a component of natural capital (Costanza et al. 1997), "the universal subject of human labor" (Marx 1977). On the other hand, soil is a commodity that can be sold and bought both as an integral component of land and as a separate component for off-site use. Unlike many other environmental components, a significant proportion of soils in the world are privately owned; this brings land and soil into a complex system of economic and social relations. An economic approach to soil is promising because it provides a link to the "basic instinct" of the society – earning money – and thus facilitates the communication with the decision makers. The other benefit is that economics provides a universal – monetary – equivalent for multiple measures of mass, concentration, energy, etc.

The economic approach is of special importance if we speak about soil security, or in other words, about the threats to land and soil. The loss of soil health that is commonly referred as soil degradation can be assessed in the terms of the economics of land degradation.

21.2 Economics of Land Degradation

The Economics of Land Degradation (ELD) Initiative was launched on 21 September 2011 by the European Commission, the German government, and the UNCCD Secretary. Its scientific basis is supported by multiple research groups: the most productive ones are those located in the International Food Policy Research Institute (IFPRI) and in the University of Bonn (Nkonya et al. 2011; von Braun and Gerber 2012; von Braun et al. 2012, 2013).

In present research we attempted to give a preliminary rough estimation of land degradation in Russian federation using the approaches proposed by the ELD initiative (Nkonya et al. 2013) and to discuss the limitations of this approach and possible ways for its improvement.

21.2.1 Land Degradation and Soil Security

Land degradation is closely linked with soil security in multiple ways. First, land degradation commonly, but not always, includes soil degradation. Second, land degradation affects soil security indirectly through the threats to water security, decline of ecosystem services, depletion of biological diversity, and especially the threat to food security. The latter threat is especially dangerous in the poorest countries of the world. Evident hotspots of food security endangered by land degradation are recognized in Africa and Southern Asia. Northern Eurasia, including Russia, has been considered as a relatively stable territory with minor impact of land degradation.

However, soil degradation is active in Russia, as it is driven by a complex of natural and socioeconomic factors.

21.2.2 Peculiarity of Biophysical and Socioeconomic Environments in Russia

In the past few decades in Russia, there was a rapid transformation from collective and state farms established under conditions of a planned centralized economy to private enterprises of various sizes and forms working under market conditions. Such transition resulted in land-use change, including of arable lands, in Russia: the area controlled by agricultural organizations decreased, while the area owned by particular households and farms increased. In the 1990s the economic reforms leaded to active reduction in arable land that continued up to 2001–2002. Since 2002 the area of arable lands in Russia has reached a stage of stabilization. According to the official state land records, the area of arable land has decreased by 8.5 million ha during the period from 1990 to 2001. Between 2001 and 2006, the land abandonment rate has decreased resulting in the decline of 1.9 million ha. Totally the area of arable land has decreased by 21.7 million ha for the period 1990–2006. The main reason for land abandonment was unregulated structural transformation of the land tenure structure in the country, i.e., the phenomenon was caused by the lack of governance rather than by objective reasons. Most of the abandoned lands were located in the regions with climate and soils unfavorable for agricultural production; however, the natural conditions in the abandoned areas were not restrictive for agriculture. The "excess" of arable land in the country does not mean that Russian agricultural soils do not degrade. Since the cultivated area decreased due to economic reasons, the pressure on the fields under use proportionally increased and leaded to the degradation of the most productive soils. It is a serious challenge for Russian agriculture, which is not properly addressed until now. We require better understanding of the socioeconomic and biophysical drivers of land degradation in Russian Federation.

21.3 Methodology

In this study we assessed the cost of land degradation in Russian Federation using a total economic value (TEV) framework. It estimates evident economic losses provoked by land degradation, such as the decline in the productivity of the main zonal crops and the decrease in nonmarket values of the ecosystem services. The methodology used in our study follows the approaches developed by von Braun et al. (2013) and Nkonya et al. (2013) and is based on the comparative evaluation of the cost of action and the cost of inaction. Ideally the calculation should include the assessment of the loss in productivity both due to land-use and land-cover change (LUCC) and without any change in land use. However, this approach requires detailed economic cost/benefit information, including indirect and nonuse values, and is difficult to access at a global and even national scale. Nkonya et al. (2011) proposed a surrogate approach that included only LUCC-related soil degradation assessment. Moderate-resolution imaging spectroradiometer (MODIS) remotely sensed datasets on land cover were used to identify the shifts in the LUCC (Bai et al. 2008). These included forests, grassland, cropland, shrublands (including woodlands), urban areas, barren lands, and water bodies. The MODIS land-cover dataset was ground-truthed and quality controlled (Friedl et al. 2010), with overall accuracy of land-use classification at 75 %.

Total economic values were assigned to each land use with the data from The Economics of Ecosystems and Biodiversity (TEEB) (van der Ploeg and de Groot 2010), using the benefit transfer approach. The difference in the action and inaction with LUCC was calculated through:

$$C_{LUCC} = \sum_{i}^{K} \left(\Delta a_1 * p_1 - \Delta a_1 * p_2 \right) \tag{21.1}$$

where C_{LUCC} = cost of land degradation due to $LUCC$; a_1 = land area of biome 1 being replaced by biome 2; p_1 and p_2 are the TEV of biomes 1 and 2, respectively.

By definition of land degradation, $P1 > P2$. In cases where $P1 < P2$, LUCC is not regarded as land degradation, but as land improvement (Nkonya et al. 2013).

The cost of taking action against land degradation due to LUCC is given by

$$CTA_i = A_i \frac{1}{\rho^t} \left\{ z_i + \sum_{t=1}^{T} \left(x_i + p_j x_j \right) \right\} \tag{21.2}$$

where CTA_i = cost of restoring high value biome i, ρ^t = discount factor of land user, A_i = area of high value biome i that was replaced by low value biome j, z_i = cost of establishing high value biome i, x_i = maintenance cost of high value biome i until it reaches maturity, x_j = productivity of low value biome j per hectare, p_j = price of low value biome j per unit (e.g., ton), t = time in years, and T = planning horizon of taking action against land degradation. The term $p_j x_j$ represents the opportunity cost of foregoing production of the low value biome j being replaced.

The cost of inaction will be the sum of annual losses due to land degradation:

$$CI_i = \sum_{t=1}^{T} C_{LUCC} \tag{21.3}$$

where CI_i = cost of not taking action against degradation of biome i. Given that the benefit of restoring degraded land goes beyond the maturity period of biome i, we have to use the planning horizon of the land user. We assumed a 30-year planning horizon for the afforestation program and a 6-year planning horizon for grassland

Fig. 21.1 The federal districts of Russian Federation

and croplands – the majority of which are annual crops. As Nkonya et al. (2013) noted, land users will take action against land degradation if $CTA_i < CI_i$.

The calculations were done for the period from 2001 to 2009 by the federal districts of Russian Federation (Fig. 21.1), which differ in biophysical conditions, population density, and economic development.

21.4 Results

21.4.1 The Cost of Land Degradation

The results showed that the total cost of land degradation due to land-use change was 189 bln USD for the period from 2001 to 2009 (Table 21.1). About two-thirds of these costs were related to land-cover change in Siberian and Far Eastern districts. Land degradation costs per capita also varied among federal districts: the highest in Far Eastern (1460 USD annually) and lowest in southern, central, and Volga districts (18, 20, and 21 USD annually, respectively). The total economic value of ecosystem goods and services was estimated to be 3750 bln USD in Russia, exceeding the GDP by three times. In the Far Eastern district the share of GDP of the total economic value was just 5 %; this value equaled 334 % in the central district and 90 % in the southern and Volga districts. This implies that population pressure on ecosystems is much higher in the latter districts.

Table 21.1 The costs of land degradation in federal districts of Russia through land-use change, including TEV values

Federal district	TEV of land ecosystems, 2009 bln USD	Costs of land degradation (2001–2009), in bln USD	Annual costs of land degradation, in bln USD	Annual cost of land degradation per capita, in USD	GDP in 2010, current bln USD	GDP/TEV	Land degradation as a share of GDP (%), annually
Central	130	6	0.8	20	434	334 %	0.2 %
Southern	80	2	0.3	18	75	94 %	0.4 %
Northwestern	439	17	2.1	154	127	29 %	1.7 %
Far Eastern	1290	76	9.5	1460	68	5 %	14.0 %
Siberian	1180	61	7.6	389	133	11 %	5.7 %
Ural	394	18	2.3	185	165	42 %	1.4 %
Volga	208	5	0.6	21	184	88 %	0.3 %
North Caucasian	30	3	0.4	42	29	97 %	1.4 %
Total	3750	189	23.6	164	1216	32 %	1.9 %

Source: Sorokin et al. (2016)
TEV total economic value, *GDP* gross domestic product

21.4.2 The Cost of Action vs Inaction

The results of the analysis of the costs of action showed that the costs of action against land degradation were lower than the costs of inaction in Russia by five to six times over the 30 years, meaning that each dollar spent on addressing land degradation was likely to have about five to six dollars of returns (Table 21.2). The action would cost less in the Central district (14 % of the cost of inaction) and more in the Northeastern district (22 %). The costs of action were found to equal about 702 billion USD over a 30-year horizon, whereas if nothing is done, the resulting losses might equal almost 3663 billion USD during the same period.

Almost 92 % of the costs of action are made up of the opportunity costs of action. This is one of the key barriers for actions against land degradation, as the costs are tangible and may need to be borne by land users and budgets of all levels. However, the benefits of action are enjoyed from additional ecosystem services by the whole world rather than particular land users.

21.5 Discussion and Conclusions

21.5.1 Limitations of the Approach

The approach used in our research helps in attracting the attention of decision makers to soil security, because we address considerable sums of money lost due to improper soil use. It may provide investment in sustainable land management project and thus strengthen soil security. However, the credibility of quantitative results is somewhat doubtful, and much further work is needed to obtain real values of the economic losses due to land and soil degradation.

The first limitation is related to the conceptual question, if LUCC is always associated with land degradation. As shown by Oldeman (1998), there are two principal types of land degradation. The first type is characteristic for the developing countries and is associated with extensive agriculture: large areas of natural landscapes, including forests, are converted into arable lands and pastures, with no basic measures for soil protection. Obviously, in this case LUCC is actually equivalent to land degradation. The second type of degradation is characteristic for developed countries with intensive agriculture, where the soil is exposed to strong anthropogenic pressure for increasing agricultural production. Specific threats to soils are pollution, including excessive use of fertilizers and pesticides, compaction, and some other degradation processes. For the second type of degradation, the approach based on LUCC is inapplicable. In Russia, where mostly the second type of land degradation is observed, LUCC have occurred during the past two decades in the opposite direction: vast areas previously used for agriculture were abandoned and overgrown with woody vegetation. The observed LUCC in Siberia and Far East should be related to extensive logging and forest fires; regarding these processes as land deg-

Table 21.2 Costs of action vs inaction in federal districts of Russia, in billion USD

Federal district	GDP in 2010	Annual TEV costs of LD in 2010 vs 2002	Cost of action (6 years)	Cost of action (30 years)	The opportunity cost of action	Cost of inaction (6 years)	Cost of inaction (30 years)	Ratio of cost of action/inaction
Central	434	6	14	14	13	43	93	14 %
Southern	75	2	5	5	5	15	32	16 %
Northwestern	127	17	81	82	75	161	348	22 %
Far Eastern	68	76	279	283	263	720	1558	17 %
Siberian	133	61	217	220	201	530	1147	18 %
Ural	165	18	77	77	71	164	355	20 %
Volga	184	5	14	14	12	39	85	15 %
North Caucasian	29	3	7	7	6	21	46	14 %
Total	**1216**	**189**	**694**	**702**	**647**	**1693**	**3663**	**18 %**

Source: Sorokin et al. (2016)

LD land degradation

radation is under question. As for soil degradation, it is not necessarily associated with forest fires and timber harvesting, though these processes may favor soil erosion. Thus, for some federal districts, the extent of soil degradation can be significantly overestimated. In opposite, for other federal districts, soil degradation can be significantly underestimated, because such threats as soil pollution, compaction, and even erosion lead to LUCC only in extreme cases. In most circumstances even the decline in productivity is compensated with the application of additional fertilizers or somewhat improved agrotechnology. It is also important to note that both assessment of soil degradation and land-use planning in the frames of federal districts would not be very productive in Russia, because these administrative entities do not reflect well the natural regions. However, we have to link our research to these districts, because economical statistics is collected on an administrative basis.

The second limitation is related to the technical difficulties in the detection of land and soil degradation using remote-sensing methods. Most assessments are based on the indexes of greenness such as normalized difference vegetation index (NDVI) that does not necessarily reflect soil degradation. The decline in the greenness of vegetation can be caused by multiple processes, including land-use change, vegetation drying due to climatic change, changes in water availability or quality, and many other reasons. All these processes are not necessarily associated with changes in soil health. The other issue is that the reasons for the trends in the biomass production indicated by such remote sensing-based indices as NDVI are not always well understood. In tropical regions the decrease in NDVI corresponds with the areas of major anthropogenic pressure on ecosystems. However, in high latitudes, including Northern Eurasia, Canada, and Alaska, the negative dynamics of NDVI is detected in remote areas with low anthropogenic pressure.

21.5.2 Challenges for the Future

There are important challenges for the capital dimension of soil security both in its theory and in practice. The preliminary research illustrates that soil security can be expressed quantitatively using the methodology proposed by the ELD. The main tasks for the future in the research in the frames of the ELD approach are as follows:

- Downscaling the results of the research: the responsibility for the credibility of the results would be higher for prediction on a farm scale.
- Searching for cost-effective method for routine, maybe, remote assessment of land and soil degradation at different scales.
- Quantifying soil degradation in an economically sound way that would require establishing monetary value for the most important soil-related ecosystem services.
- Demanding information on soil dynamics (conditions dimension) and collecting economical data on the present and past land use.

Apart from academic research we should make the following practical steps:

- Search for adequate sustainable land management practices, including validation of WOCAT database using ELD approaches.
- Develop and extend novel agricultural techniques, such as precision agriculture, landscape-adaptive techniques, iAgriculture, etc.
- Raise the awareness of administrators and civil society of the economic value of soil security.

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Chapter 22
Social Licensing to Secure Soil

Cristine L.S. Morgan, Gaylon D. Morgan, and Dianna Bagnall

Abstract The private business sector must be included in addressing global challenges to natural resource use and management as well as human health. In the context of global soil security, this chapter proposes that social licensing is an opportunity for business to capture a market of consumers that are interested in using their purchasing power to encourage sustainable resource management.

Keywords Economics • Marketing • Value ecosystem services • Labeling • Branding

22.1 Introduction

In the process of examining where soil security falls in the US policy and political framework, we began to think about other avenues to evoke social-economic change to the benefit to soil security. The idea of a soil license to progress toward achieving soil security was born from recognizing the importance of securing soil for future use in food and fiber production and, most importantly, a need to develop an *actionable* idea to achieve soil security. A social license for the purpose of developing a market could be used to increase the value of soil and products produced from soil utilization. We hypothesize that such an increase in value, based on a marketing of a social license to secure soil, provides a tangible method for the value of soil to provide ecosystem services to be actuated into the economy.

In the realm of natural resource consumption for profit, including farming, compromise and conflict over land ownership (property rights), freedom to operate, and concerns for the environment have escalated over recent years (see Wilburn and Wilburn 2011; Prno and Slocombe 2012 for examples). With more social awareness

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of the value of an environment that provide ecosystem services, interaction between environment health and human health and awareness of potential impacts of climate change on society provides opportunities to promote sustainable resource use. The concept of soil security operates in the trinity of natural resource use, society, and economics. Because it is an aim of soil security to manage soil to its capability for the purpose of securing soil resources for future generations, it is logical to discuss the value of soil to society and explore ways to realize soil value in the economy. Chapter 20 provides estimates of the value of soil ecosystem services. Other chapters in the capital section provide examples of the interaction of soil value from a farm/corporate and political perspective (Chaps. 18, 19, and 21).

This chapter explores the concept of formally recognizing value of soil in commodities and services from a marketing perspective. The central hypothesis of this discussion is marketing agricultural products and services using practices that "secure soil" which will reflect the value soil is contributing to the economy and provide further economic incentive for soil managers to improve soil condition.

To increase the market value of goods and services resulting from soil (and other natural resource), we propose to harness the concept of social licensing.

22.2 What Is Social Licensing?

A common definition of a social license refers to a local community's general acceptance of a company's activities. The social license or social license to operate exists outside of a regulatory process or entity and is commonly obtained through communication and community "buy-in" based on the perception that the community and the company share a common goal. The concept of a social license originally comes for the mining industry when Shell oil realized the importance of consent by society as a whole and consent by local stakeholders in mining operations (Prno and Slocombe 2012). In general a social license and social license to operate stem from the economic perspective that real economic loss occurs when a company fails to meet a community's expectations and includes an underlying assumption of social ethics and micro-social contracting between a company and a community. Within the perspective of soil security, we propose that a social license is not only a tool to prevent economic loss, but it is a tool for economic gain and environmental gain obtained through private-public partnerships.

22.3 Key Components

The concept of a social license can be employed for both economic and environmental benefit but is primarily perceived as an economic tool to formalize the value of soil as natural and social capital in the economy. To employ the concept, some discussion of marketing tools is relevant.

Branding or brand differentiation is a *marketing strategy that involves creating a differentiated name and image – often using a logo and/or tag line – in order to establish a presence in the consumer's mind and attract and keep customers* (Entrepreneur Media, Inc. 2016). Brand differentiation creates an opportunity for customer loyalty based on distinctive values and can be used as a strategic tactic to gain public support for a company's presence in global markets. An example of using branding in order to gain a market advantage is the Cotton LEADS program which is discussed in more detail below.

Labeling is a marketing tool that ascribes a label to a product to identify it. Labeling is a component of a brand but also has a more general application. More generally, labeling can contain a product certification, for example, rainforest alliance provides a label to products that fall under their labeling criteria. Other successful labeling examples for food are "organic" and "natural." The labeling of food as *organic* has a very clear definition and specific branding, while selling food or products as "sustainability or responsibly produced" is not clear. *Organic* requires inspection, adherence to written guidelines, and certification. In the USA, the organic label is regulated by the US Department of Agriculture.

Certification, accreditation, and/or accounting are needed to establish a certification or standard. An example of a certification that is not run by a government program is the LEED (Leadership in Energy and Environmental Design) program (USGBC 2016). The LEED program is implemented by the US Green Building Council and is the most widely used third-party verification for green building design in the USA. Regarding natural resources and food products, the organic label is probably the most developed and recognized certified labeling program for agricultural products in the USA.

US Department of Agriculture standards for organic products do identify general soil management objectives. Section 205.203 (a) includes a guideline that the producer selects and implements tillage and cultivation practices that maintain or improve the physical, chemical, and biological condition of soil and minimize soil erosion. However, many organic farming practices are highly reliant on tillage for weed control. In Section 205.203 (b), producers must manage crop nutrients and soil fertility through rotations, cover crops, and the application of plant and animal materials. These are the primary locations where soil is explicitly involved in the certification; however, guidelines that encourage improvement of soil condition are clearly very minimal in organic labeling. We do not suggest that organic certification, singularly, is an avenue for implementing a marketing strategy to socially license the concept of soil security. We include a discussion of organic labeling because it is the most mature example of labeling in an agricultural food product.

The Cotton LEADS program is more of an example of brand differentiation (Cotton Leads 2014). This program is a cooperation between Australian and US cotton farmers and founded/organized by producers and scientists. The goal of this program is to brand and market US and Australian cotton that is grown under environmental responsible practices. The cotton identification system is designed to ensure traceability and transparency from farm to manufacturer and is design to assist business along the cotton supply chain to fulfill their sustainability goals. In the USA, management certification requires best management practices as established by the US Department of Agriculture Natural Resources Conservation Service. Other principles of the group are using production practices consistent with sustainability, the use of best practices, and verification through the traceability process within the supply chain. The website lists corporate partners that include clothing stores.

22.4 Economic Incentive

The economic incentives for social licensing include the following:

1. Developing a marketing strategy for soil security
2. Providing a mechanism to reflect soil resource use and true cost of production
3. Contributing to brand preference
4. Adding value to products
5. Protecting or expanding market share

In all, these provide positive economic gains and ultimately can have positive outcomes for securing soil and improving soil function. It is important to remember that the concept of social licensing uses the consumer-driven preferences and is essentially a social contract with the consumer to provide a product the consumer wants to support.

Two examples of contracting a social license in the USA include Walmart and Rainforest Alliance. Walmart is successful contracting a social license with some consumers. Walmart uses third-party accreditation and contracting standards to ensure required practices in the supply chain contract. Walmart also has the purchasing power to help farmers in organic cotton production by providing a market for crops grown in rotation with the cotton (Plambeck and Denend 2008). The Rainforest Alliance provides certification for products that encourages farmers to grow crops and manage ranchlands sustainably. Their certification system includes aspects of environmental protection, social equity, and economic viability. The Rainforest Alliance can demonstrate that their certification has increased yield and income on cocoa and coffee farms. Rainforest Alliance Certified cocoa farms in “Côte d’Ivoire produced 40 percent more cocoa per acre than noncertified farms …. and income was increased by a factor of four for certified farms” (Rainforest Alliance 2016).

22.5 Summary

The concept of a social license to operate stems for the mining industry and assumes that there is an economic loss if there is no social contract with the local community. Our concept of social licensing focuses on developing a social contract between producers of food and fiber and the consumer (local and global) that values soil security and general security of natural resources. This contract provides for a mechanism to place social and economic value on soil security in the economy directly. This contract also provides an economic mechanism for balancing the desires of private ownership of natural resources, freedom to operate, and environment concerns of the consumer. This contract may involve a government entity for certification but there are successful models of third-party certifications.

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Part V
Connectivity

Chapter 23
Soil Renaissance and the Connection to Land Managers

Bill Buckner

Abstract The Samuel Roberts Noble Foundation was founded in 1945 to help farmers, ranchers, and land managers in the Southern Great Plains, USA, to manage soil sustainably for agricultural production, and to promote proper land stewardship so that the land could continue to be healthy and productive for future generations. The Noble Foundation established a legacy of working with agriculturalists to achieve their production goals through sustainable, land stewardship practices. To continue this legacy, the Noble Foundation and Farm Foundation, NFP, collaborated to form the Soil Renaissance to strengthen awareness of soil's central role in productive agricultural and natural resource systems. Success will be considered achieved when farmers, ranchers, and land managers, who are the guardians of soil, have all the resources, information, and support they need to maintain healthy soil.

Keywords Soil renaissance • Land management • Soil health • Outreach

23.1 Introduction

Over the last several years, I have served as president and CEO of the Noble Foundation (The Samuel Roberts Noble Foundation Inc. 2016) as the organization has begun working in soil health. As I run across colleagues from my days in the crop input business, they ask me the same two questions: Why do you care so much about soil and why is the Noble Foundation investing in this area of agriculture?

Those who know me understand my passion for agriculture and my unyielding quest to support individuals who dedicate their lives to feeding, clothing, and sustaining the world. I grew up on a farm in mid-Missouri, which I still own and operate with my two brothers. As fourth-generation farmers, we are proud of the family legacy we have continued and the industry we represent.

But we have a problem on our farm. Our soil quality is so poor that we can't sustain our production in the face of harsh climatic conditions.

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We compensate for these poor soils by using more crop inputs. This is a Band-Aid solution that requires ever-increasing funds just to maintain the same yield. We should approach our conversation on soil health the same way we do with human health: everything in balance and everything in moderation.

So how do we keep our soils healthy? The linchpin to protecting the land, soil, and our future requires us to form an unbreakable bond with farmers, ranchers, and land managers. They are the guardians of the land. They are the protectors of the soil. We must engage, listen, and empower this group if we are going to ensure healthy soils for generations to come.

Our role is twofold: provide research-driven results to answer their questions and help meet their challenges and offer broad-based education. We must also recognize that land stewards need an economic reason to invest in improving the quality of their soil. These concepts should be our understanding, and that should be our job.

These are neither new ideas nor my ideas. No, they belong to oilman and philanthropist Lloyd Noble, who established The Samuel Roberts Noble Foundation in 1945.

23.2 History of Noble Foundation

Noble was born in 1896 in Ardmore when it was a little train depot in Indian Territory. He learned the vital nature of agriculture at an early age. His father and uncle owned a hardware store that served the area farmers.

As a boy, Noble stocked shelves and swept floors in the hardware store. He delivered goods to the farmers and ranchers. Through his interactions with the farmers, he grew to respect their work ethic, their morals, and their values.

At the same time, he saw what their poor management practices were doing to the land. At the time, cotton was king. Ardmore was one of the largest inland cotton ginning centers in the country, so everyone raised cotton. Repeated planting and harvesting of cotton without proper management left once fertile soil stripped of productivity.

As Noble built his oil businesses through the 1920s and 1930s, he watched as the landscape of the Southern Great Plains deteriorated dramatically. Those poor farming practices combined with an extended drought to create the great Dust Bowl (Worster 1982).

Noble watched his state's fundamental economic engine sputter and stall. He resolved to put his energy and resources into safeguarding the soil and the land so that we would never face another Dust Bowl and so the land would remain productive for generations to come. Mr. Noble said, "No civilization has outlived the usefulness of its soils. When the soil is destroyed, the nation is gone."

Noble became one of the fathers of agricultural stewardship and established the Noble Foundation in 1945. Today the Noble Foundation is the largest, independent, private agriculture and plant science research organization in North America.

The organization has about 350 employees from more than 25 different countries and more than 100 Ph.D. scientists. The Noble Foundation annually invests about $50 million in agriculture research, education, consultancy, and philanthropy.

23.3 A Legacy of Support

The Noble Foundation launched a producer relations program in the late 1950s. The program offers no-cost consultation much like the university extension system; however, Mr. Noble never intended for our program to supplant the university system but rather to complement it.

Today, farmers, ranchers, and land managers in the Southern Great Plains come to the Noble Foundation, and, in partnership with university extension and others, we help develop management plans that achieve their goals through sustainable, land stewardship practices. The producer relations program offers experts in six key areas (forages, livestock, soils and crops, agricultural economics, horticulture, and wildlife and fisheries), so we are able to help producers across the complete spectrum of agriculture. Experts can answer any and all questions from how to determine livestock stocking rates and how to calibrate boom sprayers to managing wildlife populations and beyond.

The program is stratified to meet the needs of producers with all experience levels and backgrounds. We work with all farmers and ranchers from those with decades of experience to hobby farmers and urbanites who have bought small sections of land.

We receive countless comments and high praise from those who are a part of the Noble Foundation's producer relations program. One producer quote stands out among the rest. We helped transform Dave Wingo's life to the point that he could significantly support his local church. He greatly appreciated the producer relations program, the Noble Foundation, and the man who founded us. Mr. Wingo once said, "When I get to heaven, I'll see Jesus first and then I'm going to go find Lloyd Noble."

This is just one of the thousands of relationships that we have formed through the decades with farmers and ranchers. We have seen time and time again how a relationship with the Noble Foundation is passed from father to son and is now helping second and third generations stay on the land and be more productive.

Recently, the Noble Foundation has sought to expand its reach and created the Center for Land Stewardship (CLS). This center is designed to create effective partnerships that will enable both Noble and our partners the ability to expand the range of services through a multidisciplinary effort.

In February 2015, we announced a major partnership between the Texas A&M Institute of Renewable Natural Resources and the East Foundation, located in San Antonio, for the sole purpose of expanding stewardship services to private landowners across the Southern Great Plains.

When fully operational, the Center for Land Stewardship will provide education based on sound science and research as well as the practical experiences of our consultants. It is our hope that through a thorough education process, we can provide landowners with the fundamental skill sets to be quality land stewards.

It is with these farmers and ranchers in mind that the Noble Foundation pursued a higher level of purpose and helped launch the Soil Renaissance.

23.4 The Birth of a Renaissance

In November 2013, the Noble Foundation collaborated with the Farm Foundation to launch the Soil Renaissance (Farm Foundation, NFP, and The Samuel Roberts Noble Foundation 2015) to strengthen awareness of soil's central role in productive agricultural and natural resource systems.

The Soil Renaissance developed four working groups including measurement, research, education, and economics. To conduct research, educate diverse audiences, and understand the economics of soil, researchers need to first agree on how to measure soil health. This is the baseline from which everything else will spring. In an era when technology permeates every aspect of society, soil health measurement practices resemble those of agriculture's distant forefathers. Continued reliance on these antiquated approaches has lasting implications for today's producers and researchers.

In the past year, the Soil Renaissance's measurement working group has agreed to a two-tiered approach of soil health measurement that provides a standardized soil test. With the measurement piece soon finalized, a baseline will exist for research. Through the Soil Renaissance's research work group, scientists have identified, categorized, and prioritized research projects that will ultimately advance soil health. Running parallel to the research efforts will be an educational program for consumers and policymakers about the critical role of soil as well as the underlying economics of soil health. Soil health advocates know adoption of soil health standards hinges on showing the underlying financial impact and the economic benefit of investing in soil health as well as how healthy soil mitigates long-term risk.

Through its first year and a half, the Soil Renaissance has seen researchers, farmers, government representatives, and industry experts from across the United States with different backgrounds and perspectives come together for a common cause. This demonstrates that collaboration and unity is key to success. But how do you effectively bring together large, unique groups of people and help them interact?

23.5 Three Steps to Success

There are three key steps to bringing about successful collaborations.

First, you must identify the right people. You have to start broadly and think about all the sectors and organizations that should be included in your discussion.

You want to identify sectors and organizations that can drive change, then you want to find the right people within those areas.

Who is willing to participate? Who is willing to listen? Who is willing to have an open exchange of ideas? This takes some time and many, many phone calls. But like a chef at a fine restaurant, you only want to use the best ingredients.

Second, you must create the right environment. Most of the Soil Renaissance meetings are held at the Noble Foundation campus. I want to get all of these people together and shift the focus from our daily lives to the bigger issues. Then we enter into a facilitated/directed meeting. I am an advocate for facilitation. Designating someone with no particular "dog in the fight" helps ensure that all voices are given equal weight. There is a real art to facilitation. Sometimes you have to push a group, and sometimes you have to let up. But that third, objective party is invaluable.

You want to start your facilitation looking for areas of agreement and easy wins. What are those low-hanging fruit where a group can find unity and momentum? Then you advance to the more difficult, deeper areas where you might experience entrenched ideas. It is at this point that you must release the inevitable rise of conflict. If you have many intelligent people with differing opinions, you are going to have conflict. The trick is making sure the environment is inclusive so that you can bring forth those differing opinions, positively address them, and work toward a reasonable solution. In most cases, professionalism wins the day.

Finally, you want to do more than talk. Talking is part of the process. It's necessary to work through each aspect and hear all the sides. But you must come to conclusions, and you must turn those conclusions into action items, and those action items must be executed.

Meetings are only as good as the outcomes and the actions they provoke. You must take action.

23.6 Conclusion

So I end where I began – with the same question I keep getting asked. Why do I care so much about the soil? Just as Mr. Noble said almost seven decades ago – we do this for future generations. I'm doing this for my children and my grandchild. I'm doing everything in my power to provide a future for him and the generations to follow him. I hope someday he will play hide-and-seek in the same hay loft where I played as a boy. I hope someday he will be the sixth generation of Buckners to treasure that farm in mid-Missouri, to consider it hallowed ground, to bring his children there and talk about our family's history. I hope someday he lies out under the blanket of stars and dreams of the big idea that will propel his life.

I care about the soil, and the men and women who depend on that soil, because I want us to leave it healthier than we found it. I want to make sure that the next generation can have healthy soil, grow healthy food, have a healthy environment, and live productive lives.

I want healthy soil because it is the foundation for all life. And I want to make sure the farmers, ranchers, and land managers who are the guardians of the soil have all the resources, information, and support they need.

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Chapter 24

Links Between Soil Security and the Influence of Soil on Human Health

Eric C. Brevik, Joshua J. Steffan, Lynn C. Burgess, and Artemi Cerdà

Abstract Soil is important to human health because of (1) food availability and quality, (2) human contact with various chemicals in soil, (3) human contact with soil organisms, and (4) disposal of wastes. The five dimensions of soil security each have ties to soils and their influence on human health. Capability is related to the ability of soils to produce adequate and high-quality food and filter waste products to provide a clean environment, particularly clean, safe water supplies. Condition influences the nutritional quality of agricultural products produced in a given soil. Capital recognizes that there is value to the services soil provides in promoting human health, costs when soil constituents are detrimental to human health, and significant value in products such as medications that come from soil. Connectivity recognizes that societal interactions with and perspectives of soil influence the value we place on soil and the management strategies we use; this in turn influences human health through capability. Connectivity also recognizes that loss of land as a public good may negatively influence human health. Codification has typically focused on soil and water conservation rather than directly on human health. However, conservation policies have led to improvements in water quality and increased soil health, leading to the production of higher-quality agricultural products in those soils. Therefore, there are significant opportunities to advance soils and human health studies and our understanding of these relationships under the soil security concept.

Keywords Transdisciplinary approaches • Soil capability • Soil condition • Soil policy • Ecosystem services • Sociology of science

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24.1 Introduction

Several challenges that face modern society will require interdisciplinary and transdisciplinary approaches in order to address them (Brevik et al. 2015, 2016). One of these challenges is continued improvements in human health through an enhanced understanding of the links between soils and human health (Brevik and Sauer 2015). The five dimensions of the developing concept of soil security (McBratney et al. 2014) each have ties to soils and their influence on human health. This chapter will discuss opportunities to advance soils and human health studies and our understanding of these relationships under the soil security concept.

24.2 Dimension 1: Capability

Dimension 1 is related to the ability of soils to produce adequate and high-quality food in support of human health. There are approximately 29 elements essential to human health, although exactly which elements and how many are necessary are not universally agreed on by human health experts (Brevik and Burgess 2013a). Soils that provide a nutrient-rich growing environment for plants result in crops that contain most of the elements required for humans to lead a normal, healthy life (Combs 2005). Therefore, the capability of soils to provide nutrients essential to humans is directly related to soil's ability to provide nutrients to the plants grown in them, and from plants to the animals that feed on plant material when meat products are being produced (Fig. 24.1), is important to human health (Table 24.1).

Dimension 1 is also related to the ability of soil to filter waste products through physical filtration, chemical sorption, and biodegradation processes to provide a clean environment, particularly clean, safe water supplies (Keesstra et al. 2012). Waterborne diseases kill millions of people every year, particularly in developing countries, but on-site sewage treatment systems that take advantage of the filtration capability of soils are able to significantly reduce waterborne illness and improve human health (Massoud et al. 2009). The effectiveness of these on-site systems is highly dependent on soil properties, including soil texture, structure, thickness, and depth to the water table (Brady and Weil 2008). Therefore, practices that promote soil security through the maintenance of good soil structure and preservation of soil thickness (prevention of erosion) can also help maintain the capacity of the soil to promote human health through the filtration function.

Quantitative measures that link soil properties to various uses of soil knowledge are needed (Brevik et al. 2016). As relates to the human health topic, there is a pressing need to establish quantitative links between the assessment of soil properties and conditions and their influences on human health (Zornoza et al. 2015). The establishment of quantitative measures would then allow prediction of positive or negative influences on human health given changes in soil conditions relative to locally established reference states that relate to capability. Establishing such

Fig. 24.1 Plants derive most of their nutrients from soil. Animals that eat those plants, or that eat animals that have consumed plants, gain those nutrients as they are passed up the food web. Therefore, healthy soils are essential for the health of animals, including humans that eat the plant products grown in those soils or other products from further up the food web (Photo courtesy of Jeff Vanuga, USDA-NRCS)

Table 24.1 Examples of important sources of elements essential to human life

Element	Important sources
Ca	Kale, collards, mustard greens, broccoli, dairy products
Cl	Dairy products, meats, eggs
Cu	Beans, peas, lentils, whole grains, nuts, peanuts, mushrooms, chocolate, organ meats
Fe	Meats, especially red meat
I	Vegetables, cereals, fruit
K	Fruits, cereals, vegetables, beans, peas, lentils, dairy products, meats
Mg	Seeds, nuts, beans, peas, lentils, whole grains, dark green vegetables
Mn	Whole grains, beans, peas, lentils, nuts, tea
Mo	Beans, peas, lentils, dark green leafy vegetables, organ meats
Na	Dairy products, meats, eggs
P	Nuts, beans, peas, lentils, grains, meats, eggs, dairy products
Se	Grain products, nuts, garlic, broccoli (if grown on high-Se soils), meats from Se-fed livestock
Zn	Nuts, whole grains, beans, peas, lentils, meats, organ meats

Table based on Combs (2005)

reference states for various soils has been a long-running goal of the soil health (quality) community (Doran and Parkin 1994) and should remain a goal of the soil security community.

24.3 Dimension 2: Condition

Dimension 2 – condition, or the current state of the soil (McBratney et al. 2014), influences the nutritional quality of agricultural products produced in a given soil. There is a close connection between the condition dimension and the concept of soil health, within which healthy soils are often seen as those capable of producing abundant, nutritious crops to support the world's dietary and other needs (Brevik 2009; Tesfaye et al. 2014). Traditionally the soils and agricultural communities have recognized the importance of physical and chemical properties of the soil (Table 24.2) in plant production. Research into soil fertility of the shallow plow zone has been particularly extensive, but an increased understanding of the dynamic behavior of the greater soil body is needed (Bouma et al. 2014).

Our understanding of how the soil ecosystem influences plant production (Table 24.2) is not as well developed as our understanding of physical and chemical properties. However, we have learned much about the soil ecosystem in recent years, including enhanced knowledge of the role of soil organisms in organic matter and nutrient cycling, the control of plant pests and diseases, and the creation of several soil physical properties such as aggregates and pores (Brevik et al. 2015). All of these aspects of the soil environment are important to crop production and therefore to human health through the supply of adequate and nutritious crop products (Fig. 24.2).

Table 24.2 Some common physical, chemical, and biological measures of soil health

Biological	Chemical	Physical
Arthropod populations	Cation exchange capacity	Aeration
Decomposition rate	Organic matter	Aggregate stability
Earthworm populations	pH	Bulk density
Microbial biomass	Presence/absence of heavy metals and other plant toxins	Depth to restrictive layers
Mycorrihizal fungi	Soil nutrient status	Depth to water table
Nematode populations	Total carbon	Porosity
Phospholipid fatty acids (PLFAs)	Total nitrogen	Erosive potential
Pollutant detoxification		Infiltration rate
Respiration rate		Penetration resistance
Soil enzyme activities		Texture
		Water holding capacity

Table based on Brevik (2009)

Fig. 24.2 Healthy soils that have good biological, chemical, and physical properties are able to produce abundant, nutritious crops, such as in the photo on the *left*. However, degraded soils, such as along the hilltop in the photo to the *right*, do not have the appropriate biological, chemical, and physical properties to support good crop production and therefore cannot support human health (Photo on the left by Artemi Cerdà, photo on the right courtesy of Gene Alexander, USDA-NRCS)

Fig. 24.3 Many agricultural chemicals are applied for a variety of purposes, but some of those chemicals can end up in the soil environment and eventually be passed on to humans, sometimes with negative health effects. The photo on the *left* shows chemical application to vines in a vineyard, but note that some of the chemical is ending up on the soil surface. Agriculture workers (*right*), who handle treated products and are exposed to potentially contaminated soils, are among the first to be exposed to chemicals or pathogens in soil (Photos by Artemi Cerdà)

In addition to their impacts on plant production, soil biological, chemical, and physical properties can also influence human health through exposure to hazardous materials or organisms (e.g., heavy metals, organic chemicals from agricultural applications, pathogens) (Brevik and Burgess 2013a) (Fig. 24.3). Sediment and soil nutrients are among the largest sources of pollution in surface waters (Troeh et al. 2004), and wind-blown dust can carry chemicals and pathogens into the respiratory system (Brevik and Burgess 2013a). Some soil conditions that reduce erosion, such as adequate levels of organic matter, good aggregation, types of cations on the exchange sites, adequate soil water content, and vegetative cover, can be managed to benefit human health by reducing exposure to wind-blown dust and water-carried sediments. Climate change may also alter the dynamics of soil organisms and pathogens in the soil, particularly permafrost soils (Jansson and Tas 2014); in fact "old-world" viruses have been shown to be viable after permafrost thawing (Legendre et al. 2014). Better understanding of the soil ecosystem and the place of pathogens within that ecosystem also has the potential to benefit human health (Brevik and Burgess 2013b).

24.4 Dimension 3: Capital

Dimension 3 – capital recognizes that there is a value to the services soil provides in terms of promoting human health, a cost associated in situations when soil constituents are detrimental to human health and that there is value to products such as medications that come from soil.

Soil provides ecosystem services that promote human health including the purification of water, nutrients that are taken up by crops, and the sequestration of carbon-based greenhouse gases. There are also costs associated with situations when soils are detrimental to human health, such as exposing humans to contaminants through the food web, pollution due to wind and water erosion (Fig. 24.4), or when soils release greenhouse gases into the atmosphere (Brevik and Burgess 2013a). In a study of soil-based ecosystem services in the Waikato region of New Zealand, Dominati et al. (2014) valued those services at NZ$16,390/ha/year (approximately US$13,110/ha/year). Based on her Table 7 (Dominati et al. 2014), about 92 % of that value is from services with fairly direct links to human health, including food quantity and quality, filtering of nitrogen, phosphorus, and contaminants, recycling of wastes, and regulation of pest and disease populations. Therefore, services related to human health represented a value of approximately NZ$15,080/ha/year (US$12,060/ha/year). However, such economic calculations are very site specific (Alexander et al. 2015); therefore, these values cannot be extended to soils

Fig. 24.4 Soil particles that have been transported by wind (*left*) or water (*right*) may expose humans to contaminants through inhalation or ingestion (Photo on left courtesy of Jeff Vanuga, USDA-NRCS, on right courtesy of Lynn Betts, USDA-NRCS)

and management systems that differ from those in the study area. McBratney et al. (Chap. 20) estimated the value of global soil ecosystem services at about US$867/ha or US$75 trillion annually. If approximately 92 % of those services (based on Dominati et al. 2014) are directly related to human health, that represents a value of approximately US$69 trillion annually (US$799/ha).

Medicines represent ecosystem goods that are provided by soil, and soil is a major source of medications. Medicines from soil organisms or soil materials include antibiotics; cancer drugs; antidiarrheal medications; emollient and drying agents used to treat poison ivy, poison oak, and poison sumac cases; and others (Brevik and Burgess 2013a). In fact, about 40 % of all prescription drugs have their origin in the soil, including about 60 % of all newly approved drugs between 1989 and 1995 and 60 % of new cancer drugs approved between 1983 and 1994 (Pepper et al. 2009). Worldwide prescription drug revenue was about US$700 billion in 2014 (Silverman 2015), giving soil-based prescription drugs a value of roughly US$280 billion in 2014 (calculated as 40 % of US$700 billion). That would give the annual sale of soil-based medications a larger financial value than the 2013 GDP of all but 37 of the 219 countries that the World Bank published data for in 2015 (World Bank 2015b) (Table 24.3).

Health-care expenditures consume a major portion of the financial resources of many countries. Twenty-one countries had health-care expenses that equaled or exceeded 10 % of their gross domestic product (GDP) in 2013 (Table 24.3). Global health-care expenses in 2013 were over $7.4 trillion, about 9.9 % of total world GDP and a percentage that has been fairly consistent since 1995 (low of 8.6 %, high of 10.4 %, mean of 9.5 %) (calculated using World Bank 2015a, b). The 21 countries that spent the most money on health care in 2013 combined to spend more than $6.5 trillion, accounting for over 88 % of total global health-care spending (Table 24.4). In any way it is measured, health care is a major industry, and soils have the potential to contribute considerable financial value in this area.

24.5 Dimension 4: Connectivity

Dimension 4 – connectivity recognizes that societal perspectives of soil influence the value we place on soil and the management practices we utilize, and this in turn influences human health through the condition dimension. In modern western culture, soil and related terms, such as “soiled,” “dirty,” “dirt bag,” and “mudslinging,” are often associated with things that are undesirable (Brevik and Burgess 2013a). It is well known that image is extremely important. Large amounts of money are spent every year by businesses to promote a positive image of their company and its products as evidenced by the abundance of advertisements on television, in magazines, beside roadways on billboards, and in other media. Progress has been made toward improving the image of soil and its standing in society in recent years (Brevik and Hartemink 2010), but much remains to be done and improving the public image of soil is an important part of creating better connectivity between human societies and

Table 24.3 The 40 countries with the highest 2013 GDP values

Rank	Country	2013 GDP (2015 US$)	Rank	Country	2013 GDP (2015 US$)
1	United States	16,768,100,000,000	21	Argentina	609,888,971,036
2	China	9,240,270,452,047	22	Sweden	579,679,985,303
3	Japan	4,919,563,108,373	23	Poland	525,865,974,815
4	Germany	3,730,260,571,357	24	Belgium	524,805,525,215
5	France	2,806,427,978,234	25	Nigeria	521,803,314,654
6	United Kingdom	2,678,454,886,797	26	Norway	512,580,425,532
7	Brazil	2,245,673,032,354	27	Venezuela, RB	438,283,564,815
8	Italy	2,149,484,516,712	28	Austria	428,321,897,648
9	Russian Federation	2,096,777,030,571	29	United Arab Emirates	402,340,106,796
10	India	1,875,141,481,991	30	Thailand	387,252,164,291
11	Canada	1,826,768,562,832	31	Colombia	378,415,326,790
12	Australia	1,560,372,473,125	32	Iran, Islamic Rep.	368,904,351,627
13	Spain	1,393,040,177,014	33	South Africa	366,057,913,367
14	Korea, Rep.	1,304,553,972,502	34	Denmark	335,877,548,364
15	Mexico	1,260,914,660,977	35	Malaysia	313,159,097,401
16	Indonesia	868,345,652,475	36	Singapore	297,941,261,089
17	Netherlands	853,539,351,965	37	Israel	290,550,599,943
18	Turkey	822,135,183,160	38	Chile	277,198,774,857
19	Saudi Arabia	748,449,600,000	39	Hong Kong SAR, China	274,012,815,224
20	Switzerland	685,434,185,074	40	Philippines	272,066,554,886

World Bank (2015b)

soil. One way to further develop positive connections may be to build on the concept of terroir, which originally established a connection between those who love wine and the soils that produce those wines but now extends the connection to many other food products, including cacao, cheese, coffee, fruits, olive oil, and vegetables (Vaudour et al. 2015). If connections can be made between people and soil through their favorite foods, this may help enhance the image of soil and could lead, indirectly, to better human health through a greater respect and concern for the soil resource (Karltun et al. 2013).

Numerous studies have indicated that exposure to natural landscapes benefits human health, including more rapid recovery from surgery with less pain, improvement in children with learning disabilities, and reduced blood pressure and muscle tension (Brevik and Burgess 2013a). Gardening, with its direct connection to soil, and walking through gardens have also been shown to improve human health (Brevik and Burgess 2013a). Dimension 4 recognizes that contact with healthy soil, as described by recent studies indicating potential health benefits from such contact (e.g., Brevik and Burgess 2013a; Hanyu et al. 2014), may also benefit human health (Fig. 24.5). Therefore, the level of access people have to public lands such as parks

Table 24.4 The 21 countries that spent 10 % or more of their gross domestic product (GDP) on health expenses (left) (World Bank 2015a) and the top 21 countries in terms of absolute money spent (right) in 2013 adjusted to 2015 US dollars (calculated using World Bank 2015a and 2015b)

Count	Country	% GDP	Country	Total 2015 US$
1	Tuvalu	19.7	United States	2,867,345,100,000
2	United States	17.1	China	517,455,145,315
3	Marshall Islands	16.5	Japan	506,715,000,162
4	Netherlands	12.9	Germany	421,519,444,563
5	Micronesia, Fed. Sts.	12.6	France	328,352,073,453
6	Moldova	11.8	United Kingdom	243,739,394,699
7	Sierra Leone	11.8	Brazil	217,830,284,138
8	France	11.7	Canada	199,117,773,349
9	Lesotho	11.5	Italy	195,603,091,021
10	Switzerland	11.5	Australia	140,433,522,581
11	Germany	11.3	Russian Federation	136,290,506,987
12	Belgium	11.2	Spain	123,980,575,754
13	Rwanda	11.1	Netherlands	110,106,576,403
14	Austria	11.0	Korea, Rep.	93,927,886,020
15	Canada	10.9	Switzerland	78,824,931,283
16	Maldives	10.8	Mexico	78,176,708,981
17	Denmark	10.6	India	75,005,659,280
18	Serbia	10.6	Belgium	58,778,218,824
19	Japan	10.3	Sweden	56,228,958,574
20	Kiribati	10.1	Norway	49,207,720,851
21	Liberia	10.0	Austria	47,115,408,741

Fig. 24.5 Studies have shown that natural landscapes (*left*) are beneficial to human health. Exposure to healthy soils (*right*) may have similar benefits (Photo on left by Eric C. Brevik, photo on right courtesy of Joseph Heckman)

and reserves as a public good may influence human health. However, considerably more research is needed in this area, and the connectivity dimension of soil security provides a natural platform for such work.

Through much of human history, there was little concern for soil degradation. Rather, when soils became degraded, humans would simply move to new lands and break new, fertile soil. Eventually, there were no new lands to move to, and soil management practices that conserved soil became important (Troeh et al. 2004). Management choices influence the condition dimension and thus human health as discussed in the condition section of this chapter, demonstrating interconnectedness between human health and the dimensions of soil security.

24.6 Dimension 5: Codification

Dimension 5 – soil codification has typically focused on soil and water conservation rather than directly on human health. However, these conservation policies have led to improvements in water quality, reducing the need for water treatment prior to human consumption, and increased soil health, leading to the production of better agricultural products produced in those soils (Troeh et al. 2004). As discussed previously in this chapter, these improvements in turn can lead to improvements in human health.

There are several government-sponsored conservation programs in the USA that improve soil and water quality. These are voluntary programs that offer financial incentives and technical assistance to encourage land managers to adopt practices that conserve soil and water, leading to several environmental and human health benefits (Troeh et al. 2004; Brevik and Burgess 2013a). Major federal conservation programs currently available to landowners include Agricultural Management Assistance (AMA), Conservation of Private Grazing Land (CPGL), Conservation Reserve Program (CRP), Conservation Stewardship Program (CSP), Environmental Quality Incentives Program (EQIP), and Healthy Forests Reserve Program (HFRP). Basic descriptions of these programs are given in Table 24.5. Anyone receiving assistance from one of these programs must also comply with the Highly Erodible Land Conservation (HELC) and Wetland Conservation (WC) provisions, which provide another layer of protection to soil and water as natural resources (Table 24.5).

Beyond the USA, programs, policies, and/or goals that promote improved soil management include the Economics of Land Degradation (ELD) initiative (ELD Initiative n.d.) adopted by the European Union in 2011, which provides a forum for discussion between relevant stakeholders to investigate the potential benefits of various land management practices. A standard approach to analyze the economic impact of various land management techniques is also provided. The Resource Management Act adopted in 1991 (New Zealand Parliamentary Council Office 1991) is the main legislation that guides environmental management, including soil, in New Zealand. The United Nations' proposed Sustainable Development Goals

Table 24.5 Basic descriptions of major federal conservation programs currently available to landowners in the USA

Program	Basic description[a]
Agricultural Management Assistance	The Agricultural Management Assistance (AMA) provides financial and technical assistance to agricultural producers to voluntarily address issues such as water management, water quality, and erosion control by incorporating conservation into their farming operations. Producers may construct or improve water management structures or irrigation structures, plant trees for windbreaks or to improve water quality, and mitigate risk through production diversification or resource conservation practices, including soil erosion control, integrated pest management, or transition to organic farming
Conservation of Private Grazing Land	The Conservation of Private Grazing Land (CPGL) initiative will ensure that technical, educational, and related assistance is provided to those who own private grazing lands. It is not a cost share program. This technical assistance will offer opportunities for better grazing land management, protecting soil from erosive wind and water, using more energy-efficient ways to produce food and fiber, conserving water, providing habitat for wildlife, sustaining forage and grazing plants, using plants to sequester greenhouse gases and increase soil organic matter, and using grazing lands as a source of biomass energy and raw materials for industrial products
Conservation Reserve Program	The Conservation Reserve Program (CRP) is a land conservation program administered by the Farm Service Agency (FSA). In exchange for a yearly rental payment, farmers enrolled in the program agree to remove environmentally sensitive land from agricultural production and plant species that will improve environmental health and quality. Contracts for land enrolled in CRP are 10–15 years in length. The long-term goal of the program is to reestablish valuable land cover to help improve water quality, prevent soil erosion, and reduce loss of wildlife habitat
Conservation Stewardship Program	The Conservation Stewardship Program helps agricultural producers maintain and improve their existing conservation systems and adopt additional conservation activities to address priority resources concerns. Participants earn CSP payments for conservation performance – the higher the performance, the higher the payment
Environmental Quality Incentives Program	The Environmental Quality Incentives Program (EQIP) is a voluntary program that provides financial and technical assistance to agricultural producers through contracts up to a maximum term of 10 years in length. These contracts provide financial assistance to help plan and implement conservation practices that address natural resource concerns and for opportunities to improve soil, water, plant, animal, air, and related resources on agricultural land and nonindustrial private forestland. In addition, a purpose of EQIP is to help producers meet Federal, State, Tribal, and local environmental regulations
Healthy Forests Reserve Program	The purpose of the Healthy Forests Reserve Program (HFRP) is to assist landowners, on a voluntary basis, in restoring, enhancing, and protecting forestland resources on private lands through easements, 30-year contracts and 10-year cost share agreements

(continued)

Table 24.5 (continued)

Program	Basic description[a]
Additional provisions	
Highly Erodible Land Conservation and Wetland Conservation provisions	Highly Erodible Land Conservation (HELC) and Wetland Conservation (WC) provisions aim to reduce soil loss on erosion-prone lands and to protect wetlands for the multiple benefits they provide. HELC and WC provisions apply to all land that is considered highly erodible or a wetland and that is owned or farmed by persons voluntarily participating in USDA programs, unless USDA determines an exemption applies. Producers and any affiliated individuals or entities who participate in most programs administered by the Farm Service Agency (FSA), the Natural Resources Conservation Service (NRCS), and the Risk Management Agency (RMA) are required to comply with these provisions

[a] Basic descriptions are copied verbatim from the individual conservation program websites accessed from http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/alphabetical/

(United Nations Development Programme 2016) do not include soil specifically, but there are several goals where soil and its links to human health will play a key role such as goal 2, end hunger, achieve food security and improve nutrition, and promote sustainable agriculture; goal 6, ensure availability and sustainable management of water and sanitation for all; goal 12, ensure sustainable consumption and production patterns; goal 13, take urgent action to combat climate change and its impacts; and goal 15, protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss. Around the world at the national and international levels, codification is taking place that influences the links between soil and human health (e.g., Shelef et al. 2014; Lanckriet et al. 2015).

24.7 Conclusions

This chapter has sought to provide some examples of ways that each of the five dimensions of soil security can be tied to studying the relationship between soils and human health. Soils have been shown to have the capacity (dimension 1) to provide services that are important to human health, and the ability to provide those services is influenced by the condition (dimension 2) of the soil. There is a definite value (capital, dimension 3) to services and products supplied by soil that influence human health, and the connection (dimension 4) that we as a society make with the soil resource influences our treatment of that resource. Finally, government programs, policies, and goals (codification, dimension 5) influence our treatment of and the condition of soil. There are definite connections that can benefit soils and human health studies. Much can be done under the umbrella of each of the five dimensions of soil security to advance understanding of the soil-human health connection in a truly transdisciplinary fashion.

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Chapter 25
Soil Contamination and Human Health: A Major Challenge for Global Soil Security

Florence Carré, Julien Caudeville, Roseline Bonnard, Valérie Bert, Pierre Boucard, and Martine Ramel

Abstract This chapter aims to demonstrate, by several illustrated examples, that human health should be considered as a major challenge of global soil security by emphasizing the fact that (a) soil contamination is a worldwide issue; estimations can be done based on local contamination but the extent and content of diffuse contamination is largely unknown; (b) although soil is able to store, filter, and reduce contamination, it can also transform and make accessible soil contaminants and their metabolites, contributing then to human health impacts. The future scientific and societal challenges related to soil-human health studies and soil security dimensions are discussed based on current programs and literature review.

Keywords Soil contamination • Health risk • Scientific emerging needs

25.1 Introduction

Soil security refers to the maintenance and improvement of the world's soil resources so that they can continue to face six major challenges which are contributions to (1) provision of food and fiber, (2) energy security, (3) water security, (4) climate change abatement, (5) biodiversity protection, and (6) ecosystem service delivery (Koch et al. 2012, 2013). By being able to perform five functions, among them storing, filtering, and transforming of nutrients, substances, and water (CEC 2006), soil largely contributes to the quality of air, food, and water, which has a direct link to human health. This chapter aims to demonstrate that human health should be recognized as another major challenge of soil security. The focus is made on solid or

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liquid hazardous chemical storage, filtration, and transformation by soil, i.e., soil contamination. A state of the art on worldwide soil contamination, the relations to human health, and the emerging scientific and societal needs to identify and reduce soil contamination illustrate the demonstration.

25.2 Soil Contamination Worldwide

25.2.1 Main Soil Contaminants

Solid or liquid hazardous chemicals contaminants result mainly from industrial, agricultural land disposal, transport, urbanization, mining, irrigation, and military processes (Jones et al. 2012; Panagos et al. 2013). In Europe, the United States, and Australia, the main contaminants which have been reviewed so far are for about 60 % heavy metals and total petroleum hydrocarbons (Huber and Prokop 2012; Mulligan et al. 2001; State of the Environment Committee 2011) and then polycyclic aromatic hydrocarbons (HAP); benzene, toluene, ethylbenzene, and xylene (BTEX); chlorinated hydrocarbons (CHC); cyanides; and phenols (Panagos et al. 2013). These contaminants concern mainly sites operating under legislation which makes mandatory pollution monitoring and control, like the European Industrial Emission Directive 2010/75/EU (European Commission 2010).

25.2.2 Review of Contaminated Sites

Two kinds of contamination are usually distinguished (Murphy and Hazelton 2014):

- Local soil contamination occurs where intensive industrial activities, inadequate waste disposal, mining, military activities, or accidents introduce excessive amounts of contaminants in soil.
- Diffuse soil contamination is the presence of a substance or agent in the soil as a result of human activity that caused it to be emitted from moving sources, from sources with a large area, or from many sources. Diffuse soil contamination occurs where emission, transformation, and dilution of contamination in other media has occurred prior to their transfer to soil. Water and air actions can explain long-range transport of contaminants. As a result, the relationship between the contaminant source and the level and spatial extent of soil contamination is indistinct (Jones et al. 2012; Van Camp et al. 2004).

Panagos et al. (2013) estimated contaminated sites and potentially contaminated to be around 0.005 sites per capita for the European Union and a population of one billion. Based on these figures, Horta et al. (2015) estimated emerging economies to have 0.0025 contaminated sites and potentially contaminated per capita, their popu-

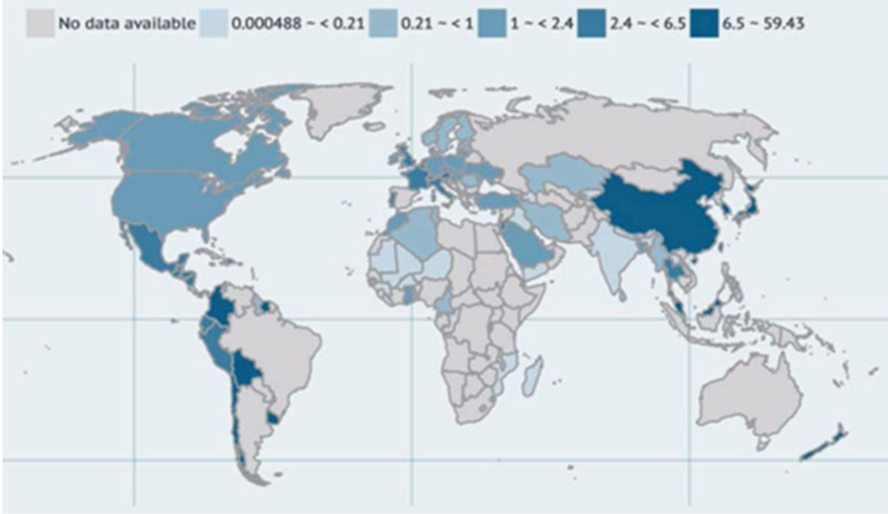

Fig. 25.1 Map of pesticides per ha of arable land (kg/ha- period 2005–2009) – (Source: FAO (2013))

lation being two billion, developing economies to have 0.001 contaminated sites and potentially contaminated per capita, their population being four billion. At global level, the estimates of contaminated sites and potentially contaminated are then between 10 million and 20 million sites (including uncertainties).

These figures, representing big numbers, concern mainly local contamination. Estimation of diffuse soil pollution could be done, for instance, by integrating available global monitoring data on hazardous chemicals, e.g., the quantity of pesticides per ha of arable land for the period 2005–2009 (FAO 2013) represented in Fig. 25.1.

This map presents the distribution of only one category of hazardous chemicals, over the 350,000 inventoried and regulated substances (CAS 2016). It shows that, where data are available, 80 % of pesticides are overused, leading to diffuse soil contamination. This is actually the case for North, Central and South America, Western Europe, Middle East, China, and New Zealand. What about the developing countries where data are currently missing? An extrapolation of the available data based on categories of economies would certainly show that 70 % of the globe is overcovered by pesticides. At this stage, more data on diffuse soil contamination are required at national level through systematic monitoring programs or food contamination controls.

As stated by Horta et al. (2015), remediation rates on identified contaminated sites are quite modest:

- European countries have undergone only 5 % remediation (Panagos et al. 2013) of the identified and potentially contaminated sites and the number of recorded polluted sites across, whereas the number of recorded contaminated site in Europe is expected to increase by 50 % by 2025 (EEA 2015a).

- Australia proceeds to about 0.5 % per annum of remediation (State of the Environment Committee 2011) certainly about the same amount as the number of newly contaminated sites every year (Horta et al. 2015).

These small remediation numbers are explained by the high costs of remediation (see Sect. 25.4.4) and lack of incentives for land valuation.

The next sections are describing the underlying processes of soil contaminants – human health relationships, the assessment procedure, and some statistically based cases.

25.3 Soil Contamination and Human Health

The study of soils and human health is a complicated endeavor: traditional scientific approaches that isolate a single variable, such as a specific contaminant, and then investigate that variable are usually not effective, because many of the issues that affect human health involve complicated and synergistic relationships (Brevik and Sauer 2015; Brevik and Burgess 2013).

25.3.1 General Principles

Soil contaminants can be exposed to humans by:

- Transport processes like leaching, infiltration, runoff, gas volatilization, dispersion, advection, diffusion, and sorption/desorption due to close connections to soil with air, water, and biota
- Fate and transformation processes variable according to the types of contaminants: organic compounds can undergo hydrolysis, oxidation, biodegradation, and sorption, while inorganic compounds undergo complexation, dissolution, and/or changes in speciation (EPA 2013a)

These processes depend on several factors that explain the bioaccessibility of the soil contaminants:

- Inorganic compounds depend on climate and soil conditions like pH, cation exchange capacity, also function of type and content of clay and type and content of organic matter, redox potential, iron/manganese oxides, soil moisture content, and soil microorganisms.
- Organic compounds depend mainly on their potential absorption in the food chain measured by their distribution coefficient (octanol/water), Henry constant, water solubility, half-life, and bioconcentration factor (EPA 2013a). The following section is dedicated specifically to persistent organic pollutants.

The routes of exposure to humans are inhalation of dust and vapor coming from soil contaminants, ingestion of contaminated soil particles (mainly for children) or contaminated food, and dermal absorption through the skin. Once the intake by inhalation, ingestion, or dermal contact has been done, the soil contaminant is absorbed by the gastrointestinal and pulmonary systems or absorbed by the skin and enters the systemic circulation system, representing the uptake and the bioavailable fraction (Murphy and Hazelton 2014; EPA 2013b; Dudka and Miller 1999; Hawley 1985).

When it exists, a soil guideline value (SGV) is a figure for the concentration of a contaminant in the soil that sets off "possible risk" alarm bells. It means that further investigation and/or risk management is needed. These SGVs are generally derived from estimates of toxicity from a certain human intake of the soil rather than actual human uptake of the contaminant (Science Communication Unit 2013). It is elaborated according to soil type, soil usage, and the population type who can ingest or inhale the soil contaminant.

Regarding a contaminant, human health risk assessment is generally not framed only to soil contamination, but it involves also the contribution of other exposure media. Indeed, the estimation of human health risk is the combination of the hazard and the exposure of the contaminants from multiple pathways and routes usually identified from a site conceptual model. The ingested or inhaled dose is compared to the reference toxicological value (RTV) varying according to the exposure route, age, sex, genetic, and health of populations (INERIS 2009; Bonvallot and Dor 2002). For a contaminant with threshold effects, an RTV means the dose or concentration below which the occurrence of an effect is not expected. For non-threshold effects, an RTV means the additional probability of occurrence of an effect to an exposure unit (INERIS 2013).

Multimedia models (cf. example presented in Fig. 25.2) which provide appropriate quantitative frameworks for evaluating the complex interactions between chemicals and the environment (Caudeville et al. 2012) can be used for assessing exposure.

These models can be spatialized (Caudeville et al. 2012; MacLeod et al. 2001; Feijtel et al. 1997) or not (Bonnard and McKone 2010). They can also be integrated with physicologically based pharmacokinetics models for assessing the uptake impact of a contaminant directly on a target tissue at individual levels (Maurau et al. 2011). The contribution of soil contaminants to the total exposure can be evaluated dividing the average inhalation or ingestion daily dose of soil contaminants by the total average daily dose of this contaminant (Caudeville et al. 2012).

When the risk is considered as unacceptable, remediation should be applied on the contaminated site in regard to its future usage.

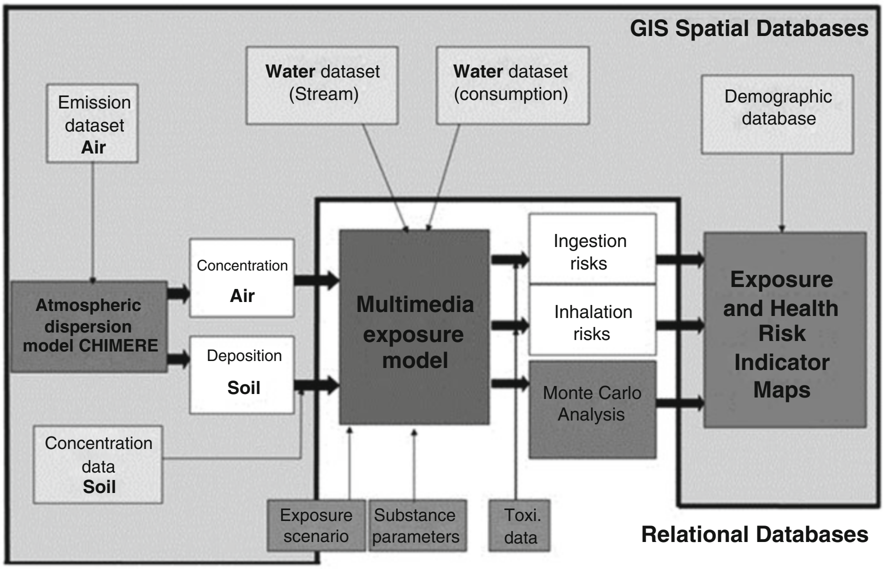

Fig. 25.2 Block diagram of the transfer and exposure pathways taken into account in the PLAINE GIS-multimedia platform (Source: Caudeville et al. 2012)

25.3.2 *Focus on Persistent Organic Pollutants*

Persistent organic pollutants (POPs) are extremely toxic substances for environment and human health at a world scale. They are persistent, bioaccumulative, and toxic (PBT) chemicals and have long-range transport (Weber et al. 2008). In people, reproductive, developmental, behavioral, neurologic, endocrine, and immunologic adverse health effects have been linked to POPs. People are mainly exposed to POPs through contaminated food ingestion coming from contaminated soil and water. In people and other mammals alike, POPs can be transferred through the placenta and breast milk to developing offspring. A number of populations are at particular risk of POP exposure, including people whose diets include large amounts of fish, shellfish, or wild foods that are high in fat and locally obtained. In addition, sensitive populations, such as children, the elderly, and those with suppressed immune systems, are typically more susceptible to many kinds of pollutants, including POPs. Because POPs have been linked to reproductive impairments, men and women of child-bearing age may also be at risk (EPA 2015).

Since 1995 the international community has been working on implementing the Stockholm Convention (United Nations 2004) measures to eliminate or reduce the release of POPs into the environment. This Convention entered into force in May 2004. Initial action has been taken toward 12 POPs: aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex, toxaphene, PCBs, PCDDs, and PCDFs. In 2009, extension has been done to nine substances: alpha

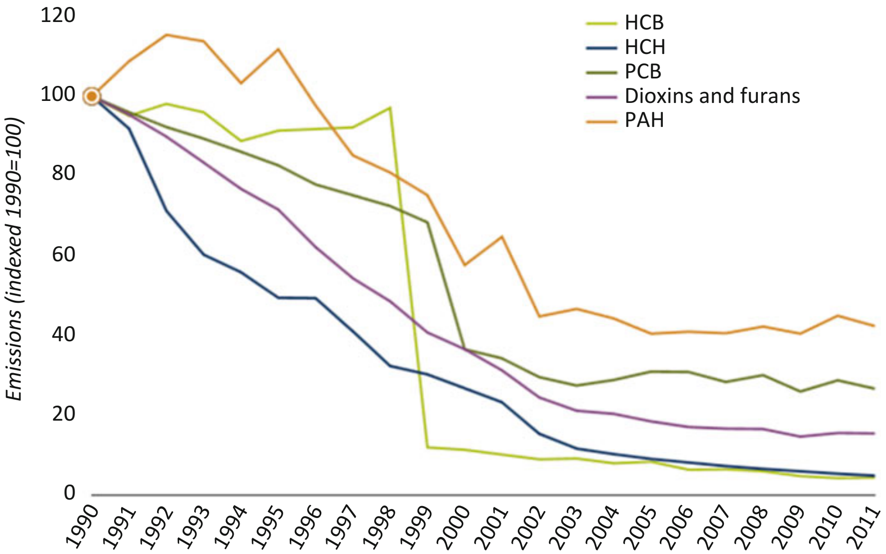

Fig. 25.3 Emission trends of POPs from 1990 to 2011 (EEA 2015b) – *HCB* hexachlorobenzene, *HCH* hexachlorocyclohexane, *PCBs* polychlorinated biphenyls; dioxins and furans; and *PAHs* polyaromatic hydrocarbons

hexabromocyclododecane; beta hexachlorocyclohexane; chlordecone; hexabromobiphenyl; hexabromodiphenyl ether and heptabromodiphenyl ether (commercial octabromodiphenyl ether); lindane; pentachlorobenzene; perfluorooctane sulfonic acid, its salts, and perfluorooctane sulfonyl fluoride; and technical endosulfan and its related isomers, tetrabromodiphenyl ether, and pentabromodiphenyl ether (commercial pentabromodiphenyl ether). Endosulfan and hexabromocyclododecane were added to the list in resp. 2011 and 2013. These 23 POPs are either pesticides, industrial chemicals, or by-products unintentionally produced during most forms of combustion. All of them can then be found in soils.

Emissions of these substances are regularly monitored in Europe, as shown in Fig. 25.3 (source: EEA 2015b).

The vast majority of the 33 country members of the European Environmental Agency have decreased their emissions due to the reduction of industrial, commercial, and household uses. But as explained previously, these substances remain in undisturbed soils for long time period and can be transferred to other locations once the soils are disturbed. Soil monitoring is then useful to complement the emission monitoring. In Europe, two attempts were done for soil mapping of POP. Villanneau et al. (2011) mapped some POPs in the North of France and demonstrated that it is possible to discriminate soils with POPs spatially correlated from others more randomly distributed perhaps due to redeposition phenomena. Ballabio et al. (2013) showed that PCB concentrations of Northern Italy, in mountainous areas, are highly correlated with soil temperature and organic carbon content, meaning that PCB concentrations follow weather seasonality.

Because POP measurements and analysis can be very expensive, mapping the soil POP burden can be facilitated through environmental bio-indicators such as lichens and mosses as indicator of air pollution (Augusto et al. 2013). Research on soil POP pollution bio-indicator is now at the initial stage. The increase of knowledge on soil microbial activity with the development of new tools could certainly lead to better identify and assess soil POP bio-indicators.

25.3.3 Some Potential and Statistically Based Cases of Health Effects of Soil Contamination

25.3.3.1 Potential Health Effects of Soil Contaminants

WHO listed some soil contaminants having potential effects of human health. This list has been completed by Brevik and Burgess (2013). It is presented in Table 25.1.

Main of the soil contaminants are indirectly ingested via the food chain.

25.3.3.2 Some Statistically Based Health Effects of Soil Contaminants

- Death Triangle of soil dioxins and heavy metal pollution (Italy)

  Hazardous waste sites in the Campania region of Italy differ in that they are distributed over a wide densely populated area, with an estimated 1230 illegal dump sites in what has been referred to as "The Triangle of Death" (Martuzzi et al. 2009). This is because, since the 1980s, hazardous waste dumping has gone on largely uncontrolled. In addition to voluminous amounts of household waste, the region has also been plagued by widespread illegal dumping of toxic industrial chemicals and low-level radioactive wastes. The situation has been aggravated by the ongoing practice of burning rubbish, which in turn creates dioxins and other toxic compounds (PAH, heavy metals). De Felice et al. (2012) demonstrated that the soil pollution in this region is significantly associated with effects on exposed population like higher oxidative stress, shorter telomere length, and lower telomerase activity. These are known determinants of cell senescence and aging-related meiotic dysfunction in women, in peripheral blood mononuclear cells from healthy pregnant women, subjected to therapeutic abortion in the second trimester of pregnancy.
- Soil organochlorine chemicals around Besançon (France)

  Viel et al. (2011) worked on a study area of three electoral wards (170,000 inhabitants), containing or surrounding the municipal solid waste incinerators (MSWI) of Besançon City (Eastern France). The MSWI of Besançon was put into service in 1971. Some legal guidelines for incinerator emissions have not been followed at this location. For example, in 1997, exhaust gases were not maintained at sufficient temperatures, allowing dioxins to be emitted. The first time that the dioxin concentration of an exhaust gas was ever measured

Table 25.1 WHO chemicals of major public health concern directly in relation to soils and human health impacts

Chemical of concern, sources/ uses	Toxic to humans how?	Health effects
Cadmium		
Zinc smelting, mine tailings, burning coal, or garbage containing cadmium, rechargeable batteries (nickel-cadmium batteries account for over four-fifths of cadmium consumption), pigments, TVs, solar cells, steel, phosphate fertilizer, metal plating, water pipes, sewage sludge	Cadmium in soil or water used for irrigation can lead to accumulation in plants that enter the human food chain. Cadmium may also accumulate in animals at levels that do not affect the animal's health but can affect humans consuming animal products	Liver and kidney damage, low bone density
		These symptoms are known as itai-itai disease. First identified when cadmium from mining in the Toyama Prefecture of Japan led to high levels of cadmium in rice, which accumulated in local people. Diets poor in iron and zinc vastly increase the negative health effects of cadmium
		Carcinogenic (by inhalation)
Dioxin		
Including polychlorinated dibenzodioxins (PCDD) and polychlorinated dibenzofurans (PCDF)	Human exposure to dioxin and dioxin-like substances occurs mainly through consumption of contaminated food. More than 90 % of human exposure is through food, mainly meat and dairy products, fish, and shellfish	Dioxins are highly toxic and can cause reproductive and developmental problems, damage the immune system, interfere with hormones, and also cause cancer
Waste incineration, reprocessing metal industry, paper and pulp industry, contaminated herbicides (a major source). Stored PCB-based industrial waste oils (often with large amounts of PCDFs)		
Lead		
Batteries, solder, ammunition, pigments, paint, ceramic glaze, hair color, fishing equipment, leaded gasoline (vehicle exhausts), mining, plumbing, coal burning, water pipes	Leaded fuel and mining activities are common causes for elevated lead levels in topsoil	Neurological damage
		Lowers IQ and attention
		Hand-eye coordination impaired
		Encephalopathy
		Bone deterioration
		Hypertension
		Kidney disease
Mercury		
Electrical switches, fluorescent light bulbs, lamps, batteries, thermometers, dental fillings, mining (particularly artisanal/small scale gold mining), pesticides, medical waste, burning coal and fuel oil, chlor-alkali industry	Main exposure route for the population at large is via eating contaminated seafood. For children is direct ingestion of soil	Central nervous system (CNS) and gastric system damage
		Affects brain development, resulting in a lower IQ
		Affects coordination, eyesight, and sense of touch
		Liver, heart, and kidney damage
		Teratogenic

(continued)

Table 25.1 (continued)

Chemical of concern, sources/uses	Toxic to humans how?	Health effects
Herbicides derived from trinitrotoluene may have the impurity dioxin, which is highly toxic. Synthetic insecticides, such as DDT (now banned) can still be found in the environment worldwide	Organic pesticides accumulate in the food chain	Organic chemicals, including pesticides, have been linked to a wide range of health problems, but humans tend to be exposed to a cocktail of these chemicals at low levels. Conclusive proof of cause and effect in humans is challenging

Sources: Science Communication Unit (2013), Brevik and Burgess (2013), US Agency for Toxic Substances & Disease Registry (U.S. Department of Health and Human Services 2016)

(December 1997), it was found to be 16.3 ng WHO1998-toxic equivalency factor (TEQ)/m^3, whereas the European guide value is 0.1 ng WHO1998-TEQ/m^3. Once emitted the dioxins and its congeners (organochlorines) are deposed in topsoil in very short time where they accumulate. Exposure pathway of organochlorines is mainly through ingestion of contaminated food (above all animal lipids from meat, poultry and eggs, fish, shellfish, and dairy products like cheese and milk). Viel et al. (2011) worked on epidemiology around the site and collected serum samples from people having declared non-Hodgkin lymphoma and from people having not declared any pathologies. They found correlations between serum organochlorine concentrations and non-Hodgkin lymphoma.

- Links between Cd and Pb soil pollution with nephrotoxicity in Mbeubeuss (Senegal)

  Cabral et al. (2015) studied the links between the population located nearby the discharge of Mbeubeuss (30 km from Dakar City center) where more than 395,000 tons per year of household solid waste have been received since 1970 with highly lead- and cadmium-concentrated soils and nephrotoxicity. Blood and urine concentrations were measured for subjects living on control (less exposure to lead and cadmium) and exposed sites for more than 5 years. They found that exposed subjects exhibited significantly higher Cd and Pb levels in the blood and urine than the controls. It has already been reported that one of the major mechanisms of the toxicity of both these metals was certainly driven by induction of oxidative stress conditions due to the overproduction of reactive oxygen species. As a result of this excessive production of reactive oxygen species in exposed subjects, a disturbance of the antioxidant defense system as well as an occurrence of lipid peroxidation were evidenced. Furthermore, changes in several sensitive and specific markers of nephrotoxicity clearly suggested the occurrence of early signs of impaired renal function for the discharge neighboring population. Regarding to these results, reactive oxygen species generation following low to moderate environmental exposure to Pb or Cd could be a possible mechanism of genotoxicity.

Regarding the contribution of soil contamination to population diseases, these case studies should be considered with caution since, as already explained previously, exposure and human health risk assessment are case by case approaches. In a widespread goal, more data on the contribution of other media; on the population, the time, and the duration of exposure (genetics, behavior, etc.); and on the presence of other kinds of contaminants (types and concentrations) would be needed (see the exposome concept developed in Sect. 25.4.3).

25.4 Future Scientific and Societal Challenges Related to Studies on Soil: Human Health Relations

This section is based on the dimensions of soil security described by McBratney et al. (2014). These dimensions are discussed in relation to the soil contamination topics.

25.4.1 Increasing the Knowledge on Soil Condition

Soil condition is the current state of the soil, including modification by human activities McBratney et al. (2014). In our case, the focus is made on soil contaminants.

25.4.1.1 Emerging Contaminants: The Unknowns of Soil Condition

The NORMAN European network of reference laboratories, research centers, and related organizations for monitoring of emerging environmental substances (NORMAN Network 2016) is providing definitions of emerging substances and emerging pollutants from the monitoring point of view:

- "Emerging substances" can be defined as substances that have been detected in the environment but which are currently not included in routine monitoring programs at EU level and whose fate, behavior, and (eco)toxicological effects are not well understood.
- "Emerging pollutants" can be defined as pollutants that are currently not included in routine monitoring programs at the European level and which may be candidates for future regulation, depending on research on their (eco)toxicity, potential health effects, and public perception and on monitoring data regarding their occurrence in the various environmental compartments.

Sauvé and Desrosiers (2014) gave a broader definition of emerging contaminants preferably termed "contaminants of emerging concern (CEC)," defined as naturally occurring, manufactured, or man-made chemicals or materials which have now been discovered or are suspected present in various environmental compartments and whose toxicity or persistence are likely to significantly alter the metabolism of a living being.

In April 2015, the NORMAN network identified a preliminary list of the 969 currently most frequently discussed emerging substances and pollutants (NORMAN 2015) in aquatic systems. Due to subsurface water movements or anthropogenic activities like application of sewage sludge (INERIS 2014), not all but main of these identified substances and pollutants can be found in soils. Some emerging contaminants are persistent organic pollutants (see Sect. 25.3.2); pharmaceutical and personal care products (PPCPs), i.e., any product used by individuals for personal health or cosmetic reasons or used by agribusiness to enhance growth or health of livestock; endocrine-disrupting chemicals (EDCs), including synthetic estrogens and androgens; naturally occurring estrogens; and other chemicals that affect at low-dose hormonal functions in aquatic and terrestrial organisms.

The main challenges related to contaminants of emerging concern will be, in the coming years, to better understand their concentrations in the environment [through very robust detection and analytical methods] as well as their toxic effects on organisms. Better management of risks to human health and the environment (Sauvé and Desrosiers 2014) should be done by prioritizing contaminants to include to existing regulations (e.g., the European Water Framework Directive, REACH Directive, Ground Water Directive, Waste Directive) for usage and production restriction at domestic and industrial levels, based inter alia on (eco)toxicological criteria.

25.4.1.2 Development of New Tools for a Better Assessment of Soil Condition

Soil monitoring of contaminants (including those of emerging concern) would be too expensive to be achieved systematically. In addition to the collection of legacy data on historical uses of sites, one of the solutions would be to intensify the coupling between soil biomonitoring and analytical tools and methods, where health effects are observed on soil fauna and flora. This can be done, for instance, with effect-directed analysis which aims to identify the compounds causing these effects after reducing sample complexity by combining biotests with fractionations (Fetter et al. 2014). More generally, further (eco)toxicological research would be necessary to better assess human health risk particularly on chemical forms of contaminants and their toxicity related to environmental and biological conditions. Research devoted to a better understanding of the soil/water/air/flora nexus and the contaminants behavior under climate change conditions, of endocrine disruptors' low-dose (eco)toxicological effects, and of soil contaminants mixture (eco)toxicological effects would be very useful in the future.

Once a site is considered as contaminated, it is necessary to provide enough accurate data to minimize lack of statistical representativeness and increase the spatial quantification. The time spent for evaluating the presence and extent of contamination can be reduced by an adequate sampling plan (Malherbe 2002) which can, at the same time, reduce the project costs (Horta et al. 2015). Proximal sensing, that is, all methods that sense the soil from outside (McBratney et al. 2011; Viscarra Rossel et al. 2011), can help in supporting the identification and characterization of contaminated site particularly with conjoint use of Vis-NIR and portable X-ray fluorescence proximal sensors and laboratory analysis (Horta et al. 2015). Extending innovation on these proximal sensors would be then of great interest for characterizing soil contamination.

25.4.2 Development of New Remediation Techniques for Improving the Soil Condition

Remediation is considered as the management of the contaminant at a site so as to prevent, minimize, or mitigate damage to human health, property, or the environment. Two distinct classes of soil remediation can be defined: (a) in situ and (b) ex situ (with *on-site* and *off-site* interventions). In situ remediation – meaning that no excavation of the contaminated soil occurs – is often preferred because it is generally less expensive. However, it generally takes a longer time to effect treatment to the desired limits, and there is less certainty about the uniformity of treatment because of the inherent variability in soil and aquifer characteristics and difficulty in monitoring progress. On the other hand, excavating a contaminated area (ex situ approach) and treating the material on the same site (ex situ, on-site) or transporting it to a remote site for cleaning (ex situ, off-site) can often be more complicated and expensive. Nevertheless, ex situ off-site remediation has the added bonus of taking the bulk of contaminants away before they can spread further. It also allows homogenization of the contaminated soil before treatment and ensures monitoring so that soils are cleaned to the desired limits within a relatively short time [suitable with transaction time of attractive land as high value commercial and residential lands] (Lodolo 2015). Ex situ remediation with soil excavation and disposal to landfill “dig and dump” currently represents one third of the remediation technologies in Europe (Panagos et al. 2013). However, since space is needed for ex situ remediation and particularly for disposal to landfill, it enhances soil grabbing which is not compatible with the UNCCD “zero-net land degradation” Sustainable Development Goal for Rio + 20 (UNCCD Secretariat 2012). More in situ remediation should then be expected in the future. The related techniques are:

- Thermal processes which use heat to increase the volatility and to burn, decompose, destroy, or melt the contaminants. Cleaning soil with thermal methods may take only a few months or several years. The time it takes depends on the type and amounts of chemicals present, size and depth of the polluted area, type of soil, and conditions present;
- Physicochemical treatments which use the physical and/or chemical and/or electrical properties of the contaminants or of the contaminated medium to destroy (i.e., chemically convert), separate, or contain the contamination. The

technologies are also sensitive to certain soil parameters which influence the contaminant availability and extractability such as the presence of clay or humic materials, pH, and soil moisture.

- Biological treatment which is a process whereby soil contaminants are transformed or degraded into innocuous substances such as carbon dioxide, water, fatty acids, and biomass, through the action of microbial metabolism. Biological processes are typically implemented at low cost. Contaminants can be destroyed and often little to no residual treatment is required. However, the process requires more time, and it is difficult, in general, to determine whether contaminants have been completely destroyed. Additionally, microbes may often be sensitive to toxins or highly concentrated contaminants in the soil (Lodolo 2015).

Biological treatments and more specifically the gentle remediation options (GRO), which include in situ contaminant stabilization ("inaction") and plant-based remediation (or phytoremediation), allow for enhancing ecosystem services by contributing to the restoration of soil functions. A lot of efforts have been done for the last 10 years to increase the efficiency of trace element remediation by testing different soil management practices, different crops under different soil conditions (Kidd et al. 2015). Further research and development are needed for remediating other kinds of contaminants and for increasing the knowledge on bioaugmentation techniques in order to improve the efficiency of these positive environmental balance technologies.

Regarding broad aspects of soil remediation, it is important to evaluate the effects of exhaustive remediation alternatives on soil functions when assessing the overall sustainability of decision options. To this aim, a generic approach conceptualizing linkages between soil functions, soil ecosystem services, and the environmental, social, and economic sustainability domains has been proposed by Rosén et al. (2015) through the development of the SCORE tool based on multi-criteria decision analysis. This tool integrates also a quantification of the uncertainties and their impact on decision-making. This approach is revolutionizing the remediation approaches by combining experts and stakeholders' judgments and preferences – which deals with the integration of the connectivity dimension (Sect. 25.4.3) – and by integrating sustainable land management concepts, which deals with the integration of soil condition and capability dimensions, in the current risk-based approaches.

25.4.3 Increasing the Connectivity and the Codification Related to Soil Contamination

Connectivity is the social connection of soil managers, custodians, and users of soil products and services to the soil and to each other, whereas codification relates to policy frameworks; it is the identification of policies that degrade soil security and those that secure soil (McBratney et al. 2014). These two dimensions are discussed together in this section because awareness raising of the broad society allows for enhancing best practices that can sometimes lead to either new policies, standards, labels, or voluntary certificates. Since connectivity is considered here as the driver of codification, this section is dedicated to connectivity.

As already emphasized by Bouma (2015), one of the keys to successfully securing soil is the involvement of the society (and all concerned stakeholders) in the preparatory and implementation phases of a soil management project. The concerned stakeholders are those involved in field-scale and regional-scale spatial planning. The potential actors are policy-/decision-makers, private and/or public funders, and citizens who live in the area and the surrounding area concerned by the project. The identification of the societal needs at the initial stages of the project, facilitated by knowledge brokers, increases the acceptability of the project and its sustainability. During the implementation phase, the societal involvement allows also for a better understanding of technical bottlenecks that could lead to deviations of the project target. Such transdisciplinary research project eases the integration of research outcomes in decision-making and policies.

Another success key raised by Bouma (2015) is the development of inter- and transdisciplinary programs dealing with food, water, climate, biodiversity, and energy problems. Health is also an important topic to target for which, as demonstrated previously, soil has a central place. Monitoring soil, water, fauna/flora, and human health through common programs would lead to a better understanding of the critical zone and would participate to the increase of knowledge on the exposome concept. The exposome is the measure of all the exposures of an individual in a lifetime and how those exposures relate to health (Centers for Disease Control and Prevention 2014). In the long-term, this knowledge will lead to a better prevention of pollution and a better land management through policies, standards, or individual and societal voluntary basis actions.

25.4.4 Increasing the Knowledge on Soil Capital

The dimension of soil capital is underpinned by the notion that by placing a monetary value on an asset enables a society to value or secure the asset and make meaningful comparisons of soil with different capabilities and conditions (McBratney et al. 2014).

Evaluating the cost of soil contamination at global level allows for emphasizing the importance of protecting soil against contamination. The cost can be evaluated according to four components as described in Gorläch et al. (2004):

- The on-site or private cost (PC) of damage which is, for instance, the costs of the reclamation of the site within redevelopment project performed by a private investor. It is also the cost of impact monitoring.
- The on-site private cost of mitigation and repair measures (MC) which is the cost of, e.g., demolition of contaminated buildings, soil decontamination and treatment, acquisition of contaminated land, and refitting of forests.

Table 25.2 Estimation of the total cost of soil contamination based on data representative of the European continent (Panagos et al. 2013; Görlach et al. 2004) and rules of three

Number of sites (total estimation in bold)	Cost (in M€/year)					
	PC (%total cost)	MC (%total cost)	SC (%total cost)	DC (%total cost)	Total cost (PC + MC + SC + DC)	Study extent (authorship)
1.5 M	192 (0.7)	6658 (26.7)	17,126 (68.7)	965 (3.9)	24,941	European extent – intermediate costs estimated from different case studies Görlach et al. (2004)
10–20 M					**166,273–332,546**	
342,000	171	6500	16,725	949	24,345	European extent-management cost has been estimated based on survey Panagos et al. (2013) and other types of costs have been estimated based on the %total cost of Görlach et al. (2004)
10–20 M					**711,842–1,423,684**	

- The off-site (social) cost (SC) which is the cost of human and environmental impacts (e.g., cost of disease, loss of agricultural income, decrease of housing prices).
- The nonuser cost (DC) which is the cost of loss of nonuse value for citizens.

This cost varies according to the type of contaminant, the spatial extent of the pollution and its intensity, the natural characteristics of the contaminated site, the socioeconomic characteristics of the surrounding area, and the tolerable risk levels depending on the regulation of each country. Based on literature review of Horta et al. (2015) which estimate the total number of locally contaminated sites to about 10 and 20 millions, and evaluation of costs made by Gorläch et al. (2004) and Panagos et al. (2013) which provided data representative of the European continent (so easily upscalable to other continents), rough estimations can be made of the total cost of soil contamination (Table 25.2).

Table 25.2 provides an estimation of the global cost of local contamination that is between 166 billion € (185 billion US $)/year and 1.4 trillion € (1.11 trillion US $)/year (between 0.25 % and 1.89 % of global GDP). This upper boundary represents 10 % of the maximum cost of climate change estimated by Stern (2006) which is about 20 % of the global GDP. This wide range cost estimation emphasizes the fact that many environmental and social drivers influence the total costs. Rough estimates of the cost are then associated with many uncertainties that would decrease when assessing the cost at field or regional scales.

These high number estimates, which show that soil contamination is a highly relevant economic issue, are based only on local contamination data, not on diffuse contamination.

Further, in a context of bringing value to contaminated sites, these numbers should be analyzed in regard to the economic valuation of ecosystem services enhanced by soil restoration. Such evaluation could enhance a dynamic and smart green businesses related to the remediation market.

25.5 Conclusions

This chapter aimed to demonstrate that human health should be considered as another major challenge of global soil security by emphasizing the fact that:

(a) Soil contamination is a worldwide issue. Estimations can be done based on local contamination but the extent and content of diffuse contamination is largely unknown.
(b) Although soil is able to store, filter, and reduce contamination, it can also transform and make accessible soil contaminants and their metabolites, contributing then to human health impacts. This has been illustrated by several examples.

The future scientific and societal challenges related to soil-human health studies and soil security dimensions are:

(a) For the condition and capability dimensions: more focus on emerging contaminants and more fast analytical tools and remediation techniques dealing with sustainable land management
(b) For the connectivity and codification: more transdisciplinary approaches, multi-actors involvement, and multidisciplinary environment-health monitoring programs
(c) For the capital dimension: better assessment of contamination costs but also economic value of remediation options

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Chapter 26

The Measurement of Soil Security in Terms of Human Health: Examples and Ideas

Sung Chul Kim, Kyung Jae Lim, and Jae E. Yang

Abstract Soil security refers to maintenance and improvement of soil resources and is closely related to food, water, and energy security. Human health is also a major concern, and food quality and consumption thus become important issues. Accordingly, the main purpose of this research was to measure the capacity of soil to meet nutrient requirements for human health in Korea. The bases for assessment of nutrient requirement are national dietary reference intake (DRI) values, total amounts of crops and food consumed, total annual crop production, and nationwide soil fertility values. The national nutritional requirements for the total population were calculated from the DRI, and the mass of nutrients that soil can supply to plants or humans was calculated based on national average concentrations of nutrients and cultivation areas. Total production and consumption of crops and food were estimated from a national database. Results showed that the nitrogen in Korean soil can meet 32–48 % of the Korean protein demand, and soil potassium can supply about 28–69 % of Korean dietary recommendations for nutrient intake. In contrast, all of the calcium and magnesium needed by Koreans was provided by soil. The primary conclusion of this research was that soil plays an important role in providing nutrients for human health and that soil security needs to extend to soil welfare.

Keywords Soil capacity • Human nutrition • Soil welfare • Plant welfare • Security

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26.1 Introduction

Human health depends on physical, mental, and social factors (Brevik and Sauer 2015; Singh 2009). In order to meet the needs of human physical and mental health, a proper nutrient supply with good quality of food is necessary. However, improper agricultural category management and increased soil degradation can decrease high-quality food production. Therefore, food security is required to ensure an adequate, nutritious, and safe food supply that meets human dietary needs (Brevik 2009).

Soil also plays an important role in human health in terms of food production. Nutrients and minerals in soil are essential for crop production and human intake from food directly or indirectly derived from soil. Consequently, nutrients supplied for human health are strongly linked with soil nutrients and minerals (Watson et al. 2012).

Recent studies reported that over 4.5 billion people suffer from micronutrient malnutrition in both developing and developed countries (Stein 2010; WHO 2003; Frossard et al. 2000; Welch 2008). Among various micronutrients, 2 billion people have iron deficiency, followed by 1.5 billion people deficient for iodine, and 0.8 billion for zinc and selenium. This human micronutrient malnutrition is related to nutritional deficiency in crops or livestock (Watson et al. 2012). Consequently, lack of macro- and micronutrients in soil can lead to decreased crop productivity.

The main purpose of this study is to show the link between soil security and human health. With the assumption that nutrient amounts in soil are strongly related to crop production and that human health is dependent on nutrient intake from crops, vegetables, and meat, this study provides examples of the capacity of soil to meet nutrient needs and methods for their assessment.

26.2 Materials and Method

26.2.1 Data Collection and Analysis

In order to determine the capacity of soil to meet human nutrient requirements in Korea, information about soil properties and nutrient values was collected from a nationwide database. Average values for soil chemical properties were provided by the National Academy of Agricultural Science (NAAS). Soil chemical properties in agricultural areas, categorized by paddy, upland, orchard, and greenhouse, have been monitored every 4 years since 1998 under a national program entitled: "Monitoring project on agri-environment quality in Korea." Information collected on soil chemical properties was entered into an NAAS database and retrieved when needed.

Food balance information provided by the Korea Rural Economic Institute (Food Balance Sheet 2014) and dietary reference intake for Koreans (KDRI) published by the Korean Nutrition Society (2014) were used. KDRIs are reference values for nutrient intake by Koreans that are considered essential to maintain optimal health and prevent chronic disease and excess nutrient intake. The KDRIs include the Estimated Average Requirement (EAR), Recommended Intake (RI), Adequate Intake (AI), and Total Upper Intake Level (UL). The EAR is the daily nutrient intake estimated to meet the requirement of half of apparently healthy individuals in a target group and is set as the median of the distribution of requirements for estimation of values.

26.2.2 Analysis Protocols

Calculation of the capacity of soil to meet nutrient requirements of Koreans required several steps. The first step was to estimate the required nutrient amount for individuals from the EAR value. In order to calculate nutrient needs (protein, phosphorus, potassium, calcium, magnesium, iron, etc.), average amounts of daily intake were determined. The second step was to calculate the amount of agricultural food consumed by individuals. Eight representative categories of food, including cereals, starchy roots, sweeteners, pulses, tree nuts, oil crops, vegetables, and fruits, were selected, and the amount available to individuals in Korea was determined. The third step was to calculate the total nutrient supply from food for the total population in Korea and the amount of nutrient supply per individual. The fourth step was to consider the nutrient values in soil. The chemical properties of soil, including quantities of Ca, Mg, K, P, Zn, Cu, and organic matter, were retrieved from the NAAS database. Land use was also considered, categorized by paddy, upland, orchard, and greenhouse, and total available nutrients in soil were calculated. Soil density and depth were assumed to be 1300 kg m^{-3} and 0.15 m, respectively.

26.3 Results and Discussion

The average amount of daily nutrient intake by age in Korea is summarized in Table 26.1. The total population of Korea was estimated at 50,891,000 according to a 2013 census, and the average amount of protein was 13.5–60 g day^{-1}, depending on age. The recommend dietary allowance of protein in the USA ranges between 11 and 56 g day^{-1} depending on age, and the daily intake in Korea is slightly higher (Otten et al. 2006). Other minerals such as Ca, Mg, Fe, and Zn showed similar values, with slightly higher amounts for Koreans compared to the USA.

The annual amount of agricultural products consumed was investigated, in order to calculate nutrient amounts supplied from crops and vegetables. Figure 26.1 shows the amount of agricultural products consumed by individuals from the 1980s to 2013. Categories of food products included meat, fruit, vegetables, wheat, and rice. Of these, vegetables were the category most consumed by Koreans, followed by

Table 26.1 Average daily nutritional intake in Korea by age according to 2013 census. Value of nutrient is recommended intake for Korean of each age

	Age	Population (thousands)	Protein	P	K	Ca	Mg	Fe	Zn
			g/day						
Infants	0–5 months				0.4				
	6–11 months	451	13.5		0.7			7	2.5
Boys	1–2	940	15	500	2.5	500	75	7	3
	3–5	1410	20	500	3.0	600	100	7	4
Male	6–8	710	25	700	3.8	700	140	9	5
	9–11	826	35	1000	4.7	800	200	12	7
	12–14	997	50	1000	4.7	1000	300	12	8
	15–19	1473	60	1000	4.7	1000	400	16	10
	20–29	3848	55	700	4.7	700	340	10	10
	30–49	8698	55	700	4.7	700	350	10	9
	50–64	5046	50	700	4.7	700	350	10	9
	65–74	1659	50	700	4.7	700	350	10	9
	Over 75	776	50	700	4.7	700	350	10	8
Female	6–8	660	25	600	3.8	700	140	9	5
	9–11	758	35	900	4.7	800	200	12	7
	12–14	912	45	900	4.7	900	280	12	7
	15–19	1314	45	800	4.7	900	340	16	9
	20–29	3514	45	700	4.7	700	280	14	8
	30–49	8348	45	700	4.7	700	280	14	8
	50–64	5061	45	700	4.7	800	280	9	8
	65–74	1988	45	700	4.7	800	280	9	7
	Over 75	1493	45	700	4.7	800	280	9	7
Total		50,891							

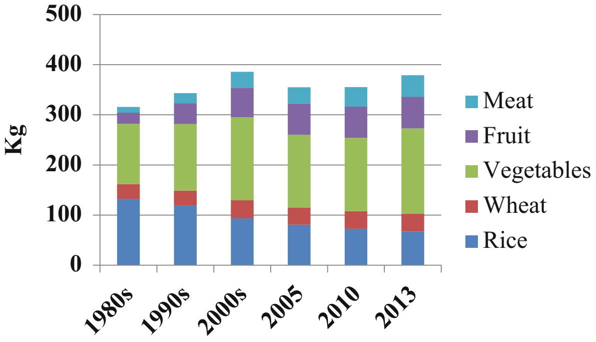

Fig. 26.1 Amount of agricultural products consumed per capita

rice, fruit, meat, and wheat. In 2013, the total per capita amount of vegetables consumed was estimated at 170 kg per year.

The annual recommended nutrient intake was calculated. However, not all nutrients can be supplied by vegetables and crops. Therefore, the total distribution of nutrients derived from crops and vegetables was assumed to be 47 % of protein and 79 % of other nutrients. The total annual intake amount of protein is about 404,709 tons, followed by potassium (66,299 tons), calcium (10,639 ton), and phosphorus (10,369 ton) (Table 26.2).

The next step was to determine the self-sufficiency ratio (SSR) for vegetables and crops. The SSR for eight selected food products is summarized in Table 26.3. The SSR ranged from 10.4 % to 97.5 %, depending on the product, with the highest SSR for sweeteners, followed by starchy roots and vegetables (Tables 26.3 and 26.4).

The average concentration of nutrients in soil was retrieved from the national soil database. Phosphorus concentration in upland, orchard, and greenhouse is about 5.5 times higher than in paddy soil. Potassium concentration in upland and orchard is about 2.5–3 times higher than in paddy and greenhouse soil. Concentration of Ca, Mg, and Zn in the greenhouse category is higher than in the other three agricultural types.

Table 26.2 Total intake amount of nutrition in Korea (unit: tons/year)

	Protein	P	K	Ca	Mg	Fe	Zn
Recommended intake	404,709	10,369	66,299	10,639	4292	160	117

Nutrient distribution from food was considered to be 47 % protein and 79 % others

Table 26.3 Calculated total nutrient supply according to self-supply ratio (SSR) of each products in Korea

Product	SSR (%)	Nutrient (g/day)						
		Protein	P	K	Ca	Mg	Fe	Zn
Cereals	22.9	131,835	4844	6553	166	2322	16	37
Starchy roots	95.9	15,149	302	2155	74	131	4	9
Sweeteners	97.5	175	–	–	34	–	4	–
Pulses	10.4	15,607	141	216	85	28	4	1
Tree nuts	57.6	2535	135	250	22	86	1	1
Oil crops	29.3	1788	58	–	93	–	1	1
Vegetables	89.7	102,733	5223	14,264	2038	670	72	20
Fruits	76.1	11,065	309	3402	135	197	10	2
Total		280,887	11,012	26,840	2647	3434	112	71

Table 26.4 Average concentration of nutrients in soil

		Paddy	Upland	Orchard	Greenhouse
P	mg/kg	130.0	607.0	600.0	598.2
K		117.3	320.6	363.6	135.1
Ca		2040.0	2440.0	2440.0	4240.0
Mg		315.9	534.6	434.9	850.5
Zn		4.6	10.9	17.8	25.5
Organic matter	%	2.7	2.7	3.8	3.6

Average value was retrieved from soil database provided by Korea Rural Development

Table 26.5 Total available nutrients in soil considering average soil density (1300 kg m^{-3}) and depth (15 cm)

	N	P	K	Ca	Mg	Zn
Soil (mg/kg)	132,446	152,568	18,403	900,636	168,159	3504

Total available concentration of each nutrient was calculated by soil bulk density, field area, and soil depth (Table 26.5). Available nitrogen concentration was calculated based on organic matter concentration (Rashidi and Seilsepour 2009).

Three main values, including total nutrient intake, total nutrient supplied by eight representative crops, and total available nutrients in soil, were calculated, in order to estimate the capacity of soil to meet human health needs. Among six nutrients, the total amount of nitrogen and potassium in soil is less than that required for human health and also less than that required for crops. Only 32–48 % of the total amount of nitrogen required for crops and human health is present in soil. Similarly, only 28–69 % of the potassium required for crops and human health is present in soil. This suggests that the concentration of nitrogen and potassium in soil is not sufficient to supply the required nutrient value for both crops and human health. Consequently, fertilizer management for nitrogen and potassium content might be required. However, the total amount of other nutrients such as phosphorus, calcium, magnesium, and zinc is sufficient in soil. This might indicate that either fertilizer was overused or the uptake of nutrients by crops was minimal.

26.4 Conclusions

Sustaining good health is always a major concern and various factors can affect human health (Gupta and Gupta 2014). Accordingly, the link between soil security and human health was investigated in this study. Assuming that the transfer of nutrients from soil to humans is important, and that many essential human nutrients originating in soil are passed through the food chain, this study calculated the capacity of soil to fully provide nutrients required for human health in Korea. Results showed that the total amounts of nitrogen (32–48 %) and potassium (28–69 %) in soil were not sufficient to support crop production and human health. However, other nutrients such as phosphorus, calcium, magnesium, and zinc were fully supplied by soil. Nutrient amounts in soil are mainly affected by fertilizer management. In other words, managing soil fertility with integrated nutrient management can lead to sustainable agriculture and eventually provide sufficient nutrients to sustain human health. Soil is an important resource and plays a major role in human health. In order to maintain a high level of human health, adequate management of soil quality is necessary.

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Chapter 27

The Meta Soil Model: An Integrative Multi-model Framework for Soil Security

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Abstract The profound human-centric dominance in the Anthropocene has created changes in land use, biomes, climate, food networks, economies, and social communities, which in turn have impacted global resources, such as food, energy, and water, as well as the soils, that humanity and other terrestrial life-forms depend on for survival. We posit that a new *integrative science* is needed to support *global soil security* that facilitates improved soil synthesis of data, knowledge, understanding, experiences, beliefs, values, and actions related to soils considering multiple perspective dimensions, such as soil-environment, soil-politics, and soil-human. *Integrative soil security* – a new term we coin in this paper – is based on (i) integration of individual and collective human needs, uses, values, beliefs, and perceptions of soils coalesced with (ii) quantitative knowledge of soils derived through empirical observation and quantitative analysis as well as (iii) systems that soils are embedded in (e.g., economic, political, social, and legal systems). We propose a Meta Soil Model (MSM) that is rooted in integral theory and integral ecology as the foundation for a new *integral soil security* with cognizance as the key integrator. We define an MSM as an integrative, multi-model framework to assess soil security within the context of regional and global human-environmental interactions. The MSM fosters enactment for securing soils rooted in inter-, trans-, and post-(integral) disciplinary thinking and allows to diagnose integration gaps, such as the values and beliefs people hold about soils and scientist's observations, data, maps, and models of soils, ultimately constraining global soil security.

Keywords Meta Soil Model • Soil security • Integration • Integral theory • Integral ecology • Multi-model

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27.1 Significance and Rationale

The terrestrial biosphere has made the transition from being primarily driven by natural biophysical processes to an anthropogenic biosphere shaped primarily by human systems in the latter half of the twentieth century (Ellis 2011). This profound human-centric dominance in the Anthropocene has created changes in land use, biomes, climate, food networks, economies, and social communities, which in turn have impacted global resources, such as food, energy, and water, as well as the soils, that humanity and other terrestrial life-forms depend on for survival (Amundson et al. 2015) (Fig. 27.1). As such, human security depends on the health/state of these resources. Generally, security denotes the state of being free from danger or threat (King and Murray 2001). Hence, securing soils can be defined as the freedom from risks of losing (i) a specific or a group of soil functions, (ii) goods and services that soils provide to benefit humans and – in its broadest sense – (iii) sustainability of life on Earth. Unfortunately, there is no absolute threshold or method that can classify a soil as "secure" or "insecure." Here we advocate a relative view along a spectrum of soil security-insecurity with the tendency, likelihood, or possibility to be in a present state of "more" or "less" secure.

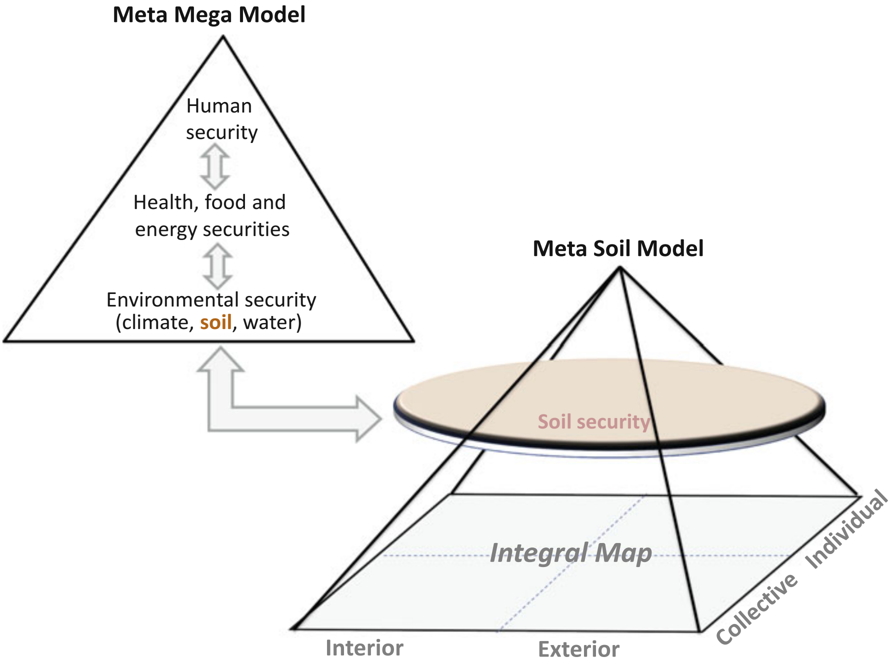


Fig. 27.1 Nested hierarchical structure of different securities with soil security placed within environmental security. Soil security serves to support other securities, such as health, food, and energy security, which are encompassed holonically by human security

The risk of losing soil security is tied to the fact that soil resources are finite (Schmidtz and Willott 2012; Oliver and Gregory 2015). The competition among uses is amplified as the specific needs (e.g., food and fiber production, bioenergy, biodiversity, recreation, preservation of natural beauty) increase, often at the expense of soil degradation. We assert that to achieve soil security depends on the vulnerability and resilience of soil and soil-ecosystems. Adger (2006) described vulnerability as "the state of susceptibility to harm from exposure to stresses associated with environmental and societal change and from the absence of capacity to adapt." Resilience has emphasized the elasticity and capacity of an ecosystem to recover from threat, stress, or continued sustained use (Folke 2006). Noteworthy, processes and response feedbacks to soil-ecosystems have accelerated in the Anthropocene jeopardizing both the resilience and sustainability of soil-ecosystems at local, regional, and global scales (Grunwald et al. 2011).

Given the complexity underlying soil security – namely, risk, vulnerability, resilience, and sustainability of soil and soil-ecosystems – an integrative framework is needed that allows us to harmonize human, soil, and ecosystem dimensions. Such an integrative framework goes beyond individualized and compartmentalized research assessing specific soil properties (e.g., soil organic carbon), soil processes (e.g., decomposition), soil functions (e.g., storage of nutrients), soil quality (e.g., aggregation of multiple soil properties), soil maps (e.g., assessment of the spatial distributions of soil properties), or soil models (e.g., assessment of soil change). These individual components of soil security are all critically important, yet individually they fall short to assess soils in a holistic manner. There are silos of studies of soils that have focused in depth on assessing separately the condition, capability, capital, codification, and connectivity – identified as the core dimensions of soil security (McBratney et al. 2014). These five dimensions of soil security have been described conceptually but at this point in time lack explicit quantification and integration. We posit that a new integrative science is needed to support global soil security that facilitates improved soil synthesis of data, maps, knowledge, understanding, interpretations, beliefs, values, and actions considering multiple perspectives, such as soil-environment, soil-politics, and soil-human. In ecology, synthesis has been recognized as a key integrative concept, and it occurs when disparate data, concepts, or theories are combined in ways that yield new knowledge, values, insights, understanding, or explanations (Pickett et al. 2007; Peters 2010). Science integration is the process by which insights are incorporated or assimilated into an individual's and society's worldviews, e.g., to improve soil quality (Grunwald et al. 2015). Therefore, *integrative soil security* – a new term we coin in this paper – is based on (i) integration of individual and collective human needs, uses, values, beliefs, and perceptions of soils coalesced with (ii) quantitative knowledge of soils derived through empirical observation and quantitative analysis as well as (iii) systems that soils are embedded in (e.g., economic, political, social, and legal systems). In short, *integrative soil security* is based on the human domain + assessment/quantification of soils and soil-ecosystems. Integration linking soil models across temporal and spatial scales is still in its infancy (Grunwald et al. 2011). Yet, they are urgently needed to connect pedon and global soil-ecosystems and assess their

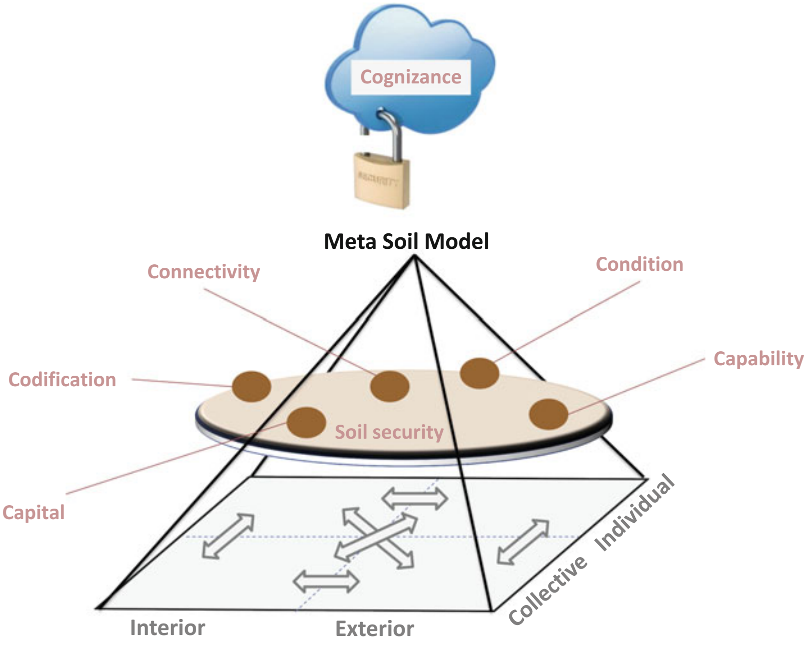


Fig. 27.2 Conceptual relationships between the integral soil security model that provides the foundation for the Meta Soil Model (MSM), the five dimensions of soil security as defined by McBratney et al. (2014) and cognizance (i.e., the sixth dimension of soil security). Note that the four quadrants of the integral model (shown in *gray*) are clearly discernible perspective dimensions that interact with each other and are revealed through cognizance arising within and across quadrants. It formalizes the MSM structure and can be applied to diverse soil security problems. The five dimensions of soil security (shown in *brown*) are not placeable in a specific quadrant because they are ambiguous dependent on their implementation

change and evolution through time. In this chapter, we adopt integral theory (Wilber 2000a, b) and integral ecology (Esbjörn-Hargens and Zimmerman 2009) as the foundation for a new *integrative soil security*. We propose a Meta Soil Model (MSM) that is rooted in integral theory with cognizance as the key integrator (Fig. 27.2). Cognizance describes the knowledge, awareness, and perceptions held by individuals and people (communities) interacting with soil-eco and other systems that pertain to secure soils. Hence, without cognizance there is no tight integration among the five Cs (condition, capability, capital, codification, and connection) proposed earlier by McBratney et al. (2014). Cognizance brings forth clarity and insight to wisely act, decide, and manage a soilscape due to intrinsic motivation to secure soils and derive other benefits and services that depend on them (e.g., food production, filtration of endocrine disruptors, carbon storage, preservation of biodiversity, and human livelihood). This point is often overlooked because simple awareness that a soil is degraded or limited in some way or another to provide a specific function or benefit (e.g., maximize crop yield) will not invoke people to act and improve and secure soils. We argue that a deep understanding or cognizance of soils and their inherent value in providing water, food, human, and other securities evokes *action*. Importantly, it is the awareness of the integrated nature of resources that motivates people to secure our common future. These ethical underpinnings of soil security are at the forefront in the Anthropocene that calls forth integration and synthesis. The MSM framework facilitates soil-ecosystem, soil-human, soil-education, soil-technology, and other syntheses. It explicitly uses integration trajectories connecting the different perspective dimensions of soil security to create the MSM structure. Our objectives are to:

1. Formalize the MSM as the underlying integrative multi-model framework for soil security.
2. Demonstrate the value of integral theory and integral ecology to create MSMs that assess soil security.

27.2 Approach

27.2.1 What Is the Meta Soil Model

At its core, the MSM can be defined as the process of synthesis in which disparate data, concepts, or theories are integrated in ways that yield new knowledge, insights, or understanding. The term meta ("after," "beyond," "self") is used to indicate a concept that is an abstraction from another concept (Grunwald 2014). Meta models are typically nested holonically. The MSM consists of coupled data of data and models of models describing soils of soilscapes embedded within systems of systems. Wilber (2000b) posited that reality as a whole is composed of holons. A holon is something that is simultaneously a whole and a part. For example, a molecule is part of an aggregate, and soil aggregates are part of a pedon, and pedons make up soil-landscapes, and so on. Yet, from another perspective molecules are a whole with their own agency and purpose. In essence, multi-models are composed of holons that are spatially nested, coupled, and interconnected in hierarchical fashion that change through time.

Meta models are prominent in computer science where coupled frameworks enable complex data analysis, knowledge integration, and big data processing (Beckman et al. 1998; Ford et al. 2006) and ecology (Larson et al. 2005). Meta modeling is not limited to quantitative applications but has also been extensively used in conceptual, descriptive, and qualitative ways. For example, Edwards (2008) presented an overview of integral meta-studies and emphasized that meta-theorizing is essential to move from single disciplinary to multi-, cross-, inter-, trans-, and post-disciplinary projects. Since soil security is not isolated from other securities (food, energy, human, etc.) a meta model structure is essential to take the leap from a classical soil-centered view (Koch et al. 2013; McBratney et al. 2014) to a more open view that embraces partnerships with other disciplines. Meta modeling has been applied in a large number of ecology-oriented studies synthesizing across domains and disciplinary boundaries. For example, Ostrom (2009) analyzed the sustainability of complex social-ecological systems adopting a multilevel, nested framework. Therefore, we define an MSM as an integrative, multi-model framework to assess soil security within the context of field, regional, and global human-environmental interactions and various systems. Importantly, the MSM includes (i) human (individual and collective perspectives of land use managers, stewards of soils, and beneficiaries of goods and services derived from soils) and (ii) environmental analytical perspectives (i.e., individual and collective views of soil particles, pedons, soilscapes, and their interactions with other biophysical, biochemical, social, economic, and other system domains). Grunwald et al. (2015) presented a MSM fusing soil, soil spectral, and remote sensing data to model soil properties for the purpose of soil quality and soil change assessment. They provided an overview of different integration pathways that fuse, synthesize, and integrate various soil-environmental data and methods/models into something bigger than single soil properties. Similarly, other MSMs can foster the integration of data, methods/models, and systems to support *integrative soil security*. In summary, this integral theory-inspired MSM framework facilitates soil, soil-ecosystem, and soil-human system syntheses based on formalized integration trajectories.

27.2.2 From Integrative to Integral Soil Security: Integral Ecology

The MSM enacts soil security through inter- and transdisciplinary (*integrative soil security*) and post-disciplinary (*integral soil security*) studies. The integration process of *integral soil security* is anchored in integral theory (Wilber 2000a, b) that interlinks four quadrants (Fig. 27.3): (i) *individual-interior* comprising subjective experiences of the soil-environment through our sense perceptions, (ii) *collective-interior* (i.e., culturally flavored communication that impact soil security, values, and beliefs of groups of people about soils and nature), (iii) *individual-exterior* (i.e., soil attributes, soil management, soil use, soil processes, etc.), and (iv) *collective-exterior* comprising political, social, environmental, legal, economic, eco-, and other systems (e.g., global and national governance structures, soil-related policies, financial resources provided to secure soils, etc.). These four quadrants are referred to as “I,” which represents first person perspective (upper left quadrant (UL)); “We,” the second-person perspective (lower left quadrant (LL)); “It” (upper right quadrant (UR)); and “Its” (lower right quadrant (LR)). The latter two represent third person perspective in the integral model and are often referred to as AQAL (all quadrants, all levels and lines) by Esbjörn-Hargens (2005). These four quadrants represent *perspective dimension* that interact with each other dynamically and evolve to higher and more complex levels along developmental lines. According to Esbjörn-Hargens (2010) the four *perspectives* of integral theory (i.e., subjective, UL; intersubjective, LL; objective, UR; and interobjective, LR perspectives, Fig. 27.3) are

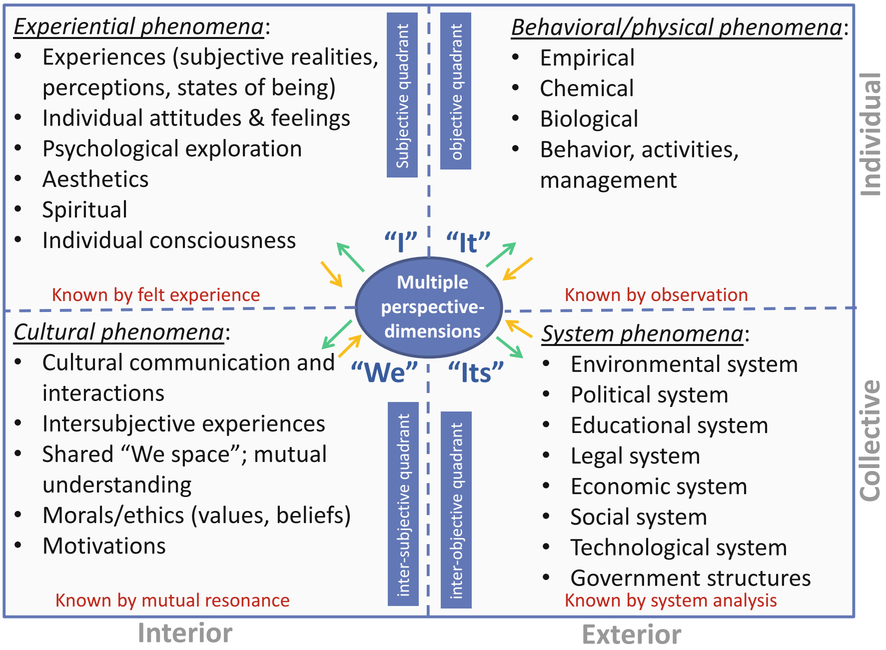
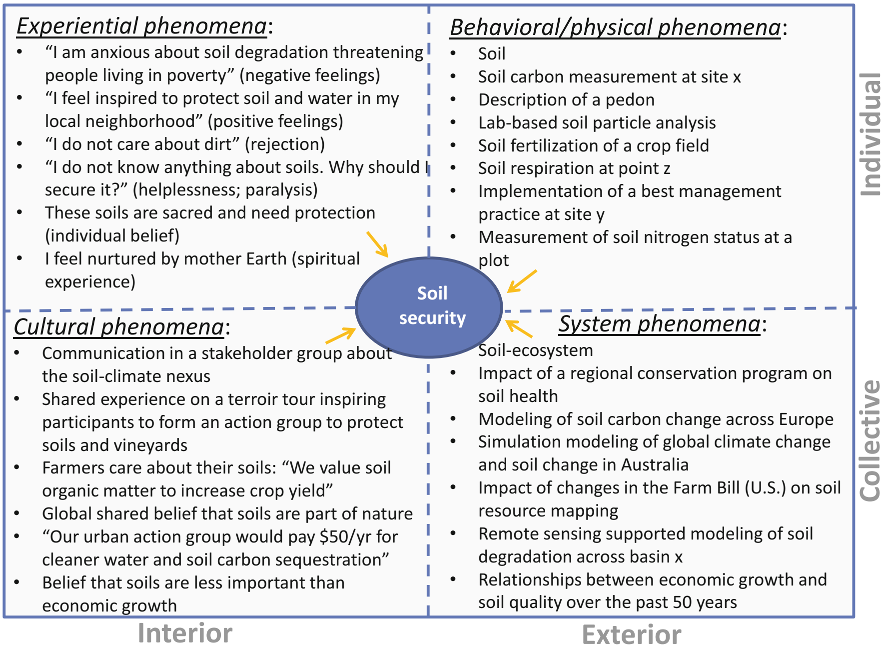


Fig. 27.3 Overview of the integral model consisting of four quadrants (perspective dimensions): individual-interior ("I"), collective-interior ("We"), individual-exterior ("It"), and collective-exterior ("Its") (After Wilber 2000a, b; Esbjörn-Hargens and Zimmerman 2009). The *green arrows* pointing out represent an individual placed in the center of the integral map (quadratic approach) viewing, perceiving, and understanding the dimensions of each quadrant. The *orange arrows* pointing to the center depict an issue/problem placed in the center of the integral map (quadrivia approach) using different methodologies to disclose the perspectives of each quadrant

irreducible and must be consulted when attempting to fully understand any issue or aspect of reality. This suggests that soil security cannot be fully understood through a one-dimensional approach that assesses only the conditions of soils or the capability of soils. For example, even if a given soil map or soil capability assessment is highly accurate and precise, it would not necessarily secure soils. The limitation of such a reductionist approach is that it does not necessarily consider the perspectives and values from all stakeholders or groups, such as land stewards, knowledge brokers, politicians, urban dwellers, and the general public (see left-hand quadrants, UL, and LL in Fig. 27.4). Examples of different perspectives and quadrants applied to soil security are presented in Fig. 27.4.

Wilber (2000b) adamantly advocates avoiding the reduction of one of the perspective dimensions into the other – what he calls "flatland." For instance, the attempt to reduce interiors to their exterior correlates (i.e., collapsing subjective and intersubjective realities into their objective aspects) leads to incomplete attempts to address an issue as complex as soil security. However, this is prevalent in soil science studies that map, quantify, model, and simulate soils ignoring people's felt



Experiential phenomena:

- "I am anxious about soil degradation threatening people living in poverty" (negative feelings)
- "I feel inspired to protect soil and water in my local neighborhood" (positive feelings)
- "I do not care about dirt" (rejection)
- "I do not know anything about soils. Why should I secure it?" (helplessness; paralysis)
- These soils are sacred and need protection (individual belief)
- I feel nurtured by mother Earth (spiritual experience)

Behavioral/physical phenomena:

- Soil
- Soil carbon measurement at site x
- Description of a pedon
- Lab-based soil particle analysis
- Soil fertilization of a crop field
- Soil respiration at point z
- Implementation of a best management practice at site y
- Measurement of soil nitrogen status at a plot

Cultural phenomena:

- Communication in a stakeholder group about the soil-climate nexus
- Shared experience on a terroir tour inspiring participants to form an action group to protect soils and vineyards
- Farmers care about their soils: "We value soil organic matter to increase crop yield"
- Global shared belief that soils are part of nature
- "Our urban action group would pay $50/yr for cleaner water and soil carbon sequestration"
- Belief that soils are less important than economic growth

System phenomena:

- Soil-ecosystem
- Impact of a regional conservation program on soil health
- Modeling of soil carbon change across Europe
- Simulation modeling of global climate change and soil change in Australia
- Impact of changes in the Farm Bill (U.S.) on soil resource mapping
- Remote sensing supported modeling of soil degradation across basin x
- Relationships between economic growth and soil quality over the past 50 years

Fig. 27.4 A quadrivia of soil security with examples of different perspectives (individual-interior, collective-interior, individual-exterior, and collective-exterior) for each of the quadrants in the integral model. The quadrants interact with each other as visualized by the *dashed lines*. Different methodologies are used in each of the quadrants to understand soil security through different perspectives ("vantage points")

sense of first- and second-person experiences which has led to ignorance, nonaction, paralysis, delusion, or helplessness toward securing soils. The integral map reveals gaps and disconnects between quadrants that cause soil security problems. Participatory approaches that link right and left quadrants are most valuable to create MSMs. For example, Chaikaew (2014) built a meta model using Bayesian belief networks to integrate multiple perspective dimensions to assess three different ecosystem services and benefits in a multifunctional region with diverse soil conditions. Bouma et al. (2012) pointed out that sharing experiences of experts with citizen groups creates more awareness and links soil information and policies that foster soil security which in essence integrates across quadrants of the integral map.

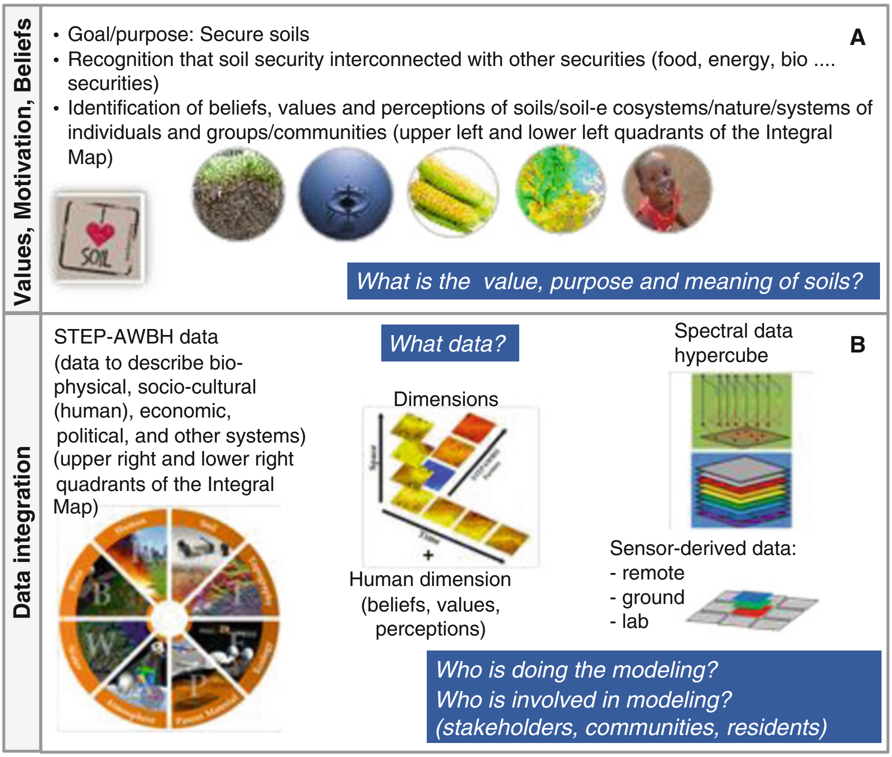
Integral theory allows viewing of the integral map based on two contrasting approaches. The "quadratic approach" depicts an individual situated in the center of the quadrants where he/she perceives reality (nature) as a result of his/her own embodied awareness. Here the individual is placed in the center of the integral map and has direct access to experiential, behavioral, cultural, and social/systemic aspects of reality because these are actual *dimensions* of his/her own existence (Esbjörn-Hargens 2010). This empowers him/her to cognize the world more intimately which subsequently evokes him/her to care and thus act in ways that are insightful. For example, an individual that cognizes the beauty and value of soils as a common global good to sustain soil security and human security is likely to deeply care about soils and is willing to contribute to secure them. In the "quadrivia approach," the different *perspectives* associated with each quadrant are directed at a particular issue (e.g., soil security) that is put in the center of the integral map (Fig. 27.4). Here different methodologies are utilized to learn, understand, and address a complex problem such as soil security. For example, individual experiences (UL) can be disclosed through phenomenology, mutual shared space of groups/communities talking and interacting with each other (LL) can be revealed through hermeneutics or structural analysis (e.g., surveys, questionnaires), the actual conditions of a pedon (UR) can be deducted from empirical observations (e.g., laboratory soil analytics, remote sensing), and the soil-ecosystem interacting with other systems (LR) can be discerned through system theory or simulation modeling (Wilber 2000a; Esbjörn-Hargens 2010).

27.2.3 How to Create a Meta Soil Model?

Grunwald (2014) first proposed the MSM concept. Here we extend the concept to create a MSM using five key questions:

- *Why* is soil security important? (to identify the value and beliefs that people hold about soils)
- *For whom* to secure soils? (to identify the motivations, needs, and purpose of securing soils)
- *What* soil? (to identify what soil characteristics to measure, describe, and experience)
- *Who* participates in the process to secure soils? (to identify key players to use, protect, benefit, and provide knowledge about soils)
- *How* to assess soil security? (to identify how to assess soil security using different methodologies)

To answer these questions, we adopt the integral map to assess soil security using *perspective dimensions* (i.e., the quadrant and the quadrivia approach of integral theory) (Fig. 27.5). First, values, motivations, and beliefs that are underlying the purpose to secure soils are identified from different individuals and groups that represent different *dimensions* of the integral map (Fig. 27.5). Ethics and moral beliefs play a major role in the values attached to soils. This step is often overlooked or ignored by soil scientists but factually the most important one in the process of meta soil modeling. Second, soil and ancillary environmental, social, cultural, and other data and knowledge are assembled to capture different *perspectives* of soil security using the integral map (Fig. 27.5). The data are integrated to create new insight and understanding of the specific soil security problem through synthesis of data of data (e.g., pooling of data and integration of databases). Third, data and methods/models are integrated (e.g., through ensemble modeling, meta-analysis, or meta-theorizing) to create multiple soil realizations derived from different paradigms, where each paradigm presents a different quadrant (e.g., soil data are collected (UR) and digital soil mapping used to assess soil security (LR), the benefits of soils are assessed using a questionnaire among residents (LL), and individual experiences and perceptions related to soils and nature are identified (UL) (Fig. 27.5)). Grunwald et al. (2015) provided a comprehensive overview of integration pathways that fuse/synthesize different data and methods applied to soil-ecosystems that are at play in this meta modeling process. Forth, the MSM creates output that is interpreted and shared with people (Fig. 27.5). Importantly, output of



- Goal/purpose: Secure soils
- Recognition that soil security interconnected with other securities (food, energy, bio .... securities)
- Identification of beliefs, values and perceptions of soils/soil-e cosystems/nature/systems of individuals and groups/communities (upper left and lower left quadrants of the Integral Map)

What is the value, purpose and meaning of soils?

STEP-AWBH data (data to describe bio-physical, socio-cultural (human), economic, political, and other systems) (upper right and lower right quadrants of the Integral Map)

Human dimension (beliefs, values, perceptions)

Sensor-derived data:
- remote
- ground
- lab

Who is doing the modeling?
Who is involved in modeling?
(stakeholders, communities, residents)

Fig. 27.5 Workflow to create a Meta Soil Model. *Panel A*: The values, underlying motivations, and beliefs of individuals and groups/communities in relationship to soil security. These are situated in the individual-interior and collective-interior quadrants of the integral model. *Panel B*: Data integration from all four quadrants of the integral model. Cognizance plays a pivotal role in the identification of data aiming to achieve soil security and becoming aware of humans beliefs, values, and perceptions.

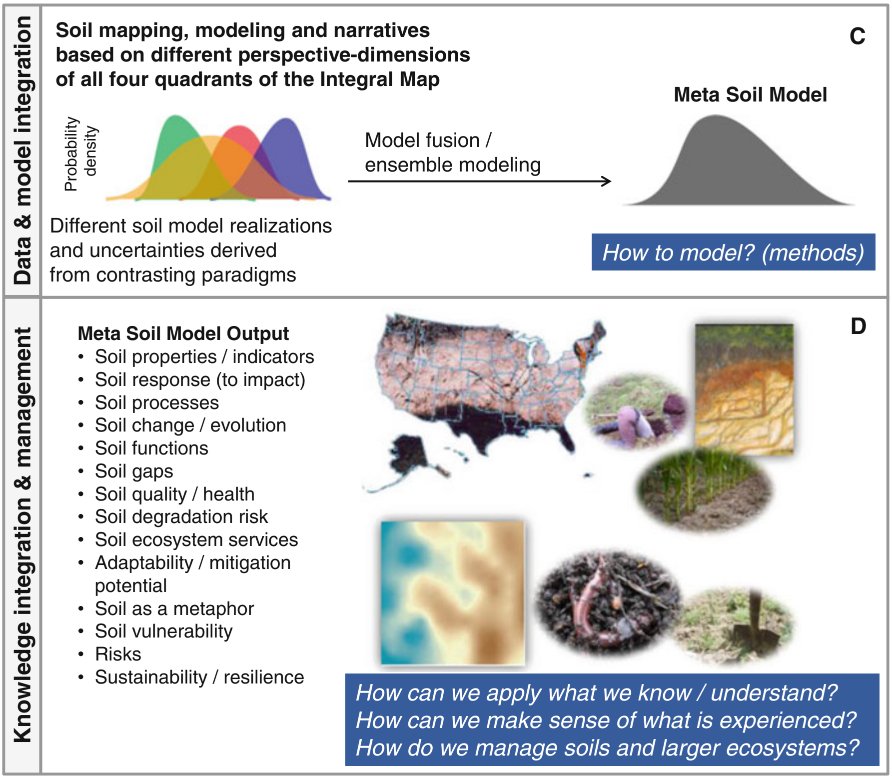


Fig. 27.5 (continued) *Panel C*: Data and model/method integration to build a Meta Soil Model. *Panel D*: The output/response from a specific Meta Soil Model. The output of a Meta Soil Model entails base properties, responses, and processes up to highly integrated metrics such as vulnerability, risks, sustainability, and resilience. The latter outputs derived through the meta modeling process depend on the former more simple metrics

the MSM is not limited to soil functions but includes a whole suite of outputs, such as soil properties, processes, gaps, vulnerability, and narratives customized to a specific soil security application. This is a co-creative process among those who are intricately involved in the development of the MSM and those who inform/provide inputs into the integral MSM that is then used for informed decision-making to secure soils.

27.3 Final Remarks

We believe that integration facilitated through cognizance within and across the integral map is pivotal for securing soils across local, regional, and global scales. Integral ecology and theory, which are both meta-theories, provide a foundation to guide the integration process to secure soils. The paradox is that as we move toward the tip of the MSM revealing risk, vulnerability, resilience, and sustainability of soil and soil-ecosystems, through pluralistic integration of multiple perspective dimensions, we gain clarity through simplicity. We are able to see gaps and disconnects with more clarity (e.g., between soil science models and people's views) that empower us to make wise decisions on how to live and connect with soils rather than to use and exploit soils. Paradoxically securing soils does not depend on understanding the full complexity of soils and "the world" by generating more soil data, finer and more accurate soil maps, and complex process-based space-time simulation models (UR and LR). Rather, global soil security depends on cognizing the values, beliefs, felt experience, and perceptions that all stakeholders have in regard to soil and nature and by harmonizing the cognizance dimension with traditional soils knowledge. *Integral soil security* provides guidance along this path into the future.

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Chapter 28
Integrating New Perspectives to Address Global Soil Security: Ideas from Integral Ecology

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Abstract Global soil security is complex, encompassing technical, socioeconomic, and political issues and people's beliefs and values. Our thesis is that global soil security and the soil health crisis we face today are due to a lack of awareness and understanding of prominent values and benefits soils provide to sustain humanity. In this paper, we use the integral lens to explore global soil security. The integral ecology model uses four interconnected perspectives (the individual-interior, collective-interior, individual-exterior, and collective-exterior) to study wicked environmental issues. We assert that cognizance is the key integrator to bring forth awareness, knowledge, and understanding within and across the four equally important perspectives. It has profound significance for global soil security because it reveals the underlying causes that jeopardize the security of soils and identifies chasms that constrain the sustainability of soil ecosystems. Cognizance is the (i) awareness and perceptions held by individuals and people (interior perspectives), (ii) the facts, knowledge, and understanding of external phenomena (exterior perspectives), and (iii) their interactive effects (i.e., integration across all four perspectives of the integral map). Importantly, cognizance is preceding any other dimension of soil security (connection, codification, capital, condition, and capability). Reductionist approaches that are one-sided (e.g., "soil science will fix the global soil security crisis") ignore people's beliefs and values and are non-cognizant of interconnected perspectives are doomed for failure. Ecological awareness is composed of exterior "scientist/observer/3rd person" qualities and interior "people/subjective" qualities. To achieve global soil security, it is necessary to grow ecological awareness evoking to value, care for, and secure the natural world including soils. Recognizing the

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significance of global soil security is closely linked to moral values and ethical beliefs people hold relative to soils. These beliefs provide the motivation and appropriate actions needed within cultural, social, environmental, and institutional contexts to secure soils.

Keywords Integration • Cognizance • Awareness • Connectivity • Global soil security • Integral ecology

28.1 Significance and Rationale

Globally, soils are at risk to degradation from improper management, erosion, salinization, and desertification, as well as domestication (Amundson et al. 2015). Soil degradation has been recognized as a global existential risk to humanity, and policy for ecological and human sustainable development has not kept pace with rapid growth and development (Koch et al. 2013). Sustainable development has become a universal concern, but the complexity, wickedness, and scale of problems call for new approaches that can overcome specialized, disciplinary thinking that has been prevalent in the soil science community (Bouma and McBratney 2013). Due to the wickedness of complex environmental problems, ecology has brought forth various new integrative frameworks. For example, human ecology bridges the gap between natural and social sciences and studies human-environmental interactions from a "whole-system" perspective (Marten 2008). Likewise, integral ecology aims to integrate human and natural domains with a holistic perspective (Esbjörn-Hargens and Zimmerman 2009). These emerging approaches in ecology have not been recognized in the global soil science community. Yet, they provide transformative potential to synthesize across geographic, environmental, and human domain boundaries.

Lines-Kelly (2004) argues that inherently all humans have a cultural, sensual, and spiritual attachment to soil, but an urbanizing Western society has lost this connection to soils due to a focus on material wealth. This has led to a disconnection from the land and a scientific culture that has fractured soil and its meaning for non-soil scientists. Globally, 54 % of the population lives in urban areas and is expected to increase to 66 % by 2050 (United Nations 2014), and in the United States, out of 249.3 million people, about 80.7 % of the population lives in urban areas and only 19.3 % in rural areas (U.S. Census Bureau 2010). These trends are raising concerns about our ability to secure soils that provide multiple services and benefits to humanity, such as food production, biodiversity and bioenergy, among many others. Most recent frameworks that have been proposed to address global soil security are segregated among dimensions (condition, capability, codification, connectivity, and capital) (McBratney et al. 2014) and are eminently agro-centric. These approaches are still in their infancy to interlink dimensions and inherently lack formalized integration pathways that would bring forth inter- and transdisciplinary approaches to solve the wicked global soil security problem.

Our thesis is that global soil security and the soil health crisis we face today are fundamentally due to a lack of awareness and understanding of prominent values and benefits soils provide to sustain humanity. This has caused threats to the sustainability and resilience of soils to withstand land use, climate, social, cultural, and technological changes that have been accelerating at rapid speed over the past decades. We posit that the core issue of environmental and soil security is due to compartmentalized approaches that are limiting integration. We postulate that cognizance is the key to integrate interactions between (i) our awareness and perceptions that define values and beliefs of people about soils and the natural world in general and (ii) facts, knowledge, and understanding of soils embedded in complex interacting social, economic, cultural, and political ecosystems.

28.2 Objectives

Our aim is to probe into the possible causes that have limited contemporary security of soils at global scale. Our specific objectives are to:

1. Expand the soil security concept to better address integration of the personal, interpersonal, and socioeconomic-political aspects of soil/soil ecosystems through the use of integral theory
2. Explore the critical role of cognizance for global soil security

28.3 Approach

28.3.1 Integral Ecology and Soil Security

We build on the ideas put forth in integral ecology to address the human and environmental aspects of soil security. Integral ecology was developed out of the realization that environmental issues are not only scientific issues but are also human issues that need to be viewed from multiple perspectives to provide adequate solutions (Esbjörn-Hargens and Zimmerman 2009). Here, we utilize the integral theory framework that integrates four perspectives (quadrants): the individual-interior (upper left, UL), the collective-interior (lower left, LL), the individual-exterior (upper right, UR), and the collective-exterior (lower right, LR) (Fig. 28.1; Wilber 2000a). Integral theory facilitates to see beyond disciplinary boundaries, e.g., soil scientists just talking to other soil scientists. Its assets go beyond technical/scientific solutions because it explicitly incorporates cultural, social, regulatory, political, economic, and ecological realms. Therefore, integral ecology is poised to provide a solution-oriented approach to overcome the global soil security crisis.

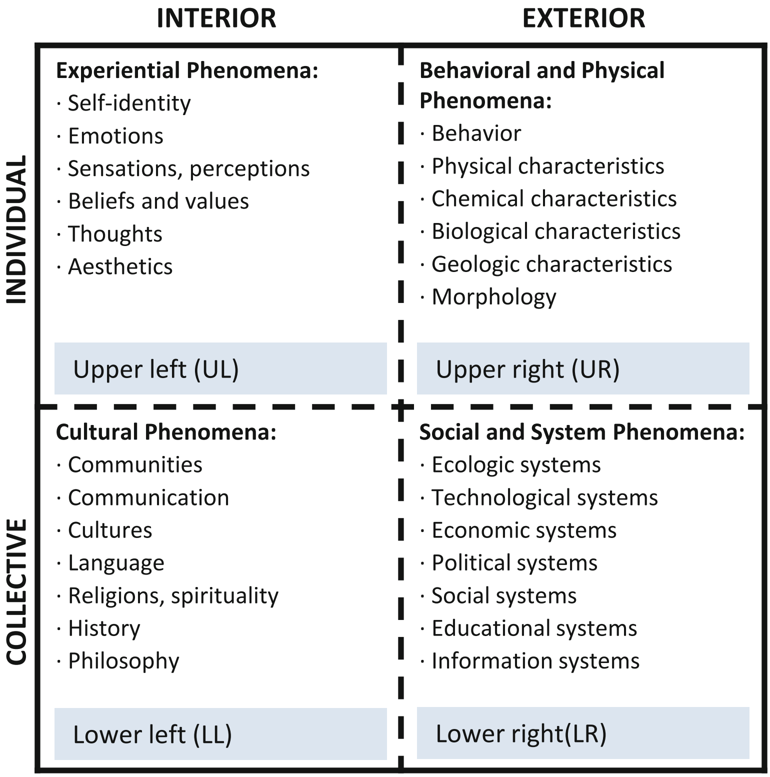

Fig. 28.1 The four perspectives (quadrants) of the integral framework with associated phenomena (After Esbjörn-Hargens and Zimmerman 2009; Wilber 2000a)

According to Esbjörn-Hargens and Zimmerman (2009), the interior space, on the left side of Fig. 28.1, is filled with subjective and intersubjective phenomena, such as selfhood, culture, and morality, which are understood by subjective methods. The UL quadrant is the individual-interior perspective, which can also be thought of as the first-person singular perspective. It represents experiential phenomena related to consciousness, experience, and aesthetics. Garcia (2014) put it bluntly: "Most people are soil blind. They walk on soil, they gaze at it on the horizon, they gain pleasure and sustenance from its bounty, but soil itself goes unseen, unappreciated. Modern life conspires to remove us from any connection to or awareness of soil." The individual-interior perspective can be investigated through introspection and the use of personal accounts, including letters/emails, journals, testimony, and self-reports. Applied to soil security (Fig. 28.2), the individual-interior perspective reveals individual's awareness (sense), perceptions, and experiences related to soils from key individuals in a region facing a soil security problem (e.g., a farmer, urban dweller, scientist, politician, and housewife). Ideally, the perspectives from individuals with different roles, societal function, cultural background, and persona (character traits) are considered. The level of awareness about the importance of

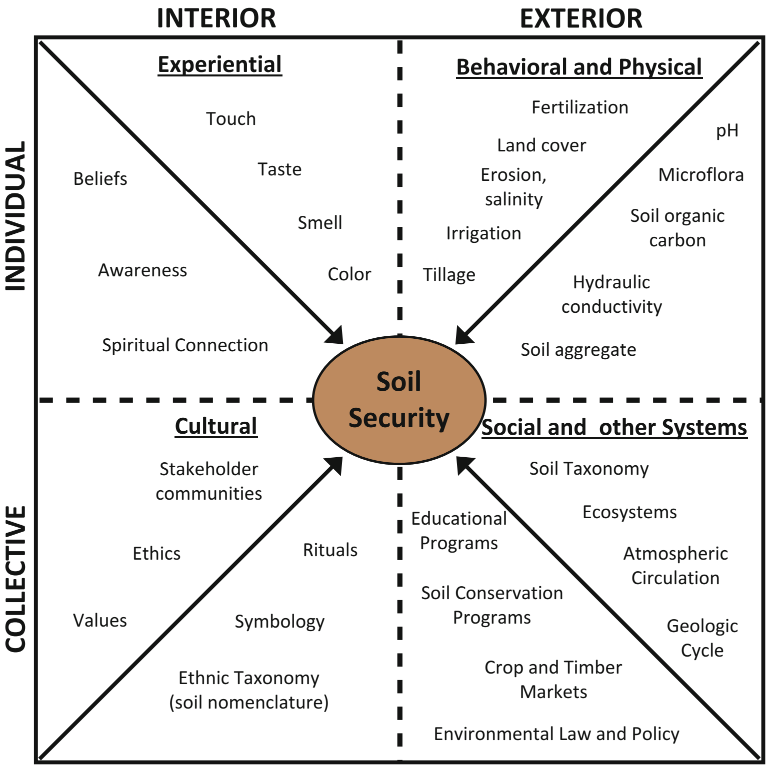

Fig. 28.2 Examples for the four perspectives (quadrants) of the integral model applied to soil security

soils to sustain their families, regional community, and humanity at global scale differs widely. For example, the awareness related to securing soils of an individual in an indigenous community in Peru, in a metropolitan area, or in a farm community is likely to vary depending on their living conditions, cultural setting, and personal family experiences (Postigo 2014). These determine the individual's proximity to soils and the goods, services, and benefits derived from them.

The LL quadrant is the collective-interior perspective, which is akin to the first-person plural perspective, and it represents cultural phenomena related to communication, values, beliefs, ethics, and motivations (Esbjörn-Hargens and Zimmerman 2009; Wilber 2000a). In this "We" perspective, people exchange and share their intersubjective perceptions and thoughts, like being in a "circle of friends" with mutual shared beliefs and understanding (e.g., "we care about this neighborhood or this farmland"). This perspective is resembled by groups and communities, cooperating stakeholders or people that share common interest (e.g., Facebook soil security site). The LL perspective can be investigated through hermeneutics and ethno-anthropologic methods to determine different cultural perspectives including nature, beauty, justice, and fairness (Esbjörn-Hargens and Zimmerman 2009).

Although some research in the field of ethnopedology has examined the individual and cultural values in relationship to the local environment to some degree, these studies have mainly focused on small indigenous or rural communities (Barrera-Bassols and Zinck 2003).

Together, these two left-hand quadrants provide an understanding of how people and communities relate to the environment and how environmental issues affect them. These quadrants disclose moral values and environmental ethical viewpoints that may range from respect for nature ("sacredness"), appreciation of natural beauty, deep connection with nature (e.g., deep ecology), ecofeminism, stewardship, holistic human ecology, indifference about the natural world, dominance of earth, and dissociation from nature (Marten 2008; Schmidtz and Willott 2012; Sessions 1995). Importantly, depending on these individual and cultural flavored values, different views emerge; e.g., soils (i) and the soul touch-evoking sacredness (Patzel 2010) (ii) are perceived as aesthetically sublime (Toland and Wessolek 2010), (iii) specifically farmland soils need to be protected on moral ground to sustain humanity (Fouke 2011), or (iv) are a major wild card in the global carbon cycle (Petit 2012). These ethical views matter, in fact determine, if people are motivated to care and secure soil or not. Values, beliefs, and ethics related to soil, as a common global good, land and nature are profoundly relevant to soil security because they reveal peoples' attitude toward soil health, how soils are used, degradation, protection, and ultimately soil security. The ethical underpinnings toward soil are directly related to the willingness to pay for soil ecosystem services, care about the protection of soils from threats, and motivation to preserve soil resources at global scale (Schmidtz and Willott 2012). Kidd (1992) posits that the attitudes that people hold toward economic growth, sustainability, and humanity determine their motivation to secure common goods, such as soils. In the interior-collective perspective, the awareness of groups and communities toward soils plays a pivotal role in securing them. Hillman (2004) pointed out ten excuses for inaction of people to address the global climate change phenomena, including denial, indifference, dissociation, blame, individualism, and projection onto others. Likewise, demotivation and inaction of people and institutions to secure soils play a crucial role to be explored in the future.

The UR quadrant is the individual-exterior perspective, or the third-person singular perspective, and represents behavioral and physical phenomena known by measurement and empiricism (Fig. 28.1). This perspective examines the characteristics and behaviors of individual objects that form the basis of reductionist fields of science such as chemistry, biology, mineralogy, physics, pedology, and psychology. Here, the exteriors (e.g., a pedon) are seen through a third-person perspective (e.g., a soil chemist investigating decomposition mediated by microbes or site-specific land use management).

The LR quadrant is the collective-exterior perspective or the third-person plural perspective. It represents social and system phenomena, such as economics, politics, climate, education, and ecology and is known by modeling and systems analysis (Esbjörn-Hargens and Zimmerman 2009). In both right-hand quadrants, the cognizance from a third-person (e.g., scientist, investigator, and observer) perspective, which objectifies soils and soil ecosystems, is relevant to infer on soil security. Facts about soils, soil science textbook knowledge, research findings related to soil ecosystems, and their transformation as measured, monitored, mapped, modeled, and simulated fall into this realm. Currently, this is the most prominent perspective voiced by soil scientists around the world. In their totality, the exterior perspectives provide a comprehensive characterization and analysis of the environment within which an issue arises. In summary, the integral framework is multi-perspectival and, thus, provides different interconnected viewpoints to capture the many perspectives needed to fully understand, maintain, and enhance soil security.

28.3.2 Cognizance and Soil Security

The premise of integral ecology and integral theory is that the less perspectives are included in an analysis the more partial our knowledge and understanding (Esbjörn-Hargens and Zimmerman 2009; Wilber 2000a). In fact, they both strive for non-exclusion suggesting that the totality of an issue, such as global soil security, can only be disclosed by including all four perspectives that are interconnected. This is inherently so, because even with “better” available knowledge about soils (e.g., an accurate, fine resolution global soil map, a comprehensive global soil database, or the most precise chemical measurement of a soil aggregate – all LR and UR exterior perspectives), it is unlikely that we could reveal or change people’s values and beliefs about soils. This change in perspective and realization of understanding the global and local threats to soils and their effect on humanity and local communities is rooted in the individual and collective domains of cognizance (UL and LL interior perspectives). Similarly, subjectively perceiving soils from a phenomenological point of view (e.g., taking a striking walk in a national park with beautiful soil landscape) or talking about soils (e.g., in a group of soil enthusiasts) would not bring forth objective measurable facts about soils and soil ecosystems (UR and LR exterior perspectives). Cognizance within the right-hand quadrants is a crucial necessity to disclose knowledge and realize understanding (e.g., soil erosion monitoring, soil health mapping at regional scale, and impact of global climate change on soil carbon sequestration). Generally speaking, cognizance *within* and *across* the four quadrants serves as the key integrator where each perspective is revealed through specific methodologies (approaches) to address a complex problem, such as soil security (Fig. 28.3). We define cognizance as the (i) awareness and perceptions held by individuals and people (UL and LL), (ii) the facts, knowledge, and understanding of external phenomena (UR and LR), and (iii) their interactive effects (i.e., integration across all four quadrants). We assert that cognizance has profound significance for global soil security because it reveals the underlying causes that jeopardize the security of soils and reveals chasms that constrain the sustainability of soil ecosystems. For example, at the moment, there is no legally binding global entity that has power to impose protective regulations onto soils at the national level, even if soils

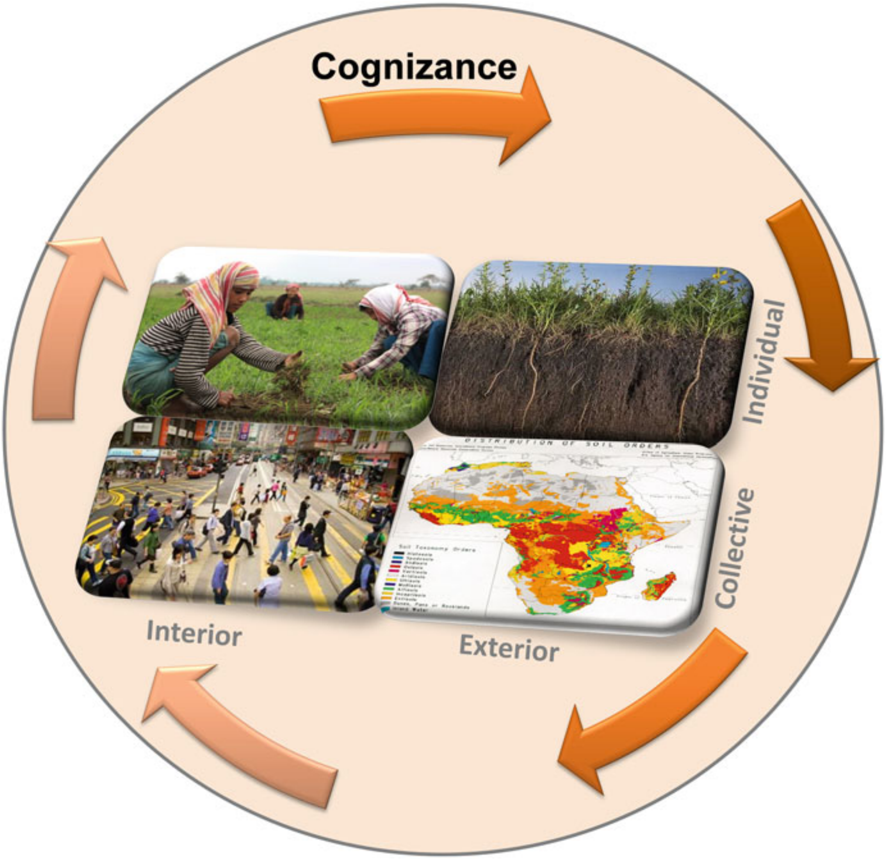

Fig. 28.3 Cognizance serves as an integrator within and across the four quadrants of the integral map: individual-interior, collective-interior, individual-exterior, and collective-exterior perspectives

in a region are not managed in sustainable manner and thus, face severe degradation. Other dichotomies may be cogently revealed among people's valuation of soils that stand in sharp opposition to the actual condition of soils by looking through an integral lens.

Bouma and McBratney (2013) argued for participatory approaches to achieve soil security where knowledge brokers connect stakeholders and policy makers facilitating joined value development. We like to emphasize that cognizance precedes the connection and codification dimensions and not the other way round. Individuals and groups may communicate, participate, and connect but may not be cognizant of an underlying issue constraining soil security. In short, there is no true connection and codification without cognizance. Bluntly speaking, politicians, entrepreneurs, land managers, or others may be completely unaware of their nonactions to secure soils although they may participate in a discussion/meeting about soils. Kahan (2010) pointed to a critical compounding issue related to cultural cognition where people tend to reject scientific information that is not in line with their cultural and moral views. Means to inform the public without threatening their values include presenting information in a manner that affirms their values and having information vouched for by a diverse set of experts that represent multiple perspectives. Understanding how people become aware of environmental issues and why they may reject new information and proposed policy changes is critical to future actions on soil security.

Cognizance is about awareness and congruence that keeps the balance among perspectives as shown in “integral soil security” (Grunwald et al. 2016). This suggests that if one perspective is predominant and overpowers the others, security of soils is threatened. For instance, contemporary soil science research from a chemical, physical, and biogeochemical perspective predominates the global soil science community. Although there are different divisions in the International Union of Soil Science (IUSS), with Div. 1 “Soil in Space and Time,” Div. 2 “Soil Properties and Processes,” Div. 3 “Soil Use and Management,” and Div. 4 “The Role of Soils in Sustaining Society and the Environment” that superficially seem to reflect the four perspectives of the integral model, it is abundantly clear that all of these topics, among them soil-human, soil-sociological, soil-economic, and others, are looked at mainly from a third-person “scientist/observer” exterior (UR and LR) perspective.

Siegel (2012), a world renounced neurobiologist, defines awareness (synonymously with consciousness) as “the fundamental aspect of mental experience with which we have the subjective sense of knowing or being conscious of something.” He suggests that awareness is a process that involves at least three aspects: a subjective felt sense, a knowing, and a known (object). When we share something in awareness with another person, it changes the nature of that experience (e.g., a student-teacher shared experience studying soils). This awareness may include many giving rise to “cultural awareness” or a “collective consciousness.” According to Siegel (2012), awareness is empowering in that it allows a person to have choice, juxtaposes things, and moves us toward integration. Damasio (2000) describes consciousness as the part of mind concerned with the apparent sense of self and knowing (about the world). Both, Siegel and Damasio, stress awareness from interior-individual and collective perspectives, while Greco (2010) describes knowing and understanding from an epistemic perspective (UR and LR). He bases the acquisition of knowledge in epistemic normativity that is different from mere beliefs of people. Importantly, he perceives knowledge as distinctly different from understanding, whereby the latter requires grasping of explanatory and other coherence-making relationships in a large and comprehensive body of information (Greco 2010). This suggests that meaning arises along the trajectory of data, facts, knowledge, understanding (“meaning making”), and clarity/wisdom – all exterior qualities (right-hand quadrants). Wilber (2000b) brings it all together; he points out that consciousness is situated and coevolves in all four quadrants of the integral model. He asserts that human’s self (UL), individual organisms/behavior (UR), culture (LL), and social/environments (LR) cause and are caused by one another; they tetra-evolve. Wilber (2000b) poignantly stresses that if we reduce knowledge gained from an observer/scientist perspective, we lose all values, meaning, and depth falling flat into subtle reductionism. Integral awareness of developmental dynamics and the capacity to take multiple perspectives are crucial elements in achieving behavioral changes and altering our current treatment of the bio- and physiosphere (Esbjörn-Hargens and Zimmerman 2009). Integral ecology stresses that awareness in and across all four perspectives is critical, including exploration of developmental psychology, and its relationship to the self (subjectivity, UL), culture (intersubjectivity, LL), individual organisms, behavior, physical aspects (objectivity, UR), and the systems members is embedded in (interobjectivity, LR). According to Esbjörn-Hargens and Zimmerman (2009), ecological awareness is composed of "knowledge by description" (UR and LR) and "knowledge by acquaintance" (UL and LL) involving transformation (growth) into wider identities where people and communities evolve to higher eco-selves that at higher levels are able to map the complexity of relationships within and between ecosystems and integrate multiple perspectives that evoke to value, care for, and secure the natural world including soils.

28.4 Final Remarks

We ascertain a wide variety of perspectives is needed to solve a problem as complex as global soil security. We demonstrated that cognizance is the key integrator to bring forth awareness, knowledge, and understanding within and across the four equally important perspectives of integral theory to address the complexity of global soil security. Recognizing the significance of global soil security is closely linked to moral values and ethical beliefs people hold relative to soils. These culturally flavored beliefs provide the motivation and appropriate actions needed within cultural, social, environmental, and institutional contexts to secure soils. Raising cognizance and forming partnerships are crucial to build a global community that finds deeper meaning in securing soils that go beyond ivory towers in Australia, the United States, and Europe. Such segregation could be construed as environmental imperialism, which would be detrimental to globally securing soils.

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Chapter 29
Applying the Meta Soil Model: The Complexities of Soil and Water Security in a Permanent Protection Area in Brazil

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Abstract Soil security denotes freedom from risks of losing a specific or a group of soil functions. This case study in the permanent protection area of Sana river (PPA-Sana), Brazil, addresses the relationship between soil security and water security. It explores the soil function "the provision of clean water and its storage, as well as filtering the contamination of water ways." The study also presents a formal way to put soil security into practice applying the meta soil model. Meta soil modeling is built on integral theory that facilitates to understand the complexity of soil, water, and other securities. The soil and water securities in the PPA-Sana are interconnected and at risk. Specifically, one of the main problems is the discharge of soil sediments in the rivers as a consequence of soil erosion. Soil erosion and compaction constrain soil and water security, and these were monitored and mapped in order to provide support for policy interventions. However, our findings suggest that producing better soil maps and more monitoring are not enough to improve soil and water security. On the contrary, awareness building, creating trust among stakeholders, and better integration among quadrants of the integral model would lead to an enhancement of soil and water security. In essence, cognizance (the sixth dimension of soil and other securities) is profoundly important to allow integration of human and biophysical system dimensions.

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Keywords Integral theory • Cognizance • Soil quality • Water quality and ecosystem service • Meta soil model

29.1 Introduction

The concept of soil security has been developed to protect and sustain the valuable soil resources by reframing the importance of soil in context of solving wicked global environmental issues (Grunwald et al. 2015). The term "security" in common usage denotes freedom from various risks (King and Murray 2001). Applied to soil science, we define soil security "as freedom from risks of losing a specific or a group of soil functions."

Many studies in soil science are focused on soil management and conservation. They focus on characterizing the soil's chemical, physical, biological, and morphological properties; soil classes; quality; nutrient contents; carbon storage; biomass; and others. However, soil is an integral component of environmental, economic, social, political, legal, educational, and other systems that show much complexity. Contemporary soil mapping and assessment that describe or quantify soils are not able to assess the full soil functionality, value, and services that soils provide and, thus, fall short to address soil security. Morris (1995), in his book titled *The Political Economy of Land Degradation*, provides us with good lessons about how politics failed to prevent and recover the soil degradation in dryland regions. According to him, the debate about soil degradation had concentrated on the "scientific" identification of problems and the consequent construction of rational and "scientific" solutions. However, "experts" have persistently failed to identify correctly the institutional dysfunctions causing land degradation. Besides, a central plan (top-down decision system) developed by those experts, did not consider the explicit wants and needs of the local peasants and the complexity of their interactions with the nature and the economic and political systems. A more integral view is needed that allows experts, stakeholders, land tenants, land users, and residents to interact and find common ground to share facts about soils, raise awareness of soil-related issues, and find appropriate solution to enhance or optimize soil functions.

Integral theory weaves together the significant insights from all of the major human disciplines of knowledge, including natural and social sciences as well as arts, philosophy, and humanities. In a certain sense, integral approaches are "meta-paradigms" or ways to draw together an already existing number of separate paradigms into an interrelated network of approaches that are mutually enriching. Because integral theory systematically includes more of reality and interrelates it more thoroughly than any other current approach to assessment and solution building, it has the potential to be more successful in dealing with the complex problems we face in the twenty-first century (Esbjörn-Hargens 2009).

Here, we apply integral theory to address the complexity of soil and water security and to show how it is connected to other securities. It explores the soil function "the provision of clean water and its storage, as well as filtering the contamination of water ways." In fact, this soil function is not the only one in the context of the study site; however, considering the importance of the landscape and waterfall in the economy of the region, it can be elected as the most important. We exemplify our integral approach to soil security with a case study from Brazil where both soil and water securities have been threatened.

29.2 Integral Theory

According to integral theory, there are at least four irreducible perspectives or quadrants (subjective, intersubjective, objective, and interobjective) that must be consulted when attempting to fully understand any issue or aspect of reality (Esbjörn-Hargens 2009). The quadrants express the simple recognition that everything can be viewed from two fundamental distinctions: (1) an interior and exterior perspective and (2) a singular and plural perspective. The four quadrants allow investigating an issue (e.g., soil-water security- Fig. 29.1) from four distinct perspectives: (1) the UL (upper left) quadrant that represents the individual-interior perspective in which individuals voice their subjective experiences based on sense perceptions and meaning they derive; (2) the LL (lower left) quadrant which discloses cultural worldspace in which groups and communities of people come together and express their values, beliefs, and perceptions from a collective vantage point; (3) the UR (upper right) quadrant that captures the individual-exterior perspective which can be objectively described through mapping, monitoring, recording, or other empirical observations; and (4) the LR (lower right) quadrant that reveals system perspectives through system theory of interconnected social, economic, political, environmental, and other systems which represent the collective-exterior point of view (Wilber 2000a, 1997). The integral model allows to put ecological problems under the integral lens providing a holistic view because it combines different perspectives – the "I" (UL quadrant), "We" (LL quadrant), "It" (UR quadrant), and "Its" (LR quadrant) (Wilber 2000a, b). Esbjörn-Hargens and Zimmerman (2009) applied Wilber's integral theory to the ecological and environmental realms which brought forth integral ecology. Weichselgartner and Kasperson (2010) asserted that there is broad agreement that more integrative assessments are needed to address global environmental problems. However, there is no consensus on *what* needs to be integrated and *how* that integration should be accomplished. We assert that integral theory and integral ecology are poised to provide a framework for soil security and interconnected securities, such as water security. The integral framework allows integration of multiple perspectives that are populated by distinctly contrasting methods/approaches. This integrative approach disclose a more comprehensive view of soil and water security than any other specialized study that looks at only the conditions or only the capability of soils a study region. Importantly, integral theory and integral ecology aim to integrate our knowledge and understanding within and across all four quadrants. Therefore, the integral approach goes beyond conventional soil and water applications. The quadrants applied in this study contextualizing the soil and water security are shown in Fig. 29.1.

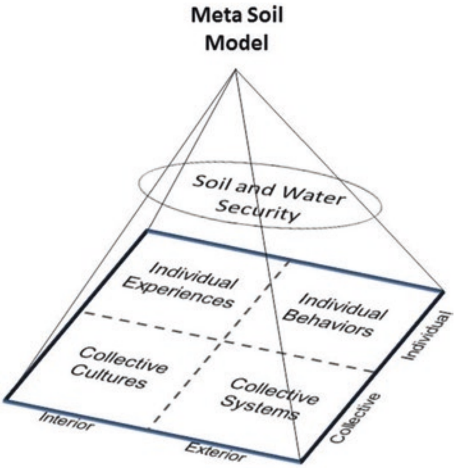


Fig. 29.1 The four quadrants of the integral map derived from integral theory that provides all perspectives to view soil and water security

29.3 Materials and Methods

29.3.1 *The Study Site*

The study site is an ecotourism area called "permanent protection area of Sana river" (PPA-Sana) which is located in the municipality of Macaé, Rio de Janeiro State, Brazil (Fig. 29.2). In the past, the region was covered by a dense rainforest (Atlantic Forest), and according to the Köppen climate classification, the region falls within the "mild temperature with dry and warm summer" (Cwb) class. The PPA-Sana covers an area of 11,802 ha (Sana watershed, Fig. 29.2), and the Sana river has an extension of 20 km. The study focused on the stretch of the river between Arraial do Sana and Barra do Sana region, which is the most populated area prominently visited by tourists. The selected stretch of the river (~30 % of the Sana river) encompasses a territory of 360 ha, which represents the land surrounding the Sana river and its respective tributaries. According to the soil survey report (Macaé 2004a), the main soil types in the region are inceptisols (77 %), ultisols (18 %), and entisols (5 %).

29.3.2 *Problem Identification*

According to monitoring and observations in the Gloria and Palmital watersheds, soil and water bodies were identified as impaired (Ceddia et al. 2012). The water quality for drinking water usage for the two watersheds (Gloria and Palmital) is shown in Fig. 29.3. The water turbidity in the outlet of each watershed was monitored to estimate the sediments delivered due to soil erosion. These measurements were used to calculate the annual cost of soil erosion based on the cost of water treatment.

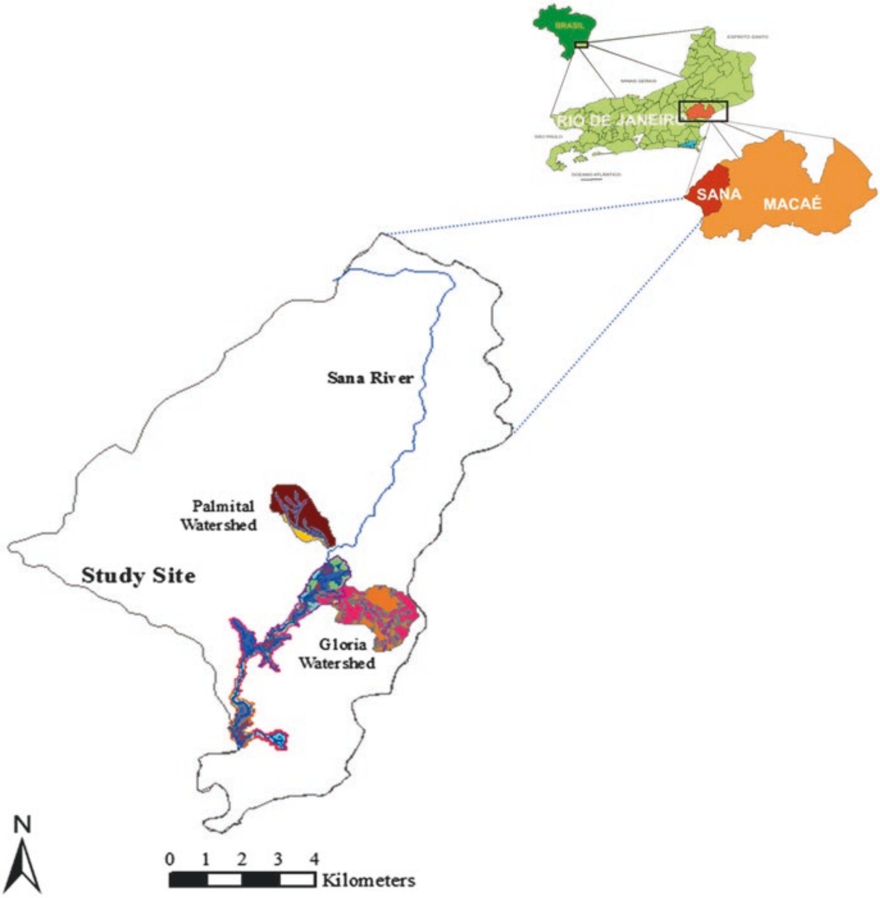
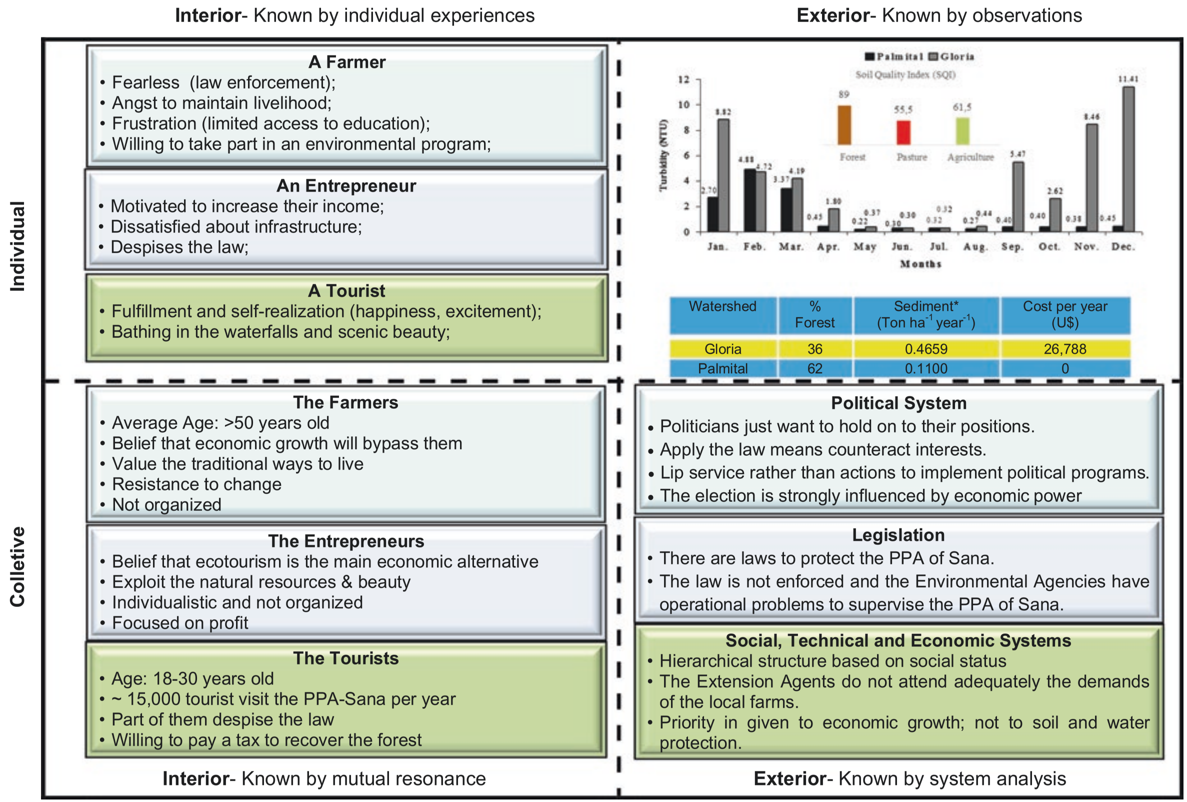


Fig. 29.2 Location of the study site, highlighting the Sana river and the watersheds

The soil quality was assessed by the soil quality index (SQI) which was computed based on the measurements of the following soil attributes: bulk density, macroporosity, water infiltration, penetration resistance, soil organic carbon, and phosphorus. The SQI was calculated considering the forest, pasture, and agriculture use, according to Eq. 29.1.

$$SQI = \sum_{n}^{i=1} Si \times wi \tag{29.1}$$

where SQI – soil quality index, a number that varies from 0 to 100; Si – is the score of the i-th input attribute, a number between 0 and 100; n – number of soil attributes; and wi – weight corresponding to the i-th parameter, a number between 0 and 1.



A Farmer

- Fearless (law enforcement);
- Angst to maintain livelihood;
- Frustration (limited access to education);
- Willing to take part in an environmental program;

An Entrepreneur

- Motivated to increase their income;
- Dissatisfied about infrastructure;
- Despises the law;

A Tourist

- Fulfillment and self-realization (happiness, excitement);
- Bathing in the waterfalls and scenic beauty;

Watershed	% Forest	Sediment* (Ton ha^{-1} $year^{-1}$)	Cost per year (U$)
Gloria	36	0.4659	26,788
Palmital	62	0.1100	0

The Farmers

- Average Age: >50 years old
- Belief that economic growth will bypass them
- Value the traditional ways to live
- Resistance to change
- Not organized

The Entrepreneurs

- Belief that ecotourism is the main economic alternative
- Exploit the natural resources & beauty
- Individualistic and not organized
- Focused on profit

The Tourists

- Age: 18-30 years old
- ~ 15,000 tourist visit the PPA-Sana per year
- Part of them despise the law
- Willing to pay a tax to recover the forest

Political System

- Politicians just want to hold on to their positions.
- Apply the law means counteract interests.
- Lip service rather than actions to implement political programs.
- The election is strongly influenced by economic power

Legislation

- There are laws to protect the PPA of Sana.
- The law is not enforced and the Environmental Agencies have operational problems to supervise the PPA of Sana.

Social, Technical and Economic Systems

- Hierarchical structure based on social status
- The Extension Agents do not attend adequately the demands of the local farms.
- Priority in given to economic growth; not to soil and water protection.

Fig. 29.3 The integral theory analysis and the meta soil model applied to the study site

29.3.3 The Economic and Social Aspects

The social and economic data of the region were surveyed by different interviews with local residents, 73 farmers, 30 entrepreneurs, and 1,081tourists, encompassing a sample of 1184 people (Fernandes 2009; Macaé 2004b). The interviews surveyed information about education and income level, water supply and sanitation, social organizations, their demands and perceptions about environmental issues, public services, and political system.

29.4 Results and Discussion

The environmental and socioeconomic data were allocated to the four quadrants of the integral map (Fig. 29.3). In the UR quadrant, the soil and water quality indices, as well as the environmental cost due to soil erosion, are shown. The Glória watershed, with less forest coverage, showed lower soil quality and a higher level of turbidity at the outlet. The discharge of soil sediments into the river implied an extra cost of US $26,788 per year for water treatment (Ceddia et al. 2012). The soil and water securities have been at risk, and the question is how to shift the procedures applied along the PPA-Sana to reverse this degradation process.

Considering the main results illustrated in the other three quadrants (Fig. 29.3), we highlight that the community has had many demands not attended by the government. And consequently, the local residents, farmers, entrepreneurs, and tourists do not trust in the political systems and public agencies. On the other hand, the environmental agencies do not trust farmers and entrepreneurs to carefully use and manage soil and water in a way that does not adversely affect the watershed. Clearly, the dissatisfaction and the mutual distrust of locals and tourists in relation to the government are a key factor that constrains soil and water security. This situation hinders the implementation of necessary changes to secure soil and water resources and enables their functioning for the greater good of the whole community. Thus, the solution to achieve soil and water security necessarily involves confronting social and political problems, which is not usually done by experts in soil and water management that focus on soil mapping and monitoring of water quality. In fact, the solution requires a broader approach integrating the various dimensions of the problem. In this context, we present the concept of *cognizance* (Clingensmith et al. 2015), a new dimension of soil security, contextualized for the case study (Fig. 29.4). Cognizance allows recognizing chasms and disconnects between and within quadrants of the integral map. For example, right (UR and LR quadrants) and left (UL and LL quadrants) are disconnected somewhat in the two watersheds constraining to secure soils and water. This suggests that a better soil map or more monitoring will not help to improve soil and water security. On the contrary, awareness building, creating trust among stakeholders, and better integration among quadrants would lead to an enhancement of soil and water security. In essence, cognizance is

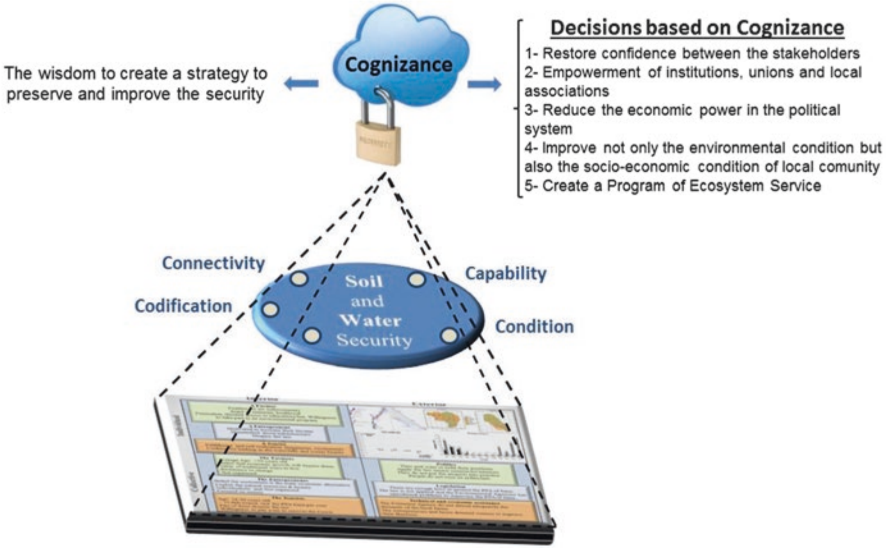


Fig. 29.4 Cognizance, the integration of the knowledge to enhance the soil and water security

profoundly important to allow integration of human and biophysical system dimensions. Cognizance also allows creating a strategy to preserve and improve soil and water security considering the complexity of the human-environmental interactions. Basically, there are at least five points to be carefully addressed: (1) restore confidence between the stakeholders; (2) empowerment of institutions, unions, and local associations; (3) reduce the economic power in the political system; (4) improve not only the environmental condition but also the socioeconomic condition of local community; and (5) create a program of ecosystem service. Essential to achieve soil and water security is the rescue of the respect and confidence of the locals in political and public institutions. The rehabilitation becomes possible when the actions not only prioritize the legal repression but also the presentation (by the political system) of solutions that respect the history, knowledge, beliefs, and aspirations of the local community. The institutions, both for the oversight and to support the farmers, entrepreneurs, and tourists, should be fortified. Fortify implies the improvement of the infrastructure, the wages of the staff, and the methods of action. A key and controversial point concerns the electoral process. The strong influence of private funding during the elections (companies and entrepreneurs) causes a sensitive bias in the results. Thus, commonly, municipality mayors and councilors of Macaé are more committed to the interests of campaign contributors than to the aspirations of most citizens. This is one of the reasons why politicians hardly put into action what they promised.

Some experiences in Brazil (São Paulo 2012) have shown that the application of payment for environmental services programs gains interest among farmers in preserving the soil and the water. Through these programs, the land owners become not only agricultural producers but also providers of environmental services. Applying this program at the study site, the farmers could receive state financial compensation for maintaining the security of soil and water.

29.5 Conclusions

The soil and water securities are connected and at risk in the PPA-Sana. Specifically, one of the main problems of the water security is the discharge of soil sediments in the rivers as a consequence of soil erosion. The discharge of soil sediments into the river implied an extra cost of US $26,788 per year for water treatment. The integral theory enhances our capacity to understand the system complexity through inclusion of multiple distinct perspectives. Our findings suggest that not a better soil map or more monitoring helps to improve soil and water security. On the contrary, awareness building, creating trust among stakeholders, and better integration among quadrants would lead to an enhancement of soil and water security. In essence, cognizance (the sixth dimension of soil and other securities) is profoundly important to allow integration of human and biophysical system dimensions.

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Chapter 30
Bridging the Research Management Gap to Restore Ecosystem Function and Social Resilience

W. Richard Teague

Abstract Modern technology, knowledge, and organization have greatly increased agricultural productivity, but management has prioritized short-term benefits from the production of food, fiber, and fuel. By not accounting for environmental and social costs, we have compromised the integrity of global ecosystems and caused negative impacts on our social environment. For humans to live sustainably, we must prevent depletion of natural resources and protect their potential for self-replenishment. To continue receiving ecosystem goods and services, we must stop counting the consumption of natural capital as income. Regenerative agriculture could help reverse these negative trends, but a different research approach is needed to understand the impacts of regenerative management. Much component research does not translate into producing sustainable results on managed landscapes. It is important to understand how cropping and grazing management can best regenerate soil and ecosystem function, while producing long-term economic returns. To this end, a framework is outlined that combines small-scale component research and whole-systems research, working in collaboration with farmers who improve the environment and excel financially. This approach addresses questions at commercial scale, and by integrating component science into whole-system responses, it identifies emergent properties that may result in synergistic positive outcomes and avoid unintended consequences.

Keywords Regenerative agriculture • Ecosystem services • Whole-systems research • Management research • Simulation modeling • Sustainable capitalism

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30.1 The Need to Regenerate Ecosystem Function in Agriculture

Through modern technology, knowledge, and organization, agricultural scientists and farmers have increased production and lowered prices of agricultural products but with insufficient regard for sustainability and disruption to our social environment (Pearson 2007; Walker et al. 2009). The Millennium Ecosystem Assessment (MEA 2005) highlights the rapid decline of the integrity of global ecosystems with negative impacts on our social environment. To live sustainably, we must account for environmental and social costs and manage natural resources to prevent their depletion and protect their potential for self-replenishment. Farm livelihoods depend on healthy ecosystems, so the output of agricultural products must be balanced with the provision of environmental goods and services (Costanza et al. 1997).

For a more sustainable future, it is vital to know how to manage for regeneration of ecological function and renewable resources that underpin the delivery of critical ecosystem services in agroecosystems (MEA 2005). This can be achieved by conducting agricultural research from an ecosystem perspective with farm and ranch managers who demonstrate how to be financially successful and simultaneously meet environmental goals.

Small-scale component scientific research does not translate automatically into producing usable results from crop or grazing agroecosystems (van der Ploeg et al. 2006; Teague et al. 2013). To bridge the gap between single-discipline component research and effective resource management, it will be necessary to work in partnership with environmentally conscious, financially successful farmers to develop adaptive practices for food production ecologically suited to local biophysical conditions (Herrero and Thornton 2013).

To improve understanding of how to manage cropping and grazing ecosystem resources more sustainably, this paper outlines a research framework that combines small-scale component research with complementary whole-systems research, working in collaboration with farmers who both excel financially and improve the environment. This approach focuses on addressing questions at commercial scale and integrating component science into whole-system responses, in order to identify emergent properties that may result in synergistic positive outcomes and avoid unintended consequences.

30.2 Agricultural Impact on the Environment

Sustaining the environment is predicated upon the maintenance of a stable resource base, the avoidance of overexploitation of renewable resources, and the reinvestment of proceeds from nonrenewable resource extraction into the development of renewable alternatives (Daly and Farley 2004). It is critical to maintain ecosystem resilience, which is the ability of an ecosystem to return to its fully functional capacity after a disturbance or damage to the system (Walker et al. 2009). The key to resilience is high biodiversity of adapted organisms to maintain an adequate genetic pool that can adapt to changing conditions (Peterson et al. 1998).

During the last two centuries, the industrialization of world economies has driven global agricultural development (Ikerd 2005). The industrial model ignores the costs of environmental damage caused, concentrating only on increasing the amount and value of a product from each unit of input. Current high-production, high-input techniques that meet this demand cause disruption of hydrological and biogeochemical processes, soil impoverishment and loss, excessive water use and aquifer depletion, contamination of water bodies by fertilizer and biocide runoff, loss of habitat and biodiversity, and increased greenhouse gas emissions through repeated soil disturbance (Delgado et al. 2011). Therefore, to ensure sustainability, more efficient, regenerative forms of agriculture requiring fewer inputs and less cost must replace current input-intensive systems (Pearson 2007).

The current industrial agriculture development paradigm is not sustainable ecologically, socially, or economically (Daly and Farley 2004; Ikerd 2005; MEA 2005). If we keep using new technologies without regard for environmental impacts, we will exacerbate global environmental degradation. There is increasing awareness of the threats industrial agriculture poses to human health (Pollan 2006; Blaser 2014). However, new technologies could be applied in ways that reflect new appreciations of how ecosystems function and our biological place in the world.

Many innovative technologies have unintended consequences. For instance, to control parasites, livestock may be treated with ivermectin, a broad-spectrum antiparasitic medication. However, ivermectin also significantly reduces diversity of invertebrates, such as dung beetles, and soil microbes (Iglesias et al. 2006), destroying the vital mineral-recycling ecosystem process. This leads to soil impoverishment and declining plant growth. Also, the buildup of feces on the soil surface leads to a proliferation of blood-sucking flies, resulting in a decrease in animal performance. Farmers who have healthy dung beetle and soil microbial populations do not need to spend money on chemicals to control these flies.

A stark reminder of the detrimental impacts of industrial cropping and grazing practices is the dead anoxic zone in the Gulf of Mexico, the anoxic polluted lower reaches of the Mississippi, and the chronic demise of pollinators in North American cropping areas (Turner and Rabalais 2003; MEA 2005). Similarly, the original deep loam soils of Queensland coastal savannahs have largely disappeared due to agricultural mismanagement. Prior to European settlement, they supported grasses taller than men on horseback (Bolton 1970). The Great Barrier Reef continues to be severely damaged by the cropping and grazing practices that caused eroded soil, fertilizer, and pesticides to pollute the ocean (Fabricius 2005).

Contrasting with the damaging impacts of current agricultural management based on tillage and high inputs of fertilizers, pesticides, hormones, and medicines, ecologically sensitive regenerative management uses low inputs that build rather than destroy the biological base of living ecosystems (Pimentel et al. 2005; Delgado et al. 2011; Gattinger et al. 2012; Aguilera et al. 2013). Appropriate crop and ruminant management in mixed crop and grazing agroecosystems contributes positively to the delivery of critical ecosystem services. Highlighted in popular literature (Butterfield et al. 2006; Pollan 2006; Schwartz 2013) and scientific journals are numerous examples indicating directions that would significantly decrease the damaging impacts of agriculture by restoring soil and ecosystem function (Liebig et al. 2010; Delgado et al. 2011; Teague et al. 2011; Gattinger et al. 2012; Aguilera et al. 2013).

30.3 Agricultural Research with an Ecosystem Perspective

Soil and ecosystem health are critically linked. Microbes mediate 90 % of soil function and form a mutual dependency with plants and the animals feeding on the plants. How we manage plants in cropping or grazing ecosystems is vital to maintaining or regenerating full ecosystem function. An ecosystem perspective requires a different way of managing and conducting research. For sustainable, economically viable agriculture, the goal in management and research must be to improve biophysical processes necessary for ecosystem health and resilience. Specific functions for consideration are efficient solar energy capture, effective water infiltration and retention, soil organic matter accumulation and retention, efficient nutrient cycling, and biodiversity.

Interdisciplinary research to investigate ecosystem behavior and response to external drivers will determine the full accumulated costs of various managerial options and evaluate production system options. It is vital to structure research to identify unintended negative consequences of management options and adapt research management to avoid these consequences. Spurious results will be obtained if improved management studies are conducted for insufficient time to effect expected changes (van der Ploeg et al. 2006; Teague et al. 2013).

In both cropping and grazing agroecosystems, soil management is the key to optimizing ecological function. From research and knowledge gained from successful conservation farmers, soil ecological function is maintained by using perennial, rather than annual, plants; managing for the most productive plants; using diverse species mixes and cover crops; leaving plant residue; eliminating tillage; keeping the soil covered with plant material and minimizing bare ground; using organic soil amendments; reducing nitrogen fertilizer use; and growing plants for the maximum number of days each year (Delgado et al. 2011; Teague et al. 2011; Gattinger et al. 2012; Aguilera et al. 2013).

Research to understand whole-system responses at the landscape level needs to be considerably different than current practices. When examining changes to whole-system ecological function, information from current small-scale component research must be augmented with more complete interdisciplinary research and conducted in tandem with whole-system ecological research. We must concurrently examine ways to use energy more efficiently, recycle nutrients and materials more effectively, regenerate soil ecological functions, and examine the role of biodiversity in ecological resilience to external perturbations.

Full life cycle assessments need to be conducted on present and alternative management systems to determine the true costs of different choices and to assess net benefits (Ikerd 2005; Pearson 2007). This should be part of related studies evaluating the efficiency of the use of all resources with various management choices. Including the human element in evaluating different management options will require partnering with managers who excel in regenerating resources and ecosystem function while improving livelihoods. Farmers learn most from other farmers, because successful farmers have developed protocols and management strategies to achieve superior economic outcomes; they have a successful blueprint that encompasses all elements relevant to succeeding in their businesses.

30.4 The Need for Whole-Systems Science

For short- and long-term success, farmers manage for the best soil and vegetation function, animal performance, and profit and do so within the constraints of their unique landscapes, weather, and market variability. To meet predetermined goals, they take into account short- and long-term responses of whole ecosystems in their farm landscapes. With changing circumstances, management must proactively adjust to minimize negative impacts.

Small-scale component scientific methods have generated considerable knowledge about soils, water, plants, and herbivores and their interactions in biophysical processes in agricultural ecosystems. However, effective study of farm *management* requires understanding farm landscape responses to alternative management actions and comparing the ways in which those actions interact with biophysical processes and evolve over time. As noted by van der Ploeg et al. (2006) and Teague et al. (2013), temporal and spatial variation in biophysical processes and their interaction with different management decisions cannot be determined using classical, replicated experiments that reduce variability and scale of enquiry to understand limited situations.

Small-scale component research incorporates very few *management*-related factors in each experiment relevant to commercial farms, thus limiting the discovery of positive or negative interactive effects important for flexibility in successful farm management. Such factors include effects of treatments pertaining to scale-dependent responses; the adequate evaluation of changes over time in soil and vegetation recovery or degradation; accounting for different soils, topography, and similar variables; and not focusing on implementation of treatments to achieve best outcomes (Teague et al. 2013).

When implementing new management treatments, many ecosystem variables are affected simultaneously, including soils, vegetation, and livestock. These changes take place at temporal and spatial scales, and the impacts of weather and previous management carry over to following years. When new management treatments are repeated over many years, the impacts of each treatment compound over time. Consequently, in an experiment, management-related treatments need to be conducted for sufficient time to account for lag effects following implementation of that treatment. If experiments use fixed (nonadaptive) management treatments in response to changing weather events and management is not adapted to get “best” outcomes, discovering the potential of different management choices and combinations is severely curtailed.

For example, leading conservation farmers have used adaptive multi-paddock grazing to achieve superior soil health, vegetation, and livestock production results (Teague et al. 2011). When research (i) was conducted at the scale of ranching operations; (ii) was managed proactively as conditions changed to achieve desired ecosystem and production goals; (iii) measured parameters indicating change in ecosystem function and not just production parameters; and (iv) when treatments had been applied for many years to incorporate additive effects of positive impacts and responses to factors like weather, scientists studying grazing management in a wide variety of environments from Australia, Argentina, Southern Africa, and the USA (Teague et al. 2013) have arrived at the opposite conclusion to that of scientists using small-scale component research protocols.

Van der Ploeg et al. (2006) cite a similar set of circumstances where small-scale component research protocols were used to determine what management would result in decreased soil nitrogen leachate levels created by the dairy farming industry. A whole-systems research approach was developed in conjunction with farmers who used less fertilizer with concentrated feed containing higher fiber and reduced levels of fed concentrates. This resulted in different forage compositions, improved livestock production longevity, improved soil nutrient retention, and improved lifetime milk products. Conventional institutional component research protocols examining the same issues concluded the opposite.

Whole-systems science facilitates finding *emergent properties* achieved by leading managers, as illustrated by van der Ploeg et al. (2006) and Teague et al. (2011). Understanding management requires assessing *systems-level, multiyear* responses. Management research should investigate what combinations of *systems-level* decisions have superior outcomes. Measuring the impact of different management on commercial farms and then using simulation models with management algorithms can determine what management inputs and interventions primarily governed outcomes from these field results (Teague et al. 2013). In this manner, a sound theoretical base can be developed to understand how changing combinations of management strategies and actions can provide superior biological and economic outcomes. Conducted in this manner, simulation results provide realistic evaluations of expected management outcomes beyond the site and circumstances of the original experiments with a high level of confidence (Soler et al. 2011; Lugato et al. 2014; Teague et al. 2015).

30.5 Learning from Outstanding Managers

Most research scientists do not understand the separate but complementary functions and roles of science and management (Teague et al. 2013). The training and skills required for research scientists and for managers are entirely different. Management involves the coordination of people with efficient and effective use of available resources to achieve specified objectives or goals in an atmosphere of incomplete knowledge and a variable and constantly changing environment. Traditional management objectives address the context of "solving a problem" without including in that context "avoidance of unintended consequences." In contrast, regenerative management involves planning for desired economic, social, and resource goals within the whole context of the unit being managed. In execution of the management plan, managers monitor responses to determine the correctness of those actions and proactively adjust management elements as conditions change (Butterfield et al. 2006; Teague et al. 2013).

Leading farmers achieve superior results by the way they allocate resources, use different techniques, use novel concepts, and adaptively change these elements to achieve outcomes that *exceed the sum of parts* involved. This is the "Art of Farming" and has long been acknowledged to produce superior results. Farmers can try different approaches with realistic whole-ranch systems. They are less constrained by convention and are more likely to test novel management practices and different combinations of practices (van der Ploeg et al. 2006; Teague et al. 2011).

In contrast, when researchers try different ideas, they usually conduct non-systems execution that limits inclusion of critical combinations of elements of a complete sociobiological system, as illustrated by van der Ploeg et al. (2006). Institutionalized research protocols and routines and non-systems training and mindsets preclude most research scientists from being able to understand, represent, or manage research projects to achieve the best possible outcomes of innovative, promising agricultural management options (van der Ploeg et al. 2006; Teague et al. 2013).

There are many studies indicating the management elements that can improve the environmental impact of agriculture, but these have been done in isolation. These studies need to be complemented by whole-farm-systems enquiries with farmers to identify synergisms in different combinations and methods of management at this systems level. Working with successful conservation farmers also provides the best scenario platforms for studying business and economic interactions that can be changed and optimized to achieve synergisms at this higher level of integration.

The regenerative approach is well outside the knowledge base and thinking of most farmers and agricultural scientists. Consequently, it will take very obvious examples of farmers successfully using regenerative principles and practices in functional whole-farm settings to educate others on how to manage regeneratively and on the advantages that accrue from doing so. Conducting research on regenerative farm businesses in every major agroecological region will be needed to provide these platforms.

30.6 Conclusions

To ensure sustainability and resilience of agroecosystems, agricultural production should be guided by policies that ensure regenerative cropping and grazing management protocols. Changing current unsustainable high-input agricultural practices to low-input regenerative practices enhances soil and ecosystem function and resilience. A primary challenge is increasing the scale of adoption of land management practices that have been shown to improve soil health.

Effective soil management provides the greatest potential for achieving sustainable use of agricultural land with rapidly changing, uncertain climate. With appropriate management of cropping and grazing enterprises, soil function can be regenerated to improve essential ecosystem services and support local populations. Affected ecosystem services include water infiltration, nutrient cycling, soil formation, carbon sequestration, biodiversity, and wildlife habitat.

Collectively, conservation agriculture supports ecologically healthy, resilient agroecosystems and simultaneously mitigates large quantities of anthropogenic greenhouse gas emissions. To accomplish this, scientists should partner with environmentally progressive managers to convert experimental results into sound environmental, social, and economic benefits regionally and globally.

Working with leading farmers is beneficial to developing more sustainable future agricultural practices. Benefits include addressing questions at commercial scale, integrating component science into whole-system responses, identifying emergent properties and unintended consequences, incorporating proactive management to achieve desired goals under changing circumstances, including the potential of the human element to achieve superior economic and environmental goals, and developing simulation models tested with on-farm field data to provide a solid theoretical foundation and to extend the usefulness of information gleaned beyond the site and circumstances of original research.

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Chapter 31
Engendering Connectivity to Soil Through Aesthetics

Richard J. MacEwan, Ayesha S.A. MacEwan, and Alexandra R. Toland

Abstract Reflecting on the isolation of most of the population from the natural environment and predominant view of soil as 'dirt', it is clear that the disconnect between many individuals and the soil is great. Predominantly urban habitats, socio-economic factors, use of language, cultural attitudes and some educational policies and practice all serve to reinforce a disconnection between individuals and nature. Something extraordinary is needed to recreate connection. The authors consider the nature and role of 'care', the relationship between care and knowledge, the role of art in promoting care, the aesthetics of soil, and the role of early childhood education in forming positive attitudes towards nature. Soil art can instil an aesthetic appreciation of soil and in some cases impact individual behavioural changes to support the lobby for soil security. Similarly, early childhood and school years' experiences are shown to affect attitudes to nature, which may persist into adult life. It is in these years that environments and activities are needed that will enhance 'biophilia'. Examples are given of early childhood and broader education programmes that could assist in engendering a lasting appreciation of nature and soil.

Keywords Beauty • Art • Early childhood education • Care

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31.1 Introduction

In this chapter, we propose the potential for engendering profound and lasting connections between individuals and the natural world. We see these connections as both emotional and cognitive, requiring both love and knowledge of the natural world and one of its most important components, the soil. Our discourse gives consideration to the causes of alienation from soil, the nature of connectedness viewed through the metaphysics of beauty, love and knowledge, and the role that childhood experiences of nature and adult experiences of art can play in stimulating a caring approach to soil.

A challenge for the 'connectivity' dimension of soil security was expressed by McBratney et al. (2014) in their Geoderma paper 'The Dimensions of Soil Security', as 'The second, and some might argue even more important, aspect of connectivity is "How does or can society connect to the soil?" How do individuals in society who are not managing or directly dependent on the soil have or develop a relationship with the soil? How does soil project itself into society? Underlying this is the notion that those who know care, and those who care lobby'.

These questions imply that there is a disconnect between societies and soil security. What is the nature of this disconnect, what are the causes and how can they be overcome? The dimensions of soil security presented in the literature (Bouma and McBratney 2013; Koch et al. 2013; McBratney et al. 2014) stress the utilitarian aspects of soil – the processes and functions that occur in soil and how they need to be understood and managed to sustain delivery of services. Thus, soil security, as well as its definition and promotion, is limited in that it sits firmly in the domain of soil scientists, land managers and environmentalists. How can this limitation be overcome? Advertising campaigns, lobbying of governments and staged events to draw attention to soil and its values, can serve to convey messages, but these messages have to strike home and be acted on. In the context of this discourse, is there anything that would predispose a person to be receptive to the clarion calls of soil scientists and their allies? Is there a role for soil aesthetics in cultivating this predisposition and overcoming the disconnect? Are there policies, practices and organised actions that can be deployed to reinforce a positive and active role for soil aesthetics as a means of connecting people to soil and promoting soil security?

31.2 The Disconnect

For 54 % of the global population, who inhabit and work in the built, urban environment, there is a physical disconnect between the individual and the natural environment, agricultural landscapes, sources of food and ultimately soil. This physical disconnect is greatest in the developed nations; for example, 89 %, 81 % and 80 % of the population in Australia, the UK and the USA, respectively, live in urban areas. Urban populations have the greatest appetite for consumption of natural resources and, apart from some remaining peri-urban land use and some growing trends in urban agriculture, have little connection with agriculture and depend entirely on imports of food into their environment. Although 40 % of the global working population is employed in agriculture, this is predominantly in the developing nations and that proportion is declining as agriculture becomes more mechanised. In the developed countries, only 4.2 % of workers are employed in agriculture, and this has declined from 35 % in 1950. These trends are expected to continue with an estimated 66 % of the world population living in urban areas by 2050 (United Nations 2014).

Except for those who choose to engage directly with soil by handling, studying and manipulating it, soil is little more than an abstract idea for the majority of humankind. Parks, urban gardens and recreational expeditions into rural environments enable contact with nature and serve to counter the disconnect to some degree, but this potential for reconnection is socio-economically determined (Strife and Downey 2009). This is the first and most powerful disconnecting factor – physical habitat.

'Soil' is a word that can have bad connotations as in 'soiled'; other terms that are used for soil also convey the sense of an unpleasant, unattractive and undesirable material – dirt, dung, mud and dust (Patzel 2010). Soil is also where death and decomposition take place, associated with deep-rooted fear, disgust and sorrow. This is the second disconnect – language and its symbology.

So, between physical habitat and the way in which language is associated with soil, we already face social and cultural challenges if we are to reconnect society at large to the soil. But there are other insidious and pervasive social forces at work, which have been around for some decades and may be getting worse. Born in this millennium, the future educators, policymakers, planners, conservationists, artists, captains of industry, their employees and clients are in their early and most formative years of life, and they are getting very different childhood learning experiences compared to those of the current and past working and voting generations. In recent decades, a drastic decline in time spent in children's unsupervised outdoor play in nature, coupled with risk averse attitudes (Gill 2007), means that if things are tough now for social connectivity to soil, they may get tougher unless these trends are reversed and countered by positive programmes (Louv 2005; Gleave and Cole-Hamilton 2012). This is the third disconnect – childhood experiences.

31.3 Connection to Soil (Security) is Imagined

Soil security is a novel term invented to synthesise the diversity of soil matters important to society, to assist with an older mission to protect and manage soil resources and to elevate the importance of soil to a level equivalent to that of energy, food and water security. But there is a big difference between the notion of soil security and its partner global issues of food, water and energy security. Every individual in human society has to solve their daily material needs for food, water and energy, so these matters are uppermost in consciousness. For all of us, our connections to these are real, tangible, immediate and intimate – we know when we need them, when we have them and when we don't. Pain, hunger, thirst, cold, darkness and other tangible impacts result from lack of food, water and energy, so individuals are strongly connected to these and they are prepared to fight for them, as the geopolitical environment testifies. Yet, even though soil is strongly implicated in the supply of these and other services, it is, for the most part, a hidden and unacknowledged servant until, through battles to protect its companion securities of food, water and energy, it becomes conjoined under the territorial concept of 'land'.

Because soil is invisible in the daily provisions that provide security to the lives of individuals, soil is only connected consciously in the world of imagination. Its presence or absence is not experienced in the same way as food, water and energy. Soil's imagined presence exists positively in hearts and minds as a symbol for life and life-giving forces in many religious and spiritual traditions (Habel 2014) and even in the personal tastes of soil scientists (Patzel 2010). Transformation of this imagined presence into ethical constructs and actions for soil security is equivalent to expressions of stewardship as described by Leopold and others (Leopold 1949; Thompson 2011). Imagination is a powerful factor, and boosting the presence of soil in the imagination of the populace should lead to greater awareness of and care for soil. Undoubtedly, without an imaginative presence and value for soil in the minds of the general populace, there is little hope for connectivity to soil and actions to support security.

31.4 Care and Knowledge

The statement by McBratney et al. (2014), 'those who care, lobby', carries the assumption that caring is the product of understanding and appreciation of value and that caring also implies action. To use the analogy of nursing, the best care is both professional and with feeling, i.e. it is not blind but is professionally informed, nor is it merely dutiful according to professional regulation but is empathetic (Pera and van Tonder 2005). The challenge is to connect the population at large to soil and to engender in that population a caring for soil that will translate into action. Is such care to lobby born only out of ethical considerations or do aesthetics have a role in this? We can consider that caring is also conducted with love and appreciation of the object of care. Examples of objects perceived to be worthy of care, ranging from the superficial to the profound and transient to the more enduring, can readily be conjured – a glass of wine, a new car, a heritage building or landscape and the planet earth. In each of these examples, there is a taste for beauty (aesthetics), as well as a utility, that attracts the carer; the perception of beauty adds to quality of care, engendering love. The circle is completed through knowledge, which gives the necessary capacity and information to execute care in appropriate ways.

In this explanation, the Platonic relationship between beauty, love and knowledge transcends the particular example and creates a powerful connection between the lover, knower and object of beauty. In the triad of beauty, love and knowledge, it is in the nature of beauty to attract and be loved, otherwise we would not call it beautiful, and it is in the loving of the object of beauty that knowledge is sought – this is a cyclic and reinforcing process, a positive feedback loop: the more that is known about the object of love (beauty), the more it is loved and the more that object is loved and known, the more the beauty of the object becomes apparent to the lover/knower of that object. Aesthetic attraction sits at the core of human behaviour, whether understood or explained in those words or not, and provides a clue for a solution to our current challenge to create better connectivity between society and soil (security). Knowledge or information alone is not enough – knowledge must find connection with something valued and loved. Love alone is not enough either – without knowledge, and as scientists, we would say without evidence base, expressions of care cannot be appropriately directed.

31.5 Aesthetics and Soil Aesthetics

Aesthetics may be defined as ‘a set of principles concerned with the nature and appreciation of beauty’ and ‘the branch of philosophy which deals with questions of beauty and artistic taste’. This is a far-reaching, highly specialised field of study in itself, and not one that soil scientists specialise in. It is, however, a key focus for philosophical considerations on the nature of mind, imagination and place of art in relation to soil. So what could constitute soil aesthetics? A superficial answer could be that soil aesthetics are the sensory appreciations that derive from the formal features of the soil such as textures, colours, shapes and smells of soil and the transformation or use of soil materials into buildings, ceramics, paintings, installations or other artistic works. But soil aesthetic appreciation of this nature requires contact with the soil or an artistic rendering thereof. In this respect, it is transient, belonging mostly to the moment or time of the experience of encounter, unless repeated encounters or products are offered. How can soil art provoke thought, ethical responses and individual actions subsequent to viewing the works? Can the art engender an ‘aha’ experience that causes insight and conviction from the encounter by providing new ways of experiencing the soil, new ways of perceiving and identifying it and new ways of interacting with soil on a creative level as participant/viewer? Can soil art complement scientific arguments for soil security? Or, simply and universally expressed by Toland and Wessolek (2010), ‘can beauty save the earth?’.

The literature on environmental aesthetics contrasts the ‘cognitive’ and ‘noncognitive’ aspects of aesthetic appreciation, the former requiring contextual knowledge and understanding and the latter an emotional response without the knowledge requirement (Carlson 2015). Soil aesthetics are by default embedded in environmental aesthetics, as soil is undoubtedly an essential part of the environment, but soil struggles to compete for attention with the more immediately pleasing subjects of the field, such as animals, plants, rivers, lakes and landscapes. In this respect, an

Fig. 31.1 Portion of a mural created using the soils from Texas close to Houston, TX. Yusuke Asai, Yamatane, 2014. Commission, Rice University Art Gallery, Houston, Texas (Photographer: Nash Baker © nashbaker.com (http://www.ricegallery.org/yusuke-asai))

appreciation of the aesthetics of soil relies more on a cognitive position, which incorporates the appreciation of soil functions, processes and values. Works of art that incorporate soil as their subject matter or use soil as the material are extremely diverse and may appeal to both the cognitive and noncognitive positions (Toland and Wessolek 2014; Feller et al. 2015).

Examples of highly aesthetic, temporary encounters with soil materials in which the public has a more passive role of observation in traditional artistic settings such as galleries and museums include, for example, the works of Yusuke Asai (www.ricegallery.org/yusuke-asai), Elvira Wersche (www.elvirawersche.com) and Ulrike Arnold (www.ulrikearnold.com). All three artists dazzle their audiences by skilfully combining the natural aesthetic features of the soil in highly aesthetic compositions. In Asai's *Earth Paintings*, the artist uses a palette of locally sourced earth tones to create elaborate personal cosmologies of nature as they spontaneously evolve from the artist's imagination as he paints (Fig. 31.1).

Arnold's work is also sourced from local soil materials and called *Earth Paintings* but presents a more abstract interpretation of the environments she encounters. Both Asai and Arnold use artistic intuition to guide their compositions during the process of making; Wersche, on the other hand, creates giant patterns on the floor using earth pigments collected from all over the world – Sammlung Weltensand (collection of sands of the earth) – in floor ornaments that she has painstakingly planned beforehand for each unique exhibition space (Fig. 31.2).

Fig. 31.2 Elvira Wersche's sand floor works: Sammlung Weltensand – Taqsim, 2009, State Museum of Nature and Men, Oldenburg, Germany (Photographer: Jörg Schwanke)

In contrast, artistic approaches that rely on longer-lasting and repeated soil encounters with a focus on soil functions and natural processes include, for example, works by the Flatbread Society and Urbaniahoeve. The international artists' collective, Flatbread Society, has worked with farmers, gardeners and members of the public for several years to collect and plant ancient grains, bake their harvests in exploratory prehistoric earth cooking pits and establish a new declaration of land use (Flatbread Society 2015). Meanwhile, the artists' initiative, Urbaniahoeve, is a social design lab for urban agriculture in the Netherlands, which has worked to establish multiple community gardens in neighbourhoods in and around Amsterdam and regularly holds public workshops on vermiculture, pickling and edible landscape architecture (Urbaniahoeve 2015).

While art has a role to play in building connectivity, its realm is often inhabited by a culturally engaged public encountering the works in galleries and public spaces. In some respects, it is probably valid to consider that most positive encounters will be experienced by individuals who are already receptive to interacting with and thinking about the subject of the works.

Is there a deeper aesthetic that can be cultivated for soil - an imaginative presence associating soil with sacred values (Habel 2014) - which will endure in the absence of sensory contact with soil or art?

31.6 Connecting Future Generations: Children, Nature and Play

Achieving soil security via connectivity of society to soil is a long-term goal that requires generational change in attitudes. There are indications in the literature on early childhood education that the early years are the most formative in terms of adult attitudes and behaviour. We have previously cited negative impacts resulting from lack of contact with nature. Wilson (1984) published his theory of 'biophilia' attributing a deep connection to nature in humans as an innate genetic characteristic that particularly manifests in children's tendency to explore and bond with the natural world. White and Stoecklin (2008) concluded that children who were encouraged to investigate unstructured (i.e. natural) environments before they were 2 years old showed strong biophilic tendencies and had a high level of confidence in tackling challenges and a low level of aversion to mud, worms and dirt. On the other hand, children who were denied this early exposure frequently exhibited 'biophobia', or a shrinking distaste for dirt, slimy creatures and smells, and a fear of getting hurt, sick or bitten by the unpredictable outdoors. Louv's (2005) *Last Child in the Woods – Saving our Children from Nature Deficit Disorder* correlates the absence of nature in children's lives with epidemic diseases such as obesity, attention deficit disorders and depression. Activities are needed for very young children that, through contact and play with soil, encourage curiosity with, and positive appreciation of, soil in all its qualities. Equally, an appropriate environment is required and may need to be designed to support these activities (Keeler 2008; Kellert et al. 2008).

Louise Chawla (2006) elegantly sums up the power of play, creativity and discovery in her study 'Learning to Love the Natural World Enough to Protect It'. 'What they (children) find in the natural world rewards their initiatives and encourages their continuing engagement ….. Children see immediate, reinforcing effects of their actions, which simultaneously show them how the world works and their own capabilities. The wet earth keeps the shape they press it into – unless they add too much water and it turns to runny mud. That means try it again with less water next time. That leads to next time ….. and when the earth moulds just right, nearby stones and grasses make perfect decorative touches. And so the hours pass away, with children immersed in a world that affords a treasury of loose parts that they can use for experimentation and construction'.

Much of our global concern with soil is driven by the perceptions of negative processes such as soil loss by erosion or sealing or degradation processes like acidification and salinisation. At what point should the child be encouraged to absorb more abstract perspectives in relation to soil? Sobel (1996) has expressed concern that 'premature abstraction', i.e. discussion of issues like global warming, species extinction and habitat destruction, can, if introduced to young children, actually promote anxiety, fear and aversion to the natural world and a disconnect from their local environment. The curriculum progression proposed by educational theorists is based on the child's developmental capabilities and interests, with early childhood focussing on fostering connection and love through open-ended action, experimentation and exploration through sensory contact, e.g. mud play, dam-making and climbing (White and Stoecklin 2008). Primary-age children still need this wholly immersive contact, but educators can guide them towards functional understanding and reflection on their experience. At this age children have a strong sense of nurturing and being effective in action, so gardening, making bird boxes, counting bugs and using materials for art and construction become a focus. High-school-age children are able to process information of a higher level of abstraction and complexity and will relate global information to their own experience. At this point, they are able to apply this knowledge to their early connectedness, and this can engender a feeling of agency rather than anxiety. Soil as a subject could readily be integrated into such curricula but should be done so at all age levels.

31.6.1 Examples

There are structured and unstructured examples of how a culture of closeness to nature and to soil can be encouraged. In Europe, the USA, Australia and New Zealand, there has been increasing implementation of an entirely nature-based kindergarten programme, variously designated Forest, Bush or Nature kinder, which promotes a total open-ended programme sited in the natural environment, in all weathers which encourages using only found materials for play (Elliot and Chancellor 2014; Debenham 2015). ‘Wild areas’ are being constructed in accessible parks by and for primary school children with a strong emphasis on experimenting and hands-on learning (White 2004; Keeler 2008).

One of the most joyfully inspiring and simple examples is ‘International Mud Day’ which was launched in 2009 ‘to find a way to help all of the children of the Earth feel closer to each other’ (World Forum Foundation 2015). The United Nations’ recognition of World Soil Day as an annual celebration of the importance of soil also provides opportunities for outreach to all ages through activities that engage them with soil through art and through science (Fig. 31.3).

In Australia, the Stephanie Alexander Kitchen Garden Foundation, set up by chef Stephanie Alexander, has a primary purpose to educate children in food choices by engaging them in the practice of growing food and now has over 800 schools participating (Kitchen Garden Foundation 2015). This programme funded all schools to develop school gardens and has given a whole generation of children an experiential knowledge of the connection between what they eat and the soil it comes from, as well as the wonder, satisfaction and occasional frustrations of the elemental processes involved.

As well as school-based activities, there has been a proliferation of nature-based websites encouraging family involvement in getting in touch with nature. The best of these use information from recognised educational organisations like the National Association for the Education of Young Children (www.naeyc.org) in the USA and Early Childhood Australia (www.earlychildhoodaustralia.org.au). Television programmes, like the Australian Broadcasting Corporation’s ‘Dirtgirlworld’, are also

Fig. 31.3 World Soil Day activities in Melbourne, Australia, engaged all ages in the discovery activities with soil through art and science (Photographer: Richard MacEwan)

promoting a hands-on approach, and the Queensland government in Australia has an environmental club for children and their families which offers practical discovery challenges for all ages.

Finally, many artists have been instrumental in introducing children to the creative potential of soil – both figuratively as a creative medium for artistic exploration and literally as a creative medium for growing food. For over 30 years, in the USA, Bonnie Ora Sherk's A Living Library project (Sherk 2015) has offered 'a powerful systemic framework, methodology, and strategy for creating placed-based, ecological change in schools and communities – locally and globally'. In Finland, artist Jan van Boeckel leads the research group on arts-based environmental education, Nature – Art – Education at Aalto University to enhance 'understanding of the value of employing artistic methods in education about the environment, develop new methods and concepts for arts-based environmental education, and act as a platform for sharing information and practices' (Aalto University 2015). In a similar vein, Beverly Naidus provides personal insight on environmental arts education as well as a compilation of 33 of her peers' work using art as a reactionary tool for teaching about nature and instilling a sense of 'biophilia' for students of all ages (Naidus 2009).

31.7 Conclusion

There is a growing body of evidence showing that early childhood and adolescent experiences in nature influence adults' appreciation of the natural environment and environmentally ethical behaviour (Dowdell et al. 2011). Studies have also shown better outcomes for health, cognitive skills, social skills and even commitment to environmental activism (Chawla 1999; 2006) and have resulted in policies and movements for more opportunities for engagement in nature and play (Gleave and Cole-Hamilton 2012; Selly 2012). Activities in early childhood and school years that engage children more with nature and soil, engendering a deeper aesthetic appreciation of soil, set the scene for development of an ecological conscience and care for soil in the adult who will be more likely to support a lobby for soil security (Figs. 31.4 and 31.5).

While soil as a subject or material for works of art may draw attention to soil's aesthetic qualities and essential ecological values, a deeper aesthetic appreciation is also needed. An aesthetic sensitivity that transcends the 'aww' factor associated with superficial perception and judgement of an object's formal features, whether it be beautiful or awe-inspiring, and which stimulates curiosity, discovery, identification with place and connection with the soil objects through new forms of knowledge and understanding – an 'aha' moment.

Fig. 31.4 Early childhood experience with nature engenders love and interest – biophilia Mia examining soil critters at 'Natured Kids' Outdoor Early Childhood Program, Victoria, Australia (Photographer: Narelle Debenham www.naturedkids.com)

Fig. 31.5 Early encounters with soil bring a wealth of sensory experiences and also connect to knowledge of soil functions: Tayte developing an early experience of tree planting at ‘Natured Kids’ Outdoor EC Program, Victoria, Australia (Photographer: Narelle Debenham)

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Chapter 32
The Role of Master Gardeners in Providing Horticulture Education to Marion County, Florida, Residents

Josephine Leyte-Vidal

Abstract According to the Miami New Times Florida has the second fewest native residents of any state. Only 36 % of Florida's population in 2012 are born Floridians. Newcomers to Florida often find it difficult to grow a garden in the sandy soil prevalent throughout the state. This presents an opportunity for Master Gardeners (MGs) to offer educational programs for residents to address identified needs. Among the objectives of this group are to teach residents how to build healthy soils and to explain their role in protecting the environment beginning with practices adopted in their backyard. This is achieved by using multiple venues, for instance, the extension office, garden clubs, homeowners' associations, and public libraries, and presentation methods are utilized by MGs to teach youth and adult residents topics such as Building Healthy Soil, Composting, Vegetable Gardening, Lawn Care, and Pest Management. A year-end survey of residents participating in horticulture activities offered by the MGs showed 82 % (n-65) never took a soil test before program participation. This number declined to 25 % after the class. A total of 64 % of the respondents adopted to implement up to three gardening practices as a result of participating in horticulture programs offered by MGs and 14 % adopted four to six practices. Participation in educational activities offered by the MGs show an upward trend. For example, the Speakers' Bureau has seen a 9 % increase in requests for educational talks between January and March 2015 compared to the same time frame in 2014. The emphasis placed on building healthy soil and the tools with which to do it are making the public more aware of the need to understand the environment as it relates to achieving productive vegetable gardens and a beautiful landscape.

Keywords Community gardens • Social media • Healthy soils • Continuing education

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32.1 Gardening to Make Connection

According to the Miami New Times (2014), only 36 % of Florida's population in 2012 are born Floridians. Newcomers to Florida often find it difficult to grow a garden in the sandy soils prevalent throughout the state. The residents seeking information immediately begin their statements with:

> I'm from up North where you can put anything in the ground and it will grow.
> You can't grow anything in this stuff.
> I live in a gated community that requires so many square feet of lawn.
> My yard man sprays every month for all those bugs and diseases.

These statements provide the opportunity for Master Gardeners to offer educational programs so that residents learn to address those identified needs.

Unfortunately, the general public sees the soil as material that holds up the plant so the chemical fertilizer can feed it. Those from urban areas want to know what should be sprayed on that insect in the ground, and those from rural areas, immediately, want to till and pour on Weed and Feed, which is ineffective in Zone 9. This perspective has made developing awareness of the soil's living food web and its role in the life of plants the primary objective of Master Gardeners.

It has been found that the best method of reaching and teaching the public is through personal contacts. These personal contact opportunities allow for an interchange of information questions and problem solving on topics such as How to Build Healthy Soil, Understanding Florida Grasses, How to Fertilize your Lawn, Why Weed and Feed Does Not Work Here, Pest Management, Composting, and many other avenues through which to teach about the soil.

In order to lead the resident in the right direction, the first question asked by the Master Gardener is "What do you want to plant?" The immediate answer is usually relating to lilacs, tulips, rhododendrons, apples, and other northern plants.

The answers open the door to a discussion of the climate conditions in Zone 9 and the fact that Marion County, Florida, is in an area where the climate is erratic. The summers are hotter, at times, than Miami and the winters may be colder than Jacksonville. Also, during the course of 1 day, the temperature may vary 40° from morning to afternoon. Ocala experienced snow one morning during the winter of 2013. Then the next day, the temperature was in the 70s. The mention of snow allows commentary about chill hours and dormancy and their effects on plants and how the soil feeds the plant during dormancy. An explanation is given by Lowenfels et al.'s (2010) edition of *Teaming with Microbes*, in relation to the microherd being inactive during winter months. Therefore, most plants will also be dormant and need less water and nutrition.

Another problem that arises is the "snowbird." These are residents that begin arriving after Labor Day and leave for the North at Easter. They leave the property in the hands of the "yardman" and/or a neighbor during the growing season. Upon returning in the fall, they are expecting to see lush green tropical plant growth. By this time the plants and the soil are preparing to enter a rest period after prolific growth. This causes the resident to want more fertilizer and water to be added to the soil when the amount of both should be reduced. June 1 through October 1 is Florida's rainy season due to afternoon storms and hurricanes. The Master Gardener then can initiate a discussion about the water needs of the soil during rainy and dry seasons. Opportunities for developing the connectivity between climate, soil, and man's intervention are available in many activities and venues open to the public.

They are:

Extension Plant Clinic: Master Gardeners are present at the Extension Office daily to answer questions and distribute educational literature either by telephone or in person.

Mobile Plant Clinic: A mobile building, towed by Master Gardeners, which is taken to festivals, fairs, and libraries to answer questions and distribute literature.

Homeowners' Associations: Sharing soil protection information with residents of gated communities who are subject to Association rules and regulations.

Farmers' Markets: Are an opportunity to explain organic vs. chemical fertilization of soil and their effects on soil health.

Libraries: An annual schedule has been developed offering Master Gardener programs and open forums on a monthly basis.

Seminars at Festivals: Present University sanctioned procedures for gardening in Zone 9.

Senior Education Series: Monroe Regional Medical Center has a program for senior residents titled Prestige 55. The courses range from health, the arts, and agriculture. Seniors are seeking healthy alternatives in their lifestyles.

Civic Clubs: Lions Club, Kiwanis, and others request gardening programs in which the Master Gardener can emphasize the role of soils in the garden.

Churches: Many local churches are seeking community garden opportunities for their membership. Master Gardeners guide and teach the basics of healthy vegetable gardening techniques.

AARP Meetings: Senior groups, seeking healthy food choices and sustainable gardening techniques.

Garden Clubs: Programs are requested from which the members attain membership credits and the newest research from the University of Florida.

Gardening 101: A five-evening seminar presenting ten topics related to sustainable gardening. The focus is to present information for those not able to attend programs during working hours.

Vegetable Gardening Expo: A once per year weekend presentation of seminars on healthy gardening and hands-on activities with local vendors of vegetable gardening materials.

Newsletters: Monthly publications containing announcements of programs, seasonal gardening information, and newest research findings.

Blog for Local Newspaper: A weekly 200-word informational, about gardening in Marion County this week, this season, and for the future.

Facebook: A daily posting of the newest findings, research data, events, classes, and what's happening in the garden today.

32.2 The Activities

The public's requests for programs by the Speakers' Bureau have shown 83 programs in 2014 while to date in 2015, January–March equaled 30 talks and 60 were scheduled through December, an increase of 9 %. The hands-on children's activities at the Spring Festival brought in 300 participants in 2014 and that number doubled to just over 600 in 2015. The 2014 data shows the Plant Clinic answered 1551 calls and 147 walk-ins. The Florida-Friendly Landscaping™ program reached 547 residents, the Vegetable Garden Expo brought in 319 residents, and two sessions of Florida Gardening 101 taught 78 residents, while in 2015 the first session had 67 in attendance. The Spring Festival had an attendance of 7960 in 2 days. Survey results show that in 2013, 18 % of program participants requested soil tests while in 2014, 75 % of participants requested soil tests.

The continuing increase in participation and requests for speakers indicates that the residents are viewing the Master Gardeners as a reliable source of information. This trust and belief brings the resident into a change of mindset from "Nothing grows here" to "I now understand how I affect the soil and my environment." With this understanding the Master Gardeners are then able to teach that rebuilding our soils is paramount to the future success of mankind.

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Part VI
Codification

Chapter 33
Soil-Water-Food Nexus: A Public Opinion and Policy Perspective

Kent E. Portney

Abstract This chapter reports on analysis of public opinion related to the agriculture-water nexus from a small number of questions asked of well over 2000 respondents in the 2013 National Public Water Survey and uses this analysis to begin to elucidate some publicly perceived connections as reflected among the general public. Results show that people perceive that water is very important to agricultural production and that drought conditions have severe negative consequences for agriculture, although not necessarily damage to plant and animal species. When people perceive that the effects of drought on agriculture are severe, they are far more likely to support actions and public policies to conserve water.

Keywords Public opinion • Nexus • Water conservation • Agriculture • Public policy

33.1 Introduction to the Soil-Water-Food Nexus and Public Opinion

Over the last decade or so, there has been a precipitous rise in interest in understanding the connections between water, soil conditions, food, and agriculture. While the science underlying these connections has made significant progress, there has not been a commensurate understanding of the public policy implications or the ways that these connections may or may not be understood by the general public. The purpose of this paper is to review some basic findings from a recent nationwide public opinion survey and to highlight research that is currently under way that promises to add significantly to our understanding of public perceptions. The fact is, little is known about perceptions and understandings of linkages among nonscientists, and even smart people who are not field experts don't have much awareness of possible linkages. The general public would not be expected to have much awareness of these connections, although there is little systematic information that can be brought to

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bear to document this. Most of the research on "nexus" issues in public opinion about water has focused on trade-offs between alternative water uses, such as urban versus rural and farm uses (Rosegrant and Ringler 2000; Rosegrant et al. 2002; Lundy and Bowdish 2014). More recently, analysis of the public perceptions of the impact of hydraulic fracturing for gas and oil extraction on water supplies has received significant attention. Public understandings of the connections between water availability and agricultural have been virtually unstudied. The Bush School's Institute for Science, Technology and Public Policy (ISTPP 2013, 2015) has conducted a number of national public opinion surveys, and some of the results give us the foundation to begin a line of inquiry around these issues. The character of public opinion on the connections between water and food in particular may well have important implications for public policy, specifically how policymakers decide to deal with public decisions affecting water, food, soil, and the linkages between them.

This chapter reports on analysis of public opinion related to the agriculture-water nexus. It focuses on a small number of questions asked in the 2013 National Public Water Survey (ISTPP 2013) and uses these results to begin to elucidate some perceived connections among the general public. None of the questions in the survey explicitly refers to "soil." The questions that were asked focus on the importance of "water for agricultural uses" and the potential negative effects from drought on agriculture, plants and animals, and food prices. Presumably, high levels of concern and perceived negative effects would be created, at least in part, through effects on soil and soil conditions. Some of the connections examined here can be seen in the responses to individual questions, such as the distribution of responses to queries about how important water is for agriculture. Other connections become clear when the answers to two questions are correlated, such as the relationship between perceived negative effects from drought and willingness to support specific public policies to address water availability and shortage issues. The National Public Water Survey provides initial entrée into this line of inquiry.

33.2 The National Public Water Survey

In 2013, the ISTPP sponsored a major nationwide "National Public Water Survey," a public opinion survey dedicated to understanding public attitudes and understandings of water issues in the USA. The National Public Water Survey (ISTPP 2013) was conducted with two independent national random samples administered within close time proximity to each other; the first consisted of 1311 respondents and was fielded from February 21, 2013, through March 2, 2013; the second consisted of 1312 respondents and was fielded from April 2 through April 13, 2013.[1] The completion rate for the first survey was 56 % and for the second survey was 55.5 %. The

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[1] The National Water Survey was designed to contain 1314 respondents, but an error in administering a series of questions not used in this analysis required that the survey be re-fielded. The results reported here are based on the combined sample of 2626 respondents from both surveys.

potential total sample size from these two samples combined is 2623 respondents. The analysis reported here pools these two water samples (Stoutenborough and Vedlitz 2014). A small number (four) of these questions on the survey were intended to provide some insight into public understandings of some "nexus" issues related to water, food, and agriculture. These questions focus on the perceived importance of water for agriculture, and the negative consequences of lack of water due to drought on agriculture. The results from these four questions set the stage for documenting the extent to which the public makes a connection between water and agriculture and whether these connections seem to at all important in terms of peoples' views of what kinds of actions would be supported to protect agriculture.

33.3 The Importance of Water (and Lack Thereof) for Food and Agriculture

In order to investigate public understandings of connections between water and drought on one hand and agricultural production on the other, the ISTPP Water Survey asked four specific questions. The first question asked about the importance of water for agricultural uses. Specifically, the survey asked respondents:

> On a scale from 0 to 10 with 0 indicating *Not At All Important* and 10 indicating *Extremely Important*, rate how important each of the following water uses is to you: Water for agriculture (e.g. crops and livestock).

Figure 33.1 provides the frequency distribution of responses. The distribution is heavily skewed toward the side reflecting substantial importance, with 40 % of the sample indicating that water use in agriculture is "extremely important." Fewer than 6 % of the respondents indicated that agricultural uses of water are relatively unimportant (0–4). Clearly, the public recognizes the connection between water and agriculture and considers it to be of great importance. This piece of information by itself does not provide much insight into the character of public views about water for food or agriculture, but it does provide one piece of a larger puzzle.

A second question focused generally on "negative effects" on agriculture from drought and adds another piece to the puzzle. Specifically, the question asked respondents to:

> Rate the degree of negative effects that could be caused by drought on the following groups in your region using a scale from 0 to 10 with 0 indicating *No Negative Effect* and 10 indicating S*evere Negative Effect*: Effect on Agriculture.

Figure 33.2 shows the distribution of responses to this question, revealing the fact that the vast majority of respondents think there will be severe negative effects from drought. Very small numbers of respondents seem to think there will be little or no negative consequences in agriculture from drought. Paralleling the findings from the first question, the general public seems to understand the potential for drought to cause severe negative effects for agricultural productivity.

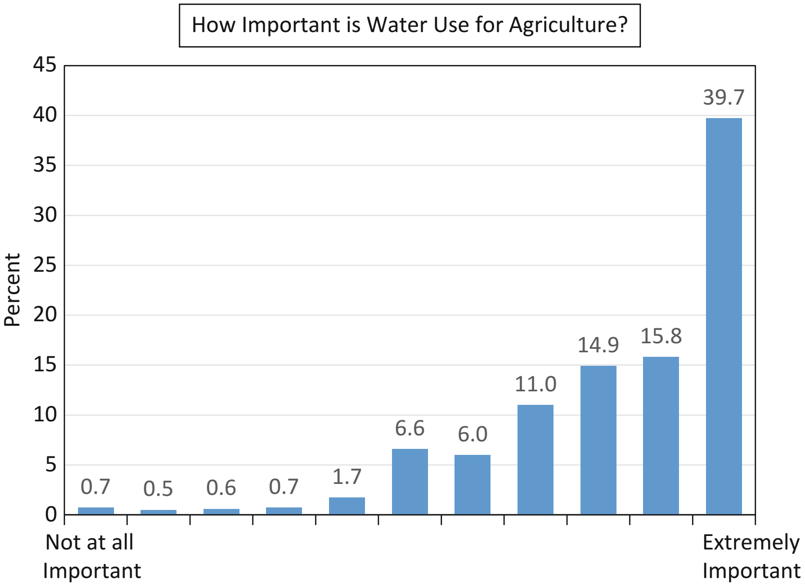

Fig. 33.1 Public importance of water for agriculture (Source: ISTPP 2013)

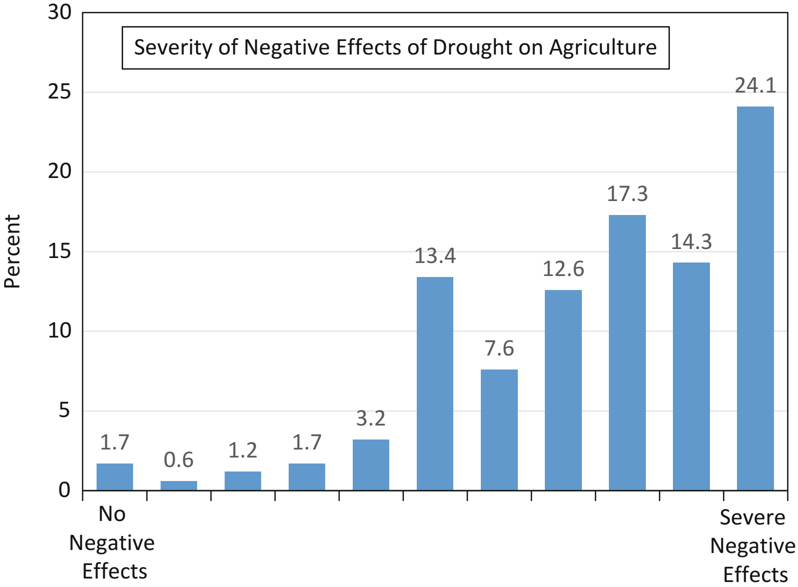

Fig. 33.2 Public views of “negative effects” on agriculture from drought (Source: ISTPP 2013)

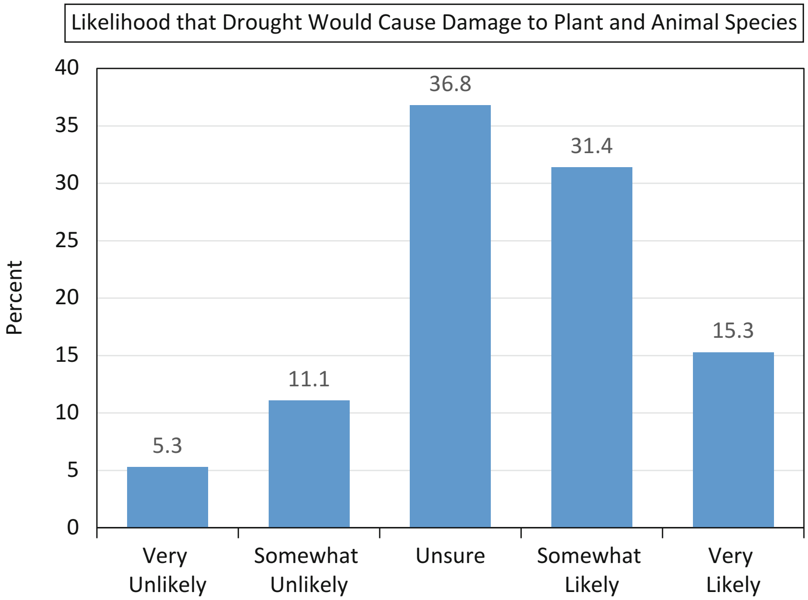

Fig. 33.3 Likelihood of damage from drought (Source: ISTPP 2013)

Nearly a quarter of the respondents indicated that the effects of drought could be severe in magnitude.

Two additional questions sought to get specific ideas about what kinds of negative consequences for agriculture people have in mind. A third question focused on the implications of drought for "plant and animal species." The question specifically asked:

> How likely are the following drought impacts to occur in your region in the next five years? Are they Very Unlikely, Somewhat Unlikely, Unsure, Somewhat Likely, or Very Likely? Damage to plant and animal species.

Figure 33.3 presents the frequency distribution for this question. These results show that, while a large portion of the sample was unsure about the connection, well over half of the respondents said that damage to plant and animal species was "somewhat likely" or "very likely." As understood by a large portion of the public, the chronic lack of water for agriculture risks damage to plants and animals. So one of the negative consequences perceived by people is that drought creates risk to plant and animal species.

The fourth question focused specifically on perceived personal financial impacts from drought related to increased food prices. The question asked:

> How likely are the following drought impacts to occur in your region in the next five years? Are they Very Unlikely, Somewhat Unlikely, Unsure, Somewhat Likely, or Very Likely? Increased food prices

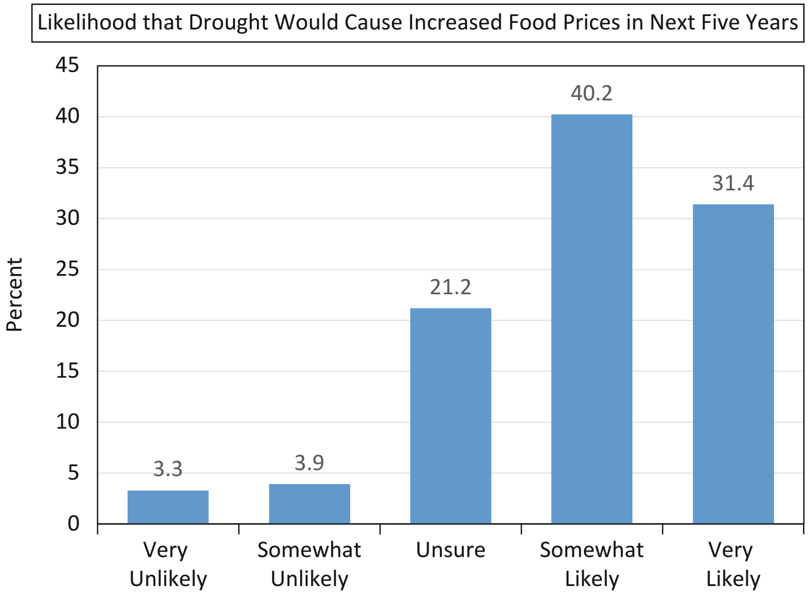

Fig. 33.4 Likelihood that drought would cause increased food prices (Source: ISTPP 2013)

The results from this question are found in Fig. 33.4, showing that large portions of the sample believe that drought is likely to cause food prices to rise over the next 5 years. Very few people think that food prices will not rise.

Taken together, the results from these four questions paint a consistent picture. The general public thinks that water for agricultural uses is very important and that drought promises to have significant negative effects on agriculture by potentially damaging plants and animals and by raising food prices. Of course, not everyone shares these perceptions. But the results are heavily skewed in this direction. The implication from these results is that the general public sees a connection between water and drought on one hand and agricultural productivity (and prices) on the other.

33.4 The Importance of Water for Agriculture and Support for Policy Actions

Although it is clear that the general public understands connections between water availability and agriculture, it does not necessarily follow that those who see these connections would be willing to change personal behaviors or to support any particular public policy response. In order to examine whether there is a connection between these understandings and a willingness to support public policy interventions, the Water Survey asked respondents questions about willingness to engage in eight different personal actions to conserve water or to support government actions, including mandatory water conservation measures. On the former, people were asked:

Have you or someone in your household done any of the following in the past year to conserve water? [SELECT ALL THAT APPLY]

1. Bought or installed low-flow shower heads
2. Bought or installed low-flush toilets
3. Taken shorter showers
4. Used the dishwasher less often and/or with fuller loads
5. Used the washing machine less often and/or with fuller loads
6. Washed car less frequently
7. Changed the way your yard is landscaped
8. Changed how often you water your yard

Distributions of answers to these questions are not shown here, but in the correlational analysis below, a variable was created to simply count how many of these eight personal actions each respondent reported willing to take. This is meant to serve as a summary measure of peoples' reported willingness to take personal actions to save water, although it does not weight any of the specific actions as being more important than any other.

On the government policy issue, respondents were asked a question related to whether they supported government actions to require mandatory water conservation, which presumably is among the most difficult type of policy option for people to support in general. They were specifically asked:

> A number of policy options have been proposed to manage water resources. Please indicate whether you Strongly Oppose, Oppose, Support, or Strongly Support each of the following options. Require mandatory water conservation.

Figure 33.5 shows the distribution of responses to this question. These responses show that over a third of the sample is "unsure" about support for government actions, suggesting that "mandatory" conservation measures do not have widespread support. Even so, over 44 % of the sample expressed "support" or "strong support" for such actions.

Analytically, an important issue is whether the perceive connection between water and agriculture translates into a willingness to take actions. Do the understandings of connections correlate with attitudes about water conservation and support for various public policies? In order to investigate this, the four water-agriculture nexus questions are correlated with the willingness to support actions questions. These correlations are presented in Table 33.1 and show significant results.

It is clear that the perceived importance of water for agriculture and negative consequences on agriculture from drought are highly correlated with willingness of people to take personal water conservation measures. Although the correlations are weaker, these perceptions are also correlated with willingness to support government actions, including mandatory water conservation measures. People who see

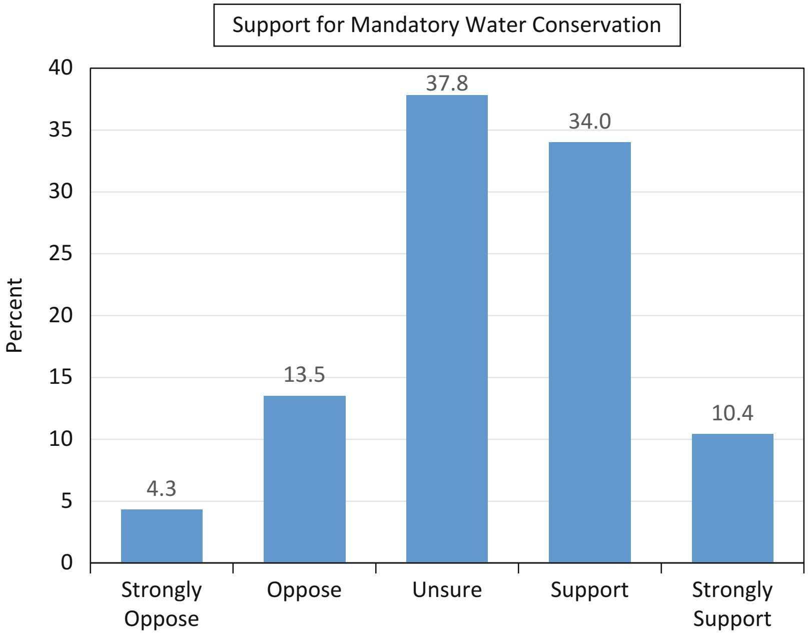

Fig. 33.5 Support for and opposition to mandatory water conservation (Source: ISTPP 2013)

Table 33.1 Correlations between water-agriculture linkages and water conservation and policy actions

	Linkages			
Attitudes and behaviors	Importance of water usage for agriculture	Degree of negative effect of drought on agriculture	Drought likely to damage plants and animals	Drought likely to increase food prices
Willingness to conserve water for agriculture	0.378** $n = 2495$	0.251** $n = 2499$	0.255** $n = 2490$	0.300** $n = 2487$
# of personal actions taken to conserve water	0.199** $n = 2579$	0.225** $n = 2578$	0.261** $n = 2571$	0.180** $n = 2567$
Support for government action on water	0.072** $n = 2525$	0.214** $n = 2527$	0.124** $n = 2521$	0.134** $n = 2522$
Support for mandatory conservation	0.098** $n = 2510$	0.216** $n = 2517$	0.163** $n = 2509$	0.148** $n = 2514$

Source: ISTPP (2013)

**Significant at the 0.01 level or beyond

Table 33.2 Connection between perceived drought damage and support for mandatory conservation

	Likelihood that drought will damage plant and animal species				
Require mandatory water conservation	Very unlikely	Somewhat unlikely	Not sure	Somewhat likely	Very likely
Strongly oppose	18.0 %	6.7 %	3.1 %	3.0 %	2.7 %
Oppose	14.4	23.5	13.6	12.9	8.7
Unsure	35.3	32.9	49.7	34.5	28.2
Support	25.2	32.3	27.3	39.9	36.9
Strongly support	7.2	4.7	6.3	9.7	23.4
Totals	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
n	139	298	971	776	333

Source: ISTPP (2013)

that water for agriculture is extremely important tend to be willing to conserve water and to take larger numbers of personal actions to do so. People who see negative agricultural consequences from drought also tend to be willing to conserve water, and they are also more likely to support government actions, including mandatory conservation measures. Thus, the way water is perceived vis a vis agriculture and food production seems to play a significant role in influencing water consumption and support for water policies.

The latter point can be seen clearly in the results presented in Table 33.2. Here the perception of negative consequences from drought for plant and animal species is cross-tabulated with attitudes toward mandatory water conservation. The correlation in this table (0.216 as shown in Table 33.1),reflects the fact that those who think such damage is "very likely" are the strongest supporters of mandatory water conservation policies, while those who see such damage as "very unlikely" are the least supportive of such policies.

33.5 Directions for Future Research and Analysis

The results from the National Water Survey make a strong case for the idea that when people make a connection between water and agriculture, they are willing to support actions and policies to protect water. Of course, this survey was not designed to address such nexus issues, and these results only begin to scratch the surface of this important topic.

Additional analysis will focus on understanding whether these relationships might be influenced by other factors and whether willingness to take actions or to support water conservation policies are more directly related to other influences, such as respondents' education, political predispositions, age, place of residence, occupation, income, and other variables.

Future research will also be able to clarify the extent to which people make or understand connections between water, soil, agriculture, and food. The ISTPP (2015) embarked on a subsequent national survey specifically to investigate these nexus issues, the first of its kind. It asked respondents' to report on whether each of these statements with respect to agriculture and water or energy is true or false:

- Fertilizer use accounts for the largest source of energy input in agriculture.
- Organic food requires less water than food that is not organic.
- Recycled water cannot be safely used to grow food.
- Corn used as ethanol fuel gives cars better gas mileage than gasoline.
- Flood irrigation is a best practice for farmers to use when growing food.
- The energy used to transport food is about the same for local farmers' markets as for local grocery stores.
- Irrigating crops in the USA uses more groundwater than all other uses combined.

The survey also examined how concerned respondents are about each of the following issues related to agricultural production:

- The ability of food crops to tolerate drought
- The ability of food crops to tolerate pests and disease
- The loss of productive crop lands due to the growth of urban areas
- The availability of fertile top soil
- The diversity of plant seed varieties to preserve genetic material
- The amount of herbicides, pesticides, and fertilizer used in food production
- The amount of food wasted by grocery stores and restaurants
- The nutritional quality of the food produced
- The amount of energy used to produce the food
- The amount of water used to produce the food
- Pollution of water due to storm water runoff from crop lands

In terms of public policies, the survey examined:

- Views of appropriate governmental and public policy responses
- Conditions under which the general public and specialized publics seem to be willing to support various public policy options
- The drivers of perceptions of risk associated with soil, agricultural production, food, water, and related environmental characteristics

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Chapter 34
Whose Security is Important? Communicating Environmental Risk About Soil to a Diverse Audience

Ronald Amundson

Abstract Scientists who do "policy-relevant science" typically are inexperienced and unproductive at communicating to the public and policy makers, the people who ultimately make the decisions that implement or ignore the science. Recent research in the field of cognitive science shows that humans are "motivated reasoners," who effectively filter out information incompatible with their, and their community's, value system. Many science education efforts are only partially effective, and some may in fact increase resistance among certain target groups. Science communication is not about improving the message, it is deeply understanding what makes people tick and what doesn't. A handful of scientists, and a few rock stars like Bono of the band U2, either have deeply considered how to communicate or are inherently endowed with skills that can reach diverse and largely incompatible audiences. "Talking about soil like a rock star" does not imply swagger or unfettered enthusiasm; it implies that the speaker has a deep understanding of ways to connect to both the heart and mind of his or her audience.

Keywords Science education • Science communication • Human security • Soil security

34.1 Introduction

To researchers and enthusiastic students in the environmental and agricultural sciences, it is clear that soil is simply an essential resource for human survival and well-being. This message has occasionally been translated to policy makers, leading, for example, to the establishment of the U.S. Soil Conservation Service – and most recently, the UN declaration of 2015 as the International Year of Soils. Yet, it

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is recognized by many researchers that a more concerted institutional and financial framework is needed to attend to the many soil-related challenges of this century, such as climate stabilization and the development of truly sustainable means of food production on a massive scale (Amundson et al. 2015). *Security* is a concept that is particularly attractive to policy makers, particularly in the guise of national security. Thus, combining *soil* and *security* is an attractive way to draw attention to soil as an essential human resource.

But while *soil security* as an emerging theme is a captivating concept (Koch et al. 2013; McBratney et al. 2014), who will be the recipients? Probably, with some notable exceptions, the largest audience will be soil scientists themselves and people working in closely related fields. Developing unifying and exciting themes for areas of science is important to help galvanize and re-energize a field, but still may fail at crossing the chasm to the policy and political arena, where science is ultimately translated into meaningful change. Scientists simply are not trained to effectively communicate – except to each other (Brownnell et al. 2013). Garnering resources and changing policy requires a complex and persistent effort to reach out to nonscientific audiences. More importantly, there is not just one "general" audience, there are multiple important constituencies, each with different philosophical frameworks and value systems. The reformatting of soil into a novel, but single, theme may fail to captivate or engage any of these important constituents.

The purpose of this essay is to build on, and draw attention to, recent research on how people respond to results from environmental research and the complex ways in which we all effectively filter out, or select from, facts and data that best align with our and our community's values. The importance of this fundamental way we think is that traditional academic communication and "education" may not only be ineffective for the goals we wish to attain, they may be counterproductive. While one might argue there is yet no proven method to gain the trust or support of all individuals, there are data and case studies that illustrate ways that are more effective than others. The ultimate lesson from these cases is that for us to communicate the importance of soils to others, we may have to abandon some of our deeply ingrained "scientific" approaches and learn to understand humans more than soil.

34.2 The Context

About a decade ago while serving on an oral exam committee, I was for some reason both struck, and somewhat critical, of the student's enthusiastic goal of engaging in public science education, particularly with respect to climate change. I had recently read the results of public opinion polls of US and European citizens and their (at that time) widely different degrees of accepting what was a growing consensus of human-driven climate change (the Europeans were much more receptive). After asking whether Europeans were simply better educated than Americans (the student disagreed with this premise), I queried (as much for myself) why the message of human-induced climate change was so difficult to convey to Americans.

While the reasons for this cultural difference were certainly not clear, we embarked on some discussion of whether more education was needed, or even fruitful, given what appeared to be far deeper seated cultural or psychological impediments to environmental risk assessment.

Today, Americans view *their security* far ahead of any environmental concerns in most public opinion polls (GALLUP Inc. 2016). This is important, as I will discuss, for finding fruitful directions to engage policy makers. Second, soil itself is a difficult entity to explain or convey to the nonspecialist in simple and captivating ways. How do we easily convey the complexities of a soil profile, the history it contains, and the complex ways it feeds back into global biogeochemical cycles? It is simply not easy, and many of the "feel-good" ways of discussing soil may instead trivialize the problems and make soil science seem like a quaint and antiquated field to some. Indeed, for most people, "soil" is seemingly everywhere, and it is hard to create empathy for something as inert as dirt. Soil obviously needs many messages, but the message will need to connect to the need people feel for their own security. This is now an emerging area of research, as I discuss below.

34.3 How We All Think

In the past decade or so, research on the communication of environmental risk has grown in concert with the increasing combativeness and divisiveness in climate change science and its continued lack of full scale public acceptance. Several general articles (Kahan 2010) and books (Mooney 2012) discuss the ways in which we all filter out, or accept, information which is constantly being provided to us. One key message that emerges from these studies is that the most effective means of conveying a message, and gaining acceptance, is through the human heart, and not the head – an avenue of communication that for most scientists is both foreign and counterintuitive. In the case of soil, rather than scientists lecturing and providing soil-centric educational materials, it may be simply better to appeal to soil's essence to the human heartstrings of family, nation, and prosperity. These issues, important to nearly all individuals, serve also as a common ground between academics and their constituents and a means of sidestepping sometimes challenging baggage that environmental scientists face when explaining or conveying controversial topics to certain groups of constituents suspicious of intellectual authority. To state this in a different way, we must (i) *first* identify and try to understand our audiences (there will be many) and their concerns and (ii) identify how our concerns about soil may resonate with their core values or interests.

Certainly, one might ask, "but does this work?" Given the continued division over climate change science, it is fair to be skeptical – though there are important individual examples that suggest serious and sincere discussions between scientists and nonacademic groups can lead to unanticipated and significant acceptance of scientific knowledge and fact – cases where the message bearer worked hard to find areas of common emotional ground.

In climate change science, John Houghton, Professor at Oxford, was a lead author on the first three IPCC climate reports. In the early 2000s, there was a slow reception of the growing scientific consensus by conservative groups in the USA. Houghton, a practicing Christian, met with leaders of Evangelical Christian groups in the USA, articulating the relationship of climate change with stewardship of the biblical creation. This effort helped lead to the creation of: *Climate Change*: *An Evangelical Call for Action* initially signed by 86 leaders and members of American Evangelical congregations (Evangelical Climate Initiative 2006). More recently, Professor Katharine Hayhoe, an IPCC climate scientist at Texas Tech, has cowritten a book with her Evangelical Christian Minister husband (Hayhoe and Farley 2014), articulating the congruence between her scientific research and her religious beliefs. For this work, Hayhoe was awarded the American Geophysical Union's Climate Communication Prize at their Fall 2014 meetings (AGU 2015).

Possibly the most well known – and in some ways most unlikely – "communication" success story is Bono's (the lead singer of the Irish rock band U2) success in the 2000 Jubilee Year event that was designed to forgive foreign debt to underdeveloped nations. In a most unusual encounter for support, Bono met with Jesse Helms, the conservative leader of the US Senate Foreign Relations Committee:

> *Helms was known for equating foreign aid with throwing money down* "*ratholes*." *Bono claimed that Helms wept when they spoke*: "*I talked to him about the Biblical origin of the idea of Jubilee Year.... He was genuinely moved by the story of the continent of Africa*, *and he said to me*, '*America needs to do more*.' *I think he felt it as a burden on a spiritual level*." *Of his meeting with Bono*, *Helms said*, "*I was deeply impressed with him. He has depth that I didn't expect. He is led by the Lord to do something about the starving people in Africa*." *However*, *after their meeting*, *Helms embraced debt relief and*, *later*, *funding to combat AIDS in the developing world. How can we explain this change*? (Busby 2008)

Certainly one explanation, beyond Bono's celebrity image, was his intuitive way of appealing to areas of shared agreement or values, which then provided a base for discussions of the issues of interest. The reader will note that the examples given here all involve cases where religious beliefs paved a way for discussion of less obvious points of agreement. These are not meant to be construed as the only means of engagement, but are some of the most widely discussed cases. Secular areas of shared values might be national pride and heritage or regional history and its economic future.

34.4 Communicating About Soil

In the past decade, there have been spikes in food prices and unusual or extreme weather events that have created a receptive audience for discussion of the importance of resource management. However, the audience is only a fraction of society and its political leadership, and the attention span is short and temperamental. Messages with strong and continued negativity have been shown, even to the most receptive audience, to lead to environmental overload or fatigue (Schuetze 2013).

Soil is a global resource, but within the individual jurisdiction of nations. Thus, the populace and leadership of each of the multitude of nations are unique audiences, and within each of these political entities are likely diverse groups with differing values and concerns – and abilities to address problems.

What we as scientists must do is not just prepare PowerPoints, research articles, and lectures and hope that they change or impact policy. They won't, because the people we need to reach will seldom even hear or read these messages, and if they do, the results will be uncertain. To convey science into change may require as much research and attention as the original science. To do policy-relevant science, without effectively connecting to policy makers, is ultimately an unsatisfactory exercise in a century with so many urgent and challenging issues. Talking and communicating about soil "like a rock star" means something far deeper than most might expect: it involves understanding people as much as the earth.

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Chapter 35
Save our Soil to Save the Planet

Michael Jeffrey and Hayley Achurch

Abstract In 2012, the Australian Prime Minister appointed former Governor-General Major General the Honourable Michael Jeffery as Australia's first National Advocate for Soil Health. This appointment was made in recognition of the need for greater public awareness of the importance of soil and the sustainable management of soil to Australia's continued prosperity.

Healthy, well-managed soils are fundamental to human existence. Not only for the production of healthy food and fibre but also to underpin the provision of clean air, water, and a regulated climate and thereby supporting sustainable and prosperous communities. Globally, soil and water resources are at risk from degradation and loss of access, and this will increasingly impact global security and human and environmental well-being. History has many examples where severe soil degradation and loss of access to freshwater has led to destabilisation, aridification and desertification. We are also seeing modern examples of this.

Resource management challenges faced in the Western world are likely to have broader implications. Without proper and coordinated action to restore and maintain soil health, our ability to feed a ten billion population by 2050 and to maintain food production in the face of climate variability will be seriously compromised. Achieving soil and water security requires urgent national and global cooperation.

Australia has a strong history of on-farm innovation and world-class scientific capability with a tradition of international collaboration. This puts Australia and other nations with similar expertise, in a strong position to share knowledge about improving soil security with other countries.

To save the planet, we must save the soil and every citizen must be involved.

Keywords Healthy soils • Human health • Nutrition • Resource protection • Citizen science

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35.1 National Advocate for Soil Health

In 2012, Major General the Honourable Michael Jeffery was appointed Australia's first National Advocate for Soil Health (Soil Advocate). The then Prime Minister, Hon. Julia Gillard, noted at the time that the condition of our soils must be a national priority. Following advice from a parliamentary working group, she indicated that a key step in recognising the importance of soil was the appointment of a person with the authority and trust of the community to raise awareness of the importance of soil – an Advocate for Soil Health. The role raises public awareness of the critical role soil plays in underpinning sustainable productivity, delivering high-quality ecosystem services and helping to meet global challenges. In March 2015, Prime Minister Tony Abbott approved an extension to the appointment and a continuation of the role throughout the 2015 International Year of Soils.

35.2 The Global Context

While the Soil Advocate role is designed to advocate on behalf of healthy soils in Australia, Major General Jeffery believes that a global approach to soil health is vital for human well-being. Healthy, well-managed soils are fundamental requirements, not only for the production of food and fibre but also to underpin the provision of clean air, water and a regulated climate to support sustainable, healthy and prosperous communities.

However global soil and water resources are at risk, as a result of continuing landscape degradation and loss of access to drinking and agricultural water, which will increasingly impact human and environmental well-being.

The world's population is projected to increase from 7.2 billion to around 9.6 billion by 2050 (United Nations 2014a). This means that sustainable food production must almost double by 2050 to meet the needs of the world's rapidly growing population and it has to be achieved while:

- The globe is losing land including arable land at an unsustainable rate.
- Critical aquifer water supply for irrigated agriculture in China, India, Africa and the Middle East is reducing rapidly and is irreplaceable. California's groundwater supply, which supports the Central Valley aquifer system which is one of the country's most productive agricultural systems, has lost over 70 million megalitres (or 60 million acre-feet) of groundwater since 1960 (US Geological Survey and U.S. Department of the Interior 2009).
- Most of the great rivers passing through populated areas of the developing countries are heavily polluted. These include rivers such as the Ganges, Tietê and Yangtze Rivers (Hamner et al. 2006; Barrella and Petrere 2003; Müller et al. 2008).
- The impacts of climate variability, are becoming more extreme, particularly the occurance of droughts, fire and flooding (Preston and Jones 2006).

Food and water scarcity is the most urgent challenge facing humanity in the twenty-first century. Countries that produce food now have to produce significantly more and in a way that maximises the efficient use of inputs and limits food wastage. Innovative and globally shared approaches will be required to successfully meet this challenge, including in relation to major infrastructure to ensure the efficient movement and storage of food to where it is to be consumed, successful management of threats from pests and diseases, a ready availability of proven high-quality inputs to production, and improving the expertise and knowledge of land managers, particularly in respect to understanding the fundamentals of what creates a suitably healthy soil. Key to this is understanding how to successfully manage the link between soil (microbial, fungal, nutrient), water (the hydrology of how water is retained and moves in the soil) and the plants (the need for diversity of plant life and keeping the land surface covered, preferably green, at all times, including in our cities). Healthy soils will help ensure the sustainable quality and quantity of food produced, and this warrants substantial government and private investment.

Today, soils are becoming less fertile through the rundown of nutrients and carbon, eroded through overgrazing and ground cover removal and wildfires. In 2000, wildfires globally burnt 350 million hectares, the equivalent of the size of the continent of India (United Nations 2007), emitting prodigious quantities of CO_2 in the process. Research indicates that improved fire management, in particular biomes such as grasslands, have the potential to reduce considerably greenhouse gas emissions (CSIRO 2015).

Around three million children under 5 die each year from undernutrition (UNICEF 2015), and 805 million people were chronically undernourished in 2012–2014 (United Nations 2014b). The ramifications of malnutrition are that many people, particularly children, will be impaired both intellectually and physically, severely limiting their capacity to work and support themselves and perpetuating the poverty cycle. It has been estimated that 100,000 children are born annually with irreversible brain damage due to inadequate nutrition during the mother's pregnancy (Kennedy et al. 2003). This is an alarming statistic, and much of this could be rectified through maintaining healthy soil, thus enabling more productive and sustainable agricultural systems.

Franklin Roosevelt, who experienced firsthand the impact of the severe dust storms that greatly damaged the ecology, agriculture and social fabric of the US and Canadian prairies during the 1930s, displayed strategic foresight when he said – "The history of every nation is eventually written in the way in which it cares for its soil" (Roosevelt 1936) and "the nation that destroys its soil, destroys itself" (Roosevelt 1937). There are many other examples from history where severe soil degradation and loss of access to freshwater has led to destabilisation, aridification and desertification, and today we are also seeing destabilisation, from tensions over natural resource availability and distribution.

35.2.1 Case Study: The Fertile Crescent

The Fertile Crescent is a region which is occupied by the modern territories of Iraq, Jordan, Lebanon, Israel, Palestine, Syria, Iran and Turkey. Farming, as we know it, began there 11,500 years ago (Diamond 1999). For centuries, the region was a major food producer and led the ancient world in agricultural innovation. Today, however, the productive capacity of the landscape is vastly different. Deforestation and large-scale irrigation caused widespread soil erosion and salinization which, without appropriate soil and natural resource management, turned productive fields into barren saltpans. This has sobering implications for present and future management of landscapes worldwide.

Today, access to water resources is further exacerbated by the construction of large dams which are used to control water flow. For example, since 1975 tensions between Turkey, Syria and Iraq have been high, largely due to water access. Turkey is upstream on the Tigris and Euphrates Rivers, meaning its dams and hydropower infrastructure impact on the water reaching Syria (reduced by 40 %) and Iraq (reduced by 80 %) (Guzman 2013). Internal conflict places further pressure on water resources. Rivers, canals, dams, sewage and desalinisation plants are military targets because control of water gives strategic control over major cities in the region, such as Baghdad. In 1980, former Iraqi leader, Saddam Hussein, drained the Mesopotamian Marshes in southern Iraq to discourage local opposition (Richardson and Hussein 2006). The UN declared this act an ecological and cultural disaster, akin to deforestation in the Amazon rainforest, and today it has still not been restored to its former good environmental condition.

35.2.2 Case Study: The Mekong Delta

Across the globe there are likely to be other conflicts over natural resources. In 2012, the day after China commissioned its biggest dam on the Mekong, Vietnamese President, Truong Tan Sang, warned that “tensions over water resources are threatening economic growth in many countries and representing a source of conflict” (Chellany 2013). Natural flows from the Mekong River have been disrupted by the increasing number of hydropower dams built by China in the upper Mekong. Consequently there are rapid changes in water levels, farmers have reduced ability to irrigate crops, fish migration to spawning grounds is impacted and downstream experiences other adverse effects. This impacts countries such as Laos, Vietnam, Thailand and Cambodia where over 60 million people rely on the river for food, water and transport (Richardson 2009).

The President of the World Bank, Jim Yong Kim, stated last year that “fights over water and food are going to be the most significant direct impacts of climate change in the next five to 10 years” (Elliott 2014). The social implications of a lack of food and water globally will inevitably impact economic growth. Soil and water security will increasingly underpin global social stability and security. The world's soil and water have such great impacts on social stability that some nations now include natural resource availability in their military threat assessment process. Other nations may need to consider this point, particularly if more resources could be allocated to fixing the soil, rather than destroying it.

35.3 Australia

Many soil problems experienced around the world also pose challenges in Australia. Australia's soil is mostly very old, strongly weathered, shallow and relatively infertile by world standards, thus presenting many challenges for its farmers.

A number of Australian farmers, scientists and policymakers have made significant progress over recent years in improving land management practices, including halting or reversing soil degradation; however, a number of serious problems remain, including:

- Degradation of arable land, through wind and water erosion, aridification, acidification, significant loss of soil organic carbon, structural decline and loss of nutrients
- Severe salinity, particularly in Western Australia
- Erosion and excision of streams and rivers and draining of wetlands for farming and urbanisation purposes
- Urban growth and larger cities encroaching on fertile agricultural land and negatively influencing climate through urban "hot spot" effects, thereby reducing local precipitation
- Increasing erratic and unreliable rainfall, bigger floods, more extreme temperatures, longer droughts and more wildfires

Australia has a number of initiatives underway that seek to address these natural resource management challenges, including:

- The appointment of a National Advocate for Soil Health to raise awareness about the importance of the sustainable management of soil to Australia's continued prosperity.
- The release of the Australian Government's National Soil Research, Development and Extension Strategy in May 2015. The strategy's vision is to *Secure Australia's soil for profitable industries and healthy landscapes*, and its implementation will work to better coordinate our national soil research effort and focus this effort on priority issues. The strategy will also improve the communication of soil knowledge, including the extension of soil research outcomes to farmers and land managers, improve our national soil data coverage and availability and adopt a national approach to building future skills and capacity.
- The Prime Minister's Commonwealth Science Council inclusion of soil, water and food in Australia's top nine national science and research priorities.

- The Australian Government's expenditure of over $140 million over 4 years on the *Carbon Farming Futures* programme, to deliver research, on-farm trials and communication activities that support on-farm emissions reduction.
- Financial institutions' consideration to include natural capital in its lending assessment criteria, policies and products. The National Australia Bank is a major agricultural lending bank which may quantify natural assets as part of their risk assessment and lending processes. This is based on the premise that farms whose natural resources are well managed have greater resilience to climate variation and market fluctuation and are also more profitable in the long term. This makes farms with high natural capital a less risky investment for banks.

Australian farmers have a strong history of on-farm innovation, and through the Commonwealth Scientific and Industrial Research Organisation (CSIRO), universities and other research providers, Australia has world-class scientific capability with a long tradition of international collaboration.

This capacity and knowledge should be expanded and shared globally as part of a collective approach to management of soil and other natural resources.

Australia, and other nations with similar expertise, can play lead roles in demonstrating what can be done in respect to soil health. Collectively, the world has solutions to reverse land degradation and improve soil health, thereby equipping the globe to better deal with impending challenges. The manner by which soil, water and biodiversity is integrated is vital. By coordinating action to restore and maintain soil health, we contribute to a strong, health resource base which can feed the global population, build on-farm resilience and promote social stability.

35.4 Conclusion

Healthy soil is vital for sustainable life and it impacts all aspects of society. Feeding the growing global population in the face of degraded landscapes and potential conflict over ownership of the world's natural resources poses an immense challenge. Lessons can be taken from the past and from all those involved in soil research and policy across the globe. Collaboration and sharing knowledge and expertise will begin the process of reversing the soil degradation that has occurred over the last half century. Australia, and other nations, is implementing a number of initiatives to this effect. Such knowledge and capacity should continue to be built over the long term and be supported by appropriate investment and coordinated government policies.

The 68th United Nations General Assembly's declaration of 2015 as the International Year of Soils creates an appropriate catalyst for a renewed focus on smart and sustainable soil management. Politicians, policymakers and scientists should take this opportunity to lead and recognise that good soil management underpins a sustainable, profitable and secure future for all.

The impending global food and water crisis is one of the most significant challenges humanity faces this century, and a healthy soil is central to rectifying this problem.

To save the planet, we must save the soil.

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Chapter 36
Protection of the Soil Resource in the Brazilian Environmental Legislation

Carlos Gustavo Tornquist and Tiago Broetto

Abstract Brazil has been attracting great interest in international environmental discussions because of its large territory and diverse natural resource base; a large part of which is still mostly pristine. Deforestation of the Atlantic and Amazonian rain forests and massive conversion of the Cerrado by haphazard land development, especially the expansion of livestock and grain/biofuel production, have sparked widespread concern of mounting soil and water degradation and loss of biodiversity. As a response to these ensuing risks of environmental degradation, comprehensive legislation has been enacted at the federal level to protect ecosystem services, with greater emphasis in waters and biodiversity. The recent revision of the Brazilian Forestry Code (BFC) in spite of the name clearly stands out as an environmental law, an overarching legislation dealing with key aspects of terrestrial ecosystems as well as land tenure. BFC contains conservation provisions that affect both private and public-owned land, not only remaining vegetation fragments but also extending onto farmed land. The word "solo" (soil) appears 40 times in the 82 articles that comprise BFC, in most instances associated with "protection" or "sustainable use." The soil resource has been historically treated in an off-handed manner in Brazilian legislation, but more recently some Brazilian states have advanced supplemental legislation (known as Leis do Solo – "Soil Laws") addressing specific conservation and management issues to safeguard this key resource for future generations. There is ample opportunity for soil scientists to engage in this new legal context, a grand effort to conserve natural resources and institutionalize sustainable land use in Brazil.

Keywords Soil quality • Soil conservation • Environmental legislation • Brazil

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36.1 Brazilian Environmental Legislation

Brazil has been long been a focal point of the global environmental debate mostly because of the threats to the Amazonian and Atlantic rain forest. Past and present threats to the Atlantic and Amazonian rain forests and other biomes such as the Cerrado and the grasslands (South American Pampas) include urban encroachment and haphazard land development, especially the expansion of livestock and grain/biofuel production (Lapola et al. 2014). In more recent times, the expansion and intensification of grain production and biofuel crops in other Brazilian biomes such as the Brazilian savanna (the Cerrado) have compounded concerns about soil degradation, water availability, and loss of biodiversity. The environmental legislation implemented at the federal level over the last decades, especially since the 1980s, aimed at consolidation of comprehensive safeguards to protect ecosystem functions nationwide with emphasis in biodiversity and soil and water quality.

The Brazilian Forestry Code (BFC) (Presidência da República 2012), since its inception in 1934, has developed from a timber conservation-focused legislation to a full-fledged (or at least attempting to become) land protection or terrestrial ecosystem code with implications on land tenure, both private and state owned (Soares-Filho et al. 2014).

A myriad of legal features were introduced in its many versions, some of which are now cornerstones of the BFC: APP ("Área de Proteção Permanente" – Permanently Protected Areas) and RL ("Reserva Legal" – Legal Reserve) (Sparovek et al. 2010, 2012). Both apply *to all non-urban land in the country with few exceptions*; APP and RL are binding provisions that were originally intended to conserve valuable timber and prevent soil and water degradation that mandated landowners to *permanently* set aside parts of rural properties for conservation or sustainable management. Key aspects of these legal features are the following:

1. APP encompass parts of the property to protect the soil and water resource and prevent degradation. APP are established according to certain critical terrain attributes and legally set without any input from the landowner. These include (a) riparian zones along rivers and other water bodies, (b) slopes >45°, (c) most mountain and some hilltops, and (4) altitudes >1800 m. No productive activities are allowed, and these areas should be maintained with the original vegetation or restored if it was degraded.
2. RL establishes a fixed percentage of property area–from a maximum of 80 % in the Amazon to 20 % in other biomes such as the Atlantic forest–that is set aside by the owner and can be managed for production if core ecosystem structure and functions are not significantly altered. Examples of this would be sustainable harvest of forest products (e.g., Brazil nuts in the Amazon, cashew in the Cerrado), beekeeping, low-intensity cattle grazing in the savannas and grasslands, and other low-input low-impact activities. RL is additional to the established APP, except for small farms.

These features as well as additional aspects of the original BFC were hardly ever enforced for many reasons: lack of personnel and infrastructure and jurisdictional overlaps with state and municipal governments. Although praised in many aspects by conservationists and the scientific community in general, the "old" FCB never attained support from farmers, ranchers, and foresters. In fact, most of organizations representing these groups denounced the code as too restrictive and hostile to property rights and lacking technological and scientific basis. A vocal section of Brazilian agribusiness has routinely claimed that FCB implementation conflicts with agricultural production and would undermine Brazil's expanding leadership in the global market of farm commodities. A substantial body of research indicates that most of these claims are unfounded (Ferreira et al. 2012).

However, extremely steep slopes and mountain tops above 1800 m (the latter affecting less than 0.1 % of Brazilian territory) have obvious limitations for intensive agriculture and even silviculture, and setting these areas aside to promote natural vegetation conservation or restoration should not be controversial. On the other hand, riparian environments have long been settled and farmed because of fertile soils and ease of access and are still under pressure in many regions.

36.2 Need for Supplemental Legislation

Several aspects of the BFC require supplemental legislation to be enacted by the Ministry of the Environment. Changes under implementation tried to resolve these original conflicts with new features and mechanisms that largely ease some of the most restrictive (and controversial) aspects. However, a new provision reclassified land with anthropic use until 2008 comprised a new legal feature called AC ("Área Consolidada" – Consolidated Areas). Depending on farm size, a fraction of the AC land that conflicts with the APP definition would have to undergo restoration to the original ecosystem. Other changes in BFC now allow small farmers to count APP areas as part of the RL of the property, significantly reducing the total protected areas outside national parks and preserves.

A crucial innovation that could have wide-ranging positive impacts for conservation in Brazil is the Environmental Reserve Quota (CRA – "Cota de Reserva Legal" in Portuguese), a negotiable instrument derived from "surplus" conserved areas (in excess of RL requirements). These CRA "credits" from a property, once underwritten by the Ministry of Environment, may be used to offset an LR deficit on another property within the same biome and same Brazilian state. Comprehensive implementation of CRA could create a trading market of protected land, reversing the notion held by farmers and their organizations that these carry high opportunity costs. Trade of CRA could become a cost-effective mechanism to promote compliance with the new code, while protecting high-conservation value ecosystem fragments which could otherwise be legally deforested, drained, or plowed under. Judicious use of CRA could benefit functional and ecological attributes of natural landscapes such as habitat integrity (and thus biodiversity) and regulation and maintenance of biogeochemical cycles (Soares et al. 2014).

36.3 Implementation Issues

The effective implementation of the BFC depends on a new web-based geospatial database, the Rural Environmental Registry System (SICAR) (Cadastro Ambiental Rural (n.d.)). Once completed, this system should store boundaries of the existing five million farms and ranches in Brazil. SICAR could create the underlying "physical" framework for establishing a comprehensive system of payments of ecosystem services and a reliable market for CRA. For a practical standpoint, the success of CRA within SICAR would be highly welcome to offset restoration costs of degraded lands, particularly for small landowners.

Meanwhile, four of the 27 Brazilian states have introduced (or are discussing) supplementary legislation underpinning soil conservation and sustainable management of the land. It was recognized that the BFC did not address the soil resource with enough detail, although the word "solo" (soil) appears 40 times in the 82 articles that comprise BFC, in most instances associated with "protection" or "sustainable use." These states (Paraná-PR, Sáo Paulo-SP, Rio Grande de Sol-RS, and Espirito Santo-ES), which have extensive agricultural production and in the past faced severe soil degradation, especially erosion, have advanced supplemental legislation (known as Leis do Solo – "Soil Laws") addressing specific conservation and management issues to safeguard this key resource for future generations.

36.4 Concluding Remarks

Brazilian soil science has much to contribute in the current scenario of evolving environmental legislation. The dramatic growth of agricultural research infrastructure of latter years has yielded a large body of locally produced knowledge about the soil resource. Many aspects of sustainable production remain as challenges, but the days of reliance on slashing-and-burning the country's forests, the massive erosion events, and insidious contamination of soils and waters are more often than not things of the past. It is a matter of national pride that the current generation of Brazilian agronomist and soil scientist has had extensive training in soil conservation and management and land use planning and monitoring.

It remains to be seen how much direct involvement Brazilian soil scientists will have in the implementation of the abovementioned legislation. Most soil professionals have had limited participation because the focus of the environmental legislation debate to date has been on restoration biology, forest management, and biodiversity conservation. The importance of these aspects notwithstanding, there is ample opportunity for soil scientists to engage in this new legal context with specific tools that could help in the management and monitoring of the legal land protection features established (APP and RL), such as land capability classifications, digital soil mapping, biogeocycle, and land use change modeling, all of which could easily fit and be incorporated in this grand effort to conserve natural resources and institutionalize sustainable land use in Brazil.

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Chapter 37
Creating Incentives to Improve Soil Health Through the Federal Crop Insurance Program

Lara Bryant and Claire O'Connor

Abstract American farmers are increasingly relying on the subsidized Federal Crop Insurance Program (FCIP) to manage weather-related risks. Unfortunately, the program is structured so that it does not recognize soil security and may actually be putting American soil resources at risk. The FCIP is highly subsidized; on average, 62 % of individual premium costs are paid for by the federal government. As climate change causes more extreme weather and the cost of the FCIP continues to rise, lawmakers will be forced to consider whether the US government can continue to afford the heavy subsidies offered by the FCIP without changes to the program. The FCIP is currently structured using a flawed formula that lets high-risk farmland and management off the hook and ignores soil regenerative practices that would secure the soil. What if the FCIP rewarded good stewardship practices, like cover crops, that could result in lower indemnity payments and also improve carbon sequestration, water quality, and biodiversity? NRDC proposes the development of a pilot crop insurance program offered by the FCIP in select areas of the Mississippi River Basin. The 508(h) pilot program would offer actuarially sound crop insurance discounts to producers whose appropriate use of cover crops puts them at a lower risk for crop loss.

Keywords Codification • Crop insurance • Cover crops • Soil health

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37.1 Introduction

The Dust Bowl of the 1930s caused devastating soil loss in the Central Plains of the USA and clearly illustrated the relationship between soil security and the economy – especially the rural economy. Richard Hornbeck estimates that land values in the Central Plains declined by $153 million in 1930 during the Dust Bowl years (Hornbeck 2012).

The US government responded by creating the Soil Conservation Service – now known as the Natural Resources Conservation Service (NRCS). Some of the current soil-focused activities of the NRCS are described in Chap. 5. While NRCS was established to secure the soil, the government also created programs to provide a safety net for American farmers and agriculture. One of these programs is the Federal Crop Insurance Program (FCIP); though it was created in 1938, it was not widely used until the 1990s (O'Connor 2013). Currently, more than 70 % of cropland acres (294 out of 390 million acres) are enrolled in the FCIP, and many farmers rely on the program as their primary safety net (Shields 2015).

Unfortunately, the program is structured so that it does not incorporate soil security and may actually be putting American soil resources at risk. The program is highly subsidized; on average, 62 % of individual premium costs are paid for by the government (Shields 2015). This distorts the actual risk of planting commodity crops so that when crop prices are high, farmers may plow more and more land with seemingly little risk, including marginal land that may not be the most suitable for growing crops. According to the Environmental Working Group, more than 23 million acres of grassland and other land with high ecological value were converted to cropland (mostly to corn, soybeans, and winter wheat) between 2008 and 2011 (Faber et al. 2012). Sadly, this follows the same pattern of events that preceded the Dust Bowl, putting soil resources in the Central Plains and Midwest at risk yet again.

American farmers are increasingly relying on the subsidized FCIP to manage weather-related risks. From 2001 to 2010, crop insurance indemnities averaged just $4.1 billion (O'Connor 2013). In 2011, the FCIP paid a record-breaking $10.8 billion in crop insurance indemnities to farmers – a record that lasted less than a year (O'Connor 2013). After an extreme drought, total indemnities soared to $17 billion in 2012 (RMA 2015).[1] Though crop insurance payments decreased in the following years to about $12 billion in FY 2013 and $9 billion in FY 2014, costs of the FCIP remain well above the average of the previous decade (RMA 2015). As climate change exacerbates extreme weather patterns that increase risk, indemnities can be expected to continue to rise.

While the 2014 Farm Bill included minimal provisions to ensure that farmers who enroll land in crop insurance follow basic conservation requirements, soil

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[1] Total indemnities are paid by the federal government and private insurance companies. While we have included total indemnity numbers because they reflect actual crop loss, the subsidized portion is a smaller number, for example, government cost of the FCIP was $14 billion in 2012 (Risk Management Agency 2015).

resources are still at risk. The FCIP is currently structured using a flawed formula that that lets high-risk farmland and management off the hook and ignores soil regenerative practices that would protect soil security (O'Connor 2013).

What if the FCIP instead rewarded good stewardship practices, like cover crops, that could result in lower payout of indemnities and also improve carbon sequestration, water quality, and biodiversity? NRDC proposes the development of a pilot crop insurance program offered through the FCIP in select areas of the Mississippi River Basin. The 508(h) pilot program would offer actuarially sound crop insurance discounts to producers whose appropriate use of cover crops puts them at a lower risk for crop loss.

37.2 Explanation of FCIP Subsidies and the Risk Problem Within

Figure 37.1 provides an overview of how actual crop production risks are distorted by FCIP subsidies:

1. First, as with any insurance program, farmers purchase a policy from 1 of the 17 private insurance companies that are authorized by the FCIP to sell crop insurance.
2. The private insurance company issues a policy to the farmer.

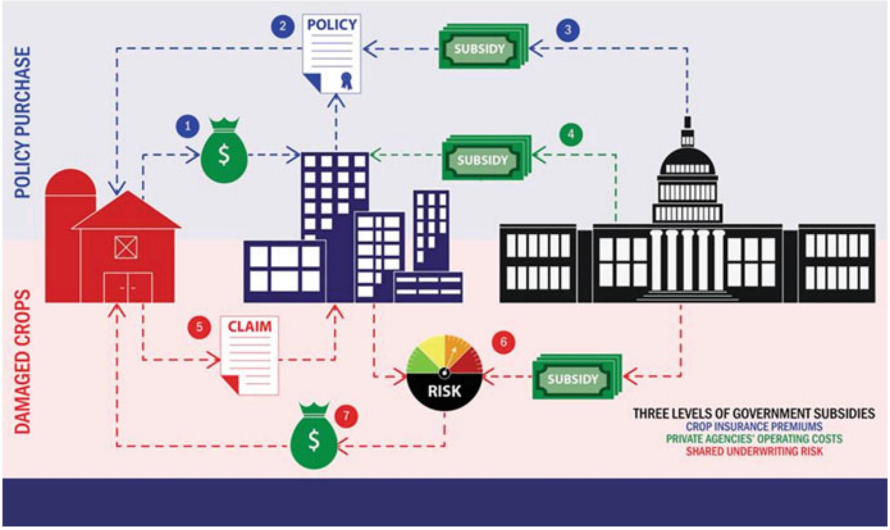

Fig. 37.1 Subsidies and risk within the federal crop insurance program (Image by Gopi Shah, Natural Resources Defense Council)

3. Premium costs are set to be "actuarially sound," defined by the Federal Crop Insurance Act to mean premiums must equal the cost of indemnities paid; this is calculated from a producer's average production history (APH), or for new farmers, the premium is set to the average cost of indemnities in the county (O'Connor 2013). In this way, producers with insured land that has been high cost in the past will pay lower premiums than perhaps they should because their higher individual cost is offset by the lower costs of other producers and land nearby. Although individual farmers' "actual production history" (APH) is used to determine premium rates, a farmer's APH often contains 10 years or more of yield information, diluting trends of increasing risk over time. Furthermore, recent changes in the 2014 Farm Bill remove extreme loss years, such as 2012, from APH calculation, further distorting the actual risk of insuring a farmer. Finally, producers do not pay the full premium as the cost is subsidized by the federal government. The average subsidy covers 62 % of the total cost of the premium (Shields 2015).
4. The government also reimburses the private crop insurance companies for their administrative costs to sell crop insurance. Reimbursement of administrative and operating costs was $1.4 billion in FY 2014 (Shields 2015).
5. When a farmer files a claim for crop insurance, it can be yield or revenue based. For example, for a yield-based claim, imagine Farmer Smith produces on average 200 bushels of corn per acre. If bad weather causes him to produce 150 bushels per acre for 1 year, he may file a claim that partially offsets the loss of 50 bushels per acre. Revenue-based claims are based on the farmer's expected revenue, which can be less due to lower yields or if the price of corn drops from what was expected at the time the policy was purchased.
6. If an insured driver repeatedly files claims for accidents, then he is in danger of losing his auto insurance. This is not true with crop insurance and high-risk farming. Crop insurance agencies are required by the FCIP to write policies for all farmers who want to apply, and the cost of reinsurance is subsidized by the program. There are two pools of risk – low-risk policies that crop insurance companies will want to keep and high-risk policies that are reinsured with federal subsidies. Although there are some rules governing how many of the low-risk policies companies are allowed to keep, this is the point in the process where most of the risk assessment is occurring. This is different than with most private insurance policies, where risk assessment occurs at the beginning of the process, during the premium-setting phase.
7. Indemnities are issued to the farmer when a claim is paid, and the overall cost of the program increases along with the program's overall risk.

As you can see, the calculation of risk for any individual's policy is far removed from what the individual pays out of pocket; the risk calculation is made when companies are assessing their reinsurance strategies. As a result, companies are not able to send any sort of direct price signal to farmers to encourage them to invest in risk-mitigating behaviors.

As the cost of the FCIP rises each year, the program has been increasingly scrutinized, and many proposals have been developed to reduce the overall cost of the program. The US Government Accountability Office (GAO) has published two recent reports recommending reductions in premium subsidies. The most recent of these, published in 2015, proposes that “if premium subsidies had been reduced by 15 percentage points for the highest income participants from 2009 to 2013, the federal government would have saved more than $70 million over the 5-year period” (GAO 2015). A recent Washington Post editorial stated that projected costs of the FCIP through 2018 will be $24 billion. The editorial further criticizes the FCIP, stating that “like so many of its predecessors, the 2014 farm bill promised cheaper, more efficient federal agricultural policy, but delivered the opposite” (Editorial Board 2015).

Despite these criticisms, there are significant hurdles to making any substantive legislative changes to the FCIP if those changes penalize farmers or are perceived to do so. The FCIP is widely supported by the US agriculture, from farmers to lawmakers and every other agricultural trade group in between. The FCIP is authorized by the Farm Bill, which is omnibus legislation that is updated and renegotiated by the US Congress approximately every 5 years. In the 2014 Farm Bill, the FCIP was reconnected with conservation compliance, a basic eligibility requirement that requires producers participating in Farm Bill programs to follow a conservation plan on highly erodible land (HEL) and to refrain from draining wetlands. Even though the FCIP is highly subsidized by taxpayer dollars and the change was proposed for the public good, this change was perceived to be a burden to farmers and was staunchly opposed by many lawmakers and agricultural interest groups. In the end, conservation compliance did go into effect due to compromise and strong advocacy by conservationists and supporters of crop insurance reform. Any future changes to the program will require equally intense efforts by a broad coalition of supporters.

In light of these political hurdles, NRDC proposes a pathway that would reduce program risk and cost while also rewarding farmers for risk-mitigating behaviors.

37.3 Solution: The “Good Steward Endorsement,” a Soil Health Discount

NRDC proposes to offer an incentive for conservation that would theoretically reduce the overall risk and cost of the FCIP. The soil health discount would be similar to the good driver discount offered by auto insurance companies to drivers with excellent records. A premium discount would be offered to farmers whose use of cover crops simultaneously improves soil health and makes them a lower risk to insure.

Cover crops are non-commodity crops grown after a cash crop rotation for the purpose of improving soil health. Two of the major principles of soil health are to keep living roots in the soil and increase plant biodiversity (NRCS 2013). Cover crops are therefore a key tool for regenerative agriculture practices that can reverse the erosion and degradation of US soil resources. An Iowa study showed that cover crops can reduce rill erosion following soybeans by up to 79 % (Kaspar et al. 2006). Field research has shown cover crops can significantly increase soil organic matter in short periods of time (Ethridge 2015). Cover crops also improve water quality by reducing nitrate and phosphorus loading to water sources, while improving nutrient cycling for the next crop (Kaspar et al. 2006). Yet despite these benefits, the 2012 Census of Agriculture showed that cover crops are only grown on a small percentage in US cropland – 10 million acres of cover crops out of 389 million acres of cropland (NASS 2014).

NRDC plans to submit a proposal for a pilot program under Section 508(h) of the Federal Crop Insurance Act, which allows for third parties to submit proposals for pilot crop insurance programs that are "(1) in the best interests of producers, (2) follow sound insurance principles and (3) are actuarially appropriate," among other factors (Federal Crop Insurance 2000).[2]

Prior to submitting a proposal, NRDC is assessing the actuarial relationship between cover cropping and the risk of crop loss. For 3 years in a row, a USDA-sponsored survey showed an increase in corn and soybean yields following the use of cover crops (CTIC et al. 2015). The same USDA survey also showed that 70 % of farmers who are not yet growing cover crops said that a reduced premium discount would influence them to grow cover crops (CTIC et al. 2015). Using this survey and other available literature, a team of consultants will determine whether there is enough data to offer an actuarially sound discount. Based on their recommendation, NRDC may submit a proposal for a product that would most likely be offered only on a trial basis in select states in the Mississippi River Basin. Our goal is to enroll 10 million acres in a cover crop pilot program within the next 2 years.

This type of incentive would encourage producers to view soil health as an economically preferable risk management tool that improves yield and reduces yield variability. It would also set a new standard for valuing soil security by US federal policy and risk management strategies and alleviate the seeming conflict between the intent and the end result of US Farm Bill programs.

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[2] 7 USCA § 1523 requires that several additional conditions be met in order for the RMA to approve a premium reduction. For instance, such a reduction must avoid unfair discrimination among farmers, be offered in an adequate geographic area, have the potential to be expanded, and meet all technical and procedural requirements. Any premium reduction program for risk-reducing management practices could be designed to meet these final criteria.

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Chapter 38
US Farm Programs and the Impacts on National and International Soil Security

Katina Dove Hanson and J. Michael Schmidt

Abstract The United States Department of Agriculture (USDA) administers numerous programs that contribute toward global soil security, many of which are under the umbrella of the Farm Service Agency (FSA). This chapter explores those programs and ways in which they contribute toward National and International Soil Security. The two primary roles where FSA programs contribute are establishing minimum working land conservation requirements related to program support and conserving environmentally sensitive land. Most farms and ranches in the United States receive payments through at least one of the disaster assistance, safety net, and/or conservation programs administered through FSA, and all farms that participate in FSA farm programs and farm loan programs as well as other conservation and crop insurance programs administered by USDA are subject to conservation compliance provisions. Conservation compliance is focused on both preventing the loss of wetlands and ensuring that soil erosion is minimized through following site-specific conservation plans. Celebrating its 30th anniversary, the Conservation Reserve Program (CRP) is by far FSA's flagship program related to soil conservation with about 24 million acres nationwide. In general, in exchange for a yearly rental payment, farmers voluntarily agree to remove environmentally sensitive land from agricultural production and plant species that improve environmental health and quality for the life of their 10–15-year contract. By targeting fragile cropland and placing these lands into protective conservation covers, CRP conserves wildlife habitat, improves water quality, and has reduced soil erosion by more than 8 billion tons and enhanced soil productivity significantly since 1986. CRP also sequesters more carbon on private lands than any other federally administered program and reduces greenhouse gases equivalent to removing 8.7 million cars from the road annually.

Keywords Agriculture • Conservation • Farm • Soil • Carbon • Program

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38.1 Introduction

The United States Department of Agriculture (USDA) administers numerous programs that contribute toward global soil security, many of which are under the umbrella of the Farm Service Agency (FSA). This chapter explores those programs and the ways in which the programs contribute toward National and International Soil Security. The two primary roles where FSA programs contribute are establishing minimum working land conservation requirements related to program support and conserving environmentally sensitive land. According to the 2012 Agricultural Census, about 915 million acres of land were on 2.1 million farms in the United States; these numbers have decreased by about 72 million acres and 130,000 farms over the last 30 years (USDA 2014). Without the safety net provided through US farm programs, this number would arguably have decreased at a much more rapid rate, but the impacts of farming on the soil would have been much greater.

38.2 US Farm Programs

Most farms and ranches in the United States receive payments through at least one of the safety net, credit, disaster assistance, and/or conservation programs administered through FSA.

38.2.1 Farm Safety Net and Credit Programs

The basic foundation of farm programs in the United States is the farm safety net and credit programs. These programs available through FSA include Agriculture Risk Coverage (ARC) and Price Loss Coverage (PLC). Margin Protection Program for Dairy Operations (MPP-Dairy) and the Dairy Product Donation Program (DPDP) are also available (see Fig. 38.1). In addition FSA farm loans are a valuable resource to establish, improve, expand, transition, and strengthen America's farms and ranches. Farm Storage Facility Loans are also available to many US producers at a low interest, as well as marketing assistance loans (MALs) and loan deficiency payments (LDPs).

38.2.2 Disaster Assistance Programs

USDA-FSA administers a variety of other programs to help producers in times of disaster, including the Livestock Forage Disaster Program (LFP), the Livestock Indemnity Program (LIP), the Tree Assistance Program (TAP), the Emergency Assistance for Livestock, Honeybees, and Farm-Raised Fish Program (ELAP), and the Noninsured Crop Disaster Assistance Program (NAP) (see Fig. 38.2). The Risk

Fig. 38.1 Representation of the farm safety net programs

Fig. 38.2 Representation of the disaster assistance programs

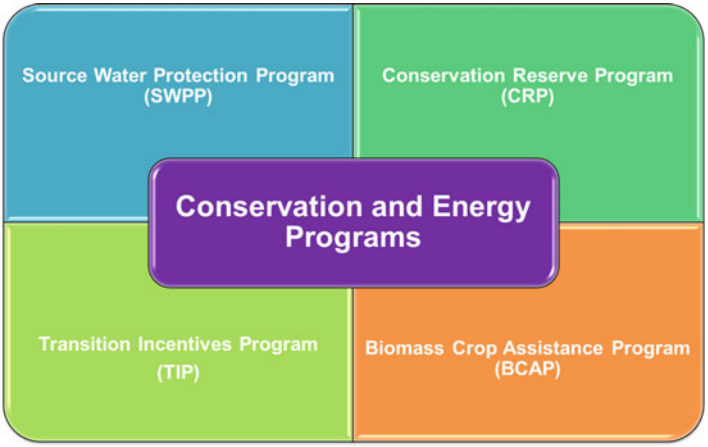

Fig. 38.3 Conservation and energy programs

Management Agency (RMA) also administers a variety of crop insurance products that are critical to US farmers; like NAP, these programs could be classified as a safety net or disaster program. Cost-share assistance is also available through the Emergency Conservation Program (ECP) and the Emergency Forest Restoration Program (EFRP). Emergency loans are also made available when disasters occur.

38.2.3 Conservation and Energy Programs

In addition to the strong safety net and disaster assistance provided to US producers, a number of conservation and energy programs are also available, including the Conservation Reserve Program (CRP), the Transition Incentives Program (TIP), the Source Water Protection Program (SWPP), and the Biomass Crop Assistance Program (BCAP). These programs combined with the working land conservation programs administered by the Natural Resources Conservation Service (NRCS) have a significant impact on land and associated resources across the United States (Fig. 38.3).

38.3 Overarching Policy That Impacts Soil Security

As described earlier, USDA farm programs have an incredible reach, which in itself has an impact on the US soil security, but the overarching policy on conservation compliance is what really makes these programs have a net positive impact on soil security for the United States and the world. Producers, and any affiliated individuals or entities who participate in most programs administered by FSA, NRCS, and/or RMA, are required to comply with these provisions. The US conservation compliance policy includes Highly Erodible Land Conservation (HELC) and Wetland Conservation (WC) provisions.

38.3.1 Conservation Compliance Requirements

Producers must complete and sign a compliance certification, certifying they will not plant or produce an agricultural commodity on highly erodible land without following an NRCS-approved conservation plan or system, plant or produce an agricultural commodity on a converted wetland, or convert a wetland which makes the production of an agricultural commodity possible. In addition, producers planning to conduct activities that may affect their HEL or WC compliance, for example, removing fence rows, conducting drainage activities, or combining fields, must notify FSA. FSA will notify NRCS, and NRCS will then provide highly erodible land or wetland technical evaluations and issue determinations if needed.

38.3.2 Impacts of Noncompliance

Noncompliance may affect USDA program benefits, including FSA loans and disaster assistance payments, NRCS and FSA conservation program benefits, and federal crop insurance premium subsidies. Implementing the 2014 Farm Bill provisions for conservation compliance is expected to result in benefits of extending HEL and wetland conservation provisions to up to 1.5 million more acres of HEL and 1.1 million more acres of wetlands, which could reduce soil erosion, enhance water quality, and create wildlife habitat (Iovanna 2015).

38.4 Farm Programs That Impact Soil Security Even More Directly

A number of farm programs have even more direct impacts on soil security.

38.4.1 Emergency Conservation Program (ECP)

ECP provides emergency funding and technical assistance for farmers and ranchers to rehabilitate farmland damaged by natural disasters as well as providing funding to carry out emergency water conservation measures in periods of severe drought (related to soil function number 2 as described in Chap. 2). Participants receive cost-share assistance of up to 75 %, 90 % for limited resource producers, of the cost to implement approved emergency conservation practices.

38.4.2 Emergency Forest Restoration Program (EFRP)

EFRP provides payments to eligible owners of nonindustrial private forest land in order to carry out emergency measures to restore land damaged by a natural disaster. Tree cover must have been on the land immediately before the natural disaster. Cost share may not exceed 75 % of the cost of the emergency measures.

38.4.3 Conservation Reserve Program (CRP)

Celebrating its 30th anniversary (on Twitter at #CRPis30), CRP is by far FSA's flagship program related to soil conservation with currently about 24 million acres enrolled nationwide (see Fig. 38.4); enrollment in CRP has varied over the years based on a variety of factors, including statutory caps, and peaked at about 39 million acres. In exchange for a yearly rental payment and cost-share assistance, farmers enrolled in the program voluntarily agree to remove environmentally sensitive land from agricultural production and plant species that will improve environmental health and quality. The long-term goal of the program is to reestablish valuable land cover to help improve water quality, prevent soil erosion, and reduce loss of wildlife habitat which are some of the soil threats described in Chap. 2. Contracts for land enrolled in CRP are 10–15 years in length. There are three primary enrollment types under CRP: continuous, general, and grasslands (see Table 38.1).

38.4.3.1 CRP General Sign-Up

Enrollment through general sign-up is based on a competitive offer process during designated sign-up periods. The general sign-up occurs when the secretary of agriculture announces that USDA will accept general sign-up offers for enrollment. Offers from potential program participants are ranked against each other at the national level. Ranking is based on the environmental benefits expected to result from the proposed conservation practices and expected costs. Each offer is assigned an environmental benefit index (EBI) score depending on ranking factors designed to reflect the expected environmental benefits and costs. The EBI ranking system is specified in detail in the CRP handbook. These EBI factors include wildlife habitat benefits, water quality benefits, farm benefits due to reduced erosion, air quality benefits, benefits that last beyond the contract period, per acre expected costs, and

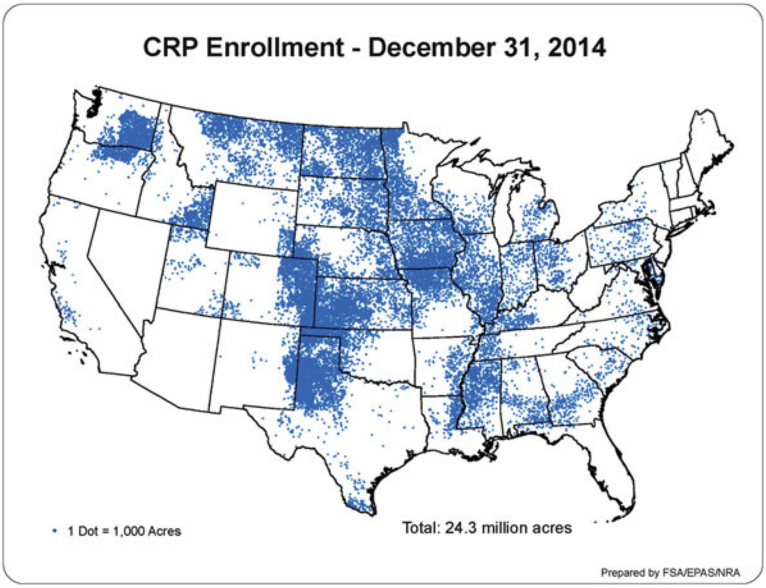

Fig. 38.4 CRP enrollment map

Table 38.1 Types of CRP enrollment

General sign-up	Continuous CRP	Grasslands
Enrollment through periodic competitive sign-ups	Environmentally desirable land devoted to certain conservation practices may be enrolled at any time	Eligible grassland including land that contains forbs or shrubland for which grazing is the predominant use may be enrolled through periodic sign-ups

local preference factors for certain benefits. In a general sign-up, the offer process is competitive and not all offers will necessarily rank high enough to be selected for CRP.

38.4.3.2 CRP Continuous Sign-Up

For practices and land with especially high environmental value, enrollment through continuous sign-up is available year-round without ranking periods. The continuous sign-up is focused on environmentally sensitive land and offers are not ranked against each other. Land eligible for continuous sign-up includes, but is not limited to, agricultural land with a high erodibility index; land in riparian areas that border rivers, streams, and lakes; land suitable for wetland restoration; and certain land to be dedicated to other specialized conservation measures. Subject to the acreage caps allocated to states, all continuous sign-up offers that meet the eligibility requirements are accepted. The CRP continuous sign-up allows for practices with inherently high conservation (and soil health) value like wetlands and riparian buffers to be enrolled on a first-come, first-serve continuous basis without competition and includes a number of initiatives, encouraging local targeting of funds and attention to address particularly important resource concerns such as under the state acres for wildlife enhancement (SAFE) and through partnerships with states and other partners under the Conservation Reserve Enhancement Program (CREP).

38.4.3.3 CRP Grassland Enrollment

A recent addition under the 2014 Farm Bill, the CRP grassland enrollment is a hybrid between the two approaches where applications for CRP grasslands are accepted continuously and the applications are ranked and accepted on a periodic basis. Eligible grasslands include land that contains forbs or shrubland (including improved rangeland and pastureland) for which grazing is the predominant use. Up to 2 million acres may be enrolled in CRP as grassland under the larger 24 million acre cap for all of CRP.

38.4.3.4 Trends in Enrollments

Today, conservation covers established through CRP are approximately 90 % grass mixes and 10 % trees. Grass plantings have been trending toward native grass. Tree plantings have been trending toward hardwood riparian buffers and longleaf pine restoration. CRP enrollment is becoming more targeted over time (Fig. 38.5).

38.4.3.5 CRP Benefits

Due to the size and scope of CRP, it has wide ranging positive impacts on soil security and ecosystem value within the United States and as a world resource. Since the program's inception, the value of the program in reducing soil loss has been apparent, and over the years, other significant benefits have been identified. Benefits identified in the 1990s such as "reversal of landscape fragmentation, maintenance of regional biodiversity, creation of wildlife habitat, and favorable changes in regional carbon flux" (Dunn et al. 1993) still hold true, while other ecological and economic benefits have also been identified (FSA 2015).

Soil and Water Quality

CRP protects soil productivity by establishing conservation covers on fragile cropland to reduce sheet, rill, and wind erosion. CRP also reduces the nitrogen, phosphorus, and sediment leaving a field in runoff and percolate.

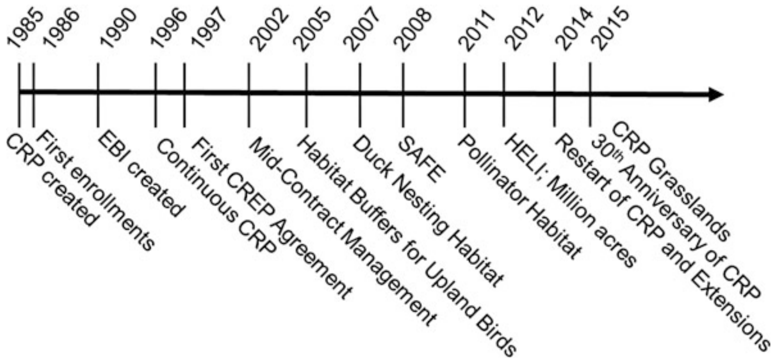

Fig. 38.5 Evolution of CRP over time

Soil Erosion

By targeting fragile cropland and placing these lands into protective conservation covers, CRP reduces soil erosion annually by over 275 million tons from pre-CRP levels and enhances soil productivity (FSA 2015). Since 1986, CRP has reduced soil erosion more than 8 billion tons.

Nutrients

CRP reduces the nitrogen and phosphorus leaving a field in runoff and percolate, 95 % and 86 % less, respectively, compared to land that is cropped (FSA 2015). Grass filter strips and riparian buffers intercept sediment, nutrients, and other contaminants before they enter waterways. Using models developed by the Food and Agricultural Policy Research Institute (FAPRI), CRP reduced nutrient losses in FY 2013, by an estimated 565 million pounds of nitrogen and 113 million pounds of phosphorus, compared to land that is cropped. Wetlands restored and constructed by CRP improve water quality by converting nitrate nitrogen into benign atmospheric nitrogen. Iowa's 94 CREP constructed wetland projects are designed to intercept and treat water from underground agricultural drainage systems. In FY 2013, these projects removed 1.1 million pounds nitrate from agricultural drainage water.

Flood Protection

Upstream CRP lands reduce downstream flood damage. Peak flows are reduced by slowing, storing, and infiltrating storm water runoff. For example, US Army Corps of Engineers found that urban areas realized significant monetary flood damage reduction benefits due to existing CRP land in the Indian Creek basin of Iowa (USACE 2013).

Groundwater Protection

USGS examined the relationship between CRP enrollment and Ogallala aquifer water-level change (Mulligan et al. 2013). The analysis reveals that the benefits of CRP are greatest in those critical areas with the greatest water-level decline. Targeting land in these areas for increased CRP enrollment or re-enrollment is likely to be beneficial to the aquifer.

Impacts on CO_2

CRP sequesters more carbon, 38 million metric tons carbon dioxide equivalent (CO_2), on private lands than any other federally administered program (FSA 2015). The total reduction in greenhouse gases from CRP is equivalent to removing 8.7 million cars from the road for a year.

Wildlife: Ducks

Since 1985, CRP has restored >2 million acres of wetlands. Studies have shown that each year CRP provided habitat producing an estimated two million additional ducks in the Prairie Pothole Region of the United States, on average, between 1992 and 2004 (Reynolds et al. 2007). Later studies report an estimated 1.5 million additional ducks annually between 2007 and 2011, due to different weather patterns and reduced CRP enrollment in the Prairie Pothole Region (Drum et al. 2015).

Wildlife: Grouse

The CRP has been recognized as an important tool for aiding sage grouse (SAGR) and lesser prairie chicken (LEPC) populations. The Western Association of Fish and Wildlife Agencies developed a range-wide conservation plan for the LEPC, reporting that CRP "supports the most robust populations of LEPC across their range." The Washington Department of Natural Resources (WDNR) found that CRP enrollment was associated with halting a decline (25 % between 1970 and 1988) in SAGR populations (Schroeder and Vander Haegen 2006).

Wildlife: Northern Bobwhite Quail

Mississippi State University researchers found that quail populations were positively related to CRP upland buffer enrollment, estimating an increase of 730,000 quail. Overall breeding season bobwhite densities were 70–75 % greater on CRP buffers than control fields.

Wildlife: Grassland Birds

The CRP has repeatedly been identified as an important conservation program for grassland birds by the North American Bird Conservation Initiative. Serious declines in grassland bird populations have been documented by the USFWS. The 2013 "State of the Birds" report states: "Conservation Reserve Program is restoring grassland habitat for breeding birds. Henslow's sparrow populations, which have declined more than 95 % since the mid-1960s, have rebounded in some areas through CRP. In Illinois, the regional Henslow's sparrow population has significantly increased; spring bird counts for the species are now about 25 times greater than 30 years ago, prior to CRP." Researchers from the United States Fish and Wildlife Service, the US Geological Survey, and the University of Montana found that CRP had a large impact on grassland bird populations in the Northern Plains, including two birds designated as species of continental importance by Partners in Flight.

Wildlife: Pheasants

In prime pheasant habitat, a 4 % increase in CRP herbaceous vegetation was associated with a 22 % increase in ring-necked pheasant counts (Burgess et al. 2006).

Direct Economic Benefits of CRP

Historically, improved wildlife habitat through CRP has resulted in a direct increase of over $1.4 billion per year in economic activity in rural areas through hunting and other recreational uses (Cowan 2010). It is also estimated that 57 % of CRP enrollees allow recreational access to at least some portion of their CRP land (Allen and Witter 2008).

38.5 A Few Final Thoughts to Keep in Mind When Trying to Impact Policy

38.5.1 Often Soils Are the Subtext

As a soil scientist, you may want to see soils addressed outwardly in every policy document that you read. This is definitely not always the case, but it does not mean that soils are not integral to the policy. Soils are often the subtext of many if not most of the policy discussions, especially in agriculture. Questions like what are we doing to help with climate change or what species of plants or animals can be saved translate to the soil scientist as how much soil carbon are we saving or what soil series is in that area. How things are worded or marketed are not always the way a soil scientist may like them, but they may still help protect soils.

38.5.2 Policy Decisions Are Usually Made with Some Degree of Uncertainty

Soil scientists are often looking for the highest degree of certainty before sharing their work. As policy makers, we often do not have the luxury of waiting until something is completely certain before making decisions. Often we are involved in adaptive management.

38.5.3 Policies That Impact Soils Are a Blend of Regulatory and Voluntary

As soil scientists, you may see practices on the land that you feel should be stopped. Depending on the practice and the politics, it may be something that can be regulated, or it may be better achieved through voluntary means. Different agencies use these approaches to varying extents. In the United States, for instance, the Environmental Protection Agency tends to implement more regulatory means, while USDA tends to implement more voluntary programs. There are pros and cons to both approaches. For regulatory approaches, it may sound easy to simply make a law that says “no citizen can do X.” However, all citizens must know and understand the law and agree to comply. Since this is not always the case, enforcement is necessary and can be expensive. On the other hand, voluntary programs also need publicity so that people know that they have the option to participate. Then, they usually need some type incentive to participate. Most people will naturally prefer to be given a choice to participate rather than be told they have to do something. There are many other details that help determine where regulatory versus voluntary approaches are appropriate, including scale, severity, adaptability, etc.

38.5.4 Keep Communication Simple

Simple statements with simple pictures and maps are generally much more useful in communication with policy makers than long reports with complicated equations. According to a recent study by the Microsoft Corporation, the attention span of people on average is only 8 s, less than a goldfish (McSpadden 2015). This means you have very little time to communicate what is important. In addition, the policy makers, with which you are interacting, likely have many more issues that they are dealing with than the single issue that you likely spend much of your time researching. This means that you need to keep your communications simple so that someone who is only hearing about the issue for the first time can easily understand the problem. Always be prepared to go deeper if questions are asked, but do not go into a dissertation from the beginning.

38.5.5 Bring Solutions

When you meet with policy makers, do not just bring problems, bring solutions. As policy makers or implementers, we often have more problems than we have resources to understand or address. You are much more likely to see action if you have ideas about how to address a problem rather than just an understanding of the problem. It is even more helpful when you have already identified and secured resources to help address the problem.

38.5.6 Understand the Money

You must understand and be able to communicate the dollar impacts of what you are proposing. Be prepared for the question, “So, how much is this going to cost?” Be able to answer at least with an estimate and if possible be able to also show any savings in the short or long term. Understanding the dollar impacts of strategies is extremely important, both short term and long term.

38.5.7 Understand Your Audience

All policy makers and implementers are not the same. You need to understand with whom you are speaking. You need to know as much as possible about your audience. Things you may want to know include whether they have addressed similar topics in the past and whether they have been involved in competing interests. Try to learn about the organization for which they work or the area that they represent, including administration priorities such as underserved or beginning farmers. Of course, you can research as much as you want, but keep an open mind when you get into the meeting. The last thing you want to do is assume that those you are meeting with do not understand your issue or are not working toward the same goals when that is far from the truth. Remember decisions of the past are not always indicators of present or future decisions.

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Chapter 39
Soil Security for Agricultural Productivity: The Policy Disconnect and a Promising Future

Andrea Koch

Abstract For industrial agricultural nations like Australia and the USA, securing the soil resource in order to ensure ongoing sustainable production of food and fiber is a vital issue for policy makers. The soil security framework provides a useful and holistic approach for planning of soil policy. Policy settings within national boundaries at multiple levels are a key determinant of soil security. In addition to traditional government policy, field policy established and applied by farmers to their land will have direct consequences for soil security. Examples are provided of this mechanism at work at an individual farm level and across the cropping sector in Australia. Despite the centrality of soil to agriculture, Australia suffers from a policy disconnect between soil and agriculture at the national and state government levels. This is due to the long-term treatment of soil as a natural resource management issue, rather than as a key resource and determinant of agricultural productivity. This has also led to lost opportunities for soil research to drive productivity. The USA is further ahead, having established a new soil health division in 2014. The policy gap in Australia will be closed by linking the trend for digitization of agriculture with technologies for digitally mapping and managing soil.

Keywords Soil security • Soil carbon • Soil policy • Sustainability • Agriculture policy

39.1 Introduction

> *A holistic framework that enables farmers to make the best use of technology, data resources, knowledge and expertise to manage and secure their soil resource will underpin the future productivity growth and success of Australia's agricultural sector. This will require collaboration and coordination across the sector, including linking research, government planning, and information systems with farmers on the ground.* (Daly et al 2015, p. 62)

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Australia and the USA are both net exporters of food and fiber – we are among the nations that feed the world. Both nations seek to increase production of food, fiber, and fuel to meet the needs of the increasing world population and in ways that also meet the environmental and social outcomes required – including climate regulation, energy, food, and water security, and sustainable soil management is central to this effort.

While soil security leads to broader positive natural resource and sustainability outcomes, arable soils around the world are primarily owned and managed as the core production base by farmers (Koch et al. 2015). Agriculture is integral to the achievement of soil security, and there is no policy space where the soil security framework is more important than in agriculture.

This chapter shows how policy in different jurisdictions within nations impacts and enables soil security. It explores the disconnect between agriculture and soil policy in Australia and through the use of case studies will highlight the role of farmers in achieving soil security at a field level.

Over recent decades, rather than being seen as an agricultural productivity issue, soil has been treated as a natural resource management issue by governments at national and state levels in Australia. This is a fundamental problem for policy makers and a potential barrier to the achievement of soil security.

Because national policy sets the course for funding of soil research in Australia, soil science over recent years has been broadly focused on environmental outcomes rather than agricultural productivity outcomes.

The US government has brought soil and agriculture policy more closely together, with the establishment of the new USDA soil health division. Further to this, the USDA could encapsulate the soil security framework to develop an agricultural research agenda that clearly drives toward soil security outcomes.

Finally, the paper looks at policy requirements for the future practical enablement of soil security at the farm level as agriculture becomes increasingly digitized, through the application of telemetry, sensing and digital soil mapping technology, and big data analysis.

39.2 Soil Security Framework

Soil is vital for the production of food and fiber and for the supply of clean water and renewable energy sources. The global soil stock is a large sink in the carbon cycle and is a core platform for the production of biomass for renewable energy (McBratney et al. 2013). Soil underpins the delivery of ecosystem services. Soil security is the concept that shows the linkage between these provisionary services of soil and the ability for humanity to solve key issues for sustainable development – food security, water security, energy security, climate regulation and biodiversity, as illustrated in Fig. 39.1 (McBratney et al. 2013).

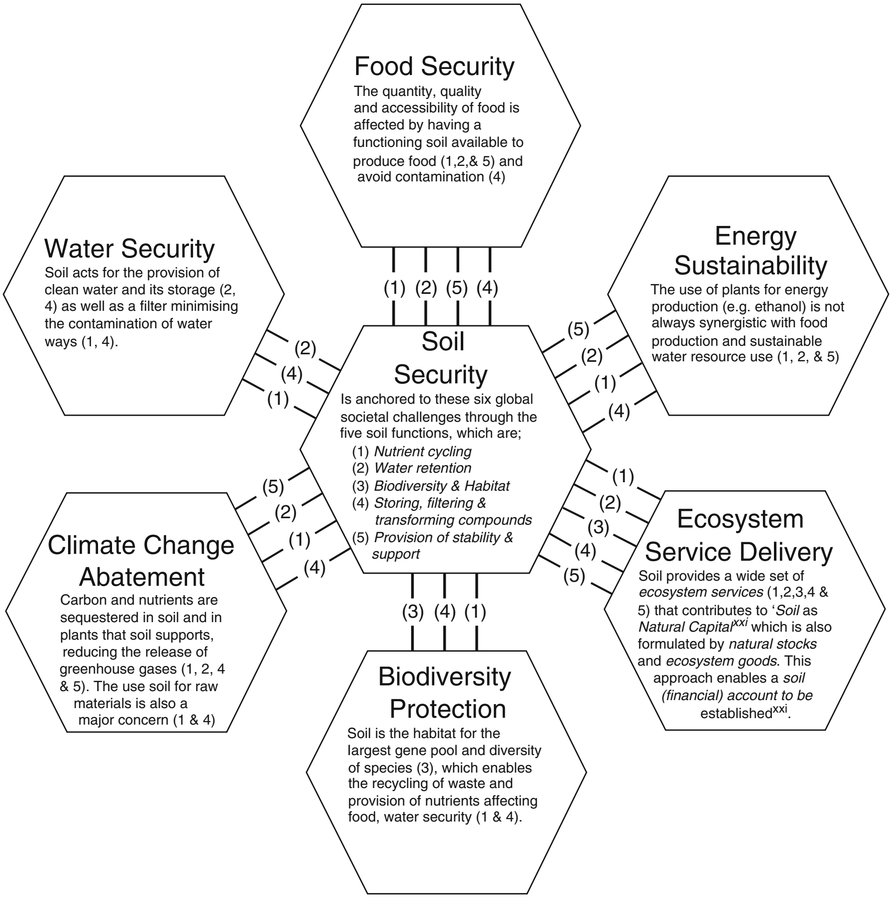

Fig. 39.1 Aligning the established scientific concept of soil functions in order of their relative immediate impact for each of the major societal challenges (From McBratney et al. 2013)

From this high-level concept, proof of concept lies in how soil functions provide the processes that deliver the required outcomes (Fig. 39.1).

Soil function must be optimized to secure soil – soil carbon flux is a measurable indicator of this (Koch et al. 2013). This can only be achieved when a soil resource is utilized according to its capability and managed properly to maintain its condition. This relies on an implicit understanding of the biophysical characteristics of the soil; however, a biophysical view on its own is not sufficient.

Soil is managed by people, and contributes to economic production, so soil security is incumbent on a broader set of dimensions than just the biophysical, as outlined in Table 39.1. As described in Chap. 2, there are five dimensions that must be addressed – the capability (1) and condition (2) of the soil, its capital value (3), the connectedness of soil to people (4), and the codification (5) of all these dimensions in public policy (McBratney et al. 2013).

Table 39.1 The five dimensions of soil security

Dimension	Description
1. Capability	Refers to the potential functionality of any given soil in the context of a reference state – either its natural state or a state brought about through ongoing management. The question that capability answers is, "What functions can this soil be expected to perform, and in doing so what can it produce?"
2. Condition	The condition of the soil is concerned with the current state of the soil and refers to the shift in capability compared to the reference state. Unlike capability, the condition of a soil is contemporary and is an outcome of how it is managed
3. Capital	The economic and natural capital value of the soil as an asset, and the value of the potential product and service flows from it
4. Connectivity	Connectivity brings in a social dimension around soil. In part it is concerned with whether the person who is responsible for the soil in any given piece of land has the right knowledge and resources to manage the soil according to its capability. It also refers to the broader connectivity of society with that soil
5. Codification	No matter how secure soil may be through proper management of condition, valuing the capital and connectivity to society, there still remains the need for public policy and regulation, at least as a safety net, and at best to synergize and positively feed back into the other aspects of soil security (dimensions)

From McBratney et al. (2013)

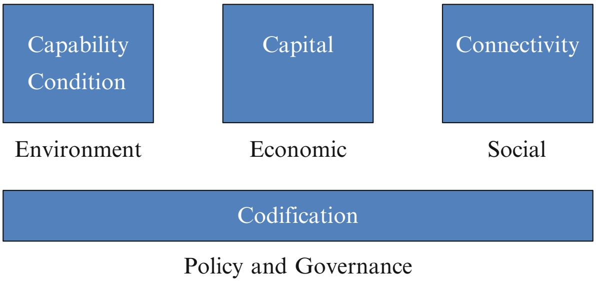

Fig. 39.2 The soil security framework and sustainable development

Together, these five dimensions provide a useful and holistic framework for use by policy makers, researchers, and practitioners when planning for soil security. The soil security framework also aligns with the three pillars of sustainable development, as demonstrated in Fig. 39.2.

39.3 Public Policy and Governance

Soil has been the forgotten resource in the international sustainable development discourse until recently. Since 2010 an international soil policy community has emerged, and there is now a global push to seek policy mechanisms to address soil degradation (Koch et al. 2013).

Soil however is a fixed resource – it is not usually intentionally moved or exported, unlike other resources. It is the nation-state that has sovereignty over its soil, and polices and laws that lead to soil security will apply primarily within national boundaries.

Within the national context, soil security is a multilevel governance issue. Policy settings at national, state, and local government levels will all impact on the ability of soil to provide ecosystem services and for soil to be secured.

There is a fourth level of policy that has a critical impact on soil security, which we can refer to as "field policy."

39.4 Field Policy

Field policy can be defined as the set of decisions and actions taken by the farmer in managing the soil in each field and across their property in the context of production, which lead to soil condition outcomes within each field (in Australia we call these paddocks).

Ultimately, how soil is managed in the field – according to the field policy of the farmer – will determine how secure it is: whether the enterprise and farm system is matched to the capability of the soil and whether the farmer is connected with the soil in terms of the knowledge, understanding, and resources to manage it to optimum condition according to its capability.

This will be influenced by the understanding of the farmer, the market, and financial institutions of the economic and natural capital value of that soil resource and the potential stocks and flows from it and whether governance arrangements and public policy support the farmer and all players in the footprint for that particular soil in maintaining its security. This shows the cross-jurisdictional policy interactions that effect soil security.

What happens on farms is the most important determinant of how secure soil is. Farmers who recognize soil degradation and choose to address it are in the most powerful position to reverse the degradation and secure the soil. An illustration of this at individual farm level is shown in the following case study.

39.4.1 Case Study: Bob Wilson Western Australia

Bob Wilson's farm is located 400 km north of Perth in Western Australia. The southwest of WA has experienced considerable climate change over recent decades, attributed to climatic effects of the ozone hole over Antarctica, which has drawn precipitation patterns to the south, away from cropping areas (Karoly 2008).

Wilson ran a cropping enterprise until this climate change occurred. Lack of rainfall on sandy soil led not only to reduced productivity but also greatly increased wind erosion – Wilson was watching his sandy paddocks blow into the sea.

He converted his enterprise to grazing by planting tagasaste, a deep-rooted perennial that acts as a wind break and fodder for cattle. Studies concluded that carbon was being sequestered in the soil by the perennial roots, up to 2 m down the profile (some calculations indicated that the amount of carbon being stored offset methane emission from the cattle and that Wilson is producing greenhouse gas neutral beef).

Through changed land practice management, Wilson not only increased soil carbon but also reversed desertification and kept the soil under production. This is a great example of farmer-led soil security.

Field policy applied on a wide-scale basis can have a wide-scale impact on soil security. An excellent demonstration of this in Australia is the impact that the uptake of no-till and conservation farming practices has had on reducing continental scale erosion, as outlined in the second case study.

39.4.2 *Case Study: Reduction of Soil Erosion Through the Uptake of No-Till in Australia*

Figure 39.3 shows the uptake of no-till and conservation agriculture across the various cropping zones in Australia from the mid-1970s to 2008. Uptake by farmers was motivated by the reduction of fuel and labor costs and soil conservation. Further to this, there was a perceived increase in capital value of the soil

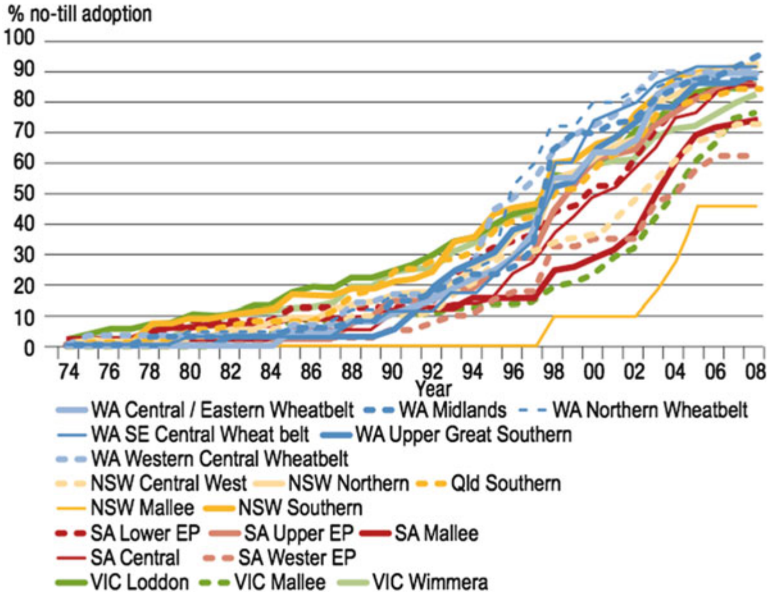

Fig. 39.3 Cumulative adoption of no-till (decision to first use no-till) across Australian cropping areas (From Llewellyn and D'Emden 2010)

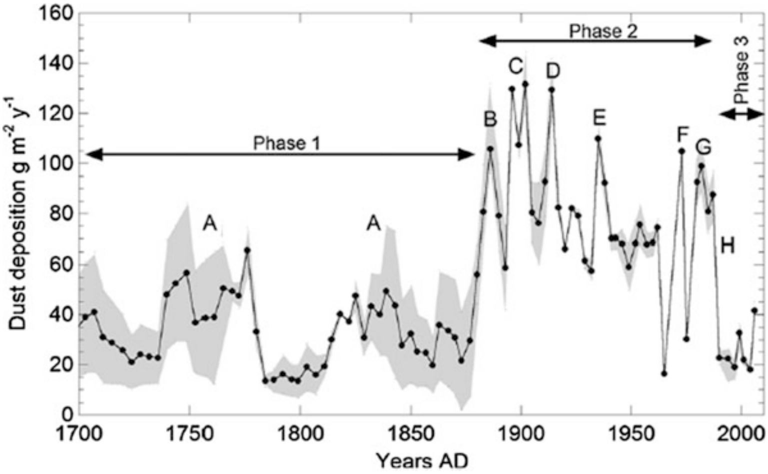

Fig. 39.4 Dust deposition rates in the Snowy Mountains based on core data plotted from 1700 to 2006

(Llewellyn and D'Emden 2010; Koch et al. 2015). With up to 90 % take-up, this is now a standard practice.

Evidence indicates that the wide-scale adoption of no-till and other conservation agriculture practices has had a marked effect in reducing soil erosion in the cropping zones since 1990. A study by Chappell et al. (2012) showed that soil erosion in southeastern agricultural Australia has declined on average from −9.7 to +3.9 t/ha/year with an interquartile range of −1.6 to +10.7 t/ha/year (Chappell et al. 2012).

In a further study by Marx et al. (2014), researchers used dust deposited in a Snowy Mountains mire to reconstruct the wind erosion history and the expansion of dust sources associated with the progression of European farming practices across southeastern Australia, from prior to settlement to 2006 (Marx et al. 2014).

They identified a rapid increase in dust deposition (erosion) after 1879 reflecting a period of agricultural expansion (B) and a rapid decrease in dust deposition after 1989 (H). The results were so significant that they defined three phases in the history of erosion linked to agriculture – phase 1, pre-European agriculture from 1700 to 1879; phase 2, agricultural expansion between 1880 and 1989; and phase 3 which they referred to as a period of agricultural stabilization, as shown in Fig. 39.4 (Marx et al. 2014).

This demonstrates the large impact that collective field policy – agriculture – can have on soil security.

39.5 Agriculture Soil Policy Disconnect

There is no place where integration of the soil security framework is more important than in agriculture, and yet in Australia soil is disconnected from agriculture policy.

At the national policy level, soil is primarily treated as a natural resource management issue, rendering it a public resource, to be stewarded by volunteers through local community action (Australian Landcare Council Secretariat 2010 p. 3). This policy is embedded within the Natural Resources Management (Financial Resources) Act 1992 and the National Heritage Trust of Australia Act 1997.

Under the Australian Constitution, responsibility for the use and management of land rests primarily with the states and territories. However, funding of federal government policy flows through the states and territories, so it effectively sets the agenda for state governments.

Over the past 20 years, responsibility for natural resource management has devolved to regional and local levels with the Australian government moving toward an integrated, landscape-scale approach to conservation and natural resource management (Love 2013).

This has placed soil within a broader plethora of environmental issues due to the fact that many of them and their solutions are interconnected. Issues such as climate change, salinity, water quality and quantity, forests, weeds, and feral animals have all become the focus of greater public concern, political attention, and consequently public investment (Love 2013; Campbell 2008).

The widespread tacit agreement that soil is a natural resource leaves little room for the idea that soil can be managed as a production resource and still provide the ecosystem services required, including environmental resilience. It is as though the economic act of producing food, fiber, and biomass has very little to do with the soil and that the inherent value of soil lies only in its role as a natural resource.

This is despite the fact that agriculture is Australia's most extensive form of land use, occupying 61 percent of the total land area, with the majority of the land being privately owned or managed (NFF 2012).

The Australian government seeks to double agricultural exports over the next 15 years. This can only be achieved with a secure agricultural soil resource, requiring agricultural policy that recognizes soil as a critical production resource. This is a critical issue of connectivity that must be addressed.

39.6 Australia's Soil Research Agenda

This soil-agriculture policy disconnect is problematic for agricultural and soil research in Australia. Policy drives funding, and scientific research follows the funding. Soil research tends to focus on fixing constraint issues and improving natural resource management, rather than discovering ways to optimize soil management for agricultural productivity. This is not surprising; it reflects the prevailing policy view that soil is primarily a natural resource.

An example is the $34 million allocated to research on soil carbon sequestration and $28.8 million to reducing greenhouse gases from soil as part of the 2011 $1.7 billion Land Sector Package (Australian Government 2011; Australian Government Department of Environment 2013). This was climate change policy. Unfortunately the opportunity was missed to seek the co-benefit of increased agricultural productivity as a research outcome.

This has led to a situation where soil management practice is now ahead of policy and science (Daly et al. 2015). Australian farmers are highly innovative. Best farming practice today integrates soil conservation practices with production; however, the limits of scientific knowledge are being exceeded. This provides an opportunity to reorientate the agricultural research agenda with a significant focus on soil security for step change in productivity – the threat is that the soil-agriculture policy disconnect will blind the government to this course of action.

39.7 United States Example: United States Department of Agriculture Soil Health Division

As detailed in Chap. 10 the US policy link between soil and agriculture is well established. The US federal government has acknowledged that efforts to improve soil health will align with the US conservation effort and the desire for enhanced agricultural production.

In particular they recognize that the critical importance of improving soil health on agricultural lands allows farmers and ranchers to "simultaneously improve water quality, increase soil water availability, enhance resilience to extreme weather, enhance nutrient cycling, increase carbon sequestration, provide wildlife habitat (including pollinators), enhance rural economic opportunity, and meet the food production needs of a rapidly growing population on a shrinking available land base" (USDA 2015).

In 2014 the new Natural Resources Service Soil Health Division was established to incentivize and facilitate producers in implementing science-based, effective, economically viable soil health management systems on the US agricultural lands (USDA 2014, 2015).

This strategy also has the hallmarks to align with the soil security framework. The US government is well placed now to consciously integrate the soil security framework into future policy planning for soil improvement in agriculture. By doing so, not only will the biophysical, economic, and social aspects of soil be addressed by policy, but this holistic agenda could also be used to set priorities for publicly funded soil research in the USA, ensuring that the return on investment includes a soil security outcome.

39.8 Next Frontier: Bridging the Gap

Bringing soil back into the agricultural policy narrative may not be as difficult as expected. Agriculture will be transformed over the coming decade as twenty-first century digital technology becomes embedded into every aspect of production and farm enterprise management. This transition is already well underway in the USA and Australia.

Soil sensing, telemetry, and digital soil mapping technologies in combination with big data analysis will lead to agronomy and farm management that optimizes soil function, enabling sustainable intensification of agricultural production and soil security. Australia has world-leading capabilities in soil data and informatics research and has much to offer in bringing this vision to reality. The USA is a world hub for leadership in the application of digital technology to agriculture.

The United States Studies Centre at the University of Sydney recently convened the world's first major conference on soil, big data, and the future of agriculture, bringing together experts from industry, science, and policy makers to discuss the potential for soil management to be enhanced for productivity and soil security, through the application of data technology, e.g., digital soil maps, soil moisture monitoring, and precision agriculture (United States Studies Centre 2015).

This massive trend will directly affect the ability of nations to achieve soil security and is a unique platform for governments to invest in research and innovation in soil management. It will provide the necessary bridge in Australia to link national and state soil and agriculture policy to support farmers in securing soil in the field.

39.9 Conclusion

Soil security is an agricultural concept; however, soil policy at the international, national, and state levels is disconnected and out of tune with policy at the farm and field level. To achieve the outcomes humanity needs, soil and agriculture must be reconnected at the policy level.

Governments are in a unique position to address this disconnect by investing in research and innovation in soil management, particularly as digital soil mapping, telemetry, and sensing technology will enable farmers to optimize the performance of their soil systems.

This will lead to a coherent soil security strategy that places agriculture front and center so to achieve the win-win of increased productivity of food, fiber and fuel, and ecosystem service delivery from the management of the precious soil resource.

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Chapter 40
Securitisation

Alex B. McBratney and Lorna E. Jarrett

Abstract This chapter provides a brief summary of the theory of securitisation as a process to frame the global existential threats. Several schools of thought are considered with particular attention given to the securitisation theory developed by the Copenhagen School, which asks the question, ‘What is a security issue?’ and how this relates to policy and politics. In doing so key concepts are identified, and a case study focusing on the water in the Ganges Basin is presented to illustrate these. Finally, the relationship of *soft* securitisation to the issue of global soil security is developed.

Keywords International relations • Constructivism • Securitisation • Securitising move • Threat

40.1 Introduction

In the field of international relations, the term *securitisation* refers to a process through which issues are framed as existential threats to some object or group of people, justifying measures and actions that fall outside normal political boundaries. According to the theorists, securitisation exists on the extreme end of a spectrum ranging from *non-politicised*, i.e. no state intervention is required, through *politicised*, i.e. governments must make decisions and allocate resources, to *securitised*, i.e. emergency measures are required (Buzan et al. 1998).

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40.2 Securitisation Theory: The Copenhagen School

The theoretical framework of securitisation was developed by the Copenhagen School (a school of thought arising from the Copenhagen Peace Research Institute) in the early 1990s. The theory addresses the following questions: What is a security issue? Why do some challenges become security issues and others don't? How are threats related to policies? How does security relate to politics?

According to this theory, the process of securitisation takes place through acts of speech, which are seen as performing an action:

> by uttering 'security' a state-representative moves a particular development into a specific area, and thereby claims a special right to use whatever means are necessary to block it. (Weaver 1993 p. 55).

Such a speech act is referred to as a *securitising move*. In order for an issue to be successfully securitised, it must also be accepted as an existential threat by the *empowering audience* at whom the speech is addressed and must result in the normal political procedures being overruled. The audience must have a relationship to the issue and must also have the ability to enable the actor to adopt emergency measures.

Issues that have been securitised include organised crime, supplies of oil and natural gas and computer hacking.

The entities who securitise issues are referred to as *securitising actors*. These are usually governments; however, non-state entities, such as professional bodies or lobby groups, may also securitise an issue when they can successfully make the case that the issue is of the utmost priority. The object deemed at risk from the threat is known as a *referent object*. Usually, referent objects are nation states. However, securitisation can also involve other types of actors and referent objects. For example, in the case of climate change, the actors who have made securitising moves are a community of scientists, namely, the IPCC (2007). The referent object under threat includes not only nation states but also individual people who are at risk from the effects of climate change.

A key feature of the Copenhagen School's theoretical framework is the *constructivist* idea that nothing is objectively an existential threat; threats are constructed through the process of securitisation, and any issue could potentially be securitised.

40.3 Different Forms of Securitisation

The traditional idea of securitisation, where the use of force is seen as a necessary tool, can be described as *hard securitisation*. The Copenhagen School refers to this as *strong securitisation*, which they define as involving military power. Conversely in *soft securitisation*, force would not necessarily be used. Hard securitisation can be problematic in that it can lead to perverse outcomes such as legitimising the breaking of normal political rules, silencing of opposition and the use of disproportionate amounts of resources in order to achieve goals. However, in cases of environmental threats, securitisation can be a useful way of drawing attention to the issues, bringing them into focus and mobilising effort into developing solutions (Buzan et al. 1998).

Herbeck and Flitner (2010) differentiated between the strong securitisation of the Copenhagen school and *humanitarian securitisation* in their critique of the security implications of climate change. While strong securitisation is concerned with military security, humanitarian securitisation is concerned with human well-being. While well-meaning, this form of securitisation suffers from being too broadly defined, because the interconnectedness of environmental issues and the impacts of globalisation mean that a very large number of issues could be seen as requiring securitisation. The risk also exists that security interventions may be directed at developing countries, distracting attention from the developed world's responsibility for climate change.

40.4 Criticisms of the Copenhagen School

A number of international relations theorists have criticised the Copenhagen School's approach. Stritzel's (2007) reconceptualised framework focuses less on the role played by language and more on social and structural relationships. It is briefly outlined here.

Stritzel's (2007) first criticism is that audiences do not always voluntarily accept securitising moves, for example, when nondemocratic states are the securitising actors, and that power differences between actors and audiences mean that they do not contribute equally to a shared understanding of an issue as an existential threat. He also questioned the Copenhagen School's idea that the framing of threats occurs solely through language and asserted that in order for securitising actors and their speech acts to be successful, they must exist in a context that gives them social significance or authority.

Stritzel (2007) proposed three layers of securitisation:

- The performative force of the threat text. *The idea of a speech act* has been replaced with that of a *threat text*, which may include images and sound, to acknowledge that the process evolves over time rather than being confined to a single utterance and is rarely the work on only one person.
- Embeddedness, i.e. interactions between the threat text and the discourse and social context in which it occurs.
- The positional power of actors to influence the construction of meaning, i.e. social status or official position affects the ability of actors to successfully make securitising moves.

40.5 An Example: Securitisation of Water in the Ganges Basin

Water security differs from food and energy security, in that threats arise not only form the absence of sufficient water but also from its presence in the form of floods (UN-Water 2013). This fact formed the basis of a successful securitisation move by the Indian government in the 1990s. During the dry season, India's agriculture is highly dependent on water flows from tributaries to the Ganges. However, during the monsoon, high flow rates have triggered serious floods affecting millions of people. This led to the Indian government's decision to construct the Tanakpur Barrage across the Mahakali River in the 1990s. Despite the reservations of the Nepali government, the work was classified by the Indian government as domestic in nature, with no requirement for an international agreement. However, in 1991, the Indian government announced to the Nepali head of state that in order to provide adequate flood protection and a permanent solution to the threat of flooding, a retaining wall would have to be constructed into Nepali territory. Further, the government stated that this must be done before the next monsoon. This comprised a securitising move: framing the upcoming monsoon as a threat to both India and Nepal and justifying the acquisition by India of 2.9 ha of Nepali territory. In a memorandum of understanding, Nepal was granted a fixed quantity of water and hydroelectricity in compensation (Mirumachi 2013).

The events took place in the context of an asymmetry of power between India and Nepal. According to Mirumachi (2013), India occupied a position of power over Nepal, due to its superior technical experience and expertise in the development hydraulic infrastructure. This contributed to the superior positional power of the Indian government and the success of its securitising move.

40.6 Securitisation of Soil

According to the Copenhagen School's definition, by articulating the concept of soil security, we have made a securitising move in relation to soil. In making this move, we have to clearly articulate the actions that must be taken in order to secure the world's soil. The nature of these actions, and the degree to which they are taken up by policy makers, will determine the form of securitisation that eventuates.

Rasmussen and Birk (2012) concluded that while hard securitisation is unlikely to be relevant to the issue of climate change, soft securitisation may be necessary in order to mobilise reform of political institutions to address the causes and consequences of climate change.

Similarly, in developing the concept of soil security, we hope to avoid framing the concept as a move for strong or hard securitisation. Rather, the issue requires weak or soft securitisation in order to achieve the goals of focusing political and public attention on the importance of and threats to the soil resource and highlighting the need for action to be taken, while minimising the risk of perverse outcomes.

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Chapter 41
The Place of Soil in International Government Policy

Robert Hill

Abstract Soil degradation is an issue of global proportion, and until recently there has been very little response at the international policy level. Thankfully, this is starting to change.

Since 2010, an international soil policy community has emerged. The United Nations (UN) system has begun to focus on soil as an issue for sustainable development. Global Soil Week, which is based in Berlin, is now in its third year. The Soil Carbon Initiative was established in 2010 and provides a US-Australian focus to national and international soil policy. And in 2015, it was named as the International Year of the Soil.

This momentum is exceptionally important and valued. It is, however, also vulnerable to the demands of individual nations and their sustainability agendas, a rising global population and issues associated with a changing climate.

This chapter charts the growing global momentum around the issue of soil degradation and advancing the soil security dialogue. Placing this within the context of Australia's national sustainability framework offers insightful observations as to the fragility of this momentum, outlining that whilst at the national and international policy level we have made progress, there is ultimately more work to be done and considerations to be made, particularly as countries such as Australia look to intensify their agriculture production and assist with global food demands.

Keywords Soil security • Soil carbon • Soil policy • Sustainability

41.1 The Place of Soil in International Government Policy

The state of the world's soils continues to remain a serious global environmental problem. Overexploitation of vegetation and soil resources, together with inappropriate agricultural systems, is resulting in accelerated rates of land degradation, soil erosion and nutrient depletion.

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Soils are essential to any form of sustainable development and underpin society's response to many of the critical sustainable development issues facing the world today. If we do not protect and sustainably use our soils, essential ecosystem services such as the provision of food, fibre and fuel, freshwater supply, catchment management and climate regulation will not be achieved.

Thankfully there is a much needed and very much valued momentum building around the issue of soil degradation, and much progress has been made in advancing the soil security dialogue.

I have been a part of the sustainability debate in Australia for many years. My engagement is in the public policy interface, serving as Minister for the Environment, 1996–1998, and Minister for the Environment and Heritage, 1998–2001, and subsequently as the Australian Ambassador to the United Nations for Australia from 2006 to 2009 (United States Studies Centre 2015a). I again returned to these issues in 2009, when I joined the United States Studies Centre (USSC) at the University of Sydney as an Adjunct Professor in Sustainability, directing the Dow Sustainability Program (United States Studies Centre 2015b).

The Dow Sustainability Program represents a commitment of US$3,000,000 over 6 years from The Dow Chemical Company in the United States. The programme brings together academic and policy experts from Australia and the USA to consider and develop solutions to a range of sustainability challenges concerning soil, energy, water, food and biodiversity and to consider what we can learn from each other in terms of developing public policy that can influence matters of sustainable development (United States Studies Centre 2015b).

In 2010, under the auspices of the Dow Sustainability Program, the Soil Carbon Initiative was established. The Soil Carbon Initiative started out as a collaboration between the USSC and the Faculty of Agriculture and Environment (FAE) at the University of Sydney and has grown into a unique network of soil science and policy institutions across Australia, the US and beyond (McBratney and Koch 2014; United States Studies Centre 2011a, c). The impetus of the programme was the acknowledgement that there was a lack of communication between soil scientists and politicians on the issue of soil degradation, and from this failure, public policy wasn't being developed to address the problem.

In 2011, in response to this concern, the Soil Carbon Initiative held the landmark Soil Carbon Summit; a small, focused gathering of 18 of the world's leading soil and plant scientists. The summit was held in Sydney over 3 days with the purpose to deliberate and discuss issues of soil degradation, public policy options to address the issues and more effective communication between policy makers and stakeholder's (United States Studies Centre 2011a, b).

A key phrase was coined during this summit, which encapsulates the required response by society: soil security. Soil security refers to the maintenance and improvement of the world's soil resource to produce food, fibre and freshwater, contribute to energy and climate sustainability and maintain the biodiversity and the overall protection of the ecosystem (Koch et al. 2012, 2013; McBratney and Koch 2014). Ultimately, for soil to be secure, it has to maintain its function (McBratney et al. 2014).

What followed was a debate on the question of how do we measure whether we are making progress on improving soil function. Whilst it was acknowledged that improving carbon levels isn't the whole answer, it was identified that a principal mechanism for achieving soil security is the management and sequestration of soil carbon through active land management systems and technologies (Stockmann et al. 2013; Koch et al. 2013). If we were returning carbon to soil, we could generally say we were making an improvement.

From a public policy perspective, soil carbon also represented the communication hook soil security was looking for – soil security can be enhanced by increasing and managing soil carbon in the world's soils. Soil carbon provides structure and stability to the soil, whilst soils low in carbon are susceptible to erosion and are less able to support plant growth without external inputs. It was an indicator that was simple and clear to communicate to the general public and thus was an appealing from a public policy perspective (Hill 2014; McBratney and Field 2015).

Following this beginning we set out to build a larger constituency. Meetings were held in Washington DC, with US universities, US public officials, organisations such as the World Wide Fund for Nature, the World Bank and a range of other financial institutions (McBratney and Koch 2014). A key part of this process was to explore the US experience with soil policy and understand market mechanisms which can be used to influence farmers and provide an incentive for them to return carbon to their soils. Ultimately, we hoped to develop the Soil Carbon Initiative and the soil security concept with an international focus and support.

41.2 With This Context in Mind, What Progress Have We Made Internationally and in Australia?

Around the time the Soil Carbon Initiative was established, an international policy response was emerging. Notably, the United Nations system began to acknowledge soil as an issue for sustainable development.

In 2011, the United Nations' Food and Agriculture Organisation (UN FAO) teamed with the European Commission to take up the issue of soil degradation and launched the Global Soil Partnership. The partnership has the mandate "to improve governance of the limited soil resources of the planet in order to guarantee healthy and productive soils for a food secure world, as well as support other essential ecosystem services, in accordance with the sovereign right of each State over its natural resources" (Food and Agriculture Organisation of the United Nations 2015).

Other UN Agencies also began to become engaged in the dialogue. The United Nations Environment Programme (UNEP), for example, dedicated a chapter of its 2012 yearbook to soil, highlighting the benefits of soil carbon and the critical need to manage soils for multiple economic, environmental and social outcomes (United Nations Environment Programme 2012).

In 2014 I was fortunate to be invited to present the key note address at the 20th World Congress of Soil Science, convened by the International Union of Soil Science in Jeju, Korea (Hill 2014). At this conference I spoke on the topic of soil security and how we can work towards putting soil into both domestic and international policy agendas and accelerate positive change.

Also in 2011, Dr Klaus Topfer and his team at the Institute for Advanced Sustainability Studies (IASS), with the support of the German government, established the Global Soil Forum (Institute for Advanced Sustainability Studies 2015). This group now convenes the annual 'Global Soil Week', now in its third year, which has become a focal point for the international soil policy community to discuss and debate policy options on soil and land degradation.

Most recently, the 2015 Global Soil Week focused on the importance of soil for sustainable development (Global Soil Week 2015). Topics included reducing land degradation, the virtual land take due to consumer habits, the goal of a land-degradation neutral world, land grabbing, as well as human rights and sustainable land governance.

Significantly, the UN decided to designate 2015 as the International Year of the Soil, highlighting the importance of sustainable soil and land management to the achievement of several of the proposed Sustainable Development Goals (SDGs) (United Nations News Centre 2014).

Overall, these initiatives amount to a significant step in the process to place soil centre stage of the international sustainable development agenda. However it must be acknowledged that much more needs to be done.

In 1992 when The United Nations Framework Convention on Climate Change (UNFCCC) was agreed, so too was the Convention on Biodiversity, (UNCBD) the Convention to Combat Desertification (UNCCD) and the United Nations Forum on Forests (UNFF) (United Nations Framework Convention on Climate Change 2014). The UN had a suite of priorities they wanted to promote, but soils weren't there. It is now 20 years later, and the soil community is only now attempting to catch up.

The 2012 United Nations Conference on Sustainable Development (Rio +20) represented a significant opportunity for the soil security dialogue. In Rio, member states decided to launch a process to develop a set of SDGs, to build upon the Millennium Development Goals and move towards the post-2015 development agenda (United Nations General Assembly 2012). At the time there were several attempts to get soil and soil degradation on to the agenda. The aim was to have the outcome documents from the Rio +20 Conference recognise the issue of global soil degradation and the need for a global monitoring system for soil, with soil carbon as a critical indicator of soil security – arguably easier to measure, and work towards clear outcomes and progress.

In April of that year, the Australian Government held a workshop on soil security at the UN in New York advocating that position (United States Studies Centre 2012). Despite these efforts there was not a sufficient constituency for a stand-alone SDG on soil security. However there are 17 SDGs and notably all, either directly or indirectly, are dependent on land and soil resources. They still provide an opportunity to advance the soil debate as we move in the 2015 post-development agenda (United Nations General Assembly 2014).

At the international policy level we have therefore made progress. It is slow and hard work, and there is still a long way to go. But it's progress, nevertheless.

In Australia, in some aspects, there has been greater progress. In 2014 the Australian Government established the National Soil Research, Development and Extension Strategy, to assist soil research to become more targeted and collaborative and ensure that research better meets the needs of farmers (Commonwealth of Australia 2014).

The strategy had followed an earlier important initiative. In 2011, the Australian Government established the Carbon Credits (Carbon Farming Initiative) Bill 2011 (Australian Government 2011), which enabled farmers and land managers to earn carbon credits by storing carbon or reducing greenhouse gas emissions on the land. By this mechanism the Carbon Farming Initiative (CFI) also helped the environment by encouraging sustainable farming and providing a source of funding for landscape restoration projects. Notably, the CFI also had a legislative base.

On 25 July 2014 the methodology, Carbon Credits (Carbon Farming Initiative) (Sequestering Carbon in Soils in Grazing Systems) Determination 2014, was approved by the Australian Government (Australian Government 2014). This represented Australia's first systems methodology established for soil carbon sequestration. The Soil Carbon in Grazing Systems methodology involves storing carbon on grazing land by introducing activities that either increase inputs of carbon to the soil, reduce losses of carbon from the soil or both.

Whilst the CFI has since been moved into the Emissions Reduction Fund by a successor government, the legislative mechanism for soil carbon sequestration has remained in place.

In April 2015 the Australian Government directly purchased AUD$50 million of abatement from projects that utilise this methodology. This can now be translated into tonnes of soil carbon abatement and an estimate of a percentage increase in soil carbon across agricultural soils in Australia.

This makes Australia the only country in the world to not only have a nationally regulated soil carbon methodology but also to have purchased abatement under such a methodology. This is a clear demonstration of Australia's leadership in developing and utilising market mechanisms to improve and maintain soil carbon and also to make a significant contribution to reducing greenhouse gases. It shows how soil carbon policy can contribute to climate change policy and is something to be encouraged and hopefully will be taken up by others.

Whilst in Australia we are making progress, there are always threats and opportunities. From an Australian perspective, there is a strong push to intensify its agriculture production, so to take advantage of the rising economic standards in Asia. If the Trans-Pacific Partnership is achieved, it will open up the markets even further.

Concurrent to this demand is Australia's rising reputation for producing clean, green and safe food (Bettles 2015; Henry 2014). The challenge for Australia will be to scale up production across all agricultural sectors and maintain and enhance agricultural competitiveness, whilst maintaining a high-quality product. It is therefore going to be very important for Australia, as it intensifies its agriculture, particularly into more fragile areas and more fragile soil, that it does so in a sustainable way and that the soil is secured in the process. Otherwise the benefits will be short lived, and the exercise will be counterproductive. Soil security provides a sound framework, within which governments can bring the subject of soil function into agriculture and trade policy and to work out the win-win of sustainable growth.

Similarly, there is a significant emphasis on the quality of agriculture aid and investment within Australia's aid programme, particularly in assisting developing countries in our region (Australian Government Department of Foreign Affairs and Trade 2014). Australia is a world leader in agriculture and soil science, and is well placed to invest in agricultural development programmes. The goal will be for Australia to ensure that this outreach gives a long productive and sustainable future for developing countries and their agriculture production. Soil, and soil security, is central to this objective.

In conclusion, soil carbon remains a good indicator of soil security. We still need to be able to tell whether we are making progress or not in the goal of sustainable agriculture, and to do so we need to be able to measure, evaluate and report. Using carbon as the indicator takes us a long way.

There is still an enormous amount of work to be done. Having said that, much progress has been made as a result of the enthusiasm and determination of the soil science community. It's a community which deserves to be congratulated. It is also a community which will be rewarded by politicians and leaders around the world, ultimately elevating soil security to a high level in national and international policy.

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Chapter 42
Translating Soil Science Knowledge to Public Policy

Luca Montanarella

Abstract A lot of scientific knowledge is available on soils in Europe and in the world. Yet, only a fraction of this knowledge reaches policy makers and is actually used in the national and global soil policy development processes. Despite the plethora of soil data and information generated by the soil science community, only a fraction of this information is actually policy relevant. Soil information, in order to be policy relevant, needs to respond to societal needs and address issues of relevance to the general public. Too often soil data and information generated by scientists are only relevant to a very small scientific community and not of relevance to the public policy development process. The establishment of an effective science-policy interface, the Intergovernmental Technical Panel on Soils (ITPS), and the results of the first comprehensive assessment of global soil resources, the Status of World's Soil Resources report, provide the first steps toward a more effective global soil policy for protecting this limited, nonrenewable, natural resource.

Keywords Soil protection • Sustainable development • Science • Policy

42.1 Science to Policy

Translating scientific results in operational policy decision-making processes has always been difficult. Appropriate science policy interfaces are required that can produce the necessary aggregation of data and scientific evidence that can be translated in relevant information for policy makers. Typically these processes are performed by organizations with a political mandate but formed by high-level scientists.

Probably the best-known and most successful example is the Intergovernmental Panel on Climate Change (IPCC), recently awarded with the Nobel Prize for peace.

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Following the success of IPCC, also the other “Rio Conventions,” the Convention on Biodiversity (CBD), and the United Nations Convention to Combat Desertification (UNCCD) have been striving toward the establishment of similar science-policy interfaces. The recent establishment of the Intergovernmental Platform for Biodiversity and Ecosystem Services (IPBES) and the Science-Policy Interface (SPI) of UNCCD are examples of this new development of institutional mechanisms for translating scientific results into operational policy recommendations.

Soil science has been experiencing an exponential increase in recent years of scientific publications and results (Hartemink and Mc Bratney 2008). Nevertheless this increased scientific output has found only limited application in the policy-making processes at national, regional, and global scales. Existing panels, like the IPCC, the IPBES, and the SPI, have only very limited expertise in soil science and often soils are completely neglected in the high-level, policy-relevant, assessments they produce.

In order to improve the policy relevance of the large body of scientific evidence available within the soil science community, a specific science-policy interface, the Intergovernmental Technical Panel on Soils (ITPS), has been created within the Global Soil Partnership (GSP) (Montanarella and Vargas 2012). The ITPS is composed by 27 members, nominated by the governments represented in the GSP (all FAO Members) according to a regional and gender balance. The members of the ITPS are recognized soil scientists nominated by governments and tasked with the mandate of providing the needed policy-relevant advice to the GSP and also to all relevant UN bodies, like FAO, UNFCCC, UNCCD, etc.

One of the main results of the first 2 years of activity of the ITPS has been the successful completion of the first comprehensive assessment of the Status of the World’s Soil Resources (SWSR). This assessment has been compiled in a similar manner as the assessments produced by the IPCC, involving possibly the entire global soil science community.

About 200 soil scientists from 60 countries contributed directly to the report. Their assessment has synthesized the scientific knowledge embodied in more than 2000 peer-reviewed scientific publications. The report provides a global perspective on the current state of the soil, its role in providing ecosystem services, and the threats to its continued contribution to these services. The specific threats to soil function considered in the report are erosion, compaction, acidification, contamination, sealing, salinization, waterlogging, nutrient imbalance (i.e., both nutrient deficiency and nutrient excess), and losses of soil organic carbon and of biodiversity.

Experience has shown in Europe that communicating scientific results to policy makers and the wider public requires a large degree of simplification, possibly distilling the scientific evidence in order to present only the key messages that need to be taken into account by concerned stakeholders.

The four main key messages emerging from the SWSR are the following:

1. Sustainable soil management can increase the supply of healthy food for the most food insecure among us. Specifically we should minimize further degradation of soils and restore the productivity of soils that are already degraded in those regions where people are most vulnerable.

2. The global stores of soil organic matter (i.e., soil organic carbon (SOC) and soil organisms) should be stabilized or increased. Each nation should identify locally appropriate SOC-improving management practices and facilitate their implementation. They should also work toward a national-level goal of achieving a stable or positive net SOC balance.
3. Compelling evidence exists that humanity is close to the global limits for total fixation of nitrogen and regional limits for phosphorus use. Therefore we should act to stabilize or reduce global N and P fertilizer use while simultaneously increasing fertilizer use in regions of nutrient deficiency. Increasing the efficiency of N and P use by plants is a key requirement to achieve this goal.
4. The regional assessments in the SWSR report frequently base their evaluations on studies from the 1990s based on observations made in the 1980s or earlier. We must improve our knowledge about the current state and trend of the soil condition. An initial emphasis should be on improving observation systems to monitor our progress in achieving the three priorities outlined above.

The possible translation of those messages into policies that provide solutions to the identified problems needs then to happen at national level. In order to provide guidance to policy makers and other stakeholders on the needed actions, a revised World Soil Charter has been released by the ITPS and submitted to FAO's governing bodies for endorsement and implementation. The revised World Soil Charter is the best example of successful translation of scientific knowledge into policy recommendations.

As a next step, the 3rd GSP Plenary Assembly in June 2015 has further recommended the ITPS to develop Voluntary Guidelines on Sustainable Soil Management to be adopted by each country. The next biennium of the ITPS activities 2015–2017 will be dedicated to the development of such guidelines. The guidelines will allow translating in concrete action on the ground the principles and recommendations endorsed by all countries in the world within the World Soil Charter. The development of such guidelines will closely match the adoption of the new post-2015 sustainable development agenda and the related Sustainable Development Goals (SDG).

The process of putting soils on the post-2015 development agenda and the SDGs provides the opportunity to address soils within the frame of a wide set of sustainable development issues, i.e., with a nexus approach. Soils are one of the main elements of sustainable development (Montanarella and Lobos Alva 2015) and are highly interlinked with the achievement of food, water, and energy security, among others. The role of soils for sustainable development was recognized by article 206 of the Rio+20 Outcome Document "The Future We Want" in the agreement to "*strive to achieve a land degradation neutral world in the context of sustainable development*".

As a limited and (in human terms) nonrenewable natural resource, we need to manage soils in a sustainable way for future generations. It is therefore imperative that these resources are coherently integrated across the SDGs. The Open Working Group formed to draft SDGs agreed on a set of 17 goals and 169 targets. Soils and land will underpin the achievement of the SDG agenda as a whole and play a direct role in at least seven of the proposed SDGs.

42.2 Sustainable Development Goals (SDGs)

These have been adopted by the United Nations in September 2015, highlighting the SDGs with a direct link to soils and land (in bold):

1. **End poverty in all its forms everywhere**
2. **End hunger**, **achieve food security and improved nutrition**, **and promote sustainable agriculture**
3. Ensure healthy lives and promote well-being for all ages
4. Ensure inclusive and equitable quality education and promote life-long learning opportunities for all
5. **Achieve gender equality and empower all women and girls**
6. **Ensure availability and sustainable management of water and sanitation for all**
7. **Ensure access to affordable**, **reliable**, **sustainable**, **and modern energy for all**
8. Promote sustained, inclusive and sustainable economic growth, full and productive employment, and decent work for all
9. Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation
10. Reduce inequality within and among countries
11. **Make cities and human settlements inclusive**, **safe**, **resilient, and sustainable**
12. Ensure sustainable consumption and production patterns
13. Take urgent action to combat climate change and its impacts
14. Conserve and sustainably use the oceans, seas, and marine resources for sustainable development
15. **Protect**, **restore, and promote sustainable use of terrestrial ecosystems**, **sustainably manage forests**, **combat desertification**, **and halt and reverse land degradation and halt biodiversity loss**
16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable, and inclusive institutions at all levels
17. Strengthen the means of implementation and revitalize the global partnership for sustainable development

Source: *United Nations Department of Economic and Social Affairs* (2014)

Soils and land are addressed, among others, under goals for food security, sustainable agriculture, and the protection of terrestrial ecosystems. The goals address, for instance, the need to ensure equal access and control over land, especially for poor and vulnerable populations. Issues of soil quality and halting land degradation are covered but will need to be managed together with targets that aim to double agricultural productivity, which could lead to an intensified use and to further degradation.

The protection of soils in the SDGs can at the same time support goals, for instance, for climate change through the conservation of soil carbon stocks, for biodiversity conservation, for water availability, and for poverty reduction though the support of livelihoods of people working in agriculture. These resources are found across the agenda, but there will be potential conflicts and trade-offs that should be addressed in a crosscutting manner. Furthermore, addressing soils in the SDGs will require knowledge-based development of appropriate indicators that can be applied locally without increasing the data collection burden of member states. But beyond indicators, which can be very costly and difficult to monitor, there is the need for innovative monitoring systems around the world. It will be crucial for this process to include different stakeholders and scientific disciplines.

Several initiatives are advocating for soils to be a part of the post-2015 development agenda. This issue has been highlighted, for example, in the communication of the European Commission (EC) outlining Europe's development aspirations for the new SDGs. The Institute for Advanced Sustainability Studies (IASS) in Germany and partners has been working for the integration of soils and land in the SDGs with a "people-centered" and transdisciplinary approach. Several country governments are also supporting the issue, for instance, Namibia and Iceland formed an informal interest group called "friends of desertification," which aims to maintain the momentum generated by Rio+20 around desertification, land degradation, and drought in the context of post-2015 development agenda. In order to have an impact on the official post-2015 process, it will be crucial that these organizations and groups cross-reference and present coordinated proposals, including collaboration with other stakeholders and initiatives.

42.3 Conclusions

Soil resources are covered across the Rio Conventions either in the text or through the implementation of actions prescribed by the conventions. This has contributed to increasing the momentum to speak about soils at the global level. However, even with the implementation of the conventions, we are still dealing with major challenges related to the degradation of land and soil resources. This is in part due to a lack of a crosscutting and integrated approach.

The SDG process further highlights the need for an integrated approach as soils and land are found across several goals and will play a key role for the achievement of the agenda. The underpinning role soils and land will play across the SDGs needs to be recognized. Putting soils on the agenda of the existing MEAs and the post-2015 development agenda requires a major shift in the discussion around soils as a limited, nonrenewable, natural resource. There is the need to recognize that soils are underpinning a wide range of services crucial for sustainable development and should, therefore, be protected for future generations.

The recently established Global Soil Partnership and its Intergovernmental Technical Panel on Soils have been highly instrumental in moving forward the relevance of soils on the political agenda. The recently adopted World Soil Charter and the comprehensive assessment of the Status of World's Soil resources provide further elements for rapidly moving toward sustainable soil management at all levels. Achieving the proposed SDGs by 2030 will require the rapid adoption of guidelines for sustainable soil management by all countries in the world.

The main difficulty in introducing soils within such a global sustainability agenda is that soils are in large majority in private ownership and are perceived by most countries of the world a topic strictly limited to national sovereignty. Accepting globally binding targets and regulations affecting national soil resources is still perceived by some governments as a major interference. The transnational dimensions of soil protection and sustainable soil management are still not sufficiently understood, and the objective evidence of such interlinkages is still limited (SERI 2011). Some of the first considerations around the bioenergy debate in relation to Indirect Land Use Changes (ILUC) have triggered some research into the interlinkages between national decision-making and their effects on the soil resources of other nations, but detailed data are still lacking for a comprehensive assessment of such interlinkages.

Moving forward, there is a need to focus on improving the implementation of the Rio Conventions with regards to soils. This will include further developing and strengthening synergies among the conventions. Additionally, soil scientists need to exchange with different stakeholders from other scientific disciplines, policy-making, and civil society to link soils to key sustainable development issues such as water and food security and sustainable agriculture, climate change, biodiversity, and ecosystem protection. Concerted efforts for advocacy within the post-2015 development agenda need to focus on keeping soils and land on the agenda and looking beyond 2015 toward an effective implementation and monitoring of the SDGs.

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Chapter 43
Synthesis: Goals to Achieve Soil Security

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Abstract To work towards achieving soil security in the next two decades, participants identified goals to secure soil so that it can contribute to solving other global issues. Specific goals for each dimension were designed to achieve the overall objective of soil security, catalyse research and practice and contribute to soil policy.

Agreed goals included:

1. Fifty percent of soil is used according to its capability by 2030.
2. Soil condition is optimally managed according to the inherent capability in 50 % of managed soil systems by 2030.
3. Increase annual capital value of soil ecosystem services by 5 % per annum by 2030 and commercial land values based on full economic value of soil capability and condition, by 2020.
4. Ninety percent awareness and understanding of soil security amongst the general public by 2030.
5. Fifty percent of national governments recognise soil security in their laws and regulations by 2025.

It was agreed that we should work towards making soil security a recognised sustainable development goal in its own right.

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43.1 Introduction

Soil security requires maintenance and improvement of the soil resource to produce food, fibre, and freshwater, to contribute to sustainable energy production, to adapt to climate changes and to maintain biodiversity, human health and function in ecosystems. Those concerned with achieving soil security recognise that attainment involves scientific, economic, industry and political engagement to effectively and credibly inform policy and legal frameworks and implement appropriate actions. Soil security, like food security, has a number of dimensions that interact with environmental, social and economic components. The discussion at the Global Soil Security Symposium was organised around the five dimensions of soil security, which include (1) capability, (2) condition, (3) capital, (4) connectivity and (5) codification.

To work towards achieving soil security in the next two decades, participants identified goals to secure soil so that it can contribute to solving other global issues. Specific goals for each dimension were designed to achieve the overall goal of soil security, catalyse research and practice and contribute to soil policy.

43.2 Capability

The capability of a soil refers to its potential functionality ("what can the soil do?"). It is well recognised that not all soils share a similar ability to provide the seven soil functions that are distinguished by the Soil Protection Strategy of the European Union (biomass production, filtering nutrients, source of biodiversity, cultural environment, raw materials, carbon pool, heritage). When the soil is not managed to its identified capability, negative impacts on soil conditions can occur that negatively affect its contributions towards general ecosystem services. Soil capability needs to be evaluated according to the seven functions. However, the function that is generally focused on is biomass production while neglecting its link with the other functions in a sustainable production system. For each function, there are indicators that evaluate capability. The USDA NRCS Soil Survey Division has developed many (hundreds) soil interpretations as indicators of soil capability and are linked to soil series descriptions. The USDA's empirical estimates can be quantified by process-oriented computer simulations that also allow risk assessments based on soil limitations. Aside from defining soil capability, it is also desirable to explore ways in which potentials can be reached using management support systems, with precision agriculture as an important component. Soil capability is also limited by erosion due to natural (i.e. wind and water) or human (e.g. used as building material) forces and by surface sealing. The current rate of surface sealing for the globe is approximately 16,000 ha day^{-1} over the next 20 years.

To achieve soil security in the capability dimension, one overall goal was identified:

50 % of soil is used according to its capability by 2030.

Towards achieving this goal, more specific objectives may include the following:

1. Reduce loss of soils with a high capability to less than 4,000 ha per day by 2030.
2. Document successful sustainable land use systems where soils have been managed to their capability in 50 % of the regions (global) by 2030.
3. Integration of soil capability criteria in 90 % of policy-oriented models on climate change, food and energy security, biodiversity loss and water availability by 2025.

43.3 Condition

The dimension of soil condition refers to the current sta*te of a soil*, *reflects human management of soil, and how state and management alters or enhances the seven* soil functions. Other concepts of valuing and caring for the soil through management include soil health, quality, change and resilience. Much of the focus on soil condition is associated with agriculture, but functions of soil not linked to agriculture (e.g. urbanisation, mining and nature preserves) are equally important. The assessment of soil condition is commonly associated with measurement of soil organic carbon as an indicator of improved soil condition; however, improvements in soil condition or function may not always be reflected by changes in soil organic carbon.

To achieve soil security in the condition dimension, one overall goal was identified:

Soil condition is optimally managed according to the inherent capability in 50 % of managed soil systems by 2030.

Towards achieving this goal, more specific objectives may include the following:

1. Reduce soil nutrient depletion by 50 % by 2030 against 2015 levels.
2. Increase water capture by 20 % by 2030 against 2015 levels.
3. Increase carbon content of agriculture topsoil above 2015 levels by 20 % by 2030.
4. Reduce soil losses to the tolerable soil erosion rate for 90 % of managed soil by 2030.

43.4 Capital

The dimension of soil capital refers to the economic and natural capital value of the soil resource. Placing a monetary value on an asset enables a society to value or secure the asset. Therefore a societal focus in soil security can be economically driven. Monetary value also provides a way for capital and risk markets to engage with valuation of soil as an asset for economic flows. Financial incentives that clarify and define natural capital and ecosystem services are ways to value soil. Other indices that describe soil value can exist, but might be more difficult to assess. Examples include soil rarity, soil diversity or where soil directly provides food for consumption (subsistence agriculture).

The economic value of soil can develop "top-down" through government, market and institutional frameworks or bottom-up through standards, labelling and social licensing of soil products.

To achieve soil security in the capital dimension, two overall goals were identified:

1. *Increase annual capital value of soil ecosystem services by 5 % per annum by 2030.*
2. *Commercial land values based on full economic value of soil capability and condition, by 2020.*

Towards achieving this goal, more specific objectives may include the following:

1. Natural capital becomes part of 90 % of lending decisions by 2030.
2. Incorporate soil management accreditation into 90 % of environmental stewardship branding or labelling of products by 2030.

43.5 Connectivity

Connectivity refers to the connection of individual land managers/farmers with the soil they manage and the broader connection of soil to society and with society to soil. Connectivity also encompasses issues of knowledge, education, training and awareness.

The group identified many ways to know, understand and value soil. Aesthetic consideration can drive the general population to appreciate and understand the relevance of soil. Participatory learning by managers and experiential learning at schools have the potential to change mindsets on soil value and management. Intergenerational equity is a strong human driver of soil security. The soil health concept provides an effective means of connecting the importance of sustainable soil management by soil managers with the broader community and the means to help build recognition by society of the important role that soil managers play in maintaining soil function for the production of food, fibre and other ecosystem services.

To achieve soil security in the connectivity dimension, an overall goal was identified:

90 % awareness and understanding of soil security amongst the general public by 2030.

Towards achieving this goal, more specific objectives may include the following:

1. Integrate soil security policy with agricultural policy in nations that are net exporters of food by 2020.
2. Establishment of community gardens in 90 % of primary schools globally, supported by a learning curriculum, by 2020.
3. Increase the area of agricultural soil managed by those with soil management certification by 50 % by 2030.
4. Engage 0.1 % of the population to nurture and connect their values with securing soil by 2030.
5. Increase the use of practices focusing on soil aesthetics (art, poetry, music, stories, etc.) into strategies to secure soil by 100 % by 2030.

43.6 Codification

Codification refers to the policies, regulations and governance arrangements, in both the public and private sectors that enable soil security.

Many countries have formulated soil policy and regulations. Both carrot (incentive programmes) and stick (regulatory penalties) approaches are used. The USA has many financed incentive programmes that implicitly embed soil security policies. Australia has a free market economy and relies less heavily on government programmes; however, an issue is that government programmes for soil tend to be weighted towards natural resource management programmes, rather than treatment of soil security for agricultural productivity.

Soil security is an internally focused goal for countries that grow and export much of their food and fibre production and an externally focused goal for those that rely on the soil of other nations for food and fibre through imports. While there are national arrangements, international policy around soil security so far has been missing, possibly due to its importance in different domains, e.g. desertification and food security, causing a degree of ownership conflict. The European Union has made the biggest attempt, so far, through the European Soil Thematic Strategy. Sustainable development goals and similar instruments may offer a way forward.

To achieve soil security in the codification dimension, an overall goal was identified.

50 % of national governments recognise soil security in their laws and regulations by 2025.

Towards achieving this goal, more specific objectives may include the following:

1. Recognition and integration of soil security policy in major international instruments for sustainable development, including the UNCCD, UNCBD and the UNFCCC and the SDG by 2025.
2. Soil carbon becomes an indicator for soil-related sustainable development goals by 2020.
3. Net exporting food nations integrate soil security with agricultural production policy and governance by 2025.

43.7 Conclusion

Finally, the idea of eventually recognising soil security as a sustainable development goal is an excellent way of framing future development of the framework and concepts and, most important of all, achieving soil security.

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