Progress in Soil Science

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Global Soil Security

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Progress in Soil Science

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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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The opinions expressed and arguments employed in this publication are the sole responsibility of the authors and do not necessarily reflect those of the OECD or of the governments of its Member countries.

Contents

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 policy-making 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 run-off 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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