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# Soil Security: Solving the Global Soil Crisis

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## Abstract

Soil degradation is a critical and growing global problem. As the world population increases, pressure on soil also increases and the natural capital of soil faces continuing decline. International policy makers have recognized this and a range of initiatives to address it have emerged over recent years. However, a gap remains between what the science tells us about soil and its role in underpinning ecological and human sustainable development, and existing policy instruments for sustainable development. Functioning soil is necessary for ecosystem service delivery, climate change abatement, food and fiber production and fresh water storage. Yet key policy instruments and initiatives for sustainable development have under-recognized the role of soil in addressing major challenges including food and water security, biodiversity loss, climate change and energy sustainability. Soil science has not been sufficiently translated to policy for sustainable development. Two underlying reasons for this are explored and the new concept of soil security is proposed to bridge the science–policy divide. Soil security is explored as a conceptual framework that could be used as the basis for a soil policy framework with soil carbon as an exemplar indicator.

## Soil security: responding to the global soil crisis

Soil security is a new concept that has arisen during a time of emerging international response to the increasingly urgent problems that face the global soil stock. Soil security refers to the maintenance and improvement of the world's soil resources so that they can continue to

provide food, fiber and fresh water, make major contributions to energy and climate sustainability, and help maintain biodiversity and the overall protection of ecosystem goods and services (Koch et al., 2012). History stands as a warning to our modern societies. Whole civilizations have fallen and collapsed when their stock of fertile soils washed or blew away. Many clarion calls to preserve our

soil stocks have been made; they must not be ignored (Jacks and Whyte, 1939; Hammond, 1939; Hyams, 1952; Kellogg, 1956; Hillel, 1992; Montgomery, 2007). Can clear hindsight be used to avoid repeating the past?

### The global soil crisis

The world now faces a modern soil crisis that eclipses those of the past. Soil degradation – the decline in soil function or its capacity to provide economic goods and ecosystem services (Lal, 2010) – is a global phenomenon with many faces. The pressures on soil are widespread and varied and the challenges created by these demands drive deep into our continued ability to provide sufficient resources for the world's growing population. Detrimental consequences include threats to agricultural productivity and food security, fresh water retention and biodiversity – all of these rely on the functions of soil. The threat of increasing carbon dioxide and methane emissions through soil degradation, including accelerated erosion (Lal, 2004) and permafrost thaw, is substantial (Shuur and Abbott, 2011).

Some forms of soil degradation – erosion, fertility loss, salinity, acidification, compaction and the loss of soil carbon – are natural processes that can be accelerated 1000-fold by excessive land clearing and inappropriate farming practices that are not fit for purpose (van Lynden et al., 1998). Amelioration and changes to land management practice can sometimes reverse the degradation, but this is often not affordable.

Other problems stem from not recognizing soil as a vital resource. Practices such as the use of topsoil to produce bricks and other building materials, and the paving over of high-quality agricultural soils for urban development, sometimes referred to as 'soil sealing' (Burghardt, 2006), contribute significantly to the loss of global soil productivity.

An estimated 55 per cent of the world's desertified land is attributable to soil degradation (Lal, 2010). Land degradation is estimated to affect 23.5 per cent of global land area (Bai et al., 2008) and has resulted in 1–2.3 million hectares of agricultural land becoming unsuitable for cultivation (Lambin and Meyfroidt, 2011). Much of this degraded area faces increasing pressure from development as a result of increasing population (Barbier, 2010). Around 1.3 billion people in developing economies live in marginal areas and on ecologically fragile lands that are prone to severe land degradation (World Bank, 2003).

Permanent topsoil loss is already limiting sustainable development in many local economies (Pimental, 2006). Lack of attention to soil degradation leaves the extent of these losses largely unmeasured and undocumented. The loss of soil, loss of access to soil or its extreme degradation does pose an existential threat to humanity because our global food production systems are almost completely reliant on soil. In short, the natural capital of soil has been

greatly undervalued (Dominati et al., 2010; Robinson et al., 2009) and the importance of halting and reversing the degradation and loss remains unacknowledged.

### Soil and sustainable development

These problems are not new. Soil scientists have been articulating the threats to global soil stocks for some time (Banwart, 2011; ISRIC, 2012; Kaiser, 2004).

Since the first UN Conference on Environment and Development (UNCED) in 1992, links between science and policy on issues of sustainable development have become increasingly sophisticated. Independent assessments, scientific expert panels and subsidiary bodies have been established to provide expert information on global issues related to sustainable development, including climate change, biodiversity and water availability (Kohler et al., 2012).

The role of soil in providing ecosystem services is scientifically established (Baker et al., 2001; Janzen et al., 2011) but these insights and other advances in soil science over the past two decades have not yet flowed through into international policy instruments. As a result, key initiatives and interventions focused on sustainable development risk failure, as they have not taken the underpinning role of soil into consideration.

The Millennium Ecosystem Assessment (MEA) report defined provisioning and regulating ecosystem services, but under-recognized soil as the key delivery platform underpinning many of these services (MEA, 2005). A degrading soil stock will directly impact food, fiber and fresh water provision. More broadly, soil forms the basis of the landscapes and ecosystems that provide biophysical, economic, cultural and spiritual services to humanity.

Despite its critical importance in the carbon cycle, soil is frequently left out of climate change debates (Schmidt et al., 2011). Soil contains at least twice as much carbon as the atmosphere, and cycles it over much longer time-scales (Lal, 2004) making it an equal partner to the atmosphere and oceans in the global carbon cycle (Lal, 2004); we directly influence and manage soils in ways that we cannot manipulate these other pools.

Discussions around biodiversity loss seldom refer to soil even though soil contains the most diverse and complex ecosystems on the planet. Soils contain over 98 per cent of the genetic diversity in terrestrial ecosystems (Fierer et al., 2007) however soil biodiversity is not addressed in the Global Biodiversity Outlook (GBO-3) from the UN Convention on Biological Diversity (Secretariat of the CBD, 2010), and is not referred to in the popular International Union for Conservation of Nature (IUCN) Red List of Threatened Species (IUCN, 2012).

Recent attempts to develop a global framework for assessing planetary resources also fail to recognize the vital role of soil in the biosphere. The Stockholm Resilience Centre led an effort to define the key planetary

boundaries that face anthropogenic pressure (Rockström et al., 2009). This important work is influential in current reviews of sustainable development, but does not address soil as a critical contributor to buffering the thresholds of those boundaries.

The closest mechanism that the international community has to address concerns about soil degradation is the UN Convention to Combat Desertification (UNCCD). Historically, the UNCCD has focused largely on land degradation and drought in Africa and in arid and semi-arid landscapes. Although regenerating soils in underdeveloped regions can make significant gains in reversing desertification, a worldwide approach to soil degradation is critical to address the wider problems from local to national to continental scales.

There are many contributors to the identified disconnect existing between science and international policy, but in this article we address two. The first relates to the use of terminology; the second is the lack of a sufficient framework to bridge the divide.

### Terminology: distinguishing between 'soil' and 'land'

For many people the word 'soil' is interchangeable with the word 'land'. This lack of distinction in terminology results in an oversight of the underpinning role of soil within landscapes.

Soil is a distinct living entity that is one of the core building blocks of land. Land consists of soils, rocks, rivers and vegetation (Lal, 2010). Soil contributes five principal functions within a landscape:

1. nutrient cycling;
2. water retention;
3. biodiversity and habitat;
4. storing, filtering, buffering and transforming compounds; and
5. provision of physical stability and support (Blum, 1993).

By failing to identify soil as a discrete component in discussions about land, we lose visibility of these functions. This is reinforced by the often poor representations of soil in comprehensive hydrological and climatic simulation models that form the basis of many policy measures (Bouma et al., 2011).

Making the distinction between land and soil in our language and policies, together with a better understanding of soil as one of the discrete components of land is important.

### A soil-centric framework is needed

The international community lacks a policy framework for addressing specific issues of soil degradation in

**Figure 1.** Soil security is a key contributor to a number of global issues, all of which are inter-related (McBratney et al., 2012).



relation to sustainable development. Attempts to address problems through the lenses of existing instruments have forced too narrow a focus on particular subsets of issues and regions (Sanchez and Swaminathan, 2005). 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. The narrative on soils must be improved and its voice must be raised if the required response is to be achieved. A soil-centric framework is needed to generate policies that raise awareness of, and reverse, soil degradation and simultaneously recognize its essential co-benefits for sustainable development.

The concept of soil security can be used to address this shortage – it provides a useful mental model that links soil with good outcomes in sustainable development (see Figure 1). When the five functions of soil are aligned against critical issues for society and sustainable development, the linkages become clear – as outlined in Table 1.

The key aim in securing soil is to maintain and optimize its functionality: its structure and form, its diverse and complex ecosystems of soil biota, its nutrient cycling capacity, its roles as a substrate for growing plants, as a regulator, filter and holder of fresh water, and as a potential mediator of climate change through the sequestration of atmospheric carbon dioxide.

**Table 1.** Aligning the established scientific concept of soil functions in order of their relative immediate impact with major global societal challenges linked to soil security (shown in Figure 1).

Global societal challenge	Relevant soil function(s)	Examples
<b>Food security</b>	(1) Nutrient cycling (2) Water retention (5) Provision of physical stability and support (4) Storing, filtering and transforming compounds	The quantity, quality and accessibility of food is affected by having functioning soil available to produce food (1, 2, 5) and avoid contamination (4).
<b>Water security</b>	(2) Water retention (4) Storing, filtering and transforming compounds	Soil contributes to provision of clean water and its storage (2, 4) and functions as a filter, minimizing the contamination of ground and surface water (1, 4).
<b>Climate change abatement</b>	(1) Nutrient cycling (2) Water retention (4) Storing, filtering and transforming compounds (5) Provision of physical stability and support	Carbon and nutrients are sequestered in soil and in the plants that soil supports, reducing the release of greenhouse gases (1, 2, 4, 5). Use of soil for raw materials is also a major concern as it removes an important sink for carbon (1, 4).
<b>Ecosystem service delivery</b>	(1) Nutrient cycling (2) Water retention (3) Biodiversity and habitat (4) Storing, filtering and transforming compounds (5) Provision of physical stability and support	Soil provides a wide range of ecosystem services (1, 2, 3, 4, 5) that contribute to soil as natural capital (Dominati et al., 2010) that is formulated by natural stocks and ecosystem goods. This approach enables a 'soil financial account' to be developed (McBratney et al., 2012)
<b>Biodiversity protection</b>	(3) Biodiversity and habitat (1) Nutrient cycling (4) Storing, filtering and transforming compounds	Soil is the habitat for the largest gene pool and diversity of species (3), which enables plant growth, the recycling of waste and provision of nutrients affecting food and water security (1, 4).
<b>Energy sustainability</b>	(1) Nutrient cycling (2) Water retention (4) Storing, filtering and transforming compounds (5) Provision of physical stability and support	The use of plants for energy production (e.g. ethanol) is not always synergistic with food production and sustainable water resource use (1, 2, 4, 5).

Maintaining the myriad of interactions between these processes is what gives soil its resilience, productivity and efficiency. Permanent loss of soil natural capital through erosion, loss of structure, soil sealing and other types of degradation will severely impact the delivery of these ecosystem services.

### Emerging soil policy initiatives

Over the past few years a number of new initiatives to give soils a policy focus have emerged. The UN Food and Agriculture Organization (FAO) launched the Global Soil Partnership (GSP) in conjunction with the EC in 2011, 'to provide support and facilitate joint efforts towards sustainable management of soil resources for food security and climate change adaptation and mitigation' (GSP, 2012). Luc Gnacadjia, Executive Secretary of the UNCCD has stated that healthy soil is critical for securing food, water and

energy, and that 'soil's caring capacity is often forgotten in global policies for sustainable development' (UNCCD, 2012).

The UN FAO, the EC, the UNCCD and the United Nations Environment Programme (UNEP) partnered with the Global Soil Forum based at the Institute for Advanced Sustainability Studies (IASS) in Germany to hold the inaugural Global Soil Week in Berlin during November 2012. This event deepened the discourse on soils as a fundamental pillar for sustainable development and developed an agenda to improve the sustainable management of soils (IASS, 2012).

As these policy initiatives develop and mature, a new policy framework for assessing and discussing soils as a resource for sustainable development becomes critical. Building on the definition of soil security proposed by Koch et al. (2012), Figure 1 and Table 1 provide an expanded conceptual framework that could be used as the basis of a policy framework. Further work must be



done to fully develop the required soil policy framework, the dimensions of soil security that must be addressed, a means of assessment and establishment of global targets and indicators.

This requires a multidisciplinary approach that extends beyond soil science *sensu stricto*. Engaging the fields of ecology and economics to determine the value of the natural capital of soil, as well as the social sciences to determine how we can better connect society with the fundamental functions of soil in landscapes will be key. Determining policy instruments that can work at the international level, and yet be implemented at local scales will be critical, and may need instruction from other resource policy areas such as water and air.

### Soil carbon: an exemplar indicator of soil security

Soil scientists from the International Union of Soil Sciences (IUSS) established the Global Soil Map project in 2009 to develop a global digital map of the world's soils and key soil attributes that can be used to define potential soil use and monitor temporal trends in soil quality (Sanchez et al., 2009). This project is akin to 'going from a 1980s printed road atlas to Google Earth in one giant leap', and progress to date is impressive (Fisher, 2012).

Given the right resources, the Global Soil Map project could be enhanced to provide a global early warning system for soils that are reaching critical thresholds of sustainability. The question then becomes, what aspects of soil would such a system track in order to monitor soil condition globally?

Soil organic carbon (soil carbon) is one of the significant universal indicators. There are other indicators, including soil pH but carbon is a workable exemplar and is easily understood by policy makers and the wider community.

The Soil Carbon Initiative (SCI), an international coalition of eminent soil scientists who came together in Sydney in February 2011 to consider the potential of soil to sequester atmospheric carbon (Stockmann et al., 2013), agreed that tracking changes in soil carbon helps to identify dangerous thresholds in degrading soils (SCI, 2011).

Soil carbon is routinely measured and plays a vital role in soil function. Generally, soils lower in carbon are less functional; soils higher in carbon have enhanced resilience. The net flux in soil carbon over time becomes an overall indicator for the natural capital of the soil. Increasing and managing soil carbon and the biota that transform soil carbon is a key mechanism for improving and maintaining the functionality of soil and its ability to support ecosystem service delivery (Soil Carbon Initiative, 2011). This can be achieved through agricultural and land

management practices that are known to increase soil carbon (Hutchinson et al., 2007; Sanderman et al., 2010; Minasny et al., 2011; Minasny et al., 2012). Supporting this view, UNEP identified better management of soil carbon to restore degraded soils as one of two critical emerging issues for the global environment in its 2012 *Yearbook* (UNEP, 2012).

### Conclusions

Soil security provides the community with a conceptual framework that puts soil at the center of addressing some of the big problems that face humanity. Getting the word 'soil' back into discussions and debates about land will help. Developing the concept into a policy framework will provide a platform for emerging soil policy initiatives to address soil degradation.

The fact that science now links soil carbon with soil function, not only as a potential mechanism for climate change mitigation, but also with fundamental provision of food, fiber, water and biodiversity provides insight into a far broader set of environmental, economic and social outcomes for the planet. As the broader community realizes the critical value of the world's soil resource, this should encourage the ambition of policy makers to aim for soil security.

The question remains: can we use clear hindsight to avoid repeating the past? Following the American dust-bowl of the 1930s, Franklin D. Roosevelt famously said, 'the Nation that destroys its soil destroys itself' (Roosevelt, 1937). Eight decades later we might paraphrase his famous statement in a global context and say, 'the world that secures its soil will sustain itself'.

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**Diana H. Wall** is Soil Ecologist, University Distinguished Professor and Director of the School of Global Environmental Sustainability at CSU.

**Michael Bird** is Australian Research Council Federation Fellow with interests in the terrestrial carbon cycle and environmental change in the tropics.

**Johan Bouma**, Emeritus Professor of Soil Science, Wageningen University, The Netherlands, focuses on sustainable land use and associated policies.

**Claire Chenu**, Chair of Soil Science at UMR Bioemco, AgroParisTech, France, focuses on interactions between soil organic matter, microorganisms and soil mineral matrix.

**Cornelia Butler Flora** is the Charles F. Curtiss Distinguished Professor Emeritus of Sociology, Agriculture and Life Sciences at Iowa State University.

**Keith Goulding** is Head of the Department of Sustainable Soils and Grassland Systems at Rothamsted Research, UK.

**Sabine Grunwald's** research focuses on digital soil mapping, pedometrics, landscape analysis and carbon modeling.

**Jon Hempel** is Director of the National Soil Survey Centre, USDA, and has research interests in technology to improve soil survey information.

**Julie Jastrow** is Senior Ecologist at the Argonne National Laboratory with research interests in soil carbon dynamics and climate change.

**Johannes Lehmann**, Professor of Soil Biogeochemistry at Cornell University, received his graduate degrees in Soil Science at the University of Bayreuth, Germany.

**Klaus Lorenz**, Biologist and Agricultural Scientist, is conducting research on the sustainable use and management of soils.

**Cristine L. Morgan** is Associate Professor of Soil Science, specializing in soil hydrology, at Texas A&M University.

**Charles W. Rice**, Distinguished Professor at Kansas State University, served as President (2011) of the Soil Science Society of America and is Divisional Chair of the International Union of Soil Sciences.

**David Whitehead** leads research in the New Zealand Agricultural Greenhouse Gas Research Centre on carbon balance and soil carbon dynamics.

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