Protecting global soil resources for ecosystem services

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Abstract. 2015 is the International Year of Soils, as adopted by the United Nations, and reflects the global importance of soil resources in ecosystem sustainability. Soil is not only required for food production, but is also critical for biodiversity conservation and a broad range of ecosystem services. However, soil degradation and loss through anthropogenic activities is highly worrying and reaching a crisis point. Protecting the physical, chemical, and biological integrity of soil is, therefore, of vital importance in securing human and ecosystem health.

Key words: biodiversity; contamination; ecosystem services; food security; human nutrition; soil crisis; soil quality.

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Introduction
We are facing a global soil crisis despite the importance of soil resources to the sustainability of both human and environmental health. This is increasingly being recognized through actions such the United Nations’ (UN) designation of 2015 as the International Year of Soils. Soil is an essential part of the Earth’s Critical Zone. Water resources are cycled through soil, which is the main reservoir of global carbon stocks. It is the substrata that we build upon, it provides a leisure resource through natural and managed landscapes and their associated flora and fauna, and it is, ultimately, responsible for the Earth’s biodiversity (Montanarella and Vargas 2012).

Soil Degradation and Food Insecurity
Food security is a global grand challenge and has been fundamental in alleviating poverty in less developed countries and beyond. According to the UN Food and Agriculture Organization (FAO), food security is achieved “when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life.” Under this definition, it is clear that both quantity and quality of soil resources determine global food security.

It has been explicitly demonstrated that for most tropical and many temperate soils the relationship between crop yield and cumulative soil loss is a curvilinear and negative exponential one (Stocking 2003). Anthropogenic processes, such as climate change, intensive farming, deforestation, and urbanization, are impacting global soil resources through erosion, pollution, and exhaustion (Montanarella and Vargas 2012). Intensive plant-breeding has led to crops that are highly dependent on high inputs of fertilizers and pesticides, while much of the diversity required to cope with nutrient-limiting soil conditions has been lost due to shifts away from traditional crop landraces, which were selected over millennia for use in low-nutrient input ecosystems (Gamuyao et al. 2012). In many regions of Africa, due to limited infrastructure and cost inhibitions, there are more highly unproductive agronomic systems compared to other regions, notably those that have seen accelerated agronomic production under the Green Revolution (Diao et al. 2008, Kerr 2012). Continuous depletion of soil nutrients and lack of access to chemical fertilizers are causing food insecurity through yield declines in poverty-stricken regions, and for subsistence farmers in these regions, yield declines mean poor income, leading to a somewhat vicious cycle of poverty and food insecurity.
We are what we eat, and most of our food is ultimately from soils; therefore, “healthy soil, healthy people.” In terrestrial agronomic systems, all of our nutrient elements, with the exception of carbon and oxygen, and many contaminants, are derived from soils. Thus, our health is heavily influenced by soils’ chemical composition. It is well known that iodine deficiency can cause goiter formations. Iodine in soils is mainly derived from marine deposition and is rarely found in Xinjiang Autonomous Region of China, the most distant region on Earth from the sea. The population of Xinjiang develop goiters at a high rate and thus, iodine deficiency is a considerable health problem. Selenium deficiency is another example of the nutritional importance of soil to humans, and in certain areas of China, the prevalence of Kashin-Beck disease (Zhu et al. 2009) is a result of such a deficiency. Parallel to trace element deficiency, soil pollution is a widespread issue, not only because of mineral elements of concern (i.e., arsenic, cadmium, lead, mercury), but because soil is also the main environmental reservoir for persistent organic pollutants (POPs; i.e., dioxins, chlorinated PAHs, PCBs; Dalla Valle et al. 2005).

**Soil as the Root Source of Environmental and Resource Challenges**

In many cases, soil is both the source and sink of contaminants. In many parts of the world, overfertilization has led to the surplus of nitrogen (N) and phosphorus (P) in soils. For example, in northern China, it was reported that surpluses of N and P reach 227 and 53 kg·ha⁻¹-year⁻¹, respectively (Vitousek et al. 2009). The immediate impact of nutrient enrichment in agro-ecosystems is the damage that it imposes on the environment, as well as the economic cost. With the improvement in point source management, the addition of nonpoint sources of N and P from agricultural soils to surface water is becoming increasingly problematic, causing toxic algal blooms.

Soil also plays an essential role in attenuating pollution and mitigating climate change. Many pollutants, both organic and inorganic, are strongly bound to soil, reducing bioavailability, though there is always concern that this sequestration can be perturbed, leading to pollutant remobilization (Dalla Valle et al. 2005). Soil is also a biological reactor, in which soil biota can transform nutrients and pollutants, and this can be harnessed for remediation, such as the use of wetland ecosystem for wastewater treatment. Climate change predictions manifest themselves in a range of scenarios (Davidson and Janssens 2006). Hotter, drier climates lead to soil organic matter (SOM) mineralization, attenuate greenhouse gas build-up, and can lead to salinization in regions of intensive agricultural irrigation (Aragues et al. 2015). Colder and wetter climates are also predicted for some regions of the globe, which may lead to SOM build-up in soils and to acidification (Frank et al. 2012) and, thus, potentially impact crop productivity.

Globally, current soil nutrient management is not sustainable in terms of resource security. To support the growing global nutrient needs, input to agroecosystems is inevitable, but unfortunately the supply of mineral nutrients, such as phosphorus and potassium, are not unlimited. Taking phosphorus as an example, under the current usage rate, it has been estimated that rock phosphate will be depleted in ~50–100 years (Cordell et al. 2009). At the same time, rapid urbanization is increasingly directing the nutrient (nitrogen and phosphorus, in particular) flow into cities in the form of food, and these nutrients will eventually end up in sewage sludge, domestic waste, and reclaimed water. However, this is not the case in the agricultural society, in which nutrients are largely recycled by returning human and animal wastes back to the field. While it is unlikely we will deurbanize our societies, advances in technology and policy make the recovery of major nutrients from sewage sludge seem essential for current food security and resource security in long term.

**Soil as a Biological and Cultural Ark: Overlooked Features for Ecosystem Services**

The importance of maintaining soils’ biological properties for ecosystem services, particularly food security, has attracted wide attention in recent years. Soil is perhaps the most remarkable habitat on the Earth, harboring rich biodiversity. Commonly, 1 g of soil contains up to 1 billion bacterial cells and 200 m fungal hyphae (Roesch et al. 2007). Soil biota is responsible for the turnover of organic matter and the transformation of nutrients, such as nitrogen and sulphur, and thus is an integral part of soil quality. The role of soil biota in plant growth and, hence, productivity is now well known (Wardle et al. 2004). One typical example is the symbiotic association between plants and mycorrhizal fungi. It has been shown that increasing the diversity of mycorrhizal fungi in soil can enhance plant productivity, quite possibly through improved nutrient acquisition (van der Heijden et al. 1998). Another example of the role of soil biota in ensuring food security is biological nitrogen fixation. It has been recently estimated that 50–70 Tg N may be fixed annually by biological agents in the global agricultural system (Herridge et al. 2008). Despite the extremely high diversity of the soil microbial community, more recently it has been shown that soil microbial communities of differing composition are functionally dissimilar (Strickland et al. 2009), thus managing soil biodiversity seems even more important than previously perceived. Increasing evidence is supportive of the hypothesis that soil biodiversity and biological commu-
nity composition determine the productivity of terrestrial ecosystems and their multifunctionality (van der Heijden et al. 2008, Wagg et al. 2014).

An often overlooked aspect of soil is that it is a repository of our history, often providing the only chronological record of our prehistoric activity, as well as a record (through micro- and macrofossil analysis) of past landscapes (Meharg et al. 2003, 2006, 2012). Also, certain soils have a particular cultural resonance, as they are visible signs of ancient cultural landscapes, such as ploughed soils and abandoned ridge and furrow cultivation. Rare soils, such as serpentine or calamine, support endemic flora, and again, need preservation (Harrison et al. 2006). Erosion, particularly coastal erosion, is often a threat to soils of archaeological importance, given early man’s predilection for living at the edge of the sea (Kraft et al. 2005).

Policy Recommendations

The preeminence of soil as the basic natural resource makes soil science an indispensable discipline in safeguarding the delivery of goods and services within the Earth’s ecosystem. Ultimately, we will have to seriously rethink how we exploit our soils, nonetheless, soil is often forgotten in national and international sustainable development policies. Recently, the term soil security was developed (McBratney et al. 2014), and we think it was developed to safeguard sustainable use of soil resources for multiple ecosystem services.

1) Develop frameworks for soil capital evaluation. Far beyond its traditionally recognized role in food production, soil as a natural resource has multiple ecosystem services and is indispensable for sustainable development. We suggest that frameworks be developed to appreciate the value of soil resources for multiple ecosystem services.

2) Map global soil resources. Alongside soil type, the resources that those soils provide should be considered, as well as their natural and historical cultural resource. This has, to some extent, been conducted in certain regions, such as Europe (Panagos et al. 2012). Provision of digitized global soil maps is a considerable challenge, but one we feel is worth making.

3) Improve nutrient efficiency. Soil nutrient depletion has a direct impact on food security, while excess use of nutrients in intensive farming systems is not only causing nutrient inefficiency but also environmental pollution. Therefore, future efforts should be directed at improved nutrient management for soil–crop–environment interactions in the food production system. An example of forward thinking was the discovery of PSTOL1, a rice gene that allows high yields on phosphorus-limited soils due to its ability to maintain a large root system (Gamuyao et al. 2012). Additionally, precision farming practices and coordinated governance are important considerations.

4) Develop frameworks for the management of contaminated sites. Policies for risk assessment and remediation of contaminated sites should be developed to improve the ecosystem services of soils in the rapidly urbanized world.

5) Forge cross-cutting collaboration. Sustainable soil management requires scientific inputs from multiple disciplines ranging from agronomy, biogeochemistry, and environmental science to engineering and economic science. Global funding agencies should set agendas to support research endeavors with a cross-cutting nature, so that systems solution can be developed to safeguard sustainable use of soil resources.

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