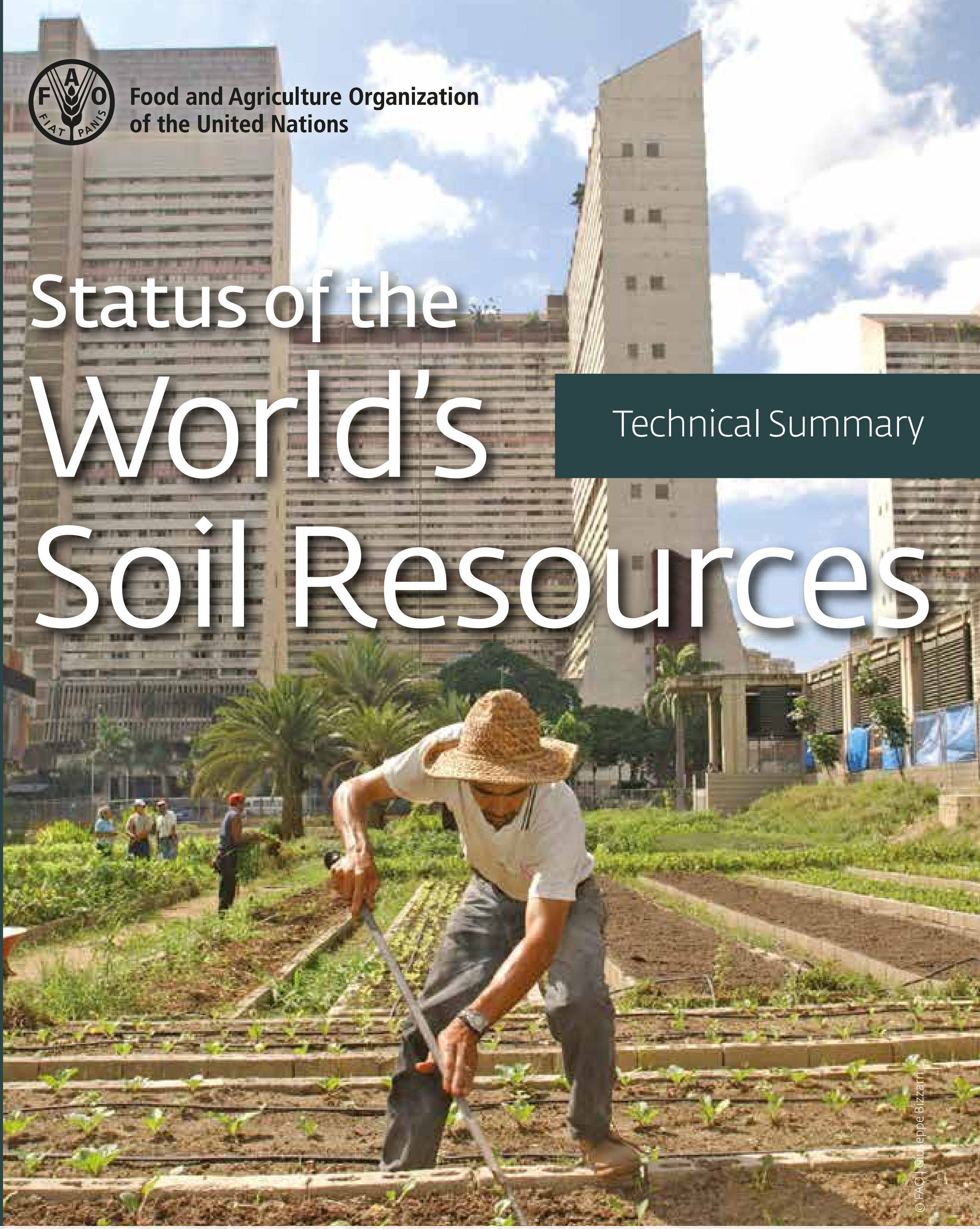
Food and Agriculture Organization
of the United Nations

Status of the World's Soil Resources

Technical Summary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GLOBAL SOIL PARTNERSHIP

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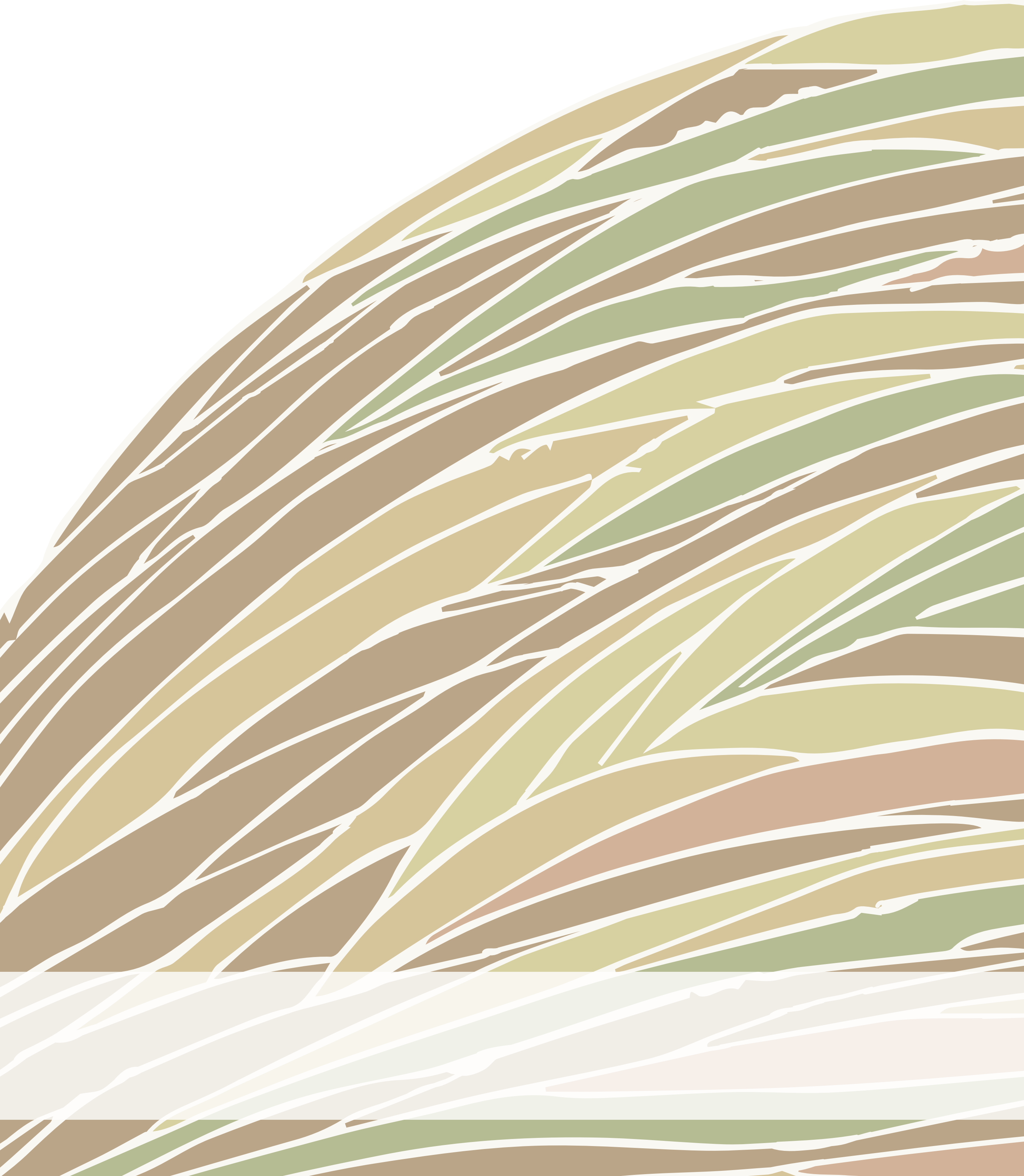
INTERGOVERNMENTAL TECHNICAL PANEL ON SOILS

2015
International Year of Soils

Status of the World's Soil Resources | Technical Summary



Status of the World's Soil Resources
Technical Summary

Prepared by the
Intergovernmental Technical Panel on Soils

Luca Montanarella (Chair)
Dan Pennock (Lead Author)
Neil McKenzie (Lead Author)

Seyed Kazem Alavipanah
Julio Alegre
Abdullah AlShankiti
Dominique Arrouays
Milkha Singh Aulakh
Mohamed Badraoui
Isaurinda Baptista
Helaina Black
Marta Camps Arbestain
Victor Chude
Elsiddig A.E. El Sheikh
David Espinosa Victoria
Jon Hempel
Carlos Roberto Henriquez
Suk Young Hong
Pavel Krasilnikov
Tekalign Mamo
Maria de Lourdes Mendonça-Santos
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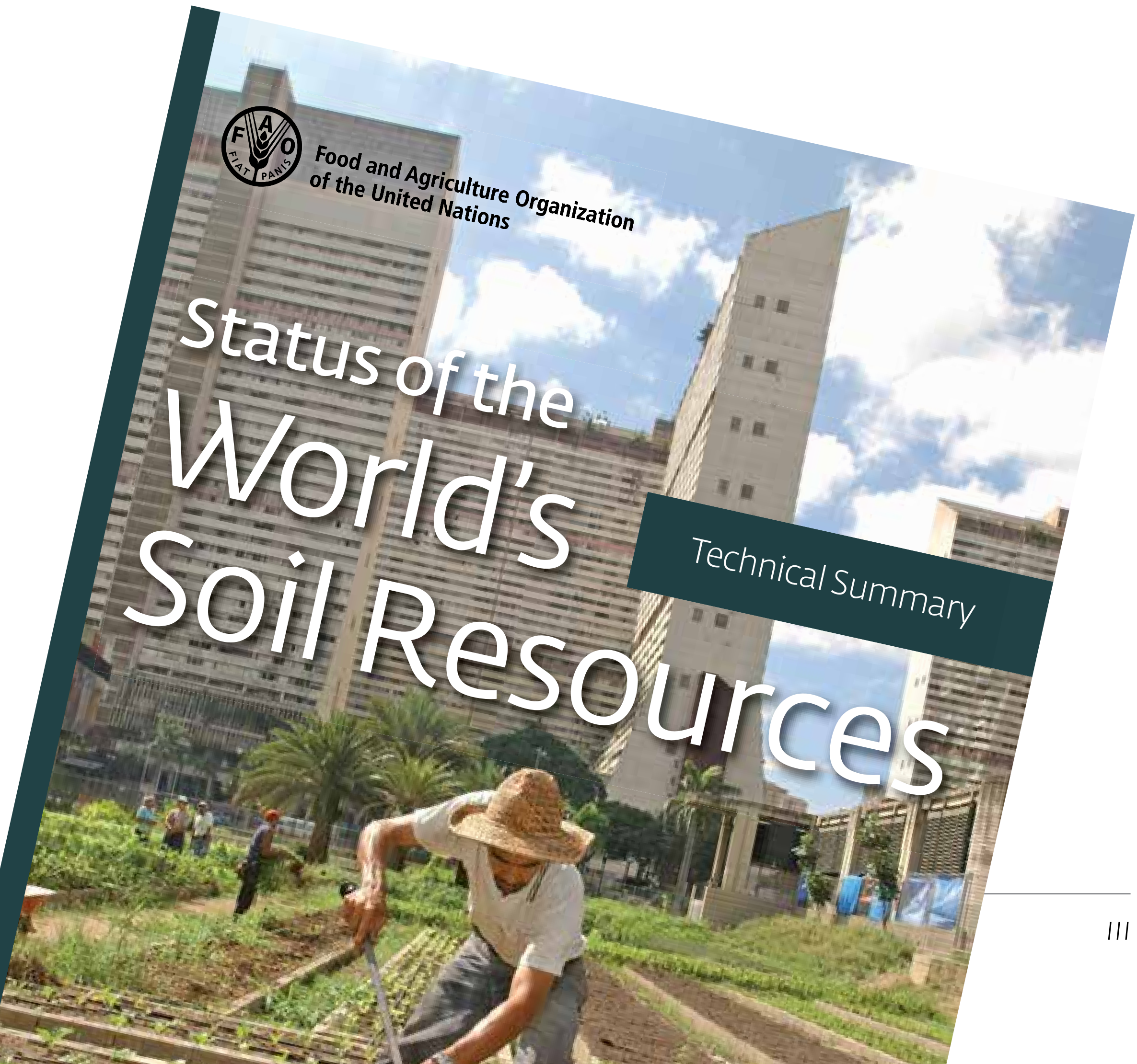
Appreciation is expressed to many Governments who have supported the participation of their resident scientists in this major enterprise. In particular, our gratitude to the European Commission who financially supported the development and publication of this report.



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Foreword

This document presents the first major global assessment ever on soils and related issues.

Why was such an assessment not carried out before? We have taken soils for granted for a long time. Nevertheless, soils are the foundation of food production and food security, supplying plants with nutrients, water, and support for their roots. Soils function as Earth's largest water filter and storage tank; they contain more carbon than all above-ground vegetation, hence regulating emissions of carbon dioxide and other greenhouse gases; and they host a tremendous diversity of organisms of key importance to ecosystem processes.

However, we have been witnessing a reversal in attitudes, especially in light of serious concerns expressed by soil practitioners in all regions about the severe threats to this natural resource. In this more auspicious context, when the international community is fully recognizing the need for concerted action , the Intergovernmental Technical Panel on Soils (ITPS), the main scientific advisory body to the Global Soil Partnership (GSP) hosted by the Food and Agriculture Organization of the United Nations (FAO), took the initiative to prepare this much needed assessment.

The issuance of this first "Status of the World's Soil Resources" report was most appropriately timed with the occasion of the International Year of Soils (2015) declared by the General Assembly of the United Nations. It was made possible by the commitment and contributions of hosts of reputed soil scientists and their institutions. Our gratitude goes to the Lead Authors, Contributing Authors, Editors and Reviewers who have participated in this effort, and in particular to the Chairperson of the ITPS, for his dedicated guidance and close follow up.

Many governments have supported the participation of their resident scientists in the process and contributed resources, thus also assuring the participation of experts from developing countries and countries with economies in transition. In addition, a Technical Summary was acknowledged by representatives of governments assembled in the Plenary Assembly of the GSP, signaling their appreciation of the many potential uses of the underlying report. Even more comprehensive and inclusive arrangements will be sought in the preparations of further, updated versions.

The report is aimed at scientists, laymen and policy makers alike. It provides in particular an essential benchmark against periodical assessment and reporting of soil functions and overall soil health at global and regional levels. This is of particular relevance to the Sustainable Development Goals (SDGs) that the international community pledged to achieve. Indeed, these goals can only be achieved if the crucial natural resources – of which soils is one – are sustainably managed.

The main message of this first edition is that, while there is cause for optimism in some regions, the majority of the world's soil resources are in only fair, poor or very poor condition. Today, 33 percent of land is moderately to highly degraded due to the erosion, salinization, compaction, acidification and chemical pollution of soils. Further loss of productive soils would severely damage food production and food security, amplify food-price volatility, and potentially plunge millions of people into hunger and poverty. But the report also offers evidence that this loss of soil resources and functions can be avoided. Sustainable soil management, using scientific and local knowledge and evidence-based, proven approaches and technologies, can increase nutritious food supply, provide a valuable lever for climate regulation and safeguarding ecosystem services.

We can expect that the extensive analytical contents of this report will greatly assist in galvanizing action at all levels towards sustainable soil management, also in line with the recommendations contained in the updated World Soil Charter and as a firm contribution to achieve the Sustainable Development Goals.

We are proud to make this very first edition of the Status of the World's Soil Resources report available for the international community, and reiterate once again our commitment to a world free of poverty, hunger and malnutrition.

JOSÉ GRAZIANO DA SILVA
FAO Director-General

Soils are fundamental to life on earth

The goal of the Intergovernmental Technical Panel on Soils (ITPS) in this first Status of the World's Soil Resources report is to make clear the essential connections between human well-being and the soil. The report provides a benchmark against which our collective progress to conserve this essential resource can be measured.

The report synthesizes the work of some 200 soil scientists from 60 countries. It 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 considered in the report are soil erosion, compaction, acidification, contamination, sealing, salinization, waterlogging, nutrient imbalance (e.g. both nutrient deficiency and nutrient excess), and losses of soil organic carbon (SOC) and of biodiversity.

While there is cause for optimism in some regions, the overwhelming conclusion from the report is that the majority of the world's soil resources are in only fair, poor or very poor condition. The most significant threats to soil function at the global scale are soil erosion, loss of SOC, and nutrient imbalance. The current outlook is for the situation to worsen unless concerted actions are taken by individuals, the private sector, governments and international organizations.

Overall the Intergovernmental Technical Panel on Soils believes the following four actions are the greatest priorities:

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.

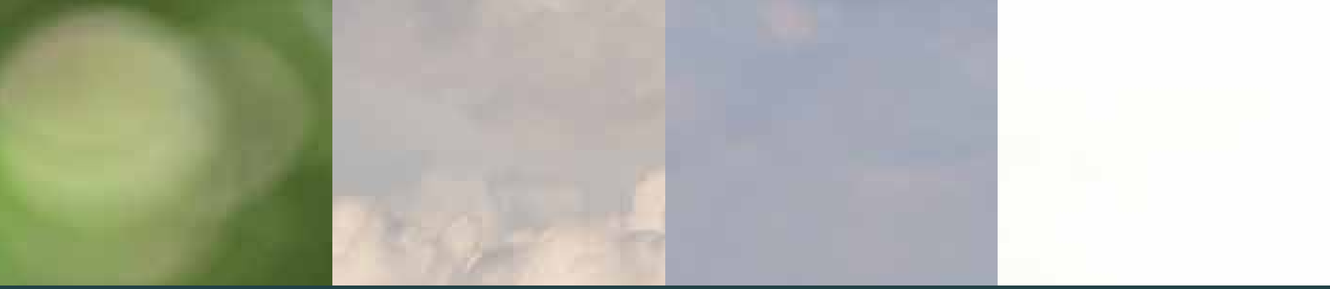
2. The global stores of soil organic matter (e.g. SOC and soil organisms) should be stabilized or increased. Each nation should identify locally appropriate SOC-improving management practices and facilitate their implementation. They should also work towards a national-level goal of achieving a stable 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 nitrogen (N) and phosphorous (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 this 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 in the condition of soil. An initial emphasis should be on improving observation systems to monitor our progress in achieving the three priorities outlined above.

We recognize that the societal responses required to address these priorities are complex and many-faceted. The implementation of soil management decisions is typically made locally and occurs within widely differing socio-economic contexts. The development of specific measures appropriate for adoption by local decision-makers requires multi-level, interdisciplinary initiatives by many stakeholders.

We hope the production of this first Status of the World's Soil Resources report in 2015, the International Year of Soils, will galvanize our collective efforts to achieve global adoption of sustainable soil management.



Technical Summary
Status of the World's Soil Resources

Introduction

Soils are fundamental to life on Earth but human pressures on soil resources are reaching critical limits. Further loss of productive soils will amplify food-price volatility and potentially send millions of people into poverty. This loss is avoidable. Careful soil management can increase the food supply, and provides a valuable lever for climate regulation and a pathway for safeguarding ecosystem services.

Achieving sustainable management of soil resources will generate large benefits for all communities and nations. In some parts of the world it will be a key to economic prosperity and in others it will even be important for their national security in the short to medium-term. Whatever the context, effective policy based on sound evidence is essential for a good outcome.

The consideration of soil in policy formulation has been weak in most parts of the world. Reasons include the following:

- lack of ready access to the evidence needed for policy action
- the challenge of dealing with property rights for a natural resource that is often privately owned and at the same time an important public good
- the long-time scales involved in soil change – some of the most important changes take place over decades and they can be difficult to detect. As a result, communities and institutions may not respond until critical and irreversible thresholds have been exceeded.

Perhaps even more significant for policy makers is the disconnection between our increasingly urbanized human societies and the soil. The proportion of human labor devoted to working the soil has steadily decreased through the past century, and hence the experience of direct contact with the soil has lessened in most regions. Soil is very different in this regard than food, energy, water and air, to which each of us requires constant and secure access. Yet human society as a whole depends more than ever before on products from the soil as well as on the more intangible services it provides for maintenance of the biosphere.

Our goal in the Status of the World's Soil Resources report is to make clear these essential connections between human well-being and the soil, and to provide a benchmark against which our collective progress to conserve this essential resource can be measured.

This report provides a summary of the major findings of the full report. References are made to the main report in the form of footnotes. For reasons of readability the text from the main report is not always quoted as per original text. The report does not presume to be prescriptive. Instead, it aims to provide the necessary global context and a preliminary structure for developing enduring and effective policy responses at the national and regional level.

Sustainable soil management (SSM) is a key foundational concept of this report. The definition of SSM used through this document is drawn directly from the 2015 World Soil Charter:

> *Soil management is sustainable if the supporting, provisioning, regulating, and cultural services provided by soil are maintained or enhanced without significantly impairing either the soil functions that enable those services or biodiversity.*

This report focuses on ten threats to soil functions: soil erosion, SOC loss, nutrient imbalance, soil acidification, soil contamination, waterlogging, soil compaction, soil sealing, salinization, and loss of soil biodiversity.

Nutrient imbalance occurs when inputs of nutrients (through additions of chemical and organic fertilizers or other sources are either a) insufficient to allow crops to achieve their development and yields or b) in excess of the nutrients exported during the harvest of the crops. Nutrient insufficiency contributes to food insecurity. Nutrient excess is a major contributor to water quality deterioration and to greenhouse gas emissions (especially nitrous oxide (N_2O)) to the atmosphere from agricultural sources.

Soil acidification is the lowering of soil pH due to the buildup of hydrogen and aluminium ions in the soil, and the associated loss of base cations such as calcium, magnesium, potassium and sodium from the soil due to leaching or product removal.

Soil biodiversity loss is a decline in the diversity of micro- and macro-organisms present in the soil.

Soil compaction is the increase in density and a decline of macro-porosity in a soil that results from pressure being applied at the soil surface. Compaction impairs the functions of both the top- and subsoil, and impedes roots penetration and water and gaseous exchanges.

Soil contamination is the addition of chemicals or materials to soil that have a significant adverse effect on any organism or on soil functions. A contaminant can be defined as any chemical or material out of place or present at higher than normal concentrations.

Soil erosion is the removal of soil from the land surface by water, wind or tillage. Water erosion occurs mainly when overland flow transports soil particles detached by drop impact or runoff, often leading to clearly defined channels such as rills or gullies. Wind erosion occurs when dry, loose, bare soil is subjected to strong winds and soil particles are detached from the soil surface and transported elsewhere. Tillage erosion is the direct down-slope movement of soil by tillage implements and results in soil redistribution within a field. Erosion is a natural process but the rate of erosion is typically greatly increased (or accelerated) by human activity.

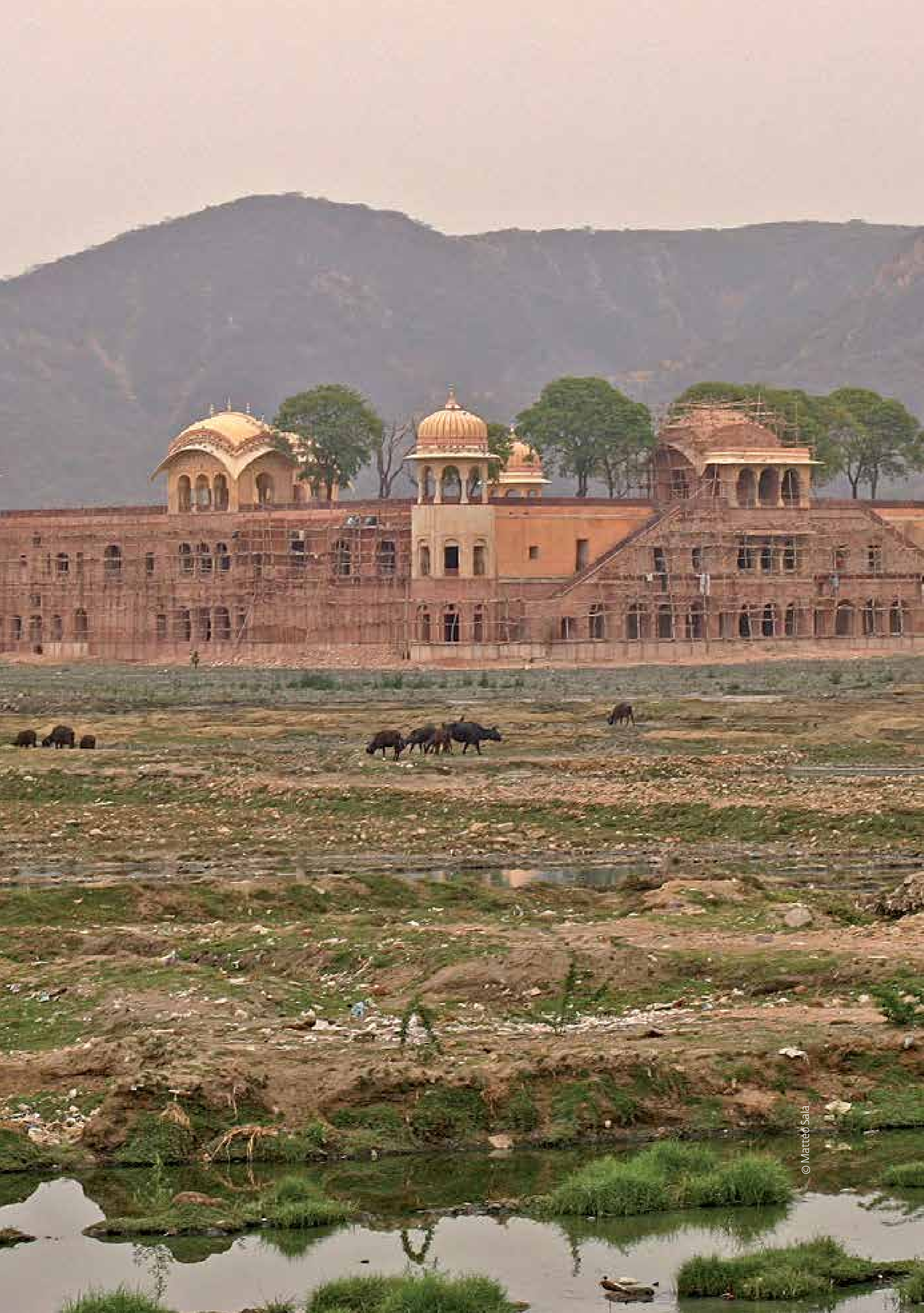
Soil organic carbon (SOC) loss is the loss of organic carbon stored in the soil; it occurs primarily due to the conversion of soil carbon to carbon dioxide (CO_2) or methane (CH_4), both of which are greenhouse gases, and to the physical loss of carbon from the soil by erosion.

Soil salinization is the accumulation of salts in the soil. The accumulated salts include sodium, potassium, magnesium and calcium, chloride, sulphate, carbonate and bicarbonate. Primary or natural salinization involves accumulation of salts through natural processes due to high salt contents in parent materials, groundwater, or long-term accumulation of salts contained in rainfall. Secondary or human-induced salinization is caused by human interventions such as inappropriate irrigation practices, e.g. with salt-rich irrigation water and/or insufficient drainage. Only human-induced salinization is considered as a threat to soil functions in this report. Sodification can be associated with salinization, and is the accumulation of sodium and/or sodium salts in the solid and/or liquid phases of the soil. Result of the sodification process is the high ratio of exchangeable sodium within the total exchangeable bases.

Soil sealing is the permanent covering of an area of land and its soil by impermeable artificial material (e.g. asphalt and concrete): for example through buildings and roads. **Land take** is the increase of the area of settlements over time. It includes the development of scattered settlements in rural areas, the expansion of urban areas around an urban nucleus, the conversion of land within an urban area (densification), as well as the expansion of transport infrastructures, such as roads, highways and railways.

Soil waterlogging is when the soil is too wet that there is insufficient oxygen in the pore space for plant roots to be able to adequately respire. Other gases detrimental to root growth, such as carbon dioxide and ethylene, also accumulate in the root zone and affect the plants. Many soils are naturally waterlogged, and it is only considered to be threat when soils that were previously aerobic (e.g. with adequate oxygen in the pore space) become waterlogged.

For the purposes of this summary report individual ecosystem services (e.g. water quality regulation, nutrient cycling) are bundled into larger issues so that the fundamental connection between soils and the broader challenges facing humanity can be more made clear. After a brief summary of the major drivers, we look at the issues of food security, climate change, water, human health, and the conservation of biodiversity. In each section we draw upon the regional assessments in the main report to summarize the major trends in soil condition. Summaries of each regional assessment are presented in section 10, followed by a section summarizing policy pathways to improve soil governance. The regional summaries were developed by ITPS members and other leading soil scientists from each region, and summarize the state and trend of the soil threats in each region. The summary concludes with a series of actions by different actors that are required to achieve the adoption of sustainable soil management as specified in the World Soil Charter.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Drivers of global soil change

The primary global drivers of soil change are population growth and economic growth. While economic growth may eventually be decoupled from increases in consumption of resources and generation of waste, it will continue to be a strong driver of soil change for the next few decades at least. Related and important factors in soil change such as education, cultural values, civil strife, the effectiveness of markets and the wealth or poverty of the land users are discussed in the main report.

The 20th century has witnessed extraordinary population and economic growth and an associated revolution in agriculture. Between 1961 and 2000, global population grew by 98 percent but food production rose by 146 percent and per capita food production increased by 24 percent. Crop yields have more than doubled and quite remarkably, the area of arable land in use only increased by eight percent. Arable land per capita reduced substantially (0.45 to 0.25 ha). The key to this period was the dramatic increase in agricultural inputs and advances in crop breeding. The use of nitrogen fertilizer increased by a factor of seven, phosphorus fertilizer by a factor of three and irrigation water by a factor of two.

The world population of 7.2 billion in mid-2013 is projected to increase by almost one billion by 2025. It is expected to reach 9.6 billion in 2050 and 10.9 billion in 2100. Most of this growth will occur in low-income countries. Many of these countries (e.g. in West Africa) have infertile soils and low levels of agricultural productivity.[1]

Estimates of global food demand based on these population forecasts and on expected dietary shifts indicate that production in 2050 will need to increase by 40-70 percent compared to 2010.[2]

However, 20th century strategies that simply increase agricultural inputs are problematic because of the implications for global emissions of greenhouse gases, increasing scarcity of inputs and limited availability of cheap water.

The global population is also becoming increasingly urbanized. One consequence is widespread urban encroachment onto good quality agricultural land. The rate of soil sealing (e.g. the permanent covering of the soil surface with impermeable artificial materials such as asphalt and concrete, typically related to urban development and infrastructure construction) is a now a serious global problem. According to the United Nations, 54 percent of the global population resided in urban areas in 2014. Moreover, all regions are expected to further urbanize and by 2050, 66 percent of the world's population is projected to be urban.[3]

Climate change is a further strong driver of soil change through its current and anticipated effects on land use and management. The impact of climate change on soil functioning is the largest source of uncertainty in any projections of the trends in key ecosystem services provided by the soil. Climate change will have significant impacts on soil resources. For instance the change in water availability due to changes of quantity and pattern of precipitation and higher temperatures which entail a higher evaporative demand will influence the rate of actual evaporation, groundwater recharge, and the generation of runoff according to local conditions. Warming-induced changes in soil temperature and moisture regimes may increase the SOC decomposition rate and the acceleration of the risks of erosion and desertification can have a reinforcing feedback on climate change. A rising sea level associated with climate change will increase coastal erosion and shoreline retreat. In coastal lowlands that are insufficiently defended by sediment supply or embankments, tidal flooding by saline water will tend to penetrate further inland than at present, extending the area of perennially or seasonally saline soils.[4]

3

Soils and food security

There is general consensus on soil-related strategies for increasing the supply of food while minimizing harmful environmental impacts.

The first strategy is to avoid productivity losses due to soil degradation and restore productivity to soils that have previously experienced productivity losses. Reduction in future productivity losses due to degradation are essential to maintain the current area used for crop production and hence avoid inappropriate land use conversions.

The greatest obstacle to improving soil functions and other ecosystem services in many degraded landscapes is the lack of nutrients and organic inputs. Even if the inputs are available, the restoration of productivity on degraded soils can be difficult because soils may have been degraded to the point where they cannot readily respond to fertility-improving management techniques.

The second strategy, closing the yield gap, holds much promise. The yield gap is the difference between crop yields observed at any given location and the potential yield of the crop at the same location if best agricultural practices and technologies were applied. The yield gap is the greatest in Central America, much of West and East Africa, and Eastern Europe, due primarily to nutrient limitations. Smaller pockets of nutrient limitation also exist in Northern India and throughout China, although larger areas experience nutrient excess in these two countries.[5]

The third strategy is to ensure soil use and management maintains or enhances stocks of soil carbon and the biodiversity pool. For example, this requires promoting sustainable agriculture and land management practices in all regions, halting, where possible agricultural expansion in target sensitive biomass (e.g. clearing of forests and woodlands, conversion of pasture to cropland, or


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drainage of wetlands) because of the environmental harm due to release of carbon and the impact on biodiversity. Likewise, the sealing of agriculturally productive soils must be controlled.

The fourth strategy involves increasing the efficiency with which agricultural inputs such as irrigation, fertilizers and pesticides are used in farming systems. This strategy reduces the environmental and human-health impact of high-input agricultural systems rather than increasing the food supply directly, but also increases the economic return to producers from application of these inputs.[6] Many of the major soil threats examined in the report have implications for the provision of food and are briefly summarized in the remainder of section 3.

Soil erosion

A synthesis of meta-analyses on the soil erosion-productivity relationship suggests that a global median loss of 0.3 percent of annual crop yield due to erosion occurs.[7] If this rate of loss continues unchanged into the future, a total reduction of 10 percent of potential annual yield by 2050 would occur. This yield loss due to erosion would be equivalent to the removal of 150 M ha from crop production or 4.5 M ha yr^{-1} (e.g. approximately one football field (soccer pitch) every five seconds).[8]

Overall there are major differences in the condition and trend for soil erosion in the different regions. Parts of Europe, North America, and the Southwest Pacific generally show an improving trend, although this follows many decades of significant soil loss due to erosion associated with agricultural expansion. Sub-Saharan Africa has a variable trend in erosion, whereas Asia, Latin America and the Caribbean, and the Near East and North Africa have poor or very poor erosion conditions and a deteriorating trend. In the latter region wind erosion is the major cause of the very poor soil conditions and trend.

While rates of soil erosion are still far too high on extensive areas of cropland and rangeland, erosion rates have been significantly reduced in several areas in the world over the last decades. The best-documented example is the reduction of erosion rates on cropland in the United States. Average water erosion rates on cropland were reduced from 10.8 to 7.4 tonnes ha^{-1} yr^{-1} between 1982 and 2007, while wind erosion rates reduced from 8.9 to 6.2 tonnes ha^{-1} yr^{-1} over the same time span.[9] Although less well documented, significant decreases in erosion occur wherever minimum tillage has been adopted, such as in large areas in Latin America.

Nutrient imbalance

Infertile soils and the undersupply of nutrients to crops in some regions is a major contributor to the yield gap. As outlined above, several recent studies and the regional assessments prepared for this report indicate that the yield gap is greatest in Latin America, much of West and East Africa, and Eastern Europe.

The soil-nutrient balance can be assessed through a mass-balance of nutrient inputs, outputs and changes in stores in the soil.[10] A negative balance indicates mining of nutrients from the soil. A 2010 meta-analysis of 57 studies in Africa found that N budgets were largely negative and P budgets were negative in 56 percent of the studies.[11] In Asia both strongly positive and strongly negative balances have been reported.[12]

Many studies emphasize the inability of mineral fertilizers alone to significantly increase food production in regions where the yield gap is the greatest unless significant inputs of organic material through crop residues or manures also occur. Removing the nutrient limitations through additions of mineral fertilizers alone will also exacerbate the range of environmental issues (e.g. N_2O emission from N-fertilizer, surface and groundwater contamination) in all food-producing regions unless the efficiency of agricultural inputs can be increased.[13]

Recent analyses suggest that globally higher annual additions of N in agricultural systems cannot occur without causing significant environmental harm, and that additions of P exceed safe boundaries in several major agricultural regions. In these regions, improvements in nutrient-use efficiency are essential and they should lead to substantial reductions in the use of agricultural inputs. In contrast, regions with strongly negative nutrient balances and large yield gaps require increases in inputs and a similar focus on nutrient-use efficiency. This task is especially difficult in low-income countries where subsistence farmers are unable to afford inputs to improve the fertility of their impoverished soils.[14]

Soil carbon and biodiversity losses

Soil organic carbon (SOC) and soil biodiversity are commonly linked to three dimensions of food security: increases in food availability, restoration of productivity in degraded soils, and the resilience of food production systems.

The roles of SOC and soil biodiversity in increasing food availability are inextricably bound together – increases in SOC and biodiversity are generally beneficial for crop production, and decreases in both are equally deleterious for crops; however providing evidence for these qualitative statements and establishing predictive relationships has been difficult because crop growth is dependent on a suite of interacting factors.

Research in tropical and semi-tropical lands has established that inputs of organic material through the return of residues and external sources of organic material such as manure and compost to the soil are essential for fertility restoration in degraded soils, but that low residue production and competing uses for residues and manure limit the adoption of these SOC-increasing approaches.[15] Achieving an increase in carbon stocks without an external source of nutrients is extremely difficult in soils that are strongly weathered and naturally infertile.

A final role for SOC enhancement and maintenance of soil biodiversity is to increase the resilience of the soil for food production, especially its ability to withstand disruption due to human-induced climate change. The soil organic carbon buffers the impact of climate extremes on soils and crops by (i) regulating water supply to plants, (ii) reducing erosion through runoff decrease, and (iii) providing sites for nutrient retention and release.

Land take and soil sealing

Land take affects food security because in most countries it preferentially affects agricultural lands. For example, 70.8 percent of the land take in the European Union between 1990 and 2000 consumed agricultural land. This decreased to 53.5 percent between 2000 and 2006. The impact was estimated to be equivalent to a loss of more than 6 million tonnes of wheat over the complete period (p. 170, main report) which equates to a loss of 1 percent of potential production capacity. While this may appear to be a marginal loss, the global effect of such losses in different regions simply makes the task of increasing food production by approximately 70 percent by 2050 that much more difficult.

Land take and soil sealing are regarded as the greatest threat to soil functions in Europe and Eurasia. Urbanization of the population is, however, increasing in every region, and hence the trend in each region is deteriorating. A 2009 analysis found that in 2000 the extent of urban areas globally was 657,000 km^2, equivalent to 0.45 percent of the Earth's surface. At the current rates of urbanization, loss due to soil sealing may double in the next 20 years and even triple in developing countries by 2030.[16] Appropriate mitigation measures can be taken in order to maintain some soil functions and to reduce negative effects on the environment and human well-being.

Soil acidification, contamination and salinization

These three threats all lead to changes in the chemistry of the soil that can, once specific thresholds are passed, lead to significant decreases in crop yields.

Naturally acidified soils are common in well-drained areas where precipitation exceeds evapotranspiration and causes the loss of base cations from the soil profile. Human-induced acidification of agricultural soils is primarily associated with product removal or increases of nitrogen (N) and sulfur (S) inputs (e.g. legume pastures, fertilizer inputs, atmospheric deposition). Soils with low pH-buffering capacity are most prevalent when they have a low content of weatherable minerals (e.g. ancient, strongly weathered soils, soils developed from quartz-rich parent materials).[17] Acidification is a significant threat to crop yields in countries such as Australia and in areas of South America, Southeast Asia and Sub-Saharan Africa.[18]

Soil contamination occurs from a wide range of causes. In regions with mature industrial sectors and a well-developed regulatory framework such as Europe, North America, and parts of the Southwest Pacific, the primary issue is the identification and remediation of legacy sites of contamination. Rapidly industrializing countries continue to experience significant new levels of contamination. For example in China 19.4 percent of farmland has been estimated by the Ministry of Environmental Protection to be contaminated with cadmium, nickel, and arsenic.[19]

The contamination pathways may involve atmospheric deposition, herbicide and pesticide application and heavy metals in fertilizers and in land-based applications of waste. Contamination is examined in more detail in Section 6.1 of this Summary Report.

Salinization is a consequence of both natural (primary) and human-induced (secondary) processes. Despite the extent and severity of the problem, no accurate and recent statistics are available on the global extent of salt-affected soils.[20] Salinization reduces crop yields and, above certain thresholds, completely eliminates crop production.

The largest cause of human-made salinization are ill-designed, large-scale irrigation projects. Already, irrigation of agricultural lands accounts for about 70 percent of ground and surface water withdrawals, and in some regions competition for water resources is forcing irrigators to extract water at unsustainable rates. The removal of surface or groundwater for irrigation disrupts the natural water cycle and may stress downstream ecosystems and communities. Water-use efficiency in irrigated systems can be improved through management practices that reduce system losses (e.g. leaking supply systems), evaporation from the soil and the infrastructure itself. Irrigation can potentially increase soil salinity in dry regions with high salt content in the subsoil. Where salinization occurs, additional irrigation is needed to move the salts beyond the root zone of the crops, which can further exacerbate water stress, particularly when using groundwater.[21]

The increasing scarcity of water for irrigation along with the technical challenges of building sustainable systems are significant constraints on the expansion of conventional irrigation schemes. However, there is significant potential in Africa for the development of local-scale distributed irrigation systems that rely primarily on near-surface groundwater that is replenished annually.

Soil compaction and waterlogging

Both of these threats create rooting problems for plants, thereby reducing yields. The oxygen-depleted conditions associated with waterlogging can also cause contaminants such as arsenic to become mobile in the soil, and a range of environmental problems arise from this change in the mobility of toxic elements.

The regional assessments show that compaction is common and deteriorating in Asia, Latin America and the Caribbean, and the Near East and North Africa regions, and in fair or good condition in the remaining four regions. Overgrazing and the spread of mechanized agriculture into regions such as Asia and Latin America and the Caribbean are cited as major contributing factors.

Chronic waterlogging is not considered to be a major threat in any of the regions. However, the related but separate issue of flooding is a major issue in several regions.

Sustainable soil management

The general principles of sustainable soil management to support increased food security are, for the most part, well understood. A number of soil threats can be simultaneously addressed by adopting specific management practices. The practices of greatest relevance to soils are:

1. enhanced plant nutrition through balanced measures that include crop rotations with N-fixing crops, judicious use of organic and inorganic fertilizers, and targeted amendments such as lime to address specific soil chemical conditions such as high acidity,
2. minimize soil disturbance by avoiding mechanical tillage through adoption of conservation tillage and no-till systems, and
3. enhance and maintain a protective organic cover on the soil surface using cover crops and crop residues.

These management practices are highly interlinked and all, in the long term, will minimize specific soil threats such as soil erosion by wind, water, and tillage, SOC loss (and hence reduce soil CO_2 emissions to the atmosphere), and soil compaction and physical deterioration; it also seems likely that these measures would reduce the loss of biodiversity from the soil. The judicious use of N fertilizer would also minimize, as far as possible, N_2O emissions from the soil. The reduction to these threats will in turn improve the supporting services offered by the soil and hence the regulating, provisioning, and cultural services that rely on these supporting services.

4

Soils and water

The quantities of freshwater moving into, through and out of the soil each year are truly vast. It is estimated that the total annual precipitation onto land masses is 116 500±5 100 $km^3 yr^{-1}$ – equivalent to approximately five-times the water stored in the Great Lakes of North America. Sixty percent of this (70 600±5 000 $km^3 yr^{-1}$) returns to the atmosphere through evapotranspiration. The remaining 40 percent (45 900±4 400 $km^3 yr^{-1}$) leaves the continents as runoff, with the greatest proportion either running off the surface of the soil or returning to streams via the groundwater flow system after passing through the soil.[23]

Water erosion, regulation of surface water quality, and the health of aquatic systems

Water that fails to infiltrate and hence runs off the soil surface is the agent for water erosion of soil and for transport of soluble soil components including contaminants.

Soil that is eroded from fields and reaches surface waterways has major negative effects on water quality. Soil erosion by water worldwide is estimated to transport 23 to 42 million tonnes of N and 15 to 26 million tonnes of P off agricultural land. These fluxes may be compared to annual fertilizer application rates, which are approximately 112 million tonnes for N and 18 million tonnes of P.[23] These nutrient losses need to be replaced through fertilization at a significant economic cost of US$ 33 to US$ 60 billion for N and 77 to US$ 140 billion for P.[24] The fraction of sediment and nutrients lost from agricultural land that reaches surface waterways varies greatly depending on catchment characteristics but in many regions it is large enough to cause widespread eutrophication. The waterbodies affected range from small wetlands embedded in agricultural landscapes through to the vast hypoxia or dead zones in near-shore marine areas.

The negative environmental effects of nutrient transport to water bodies by water erosion are the greatest in areas where excess nutrient applications in agriculture and high levels of water erosion[25] occur together. The regional assessments of soil threats indicate this correspondence of high erosion-high excess nutrient imbalance occurs in the upper Mid-West and Mississippi valley regions of the United States, southern Ontario in Canada, areas in northern Europe, a broad area in northern India, and several regions in China. In the regional assessments for North America and for Asia the condition for nutrient imbalance is poor and the trend is deteriorating, indicating the gravity of the situation and the need for better soil and nutrient management.

Soil eroded from agricultural landscapes also contributes to sedimentation in lakes and reservoirs, shortening their effective life. The linkage between current soil erosion and sedimentation in floodplains and reservoirs is often, however, complex: the deposition of sediments and nutrients in large floodplains is not directly coupled to actual agricultural soil erosion, as in most cases sediments are provided by other sources (natural erosion, landslides) and the residence time of such sediments in large river systems is several thousands of years.

Filtering and transformation of contaminants and groundwater quality

Soils have a considerable capacity to remove contaminants from water within the soil. This is most evident for charged metal and organic compounds. One mechanism that prevents contaminants from reaching groundwater is strong absorption of contaminants by soils at the land surface. This absorption is greatest for soils that have a large surface area and a high density of charged surfaces such as organic matter and clay. There is also considerable evidence for microbial transformation of contaminants in the soil into non-toxic forms. Water content and transmission times within the soil are important to the filtering function of soil because contact with soil surfaces and residence time in soil are important controls on contaminant absorption.

Regulation of water quantity and floods

The permeability and water storage capacity of soils have a major influence on the capacity of a landscape to act as a buffer. If the soil can absorb precipitation during high intensity rainfalls, then peak flows and flooding in streams will be less. Likewise, if the soil can store water and retain it during dry periods, then plants are buffered against short periods of rainfall deficit.

The influence of poor soil and land management on rainfall-runoff relationships is widely recognized and often implicated as a factor that increases peak flows and the damage caused by floods. However, reliable estimates of the costs and benefits of soil management for flood regulation are not available at a regional or global scale. A major impact of soil sealing (where the natural soil is covered with an impervious surface) is the large increase in runoff and this becomes critical in landscapes where a significant proportion of the land surface is affected (e.g. Europe and Eurasia).

Flood forecasting systems require reliable estimates of soil-water contents across watersheds. However, more precise information on land management changes and soil conditions is needed to improve these emergency forecasting systems which operate on time scales of hours to days. At longer times scales (weeks to months), forecasts of the soil water balance are being used to produce seasonal outlooks for agriculture, particularly in districts with inter-annual fluctuations and where management decisions (e.g. choice of crop varieties or rates of fertilizer application) are strongly influenced by climatic conditions. Improving the efficacy of these systems will be important for improving the efficiency of nutrient and water use in agriculture.

5

Soils and climate regulation

Soils play a major role in global climate processes through their regulation of carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) emissions. The specific soil functions that regulate these emissions are complex, and interact strongly with ecosystem processes such as water supply regulation and nutrient cycling.

Soil organic carbon loss

At the global scale, soils are the major terrestrial reservoir of carbon and therefore have a major influence on the concentration of carbon dioxide (CO_2) in the atmosphere. Global estimates of SOC stocks have been published for many decades. The estimate of 1 502 billion tonnes of SOC for the first meter of soil was adopted by the Intergovernmental Panel on Climate Change (IPCC). Current global estimates derived from the Harmonized World Soil Database (HWSD) suggest that approximately 1 417 billion tonnes of SOC are stored in the first meter of soil and about 716 billion tonnes of SOC in the top 30 cm.

Globally the primary driver of SOC loss from soil is land use change. A 2014 meta-analysis of 119 publications showed that SOC stocks decreased at 98 percent of sites by an average of 52 percent in temperate regions, 41 percent in tropical regions, and 31 percent in boreal regions. A 2002 meta-analysis of 74 publications across tropical and temperate zones showed a decline in soil C stocks after conversion from pasture to plantation (–10 percent), native forest to plantation (–13 percent), native forest to crop (–42 percent), and pasture to crop (–59 percent). Soil C stocks increased after conversions from native forest to pasture (+8 percent), crop to pasture (+19 percent), crop to plantation (+18 percent), and crop to secondary forest (+53 percent).[26] Relative changes were equally high in the subsoil as the surface soil.[27] The global loss of SOC pool since 1850 is estimated at about 66 ±12 billion tonnes.[28]

The determinants of the magnitude and rate of SOC change depend on both inherent soil properties and on management practices. Rates of SOC turnover are greater for soils within the tropics than for those of the temperate climates. They are also greater for coarse-textured than for heavy-textured soils. Loss of SOC in all regions is exacerbated by drainage of wetlands, ploughing and biomass burning or removal.[29]

In the regional assessments of soil threats (Section 9 of this report), continuing pressure to convert forest and pasture to agricultural land was identified by Africa and Latin America and the Caribbean as a major driver for the poor condition of SOC. The expansion of agriculture in the tropics accounts for most of the total CO_2 emissions from land clearing, and several recent studies have concluded that halting this expansion is essential for reducing carbon emissions.

In Europe the opposite is true in some regions – the abandonment of agricultural land in areas of Eastern Europe lead to SOC gain in the abandoned lands. This pool of stored carbon can, however, be readily emitted as CO_2 if re-conversion to agriculture takes place. All peatlands are very susceptible to SOC loss when they are drained for agriculture and commercial forestry – this is an issue in several regions, particularly Asia and Europe.[30]

Agricultural management is the second major driver of SOC change. The regional assessments for Africa, Asia and parts of the Southwest Pacific identify decreasing length of fallow periods and competing uses for organic inputs as major drivers for the generally poor condition of SOC stocks. On the more infertile soils in Africa, the low yields of many crops under subsistence/extractive agriculture lead to low amounts of organic residue production. The combination of low organic inputs and the competing uses for those inputs, coupled with the naturally high rates of SOC decomposition in these regions, lead to low SOC stocks in these naturally infertile soils.

As well as contributing to global climate change, SOC levels will also respond to changes in global temperatures and precipitation patterns. The effects of global warming on SOM decomposition are governed by complex and interactive factors, and are challenging to predict. This is a particular concern for organic and tundra soils, which are major terrestrial reservoirs for carbon. The 5th assessment report of the IPCC states that there is high confidence that reductions in permafrost due to warming will cause thawing of some currently frozen carbon, but there is low confidence on the magnitude of CO_2 and CH_4 emissions to the atmosphere caused by this thawing.

Methane emissions from soils

Soils emit methane (CH_4) through methanogenesis when decomposition of organic matter occurs in anaerobic (e.g. oxygen-depleted) soil layers. Waterlogged soils, particularly wetlands, peatlands and rice paddies, are the largest source of methane emissions. CH_4 emissions from rice paddies have increased from 366 million tonnes CO_2eq.yr^{-1} in 1961 to 499 million tonnes CO_2eq.yr^{-1} in 2010. Total global emissions of CH_4 from wetlands were estimated to be 145 million tonnes yr^{-1}, of which 92 million tonnes yr^{-1} came from natural wetlands and 53 million tonnes yr^{-1} from paddy fields.[31]

Most mitigation options for reducing CH_4 emissions have been developed for rice paddies, the major soil use responsible for methane emissions. These include draining wetland rice once or several times during the growing season, selection of rice cultivars with low root exudation rates, off-rice season water management, fertilizer management and the timing and composting of organic residue additions. For managed peatlands and wetlands (e.g. those used for forestry or agriculture), methane emissions can be reduced by fertilizer, water and tillage management. Rewetting of drained/cultivated peatlands to restore wetland function and maintain carbon stocks is likely to increase CH_4 emissions.[32]

By contrast, aerobic soils tend to act as sinks for CH_4, thereby having a positive impact on climate regulation. Temperate and tropical aerobic soils that are exposed to atmospheric concentrations of CH_4 usually exhibit low levels of atmospheric CH_4 oxidation but, since they cover large areas, they are estimated to consume approximately ten percent of the atmospheric CH_4.[33]

Nitrous oxide emissions from soils

Nitrogen fertilizer inputs in excess of crop requirements in soils are linked to the enhanced release of the potent greenhouse gas (N_2O) from soils. Of the approximately 16 million tonnes N_2O N yr^{-1} emitted globally in the 1990s, between 40 and 50 percent was a result of human activities. Agricultural soils are the dominant source, contributing over 80 percent of global anthropogenic N_2O emissions during the 1990s. Nitrous oxide emissions from agricultural soils are projected to increase from just over four million tonnes N_2O N yr^{-1} in 2010 to over five million tonnes N_2O N yr^{-1} by 2030.[34] In terms of its effect as a greenhouse gas, one unit of N_2O is equivalent to approximately 300 units of CO_2 and hence this is a very significant increase in global emissions. In developed countries such as Canada or the United States where, in some regions, N fertilizer inputs exceed plant demand, agriculture accounts for six to seven percent of total greenhouse gas (GHG) emissions, and N_2O emissions from agricultural soils account for 65 to 75 percent of the agricultural total. Nitrogen excess is also very high in Western Europe, China, and Northern India. Highest N_2O emissions occur under anaerobic conditions as part of the denitrification pathway and hence are intimately linked to changes in waterlogging in agricultural landscapes.

Soils and human health

Human (and animal) health problems can be caused by soil through several mechanisms: 1) toxic levels of trace elements and organic contaminants or disease-causing organisms can enter the food chain from the soil; 2) direct encounters with pathogenic organisms; 3) production of nutrient-deficient crops from soils, contributing to malnutrition; and 4) direct exposure to dust.

Soil contamination

In many countries there is significant public concern about health effects from exposure to trace elements (which are also called heavy metals) and to organic pollutants in the soil. Increasing inputs to soils of trace elements have led to a growing concern worldwide, particularly in rapidly developing countries such as China and India, where regulation, management and mitigation have struggled to keep pace with the rate of pollutant release to the environment. However, developed nations are not immune to threats to soil function imposed by trace elements. The long legacy of toxic waste disposal and metal build-up in soils presents grave challenges for use and reclamation of contaminated land.

Arsenic in groundwater

The primary trace elements of concern for human health are arsenic, lead, cadmium, chromium, copper, mercury, nickel and zinc. Each element has its own source and pathways within the soil. For example, arsenic (As) has multiple effects on human health. Changes in soil water saturation by flooding (waterlogging) or draining impact arsenic mobility, with arsenic becoming mobilized under flooded, anaerobic conditions. Of greatest concern from a human health perspective, soil processes contribute to arsenic contamination of groundwater, resulting in human exposure to arsenic through well-water consumption.

Arsenic causes a number of conditions in humans including nervous system disorders, kidney and liver failure, as well as anaemia and skin cancer. Over 130 million people worldwide routinely consume well-water with arsenic concentrations that exceed the World Health Organizations recommended limits.[35]

Mining

Mining is a land use that often results in both land take and soil contamination.[36] Mining operations themselves affect relatively small areas compared to the environmental problems caused by tailing and waste rock deposits, as well as the smelting operations from which contaminants can be transferred to their surroundings by acid mine drainage and/or atmospheric deposition of gaseous and particulate contaminants.

Mine-soils develop upon weathering of the newly exposed materials and generally have properties that limit their functions. Quite often, restoration of mine-soils requires the addition of exogenous materials to allow them to support the growth of vegetation. Although many countries require reclamation plans for mining sites to be restored to their former functional states, mine restoration is still problematic, mainly because the whole raft of environmental impacts has only recently been understood and appreciated. Recent progress in the development of tailor-made Technosols (e.g. human-made soils) to restore mine soils[37] offers a new avenue for the rehabilitation of mine soils.

Agriculture and Forestry

There are significant public concerns in many countries about the effects of pesticide contamination in soil and water on human and ecosystem health more generally. The advances in our ability to monitor soil biodiversity (which is most immediately impacted by pesticides) discussed in the main report of the Status of the World's Soil Resources will allow significant progress to be made in this area.

Atmospheric deposition of contaminants has a significant effect on agriculture, forests and aquatic systems. In 2001, regions with atmospheric sulphur deposition in excess of 20 kg S ha^{-1} yr^{-1} were China and Republic of Korea, Western Europe and eastern North America.[38] Regions with nitrogen deposition in excess of 20 kg N^{-1} ha^{-1} yr^{-1} in 2001 were Western Europe, South Asia (Pakistan, India, and Bangladesh) and eastern China.[39] Although acidifying inputs are decreasing in Europe and eastern North America, sensitive soils in these regions have been significantly acidified in the past and are still impaired in their functioning. Nitrogen deposition in China in the 2000s was similar to peaks in Europe during the 1980s before mitigation[40] and hence the issues with acidification may still be intensifying in China.

Radioactivity

Small areas have seen the total removal of land from human use due to hazardous levels of contamination of various types - the 2 600 km² Chernobyl Exclusion Zone that resulted from the nuclear reactor disaster of 1986 is perhaps the best known of these. Other examples include Pacific Islands used for nuclear-weapons testing prior to the 1980s.

War zones

Minefields represent a particularly dangerous form of contamination: for example, in Bosnia and Herzegovina alone 4000 km² of agricultural and forest lands remained mined and unusable when the war ended in 1995.[41]

Trends

The regional assessments for soil contamination show that the trend for contamination is improving in Europe, North America, Australia and New Zealand. In these countries legacy contamination sites exist, but increasingly stringent government regulation limits the spread of contamination and specifies the level of remediation of existing contaminated sites required. Hence, contamination is arguably a soil threat that responds directly to policy initiatives, at least in situations where the contamination can be readily linked to a specific contamination source and where significant public concern about contamination spurs policy development and implementation.

Soil and biodiversity

Soils host a tremendous diversity of organisms that play fundamental roles in driving many ecological services on which the functioning of terrestrial ecosystems depend. In doing so, soil organisms, and their interactions with each other and with plants impact on a range of ecosystem services, including soil formation and nutrient cycling, the production of food and fibre, climate regulation, disease and pest control.

The biodiversity of soil is immense compared to aboveground biodiversity: for example, ten grams of soil contains about 10^{10} bacterial cells of more than 10^6 species. An estimated 360 000 species of animals are dwellers in soil.[42] It has been estimated that the biodiversity of soil could make up as much as 25 percent of the total amount of described living species worldwide, although most of this diversity remains unknown.[43]

Stocks of soil biodiversity also represent an important biological and genetic resource for biotechnological exploitation. The contribution of soil biota to human health has already been immense: for example, nearly 80 percent of antibacterial agents approved between 1983 and 1994 have their origin in the soil.

Soil biodiversity is vulnerable to many human disturbances, including land use and climate change, nitrogen enrichment, soil contamination, invasive species and the sealing of soil. A recent sensitivity analysis revealed that increasing land use intensity and associated soil organic matter loss are placing the greatest pressure on soil biodiversity, and numerous studies report soil biodiversity declines as result of the conversion of natural lands to agriculture and from agricultural intensification. In particular, studies show larger bodied soil animals, such as earthworms, mites and collembolans, and soil fungi, to be especially vulnerable to intensive land use. Soil management practices that minimize SOC loss or increase SOC levels are likely to have a beneficial effect on soil biodiversity.[44]

The large-scale use of pesticides may have direct or in-direct effects on soil biodiversity. With the intensification of agriculture, the use of pesticides has increased on a global scale.[45] The studies on the effect that pesticides have on soil biodiversity have shown contradictory results. The effect depends on a variety of factors including the chemical composition, rate applied, buffering capacity of the soil, the soil organisms in question and the time-scale. In many cases the data are simply lacking: for example, a 2006 review of pesticide application effects on soil organisms could not find published data for 325 of 380 active constituent pesticides registered for use in Australia.[46]

Previous methodological challenges in characterizing soil biodiversity are now being overcome through the use of molecular technologies, and currently significant progress is being made in opening the "black box" of soil biodiversity. Closing these knowledge gaps is of fundamental importance to better inform the likely consequences of land use or climatic change on both biodiversity and soil ecosystem services. Alongside new developments with respect to assessing biodiversity, it is essential to link biodiversity measures with specific soil functions in order to understand the pivotal roles of soil organisms in mediating soil services.[47]

Clearly we are learning more and more about the stocks and change in soil biodiversity. However, global scale syntheses are still largely absent. The regional assessments of soil threats in this report are consistent with regard to soil biodiversity – the evidence in each region is limited and there is little consensus about the trend.

8

Regional trends in the condition of soils

A key element of the Status of the World's Soil Resources report is the regional assessments of the state of the soil. These were coordinated by members of the Editorial Board, and involved the ITPS members from each region and, in some regions, members of the broader soil science community. The assessments included a ranking of the threats to soil function in each region. These have been expressed as a simple estimate of the status and trends in soil condition along with assessments of the confidence for each estimate. The tabulated estimates are based on a qualitative assessment of the peer-reviewed scientific literature. The diversity of published studies, general paucity of information, and limited time available meant that more formal assessment methods were not feasible. Improving on this through the implementation of a more transparent and technically defensible assessment method is a major challenge for future reports on the status of the world's soil resources.

In preparing the assessments, the ITPS is keenly aware of the complex reasons that give rise to regional differences in soil conditions and trends.
The following factors are influential:

- The natural endowment of soils and landforms varies substantially between regions and some are fortunate to have extensive areas of fertile, versatile and resilient soils whereas others do not.
- The history of land use also varies substantially. Most countries experience a significant phase of land degradation when agricultural systems are first established. This is particularly true of ancient landscapes that typically have strongly weathered and infertile soils that are more vulnerable to disturbance. In some parts of the world, this phase of land degradation occurred long ago whereas in others it is a contemporary phenomenon.
- The economic history of each region is an important factor that influences

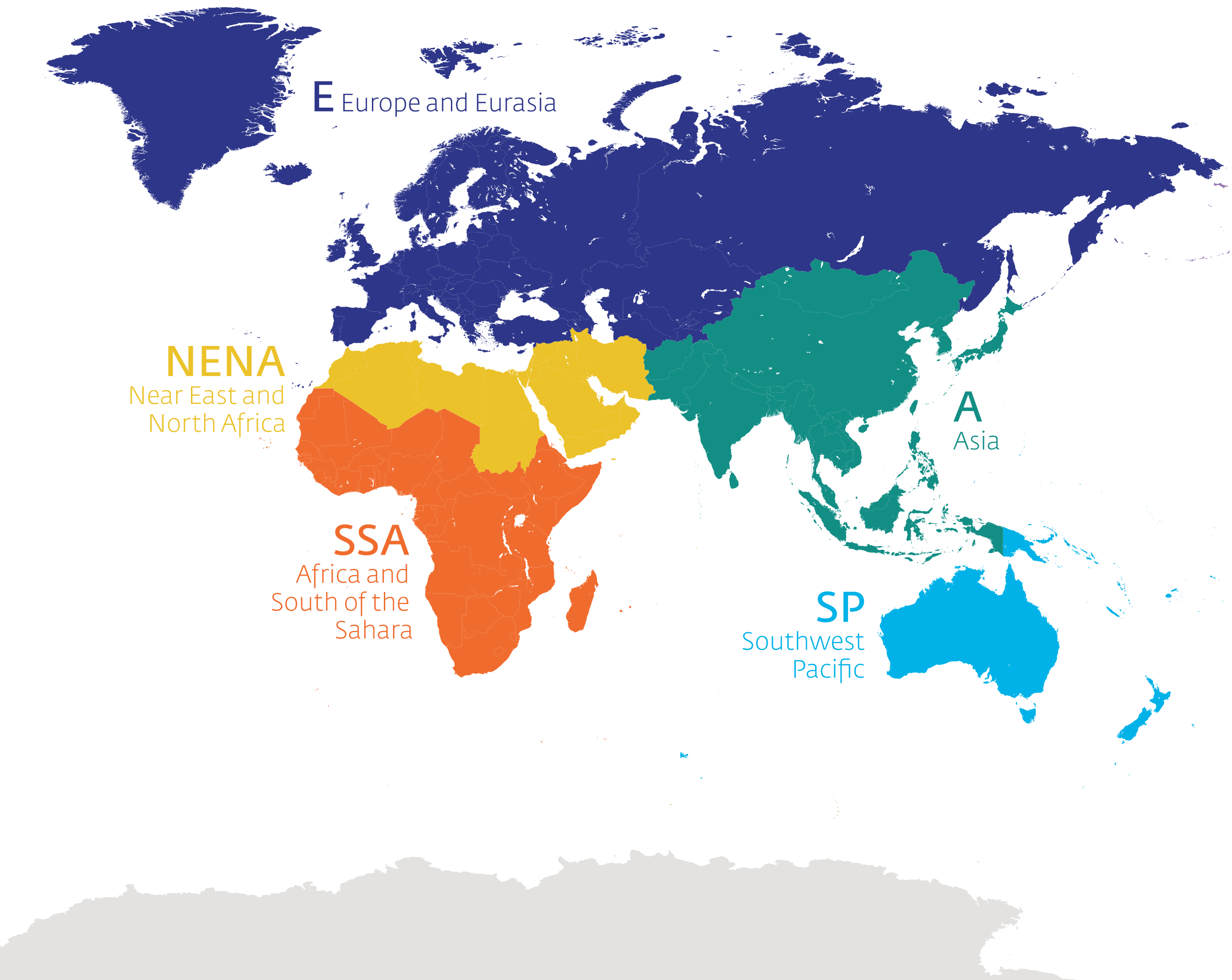
soil condition – exploitative systems of land use in past decades or centuries have in some regions left a legacy of soils in poor condition. Furthermore, countries with abundant financial and natural capital can provide support systems to ensure more conservative forms of land management (e.g. via publicly funded programs of soil conservation).

- Large population pressures in both industrialized and low-income countries can have a direct impact on soil condition that overrides all other drivers of soil condition.

Figure 1
Regions used for this report. Member countries for each region are presented in the main report.

The regions used for the assessments are shown in Figure 1 and a full list of member countries for each region is presented in the main report.[48] One-page summaries of the reports from each region have been prepared for this Technical Summary.

This section concludes with a graphical summary of the state and trend of each soil threat in the regions prepared by the coordinating lead author for each region. There are similar graphical assessments for the soil threats for each region in the main report. Overall in these regional assessments there is slightly more confidence in the rankings of soil condition than there is in the assessments of trends. There is the greatest certainty in relation to assessments of soil erosion, low certainty about compaction and very low certainty about soil biodiversity.



Africa South of the Sahara

The Africa South of the Sahara (SSA) region (2,455 million ha) consists of six agro-ecological zones (AEZ) each characterized by a combination of relief, climate, lithology, soils and agricultural systems. Table 1 presents a summary of soil threats (listed in order of importance), condition, trends and uncertainties for Africa South of the Sahara.

Soil degradation, mainly manifested in the form of soil erosion, is considered one of the root causes of stagnating or declining agricultural productivity in SSA. Other related problems that reduce agricultural land productivity include soil organic matter loss, nutrient depletion, soil biodiversity loss, acidification, salinization and waterlogging. Unless these problems are controlled, many parts of the continent will suffer increasingly from food insecurity. The consequences of the productivity decline of Africa's soil resources, if continued on its present downward spiral, would be severe, not only for the economies of individual countries, but also for the welfare of the millions of rural households dependent on agriculture for meeting their livelihood needs.

There is no consensus on the extent and severity of the various forms of soil degradation or their impacts in the component zones or in SSA as a whole, but it has been estimated that of the approximately 494 million ha of land in SSA affected by soil degradation, 46 percent is affected by water erosion, 38 percent by wind erosion, 12 percent by chemical degradation and four percent by physical degradation. The four types of soil change that are considered as major threats are: soil erosion, soil organic matter depletion, soil nutrient depletion and loss of soil biodiversity. These are discussed in detail in the main report. Other key features that contribute to soil fertility decline in SSA are: complete crop removal from farmlands, unbalanced fertilization and little or no use of fertilizers. At the national level, detailed information is available about soil degradation in some countries as illustrated by the documented results presented in the main report for Senegal and South Africa.

Soil degradation constitutes a great threat to ecosystem services in SSA, particularly sustainable food production and security and is caused by several factors including: overgrazing, deforestation, inappropriate cultivation techniques; and expansion of agriculture into marginal lands, population increase, climate change and poverty. Soil degradation is increasing in the region, with over 20 percent of land in most SSA countries already being degraded, affecting over 65 percent of the population and resulting in significant adverse effects on food production and human livelihoods. There is an urgent need for pro-active interventions to arrest and reverse soil degradation. Agricultural lands are especially prone to erosion and nutrient depletion. Reported yield losses range from moderate (two percent decline over several decades) to catastrophic levels (more than 50 percent), depending on crop, soil type, climate, and production systems, with most studies reporting significant losses. Direct economic losses due to declining yields and lost nutrients are large in terms of the national economies concerned.

Rehabilitation of degraded land and conservation of those not yet degraded are the most desirable steps for every country in the region. The development of comprehensive soil resource information databases and the establishment of soil monitoring systems in every country should complement these steps.

Table 1 | Summary of soil threats (listed in order of importance), condition, trends and uncertainties for Africa South of the Sahara

Threat to soil function	Summary
Soil erosion	Soil erosion constitutes >80% of land degradation in SSA, affecting about 22% of agricultural land and all countries in the region. The majority of causes related to the exposure of the bare soil surface by cultivation, deforestation overgrazing and drought.
Organic carbon change	The replacement of the natural vegetation reduces nearly always the soil carbon level. Further carbon release from the soil is caused by complete crop removal from farmlands, the high rate of organic mater decomposition by microbial decomposition accentuated by high soil temperature and termite activates in parts of SSA.
Nutrient imbalance	Nutrient imbalance, which is generally manifested by the deficiency of key essential nutrients is mainly due to the fact that fertilization has not been soil and crop specific, farmers are unable to pay the price for fertilizers and the inability to follow the rates that are recommended. Nearly all countries in the region show a negative nutrient balance.
Loss of soil biodiversity	SSA suffers the world's highest annual deforestation rate. The areas most affected are the in the moist areas of West Africa and the highland forests of the Horn of Africa. Cultivation, introduction of new species, oil exploration and pollution reduce the population of soil organisms thus reducing faunal and microbial activities.
Soil acidification	Over 25% of soils in Africa are acidic. Most of these occur in the wetter parts of the continent. In South Africa it poses as a serious chemical problem and the greatest production-limiting factor.
Waterlogging	Most waterlogging threats are due to rise in water table due to poor infiltration/drainage or occurrence of impervious layer in the subsoil. Waterlogging generally reduces crop productivity, but in paddy fields is deliberate and beneficial.
Compaction	The major cause of compaction is pressure on the soil from heavy machinery. It is more serious in forested regions where land clearing (and even other cultivation activities) cannot be done without mechanization.
Soil sealing and land take	These constitute problems mainly in peri-urban agriculture and valley sites used for dry season vegetable production.
Soil pollution	Soil contamination by chemicals (fertilizers, petroleum products, pesticides, herbicides, mining) has affected agricultural productivity and other ecosystem services negatively. Nigeria and South Africa are the most affected.

Stable =
Variable ↗↙
Improving ↗
Deteriorating ↙
Evidence and consensus is **low**
Evidence and consensus are **limited**
Adequate high-quality evidence and **high level** of consensus

	Condition and Trend					Confidence	
	Very poor	Poor	Fair	Good	Very good	In condition	In trend
		↙				Adequate	Adequate
		↙				Limited	Limited
		↙				Adequate	Limited
			↙			Low	Low
		↙				Adequate	Limited
				=		Low	Low
				=		Low	Low
				=		Low	Low
				↙		Low	Low

Asia

The status of soil resources in the 24 member countries of the Asian Soil Partnership (ASP) is reviewed. Table 2 presents the key threats to soil function in the region listed in order of importance. In terms of climate, the region is blessed with a warm and seasonally humid climate favourable for agriculture. Recently, however, Asian countries have been facing rapid changes in both socio-economic and natural conditions which have had extraordinary impacts on soil resources in the region. Regional soil assessments - Global Assessment of Human-induced Soil Degradation (GLASOD) in the 1980s and Assessment of Human-Induced Soil Degradation in South and Southeast Asia (ASSOD) in the 1990s - revealed that human-induced soil degradation in Asia was the highest amongst all global regions.

Soil erosion is the most important threat to soil in Asia region. Serious water erosion occurs in those areas of South and East Asia which have pronounced dry and wet seasons, particularly in hilly and mountainous landscapes. However, soil erosion is of lesser concern in established forests and paddy fields. Wind erosion is concentrated mainly in the extreme western and northern arid and semi-arid regions. Soil organic carbon (SOC) change in Asian countries differs amongst sub-regions. Increases in nutrient inputs, crop yield and biomass production result in a retention and sometimes an increase in SOC across the croplands of East and Southeast Asia, whereas SOC is decreasing in South Asia through removal of crop residues or through land use change which presents a major threat.

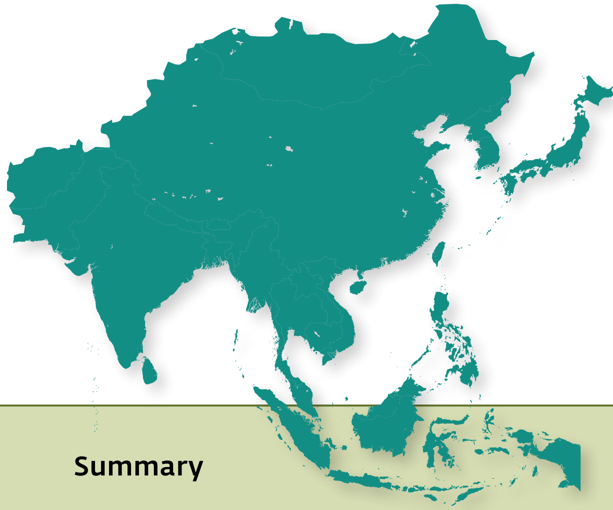
The degradation of grassland has also caused great losses of SOC stock. Throughout the region, the threat of salinisation/sodification is very widespread, although to varying extents. In semiarid and arid zones of Central Asia, salt-affected soils are widely distributed. Salt-affected soils are also developing in certain coastal area in monsoon zones in South and Southeast Asia, mainly through salt water intrusion. Negative soil nutrient balances have been reported for nitrogen (N), phosphorus (P) and potassium (K) in many South Asian countries, whereas large excesses of nutrients, in particular N, cause serious environmental problems for water bodies and for the atmosphere.

Soil contamination by heavy metals, such as cadmium (Cd), arsenic (As), lead (Pb), copper (Cu) and zinc (Zn), as well as by pesticides is widely observed in various parts of the region due to rapid urbanization, industrialization, and intensive farming. Action to reduce this contamination is urgently needed, especially in paddy soils and in the rice grains they produce. Acid sulphate soils occur in tropical and subtropical regions. Unbalanced and unsuitable application of chemical fertilizers causes soil acidification of other soils. Anthropogenic activities such as poor drainage systems and deforestation in the upstream areas increase the threat of waterlogging in flood-prone downstream areas. Mechanization of land management has increased compaction of soils in cropland, grassland and timber forests. Increase in livestock trampling is also a major cause of surface soil compaction in grassland and hilly region. Rapid urbanization and development of mega-cities significantly have increased the rate of sealing and land take. Asia region has the largest impervious surface area (ISA) of all the global regions. Although limited information is available for soil biodiversity in the region, it is reported that potentially the greatest contributor to soil biodiversity loss in Asia is land use change.

The main report contains country case studies from India, Indonesia and Japan. Nearly half of soils in India are degraded. The largest degraded area is affected by water erosion, followed by wind erosion, salinization, loss of nutrients and waterlogging. Depletion of SOC from organic soils in peatlands is considered as one of the major threats in Indonesia. The status of SOC change, heavy metal contamination (including radioactive cesium contamination), nutrient imbalance, and erosion are reported from Japan. The main report also contains a case study on greenhouse gas emissions from paddy fields.

In conclusion, management of land and water resources has been identified as one of the priority issues for achieving sustainable food security in the Asia region. This requires raising land productivity, reversing land degradation and water loss, and increasing biodiversity and the quality of the environment. There is a pressing need to conduct a new and extended assessment of recent changes in soil resources in the region. These needs have been recognized in the Nanjing Communiqué. Development of a regional implementation plan for sustainable soil management is the next step to put the plans into practice.

Table 2 | Summary of soil threats (listed in order of importance), condition, trends and uncertainties for Asia



Threat to soil function	Summary
Soil erosion	Serious water erosion occurs in regions with dry and wet seasons covering South Asia to East Asia, particularly in the hilly and mountainous landscapes. However, it is of little concern for well-established forests and paddy fields. Wind erosion is concentrated mainly in the most western and northern arid and semi-arid regions of Afghanistan, Pakistan, India, and China.
Organic carbon change	Increase in crop yield retains soil organic carbon (SOC) in croplands of East and Southeast Asia. Whereas, SOC is decreasing in South Asia, because crop residues are widely used as fuel and fodder, and not returned to the soil. The degradation of grassland has caused great losses of SOC stock.
Salinisation and sodification	The threat of salinisation/sodification in the Asia region is widespread but variable. In semiarid and arid zones of central Asia, salt-affected soils are widely distributed. On the other hand, salt- affected soils are developed in certain coastal areas in monsoon zones, mainly by salt water intrusion in South and Southeast Asia.
Nutrient imbalance	Negative soil nutrients balances have been reported for N, P, K and micronutrients in many..." South Asian countries. Whereas, large excess of nutrients, in particular N, causes serious environmental problems in other countries.
Contamination	Rapid urbanization, industrialization, and intensive farming causes contamination of heavy metals (Cd, Ni, As, Pb, Zn, etc.) and pesticides in various parts of Asia, which, in turn, poses a serious risk to human health.
Soil sealing and land take	Rapid urbanization and development of mega-cites significantly increased the rate of impervious surface area (ISA). Asia region has the largest ISA within the global regions.
Soil acidification	There is substantial area of acid soils distributed in tropical and subtropical regions of Asia, mainly in Southeast Asia, parts of East and South Asia. This is mainly caused by unbalanced and unsuitable application of chemical fertilizers. Distribution of acid sulphate soils in tropical Asia also limits crop production.
Compaction	Mechanization of land management has increased compaction of surface soil and/or subsoil in cropland, grassland and timber forests. Increase in livestock trampling is also a major cause of surface soil compaction in grassland and hilly region.
Waterlogging	Anthropogenic activates such as poor drainage system and deforestation in the upstream areas increase the threat to waterlogging in the flood prone areas.
Loss of soil biodiversity	Limited information is available for soil biodiversity in Asia. Some reports show high microbial biodiversity in the soils of organic farming lands.

Stable: =
Variable: ↗↙
Improving: ↗
Deteriorating: ↙

Evidence and consensus is **low**
Evidence and consensus are **limited**
Adequate high-quality evidence and **high level** of consensus

	Condition and Trend					Confidence	
	Very poor	Poor	Fair	Good	Very good	In condition	In trend
		↙				Adequate	Limited
		↗↙				Limited	Limited
		↗↙				Adequate	Limited
		↙				Adequate	Adequate
		↙				Limited	Limited
		↙				Limited	Limited
		↙				Adequate	Limited
		↙				Limited	Limited
			↙			Limited	Low
			↗↙			Low	Low

Europe and Eurasia

The majority of reports on the global state of soil degradation regard the European region as less affected compared with the situation in other regions: according to a global study the average cumulative loss of productivity in Europe due to human-induced soil degradation during the post-second world war period was estimated as 7.9 percent. However, the extent of soil degradation in Europe seems to be underestimated, because soil degradation in the European region has many facets, not all considered in the previous estimate. Table 3 summarizes the threats (listed in order of importance), soil condition, trends and uncertainties for Europe and Eurasia.

The processes of human induced soil degradation started in many parts of this region in ancient times, because many centres of agrarian civilization emerged here several millennia ago: Greece, Anatolia and the Amu Darya delta are just the most significant examples. Since that time, pressure on the land has increased because of growing population and intensive migration of people due to a decline in natural resources and climatic fluctuations in neighbouring areas. In addition, the western part of the European region, unlike other regions of the world, has a history of over 200 years of industrialization, putting additional pressures on the soil, particularly through contamination.

Today anthropogenic pressures are the main reason for soil degradation in many parts of Europe. Soil resources are being over-exploited, degraded and irreversibly lost due to poor management practices, urbanization, industrial and mining activities, and land-use changes. Soil threats in the region put at risk the soil's key ecosystem role as the basis for provision of food, feed, fibre and energy, as well as other ecosystem services and mitigation of climate change. The four most serious soil threats in the region are sealing, salinization, contamination and loss of soil organic matter.

Knowledge on the state of soil resources in European region is good because of the long tradition of soil science and soil monitoring in most countries of the region. Nonetheless, an overview of the state of soil resources and the development of soil degradation for the whole region remains difficult because of the lack of harmonization of the data obtained at different dates using different methodologies. This is illustrated by the national case studies for Austria, Ukraine and Uzbekistan presented in the main report.

Different historical developments in Western Europe and in Eastern Europe (Eurasia) have determined very diverging developments for the available soil resources. It is therefore difficult to compile a consistent qualitative assessment of these resources in a single framework. Table 3 lists the major soil threats in the region while reflecting the strong differences between Western Europe and Eastern Europe (Eurasia). Soil sealing and land take by infrastructure and housing are the predominant threats to Western European soils while soil salinization and sodification are the predominant threats to Eastern European soils (Eurasia). Both are listed as first priorities for Eastern Europe but do not show any sign of short-term improvement. Common to the entire region is the concern for soil contamination, mainly related to a large number of contaminated sites that are the heritage of a very long history of industrialization. This is especially true in Western Europe. While a full inventory of all existing contaminated sites for the entire region is still missing, there are signs of improvement, with an increasing number of sites being remediated and more stringent environmental legislation on chemicals being applied, especially in the European Union. The remaining soil threats are of lower importance in the region and in some cases are showing signs of improvement as they are for soil erosion (due to the increase in forest cover) and acidification (due to more stringent regulations on atmospheric emissions from industry).

Table 3 | Summary of soil threats (listed in order of importance), condition, trends and uncertainties for Europe and Eurasia

Threat to soil function	Summary
Soil sealing and land take	In densely populated Western Europe soil sealing is one of the most threatening phenomena.
Salinization and sodification	Salinization is a widespread threat in Central Asia, and it is challenging in some areas in Spain, Hungary, Turkey, and Russia.
Contamination	Soil contamination is a widespread problem in Europe. The most frequent contaminants are heavy metals and mineral oil. The situation is improving in most regions.
Organic carbon change	The loss of organic carbon is evident in most agricultural soils. Peatland drainage in northern countries also leads to rapid organic carbon loss. In Russia, extensive areas of agricultural lands were abandoned that resulted in quick organic mater accumulation; however, some of these areas are now again used for agriculture.
Nutrient imbalance	In the western part of the region the loss of nutrients is compensated by application of high doses of fertilizers. In the eastern part the use of fertilizers is insufficient, and in most soils nutrient mining results in intensive mineral weathering.
Soil erosion	Water erosion is active in all the cultivated mountainous and rolling areas; the worst situation is observed in Turkey, Tajikistan and Kyrgyzstan. Due to the attention paid to this threat it is controlled in most areas, especially in the EU.
Loss of soil biodiversity	Loss of biodiversity is expected in the most urbanized and contaminated areas of the region. However, there are almost no qualitative estimations of the biodiversity loss in soils.
Soil acidification	Acidification due to acid rain was a challenge in Northern and Western Europe. The situation is now improving, though several decades will be needed for complete soil recovery.
Waterlogging	Waterlogging is mostly associated with irrigation in Central Asian countries. Most cultivated irrigated soils there are waterlogged. This phenomena in Central Asia is commonly associated with salinization.
Compaction	The use of heavy machinery and overgrazing are threatening in almost all the agricultural areas.

Stable =
Variable ↗↙
Improving ↗
Deteriorating ↙
Evidence and consensus is **low**
Evidence and consensus are **limited**
Adequate high-quality evidence and **high level** of consensus

	Condition and Trend					Confidence	
	Very poor	Poor	Fair	Good	Very good	In condition	In trend
		↙				Adequate	Adequate
		↙				Adequate	Adequate
		↗				Adequate	Limited
		↗↙				Limited	Limited
		↗↙				Limited	Limited
			↗			Adequate	Limited
			↙			Low	Low
			↗			Limited	Limited
			↗↙			Adequate	Limited
			↗↙			Limited	Limited

Latin America and the Caribbean

For Latin America and the Caribbean (LAC), soil is an essential resource to meet the needs of a rapidly growing population. It is estimated that the agricultural potential of LAC is about 800 million ha of land. However, most of this land is under tropical rain forest, and deforestation would initiate several soil degradation processes with dramatic effects on many ecosystem functions. Table 4 presents a summary of soil threats (listed in order of importance), soil condition, trends and uncertainties for Latin America and the Caribbean.

In terms of natural resources, Latin America is one of the richest regions of the world. With only eight percent of the global population, it has 23 percent of the world's potential cropland, 12 percent of the actually cultivated land, 46 percent of the globe's tropical forest and 31 percent of fresh water on the planet.

Agricultural conversion of natural ecosystems (Grass-shrub-savannas and forest) as a percentage in LAC is of the order of 30 percent, representing slightly over 600 million ha of agro ecosystems. A significant part of those areas is affected by degradation processes. Climate change and human pressure are the main factors driving soil degradation in the region. Soil degradation affects climate regulation and also entails biodiversity and soil resilience loss and an increased vulnerability of human settlements to natural disturbances and extreme weather events.

The main soil threats in LAC are related to natural features of physiography and the type of vegetation cover. Human and cultural features such as poor agricultural practices that may result from insecure land tenure, insufficient research and especially a lack of extension services also play an important role. Water erosion and landslides are leading factors of degradation in the sloping lands of the mountains, especially when lands are burned or overgrazed, while wind erosion is mostly concentrated in the drier regions. Loss of soil carbon mostly occurs after deforestation. In locations with more intensive agriculture using farm machinery, other threats such as salinization, nutrient imbalance, loss of biodiversity and compaction may be important.

Overall, the most important ecosystems services affected in LAC are: climate regulation through the disturbance of the C and N cycle due to deforestation, especially of the humid tropical forests; water regulation through changes in the quantity and quality of water production in the mountains, also due to deforestation of sloping lands accompanied by strong water erosion and landslides; food production on sloping lands, also due to deforestation and erosion caused by poor land use practice without conservation measures; and loss of biodiversity due to deforestation and change in land use/land cover. Two case studies are presented in the main report and these focus on soil degradation in Argentina and Cuba.

An enhanced natural resource information system is necessary in many countries of LAC, in order to perform a better diagnostic study of soil conditions and of the level of degradation and to identify adequate solutions, including land use planning and appropriate legislation. Prevention is the most cost effective way to avoid deterioration of physical soil conditions. Different techniques of conservation tillage have proven, in various LAC countries, to be good practice for both annual and permanent crops. Conservation tillage can enhance soil quality and soil physical structure as well as chemical fertility. Other recommendations include the dissemination of good research results, adoption of indigenous practices related to deforestation in tropical forest areas, and irrigation of dry areas.

Table 4 | Summary of soil threats (listed in order of importance), condition, trends and uncertainties for Latin America and the Caribbean

Threat to soil function	Summary
Soil erosion	Widespread across the region. Landslides are accelerated by land use in highland areas
Organic carbon change	Declines are caused by deforestation, intensive cultivation of grasslands and monoculture.
Salinization and sodification	Caused by inadequate irrigation technology and water quality. Land use changes also promote salinization.
Nutrient imbalance	Most countries have negative nutrient balances due to over-extraction. In some cases over fertilization also causes nutrient imbalance.
Loss of soil biodiversity	Suspected to occur in deforested and over-exploited agricultural areas.
Compaction	Caused by overgrazing and intensive agricultural traffic.
Waterlogging	Due to deforestation and poor structural conditions in agricultural areas.
Soil acidification	Soil acidification is limited to some areas with overuse of N fertilizers
Contamination	Industrial sources cause soil contamination in some places. Non-point soil pollution prevails in sites with intensive agriculture (e.g. herbicides residues).
Soil sealing and land take	In some valleys and floodplains, urbanization has expanded onto fertile soils.

Stable	Variable	Improving	Deteriorating	Evidence and consensus is **low**	Evidence and consensus are **limited**	**Adequate** high-quality evidence and **high level** of consensus
=	↗↙	↗	↙	Low	Limited	Adequate

	Condition and Trend					Confidence	
	Very poor	Poor	Fair	Good	Very good	In condition	In trend
		↙				Adequate	Limited
		↙				Limited	Limited
		↙				Adequate	Adequate
		↙				Limited	Limited
			↗↙			Low	Limited
		↙				Limited	Limited
			=			Adequate	Adequate
			↗↙			Low	Low
			↗↙			Low	Limited
			↗↙			Limited	Limited

Near East and North Africa

The Near East and North Africa (NENA) region has a land area of approximately 14.9 million km² that is nearly completely hyper-arid, arid or semi-arid. The region occupies the heart area of the world's drylands; land resources in the region face three climatic constraints which are partly also human induced: aridity, recurrent drought and desertification. Table 5 presents a summary of soil threats (listed in order of importance), soil condition, trends and uncertainties for the Near East and North Africa.

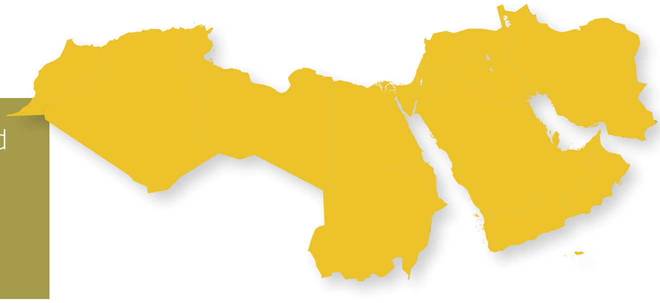
Although there is a wealth of local and national studies of soil change in the NENA region, a systematic and standardized approach is lacking. Results on the extent and intensity of the soil change processes still refer to the GLASOD study carried out in the late 1980s. Nevertheless, as shown in the case studies of Tunisia and Iran, national approaches to soil change assessments are possible and yield verifiable results.

The degradation of natural resources in arable lands is considered as one of the main threats to agricultural production in all countries of the region. Ecosystem service quality and capacity are greatly reduced by degradation caused by salinity, erosion, contamination and management factors that lead to a loss of soil organic matter. Water erosion is predominant in that part of the region which has sloping lands and where rainfed agriculture is practiced where it may even occur in gently sloping areas. Wind erosion is also a causative factor of topsoil removal. Heavy and frequent dust storms carry topsoil away, burying fertile soils and filling irrigation canals. For instance Iran has on average 60 days a year of dusty days and dust storms, while in certain regions of Iraq 300 days a year of dusty days and storms may occur. Population increase has resulted in soil disturbance due to uncontrolled human activities such as mining and open quarries that have triggered and accelerated erosion processes. Degradation due to salinity and sodicity varies geographically with climate, agricultural activities, irrigation methods and land management policies and is mainly restricted to irrigated farming systems. Causes include saline and sodic soils, sea water intrusion and irrigation with poor quality groundwater. Degradation due to contamination is mainly found in countries with high population, high oil production or heavy mining. In irrigated farming systems with overuse of chemicals, the loads of toxic elements percolating to groundwater increases.

Salinity has greatly reduced crop yield (e.g. from 5 to 0.5 tonnes ha^{-1}), with estimated annual economic losses of nearly one billion US$, equivalent to US$ 1 604 ha^{-1} and US$ 2 748 ha^{-1}. In some countries the damage to soil productivity was estimated to be in the range of 30 to 35 percent of the potential productivity.

Responses to reverse degradation caused by erosion include improving soil resilience through increasing C inputs using organic manures, compost and synthetic soil conditioners and soil conservation measures on sloping lands. Positive government policies and legislation and socio-economic factors at individual country level were found to reverse land degradation due to erosion. Efforts at reclaiming salt-affected soils consist mainly of salt leaching and drainage interventions, crop-based management, chemical and organic amendments, fertilizers, the use of salt tolerant plants, and crop management and phytoremediation. Ways to contain degradation caused by oil contamination include techniques that can partly eliminate hydrocarbons through enhanced decomposition and bio-remediation using some grass species. With effective desertification control, the potential annual C sequestration rate could reach values between 0.2 to 0.4 Pg C yr^{-1}, compared to the 1.0 Pg C yr^{-1} in total global drylands.

Table 5 | Summary of soil threats (listed in order of importance), condition, trends and uncertainties for Near East and North Africa



Threat to soil function	Summary
Soil erosion	Wind erosion and dust storms are a problem throughout the region. Sand stabilization in source areas is difficult and expensive to undertake. Water erosion can be controlled with adaptive management.
Salinization and sodification	Salinization is a widespread problem in the region due to the high temperatures, inappropriate irrigation practices and sea water intrusion in coastal areas. There is adequate research and technical knowledge in the region to counteract the problem. Socio-economic conditions hamper widespread implementation in some countries.
Organic carbon change	High temperatures throughout most of the region result in a very high turnover of soil organic Carbon. SOC change is sensitive to soil management changes.
Contamination	Contamination is locally a significant problem in the region particularly in urbanized areas that produce waste dumped on the land and in oil producing areas.
Sealing	Substantial expansion of housing, quarrying and infrastructures is a concern. There are no reliable data on sealing and land take.
Compaction	Compaction is a problem where heavy clay soils are intensively tilled (e.g. rainfed and irrigated Vertisols) and to a lesser extent is caused by off-road vehicles.
Loss of soil biodiversity	The extent of loss of soil biodiversity due to human impact is largely unknown in the NENA region. More studies need to be undertaken to understand the scope of the problem.
Soil acidification	Given the dry conditions throughout most of the region, acidification is restricted to some coastal areas with higher rainfall.
Nutrient imbalance	Nutrient imbalances occur in areas with continuous cultivation where nutrients are lost in harvested crops and no engagement in fallowing, manuring or mineral fertilizer application.
Waterlogging	Waterlogging is a very localized problem in the region limited to flash floods, heavily irrigated areas and excessive rise in subsoil water level.

Stable =

Variable ↗↙

Improving ↗

Deteriorating ↙

Evidence and consensus is **low**

Evidence and consensus are **limited**

Adequate high-quality evidence and **high level** of consensus

	Condition and Trend					Confidence	
	Very poor	Poor	Fair	Good	Very good	In condition	In trend
	↙					Adequate	Adequate
		↙				Adequate	Adequate
		↙				Limited	Limited
	↙					Adequate	Adequate
	↙					Adequate	Adequate
		↙				Limited	Limited
		↙				Low	Low
					=	Adequate	Adequate
				=		Low	Low
				=		Adequate	Adequate

North America

North America has a vast area devoted to food, fibre, and fodder production – approximately 180 million ha of cropland and a further 200 million ha of rangeland. The great forested and tundra areas of North America play a vital role in climate and water regulation and are potentially vulnerable to human-induced climate change but the direct effects of human activity on soil functions are less evident in these areas.

Overall there has been significant progress made in reducing threats to soil function in North America but major areas of concern remain. Table 6 presents a summary of soil threats (listed in order of importance), soil condition, trends and uncertainties for North America.

Both wind and water erosion have decreased significantly in North America. The largest driver for this decrease is the adoption of reduced tillage in many cropping systems coupled with a major decrease in summer fallow in the Great Plains of Canada. Erosion rates are still, however, above what are believed to be tolerable levels in the Temperate Prairies ecoregion of the United States and throughout the Mixed Wood Plains ecoregion of Canada and the United States. The delivery of high levels of particulate nitrogen (N) and phosphorus (P) to waterways in these ecoregions is a major contributor to nutrient-related water quality problems in the rivers and lakes of central and eastern North America and the surrounding oceans.

Excess application of nutrients occurs in several regions of North America. The oversupply of nutrients causes substantial issues in water quality and is the major source of N_2O emissions to the atmosphere in North America. Although a wide variety of best management practices for optimum nutrient application and erosion control have been developed and promoted, the problems of erosion and nutrient imbalance persist.

At the regional scale, salinization is a growing concern in areas such as the West-central Semi-arid Prairies in North Dakota. As with water erosion, changes in salinization are coupled to climate-induced changes in the hydrological system and the human response to these changes.

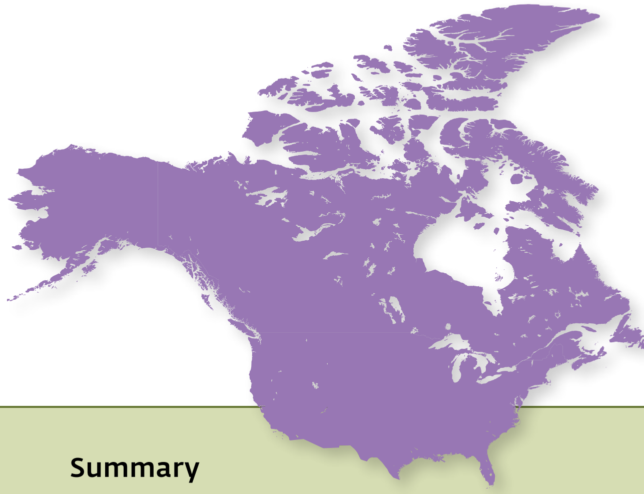
The threats to soil functions posed by contamination and acidification have decreased in the past few decades due to both transnational legislation such as the Air Quality Agreement of 1991 between Canada and the United States and strengthened regulations at all levels of government. Nonetheless, significant legacy issues persist as well as point-specific concerns in areas with major resource extraction activity.

Both sealing and waterlogging have been relatively little studied in North America and are not generally perceived as major threats. In the case of sealing this lack of concern is misplaced – the loss of high quality farmland in both Canada and the United States is significant and should be better quantified. In both countries the loss of wetlands is probably a greater issue than waterlogging, and should be considered more fully in future reports. Compaction continues to pose a threat to agricultural and forest soils but is not a major area of research or assessment and hence it is difficult to evaluate its regional significance.

Changes in carbon stocks in North America have been extensively modelled as part of national reporting programs on greenhouse gas emissions, but only in a few landscapes are the models adequately supported by field observations. There are distinct regional differences in SOC change within North America – for example, in Canada SOC has increased in the Temperate Prairie ecoregion but continuing losses occur in the Mixed Wood Plains in Ontario and Quebec. The greatest uncertainty surrounding SOC change lies in the response of SOC in permafrost and peatland soils in northern Canada and Alaska to climate change and improved monitoring of this response is essential. Beyond the change in C stocks themselves, the proportion of C released as CH_4 from these environments is also a significant concern.

The greatest uncertainty overall in our knowledge about the threats to soil functions lies in our limited understanding of the changes in soil biodiversity in the past and present and the implications of these changes for sustainable soil management. Programs such as the recently established Global Soil Biodiversity Initiative are essential if progress is to be made in this area.

Table 6 | Summary of soil threats (listed in order of importance), condition, trends and uncertainties for North America



Threat to soil function	Summary
Soil erosion	Reduced tillage and improved residue management have lowered erosion rates in regions such as the Great Plains in Canada but water erosion rates continue to be too high in the northern Mid-West of the U.S. and agricultural areas of central and Atlantic Canada.
Nutrient imbalance	Excess application of fertilizers in many regions causes significant degradation of surface water quality and increased emissions of nitrous oxide to the atmosphere. Contamination of surface water is strongly linked to high erosion rates, and occurs in the same regions (northern mid- west U.S., Mississippi River Basin, and agricultural regions of central Canada).
Organic carbon change	The majority of cropland in the U.S. and Canada has shown improvements in SOC stores due to the wide-spread adoption of conservation agriculture (i.e., reduced tillage and improved reside management). There is a lack of field validation sites to support the national-level modelling results. Loss of SOC from northern and Arctic soils due to climate change is a major concern.
Loss of soil biodiversity	The extent of loss of soil biodiversity due to human impact is largely unknown in North America. The effects of increasing agricultural chemical use, especially pesticides, use on biodiversity is a major public concern. Known level of carbon loss suggests similar loss in biodiversity.
Compaction	Compaction continues to be a low-level issue, especially in regions with texture-contrast (Luvisol, Alfisol, Ultsol) soils. The regional-scale impact of compaction on plant growth is largely unknown.
Sealing and land take	Substantial expansion of housing and infrastructure in areas of high quality farmland continues in both countries but is (incorrectly) not perceived as a concern. Neither country has reliable data on sealing and land take.
Salinization and sodification	Salinization is believed to be increasing in parts of the northern Great Plains in the U.S.A. but the risk of salinization is decreasing in western Canada.
Contamination	Although many legacy contamination sites exist, improved regulatory systems in both countries has limited the creation of new areas of contamination. Large-scale land disturbance due to resource extraction activities continues to be a significant issue.
Soil acidification	Trans-national environmental legislation has significantly reduced soil acidification in forested areas of eastern and central North America. Localized areas of acidification in agricultural land managed through lime application.
Waterlogging	Waterlogging is not believed to be a significant threat in North America. Localized flooding has occurred due to a wider amplitude of precipitation events in the past decade. Loss of wetlands is a more significant threat in North America.

Stable =

Variable ↗↙

Improving ↗

Deteriorating ↙

Evidence and consensus is **low**

Evidence and consensus are **limited**

Adequate high-quality evidence and **high level** of consensus

	Condition and Trend					Confidence	
	Very poor	Poor	Fair	Good	Very good	In condition	In trend
			↗			Adequate	Adequate
		↙				Limited	Limited
			↗			Limited	Limited
			↗↙			Low	Low
			=			Limited	Limited
			↙			Low	Low
			↗↙			Limited	Limited
				↗		Adequate	Adequate
				↗		Adequate	Adequate
				=		Limited	Limited

Southwest Pacific

The Southwest Pacific region includes the 22 island nations of the Pacific, New Zealand and Australia. The status of soil resources in the region is mixed. The region is a globally significant exporter of agricultural products and nearly all of the 24 countries rely heavily on soils for wealth. The threats to soil function in some countries are serious and require immediate action to avoid large-scale economic costs and environmental losses. These threats to soil function combined with other pressures caused by increasing population and climate change are especially challenging in southwest Western Australia and on the atoll islands of the Pacific. It is difficult to assess some threats because of the lack of surveys and monitoring networks. Table 7 presents a summary of soil threats (listed in order of importance), soil condition, trends and uncertainties for the Southwest Pacific.

Acidification is a widespread and serious problem that has the potential to cause irreversible damage to soils particularly in southern Australia and tropical landscapes where product removal and leaching are contributing factors. It also affects the hill country of New Zealand.

Improved land management practices in Australia and New Zealand have reduced erosion rates but the problem is still serious in some districts. Unsustainable rates of soil loss are associated with logging and clearing in several Pacific nations (e.g. Papua New Guinea and the Solomon Islands).

The conversion of land to agricultural uses has generally caused large losses of SOC. Improved land management practices have stabilized the situation but there is only limited evidence of increasing soil carbon even under these more conservative management systems.

Rapid intensification of agriculture in New Zealand and more recently Australia is causing significant environmental impact, particularly due to the large increase in fertilizer use and in numbers of ruminant animals. In other districts, nutrient mining and decline are occurring due to insufficient replacement of nutrients removed through harvest or other loss-pathways.

Limited evidence suggests that soil compaction is constraining plant growth across large areas, particularly in the cropping and pasture lands of Australia and smaller areas in New Zealand. Controlled traffic and other improvements in farm management may have halted this decline in soil physical fertility.

Loss of good quality agricultural land due to urban and industrial expansion is an emerging and potentially major problem for all countries in the region. Most sources of soil contamination are now regulated and controlled although the legacy of past practices is significant (e.g. cadmium in fertilizers). Contamination caused by mining and waste disposal is a significant issue for several Pacific nations.

Salinization is a widespread and expensive problem in Australia and some atoll islands. After a temporary respite due to dry years, the problem may continue to expand in Australia over the next few decades.

The rate of soil biodiversity loss was most likely highest during the expansion of agriculture (particularly over the last 100 years) and it may have slowed in recent years. However, information on baselines and trends is lacking in nearly all districts and countries.

The intensification of land use in New Zealand and to a lesser extent Australia provides an indication of the soil management challenges that will dominate in coming years as countries attempt to substantially increase food production within a resource-constrained world. Poor land management practices, and especially uncontrolled logging, in the low-income countries in the Southwest Pacific are a significant challenge to their national prosperity.

Table 7 | Summary of soil threats (listed in order of importance), condition, trends and uncertainties for Southwest Pacific

Threat to soil function	Summary
Soil acidification	A widespread and serious problem that has the potential to cause irreversible damage to soils particularly in southern Australia, tropical landscapes and areas where product removal and leaching are contributing factors.
Soil erosion	Improved land management practices in Australia and New Zealand have reduced erosion rates but the problem is still serious in some districts. Unsustainable rates of soil loss are associated with logging and clearing in several Pacific nations
Organic carbon change	The conversion of land to agricultural uses has generally caused large losses of organic carbon in soils. Improved land management practices have stabilized the situation but there is limited evidence for increasing soil carbon even under these more conservative management systems.
Nutrient imbalance	Rapid intensification of agriculture in New Zealand and more recently Australia is causing significant environmental impact, particularly due to the large increase in fertilizer use and ruminant animals. In other districts, nutrient mining and decline is occurring due to insufficient replacement of nutrients removed through harvest or other loss-pathways.
Compaction	Limited evidence suggests the problem is constraining plant growth across large areas, particularly in the cropping and pasture lands of Australia and smaller areas in New Zealand. Controlled traffic and other improved management practices may have halted this decline in soil physical fertility.
Soil sealing and capping	Loss of good quality agricultural land due to urban and industrial expansion is an emerging and potentially major problem for all countries in the region.
Contamination	Most sources of soil contamination are now regulated and controlled although the legacy of past practices is significant (e.g. Cd in fertilizers). Contamination caused by mining and waste disposal is a significant issue for several Pacific nations.
Salinization and sodification	Salinization is a widespread and expensive problem in Australia and some atoll islands. After a temporary respite due to dry years, the problem may continue to expand and the time to equilibration is likely to be in the order of decades.
Loss of soil biodiversity	Rates of loss were most likely highest during the expansion of agriculture, particularly over the last 100 years, and this may have slowed. However, information on baselines and trends is lacking in nearly all districts and countries.
Waterlogging	Waterlogging is a constraint to agricultural production in some wet years but evidence on the extent and severity is lacking. Large areas were drained to address the problem, particularly in New Zealand and parts of coastal Australia.

Stable: =
Variable: ↗↙
Improving: ↗
Deteriorating: ↙
Evidence and consensus is **low**
Evidence and consensus are **limited**
Adequate high-quality evidence and **high level** of consensus

	Condition and Trend					Confidence	
	Very poor	Poor	Fair	Good	Very good	In condition	In trend
		↙ (Deteriorating)				Limited	Adequate
			↗ (Improving)			Limited	Limited
		↗↙ (Variable)				Adequate	Limited
			↙ (Deteriorating)			Adequate	Limited
			= (Stable)			Limited	Adequate
				↙ (Deteriorating)		Limited	Adequate
				↗ (Improving)		Adequate	Adequate
			= (Stable)			Adequate	Limited
			↗↙ (Variable)			Low	Low
				= (Stable)		Limited	Limited

Antarctica

Soils only occur in the very small ice-free areas of Antarctica, mostly on the Antarctic Peninsula and along the Transantarctic Mountains. The focus for studies on Antarctic soils is not on their potential for food production but rather on their genesis, diversity, and vulnerability to impacts of human activity.

Most of the human activities in Antarctica are concentrated in the relatively accessible, small, ice-free areas on the coast, particularly in the Ross Sea region and the Antarctic Peninsula. In the last sixty years, human activity has increased significantly with over 70 scientific research bases established. Ship-based Antarctic tourism has become popular with 46 000 tourists reported in the 2007/08 summer and 27 700 in the 2013/14 season. The amount of contaminated soil and waste has been estimated at one to ten million m^3 and the presence of persistent organochlorine contaminants has been attributed to long-range atmospheric transport from lower latitudes. Fuel spills are the most common source of soil contamination and they can persist in the environment for decades.

Antarctic soils are easily disturbed and natural recovery rates are slow due to low temperatures and often a lack of liquid moisture. The older, more weathered, desert pavements and associated soils are the most vulnerable to physical human disturbance. Active surfaces (e.g. gravel beaches, sand dunes and areas where melt-water flows) recover from disturbance relatively quickly.

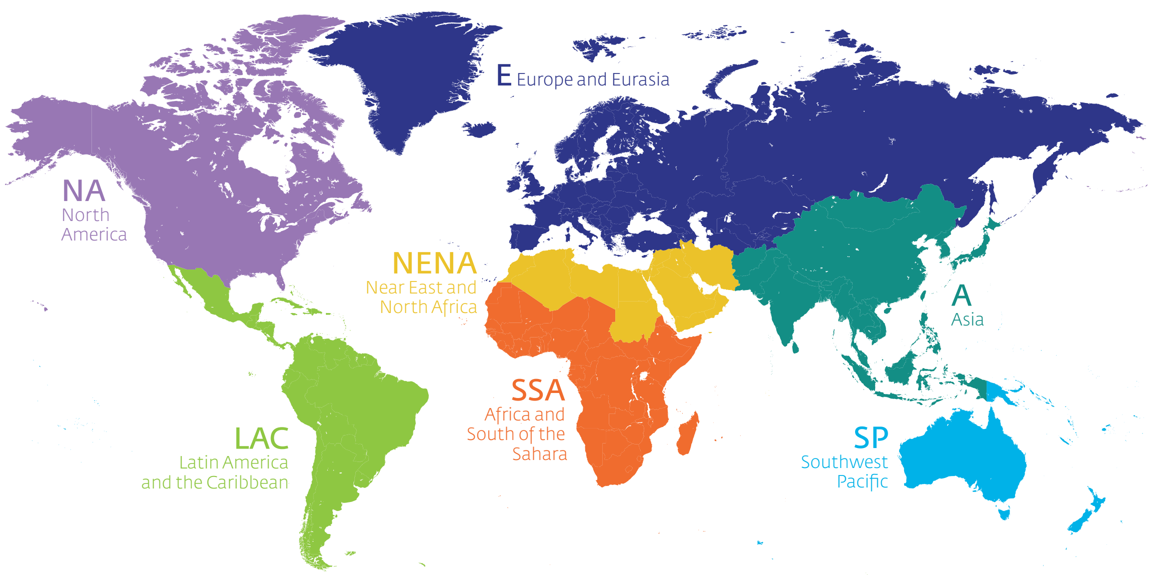
All activities in Antarctica are regulated through the national laws of the countries active in the region and these are underpinned by international legal obligations resulting from the Antarctic Treaty System. The Madrid Protocol designates Antarctica as "a natural reserve devoted to peace and science". It requires environmental impact assessment before any activity is undertaken. Since the Protocol's ratification in 1991, environmental awareness has increased and stringent standards are now in place. Procedures to prevent spills, remove wastes, phase out incineration, limit soil disturbance and protect sites of particular cultural or environmental significance, are proving effective at preventing further damage to Antarctic soils.

9

Global summary of threats to soil functions

Table 8 presents a global summary of the condition and trend for the ten soil threats excluding Antarctica. The threats are listed in order of priority. While there is cause for optimism in some regions, the overwhelming conclusion from the regional assessments is that the majority of the world's soil resources are in only fair, poor or very poor condition. The most significant threats to soil function at the global scale are soil erosion, loss of SOC and nutrient imbalance. The current outlook is for this situation to worsen unless concerted actions are taken by individuals, the private sector, governments and international organizations.

Table 8 *(next page)* **|** Summary of the condition and trend for the ten soil threats for the regions (excluding Antarctica) (legend below) – the threats are listed in order of importance



Threat to soil function	Condition and Trend				
	Very poor	Poor	Fair	Good	Very good
Soil erosion	↙ NENA	↙ A ↙ LAC ↙ SSA	↗ E ↗ NA ↗ SP		
Organic carbon change		↗↙ A ↗↙ E ↙ LAC ↙ NENA ↙ SSA	↗ NA ↗↙ SP		
Nutrient imbalance		↙ A ↗↙ E ↙ LAC ↙ SSA ↙ NA	↙ SP	↗↙ NENA	
Salinization and sodification		↗↙ A ↙ E ↙ LAC	↙ NENA ↗↙ SSA	↗ NA ↗↙ SP	
Soil sealing and land take	↙ NENA	↙ A ↙ E	↗↙ LAC ↙ NA	= SSA ↙ SP	
Loss of soil biodiversity		↙ NENA ↙ LAC	↗↙ A ↙ E ↙ SSA	↗↙ NA ↗↙ SP	
Contamination	↙ NENA	↙ A ↗ E	↗↙ LAC	↙ SSA ↗ NA ↗ SP	
Acidification		↙ A ↗↙ E ↗ SSA ↙ NA	↗↙ LAC ↙ SP	↗↙ NENA	
Compaction		↙ A ↙ LAC ↙ NENA	↗↙ E ↗↙ NA ↗↙ SP	= SSA	
Waterlogging			↙ A ↗↙ E = LAC	↗↙ NENA = SSA ↗↙ NA ↗↙ SP	

Stable = Variable ↗↙ Improving ↗ Deteriorating ↙

10

Soil policy

The regional and global summaries in the previous sections reveal that some of the world's soil management challenges are immediate, obvious and serious – they arise partly because of the nature of soils in different regions and of the associated history of land management. Other problems are more subtle but equally important in the long term – they require vigilance and a sustained policy response over decades. At present, few countries have effective policies to deal with these problems.

In 1937, the United States President Franklin D. Roosevelt stated 'The Nation that destroys its soil destroys itself.' This is perhaps the most succinct and sharpest challenge for policy makers and it is an all-too-real challenge for policy makers in some countries today.

The task of developing effective policy to ensure sustainable soil management is neither simple to articulate nor easy to implement. This is true regardless of a country's stage of industrial development, its natural endowment of soil resources or the immediate threats to soil function. In this report, we suggest the following seven policy pathways as a starting point for action along with a commentary on broader cross-cutting issues.

Education and awareness

Knowledge of soil and land resources is the foundation for achieving sustainable soil management. It should be integrated into formal education, preferably at all levels of schooling. Some countries are developing comprehensive and imaginative curricula that use an understanding of soils as a basis for teaching a wide range of cultural, social, scientific and economic subjects. At a more advanced level, the training has to encompass a range of soil science sub-disciplines (e.g. soil physics, soil chemistry, soil biology and pedology) as well as connections with related disciplines such as ecology, forestry, agronomy, geology, hydrology and other environmental sciences. The formal education system also requires mechanisms for outreach, vocational training and extension. In some regions, knowledge of the land is deeply embedded in indigenous cultures and traditions. This knowledge requires nurturing and support.

At a minimum, this policy pathway involves assessment of whether education and extension systems are coordinated and providing sufficient understanding and training for a nation to achieve sustainable soil management. Those directly involved in soil management require sufficient education to ensure their actions are profitable and sustainable.

Monitoring and forecasting systems

The distribution and characteristics of the soils in any district or nation are neither obvious nor easy to monitor. As a consequence, understanding whether a land use is well-matched to the qualities of the soil requires some form of diagnostic system both to identify the most appropriate form of management and to monitor how the soil is functioning. Four important components of the diagnostic system necessary for sustainable land use and management are:

- an understanding of spatial variations in soil function (e.g. maps and spatial information);
- an ability to detect and interpret soil-change with time (e.g. via monitoring sites, long-term experiments, environmental proxies);
- a capacity to forecast the likely state of soils under specified systems of land management and climates (e.g. through the use of simulation models);
- an understanding of the soil requirements of plants.

Preparation of the State of the World's Soil Resources Report was severely constrained by the lack of relevant information. Soil map coverages are variable and, in some regions, out-of-date. The capacity to monitor and forecast soil change is also rudimentary. All nations require coordinated soil information systems that parallel those that exist in many countries for economic data, weather and water resources.

This policy pathway requires countries to create appropriate institutional systems for information gathering and dissemination. In the case of soils, this is challenging for the following reasons.

- All levels of government need reliable information on soil resources but often no single level of government or department has responsibility for collecting this information on behalf of other public sector agencies.
- Public and private interests in soil are large and overlapping, and mechanisms for co-investment by public and private agencies are therefore needed.
- Market failure in relation to the supply and demand of soil information is a significant and widespread problem. In the simplest case, beneficiaries of soil information do not pay for its collection and this reduces the pool of investment for new survey, monitoring and experimental programs.
- Partly as a result of the above, soil-information gathering activities in many countries are currently funded through short-term government programs, private companies, individuals or in response to specific regulatory requirements. This does not produce the enduring, accessible and broadly applicable information systems that are needed to meet the requirements of stakeholders.

As stated in the World Soil Charter, policy makers should address the above challenges and ensure that national soil information systems are developed and maintained. They also need to ensure these systems are integrated with the global soil information system. These information systems need to include a capacity for monitoring the extent of sustainable soil management and the overall state of soil resources.

The challenge at the international level is to facilitate the compilation and dissemination of authoritative reports on the state of global soil resources and sustainable soil management. A coordinated effort is also needed to develop an accurate, high-resolution global soil information system and ensure its integration with other global Earth-observing systems.

Informing markets

A large number of markets involving soils will achieve greater efficiency and better resource allocation if they are reliably informed. This can range from traditional real estate markets having improved information on the capital value of soil resources (e.g. the nutrient status of a farm, presence of contaminants and options for improved soil management) through to formal markets for carbon stocks in soils and accurate assessments of risks for insurance purposes (e.g. crop insurance, environmental hazards).

Oversight and regulation of market activities is a central function of governments in most countries. The productivity and economic benefits from this policy pathway rely heavily on success with the first and second policy pathways. The key point-of-entry for policy makers is to ensure the availability of reliable soil information.

Appropriate incentives and regulation

The amount of regulation on land use and management varies substantially between countries depending largely on the degree of government intervention. Effective regulations on land use and management require a good information base for setting critical limits, for implementing zoning schemes and for monitoring compliance. While this may seem obvious, regulating soil management practices (e.g. application of manure, excessive use of fertilizers, control of dryland salinity) and implementing zoning systems (e.g. to protect the best agricultural soils) involves complex technical, institutional and policy challenges.

Countries that rely less on regulation often opt for incentive schemes to achieve related outcomes. This can range from subsidy systems (e.g. for fertilizer in poor countries or the purchase of equipment for conservation tillage in more industrialized countries) through to various forms of certification for the adoption of specified soil management practices (e.g. organic farming). Some of these systems have strong economic drivers because they are mandatory for market access (e.g. participation in supply chains to supermarkets).

Once again, the policy challenge depends heavily on organized systems for monitoring soil condition and for understanding the relationship with land management. Without this basic information, policy makers have no way of knowing whether their regulations and incentive schemes are achieving the desired result. Getting it wrong can be very expensive.

Ensuring intergenerational equity

Ensuring intergenerational equity is becoming more difficult as human pressures on soil resources reach critical limits. Most traditional cultures and systems of family farming have strong cultural norms that ensure tribal lands or family farms are passed to the next generation in the same or better condition than when they were inherited. However, dramatic changes to land management associated with industrial agriculture, the adoption of green revolution technologies and intensification of land use more generally, are having a major impact on soil resources (e.g. Table 8 and Section 10). The area of arable land per capita is decreasing sharply (0.45 ha in 1960, 0.32 ha in 1980 and a forecast of 0.22 ha in 2020) and it is obvious that the interests of future generations are not being protected.

Many countries have sophisticated reporting systems for assessing issues relating to intergenerational equity (e.g. long-term forecasts to determine the viability of pension and health systems). While scenario analysis and futures forecasting is a challenging activity, it is fundamental to national preparedness and long term sustainability. Policy makers do this as part of their normal business.

This policy pathway requires policy makers to factor into policy analysis the consequences of current trends in soil condition and natural resource scarcity.

Supporting local, regional and international security

It was noted in the introduction that further loss of productive soils will amplify food-price volatility and send millions of people into poverty. This human suffering has a range of associated risks include the potential for conflict and civil unrest. Land degradation and resource scarcity can play a role in the rise of conflicts, but these conflicts are rarely purely resource driven. Where tensions about access and use of natural resources do exist, they depend on a variety of factors – the outcomes of which may sometimes cascade from tension into violent conflict, but certainly not always. More often than not, natural resource degradation is a result of conflict rather than a cause. The existence of land degradation can also lead to cooperative solutions. The opportunity for policy makers and those responsible for soil governance is not only to help resolve resource conflicts, but also to prevent them and to find peaceful mutual relations.

There are many other dimensions to this policy pathway, however, the key point is that policy makers responsible for local, regional and international security need to consider the availability of soil resources and the capacity of countries to achieve food security. At present, seemingly simple tasks such as estimating the area of arable land and determining potential agricultural productivity in some countries is difficult because of the lack of basic information on soil resources.

Understanding interconnectedness and consequences

Achieving sustainable soil management and ensuring success with related policies (e.g. food security, conservation of biodiversity, climate change adaptation and mitigation) requires an understanding of the interconnectedness of policies and the consequences of interactions. While this is very well understood in most fields of economic, social and environmental policy, the understanding in relation to soil resources has come only recently. This is partly because soil-related issues have been viewed traditionally as local and occasionally national matters. However, a range of policy questions now require soils to be viewed within a global context. For example:

- Is there enough arable land with suitable soils to feed the world in coming decades?
- Are soil constraints partly responsible for the apparent yield plateau for major crops?
- How will climate change interact with the distribution of soils to produce new patterns of land use?

A comprehensive global view is also needed to deal with the trans-national aspects of food security and soil degradation. Because of trade, most urbanized people are protected from local resource depletion. The area of land and water used to support a global citizen is scattered all over the planet. As a consequence, soil degradation and loss of production are not just local or national issues – they are genuinely international.

International organizations, national governments and transnational industries have an interest in understanding how policy decisions in one domain, country or region have consequences elsewhere. The State of the World's Soil Resources Report provides some pertinent examples. For example, decisions on biofuel policy in the United States and Europe and their impacts on soil resources in South-East Asia; and the removal of trade barriers in New Zealand and the subsequent changes in land use and intensification of land management.

Cross-cutting issues

The policy issues outlined above provides a starting point for developing more effective policy responses. Most of the policy pathways are related to each other in various ways. Furthermore, there are cross-cutting policy issues that relate to all pathways. Most prominent is policy relating to science and technology. The Green Revolution demonstrated the power of agricultural science and technology, but also exemplifies the trade-offs required to focus on a single ecosystem service (food production) at the expense of others (e.g. water quality).

Contemporary science policy often focuses on impact and public benefit. In this regard, soil research is often considered simply as a means to an end. Although it is relevant to several important such 'ends' (e.g. agriculture, environment, water management and climate change), soil research is often overlooked in priority setting exercises. More formal recognition of soil resources as a cross-cutting issue in science policy is necessary to ensure it receives sufficient support.

11

The way forward

This is the first ever report on the status of the world's soil resources. The assessment is long overdue. The singular focus on soil has a simple but yet profound basis. Managed well, soil circulates chemical elements, water and energy for great human benefit. If soil is managed poorly, it is impossible to imagine an optimistic future.[50] In taking this view, we have framed our assessment within the broader perspective of land, ecosystem and Earth-system processes which are the domains of the United Nations Convention to Combat Desertification (UNCCD), Convention on Biological Diversity (CBD) and United Nations Framework Convention on Climate Change (UNFCCC) international treaties.

The assessment has synthesized the scientific knowledge embodied in more than 2 000 peer-reviewed scientific publications. In doing this, the ITPS has reached some disturbing conclusions. The current trajectories in soil condition have potentially catastrophic consequences that will affect millions of people in some of the most vulnerable regions over coming decades. More importantly, the global community is presently ill-prepared and ill-equipped to mount a proportionate response.

The ITPS is firmly of the view that countries can change current trajectories. The starting point is implementation of the actions outlined in the World Soil Charter, listed below:

Actions by Individuals and the Private Sector

- All individuals using or managing soil must act as stewards of the soil to ensure that this essential natural resource is managed sustainably to safeguard it for future generations.
- Undertake sustainable soil management in the production of goods and services.

Actions by Groups and the Science Community

- Disseminate information and knowledge on soils.
- Emphasize the importance of sustainable soil management to avoid impairing key soil functions.

Actions by Governments

- Promote sustainable soil management that is relevant to the range of soils present and to the needs of the country.
- Strive to create socio-economic and institutional conditions favorable to sustainable soil management by removal of obstacles. Ways and means should be pursued to overcome obstacles to the adoption of sustainable soil management associated with land tenure, the rights of users, access to financial services and educational programmes.
- Participate in the development of multi-level, interdisciplinary educational and capacity-building initiatives that promote the adoption of sustainable soil management by land users.
- Support research programs that will provide sound scientific backing for development and implementation of sustainable soil management relevant to end users.
- Incorporate the principles and practices of sustainable soil management into policy guidance and legislation at all levels of government, ideally leading to the development of a national soil policy.
- Explicitly consider the role of soil management practices in planning for adaptation to and mitigation of climate change and maintaining biodiversity.
- Establish and implement regulations to limit the accumulation of contaminants beyond established levels to safeguard human health and well-being and facilitate re-mediation of contaminated soils that exceed these levels where they pose a threat to humans, plants and animals.
- Develop and maintain a national soil information system and contribute to the development of a global soil information system.
- Develop a national institutional framework for monitoring implementation of sustainable soil management and the overall state of soil resources.

Actions by International Organizations

- Facilitate the compilation and dissemination of authoritative reports on the state of the global soil resources and sustainable soil management protocols.
- Coordinate efforts to develop an accurate, high-resolution global soil information system and ensure its integration with other global earth observing systems.
- Assist governments, on request, to establish appropriate legislation, institutions, and processes to enable them to mount, implement and monitor appropriate sustainable soil management practices.

More specifically, the ITPS draws attention to the priorities outlined in the plans of action for the Pillars of the Global Soil Partnership.[51]

These are key steps towards:

- **a dramatic improvement in our observation and forecasting systems** for determining when and where soil function is being compromised (Pillars 4 and 5);
- **implementation of sustainable soil management** across large regions with urgent priority being given to regions where livelihoods are vulnerable and heavily dependent on subsistence agriculture (Pillars 1, 2 and 3);
- **improved governance** and the **development** of more effective institutional arrangements for the implementation of sustainable soil management (starting with the preparation of voluntary guidelines) (Pillars 1 and 2);
- **mobilization of resources and the training** of a new generation of soil specialists (Pillars 1 to 4).

The International Year of Soils in 2015 will be remembered in the coming decades as the year when the challenges confronting the world's soils was clearly articulated. We hope that substantial progress will have been made to address the issues that have been identified by the time the second Status of the World's Soil Resources report is published in 2020.

References to sections, figures and tables in the main report

[1] Section 5.1.1
[2] Sections 5.4 and 7.2
[3] Section 5.1.2
[4] Sections 5.6 and 6.2.7
[5] Section 7.2
[6] Section 7.2
[7] Section 7.2
[8] Section 7.2
[9] Section 6.1.10
[10] Figure 6.124
[11] Section 6.8.3
[12] Section 6.8.4
[13] Section 7.2
[14] Section 7.2
[15] Section 7.2
[16] Section 6.7
[17] Figure 6.4.1
[18] Section 6.4.4
[19] Section 10.3.3
[20] Section 6.5.1
[21] Section 6.5
[22] Section 6.10.5
[23] Section 6.1.5
[24] Section 6.1.5
[25] Figure 7.2
[26] Section 4.3.1
[27] Section 4.3.1
[28] Section 6.2.6
[29] Section 6.2.6
[30] Section 4.3.1
[31] Section 7.3.3
[32] Section 7.3.3
[33] Section 7.3.3
[34] Section 7.3.2
[35] Section 7.5
[36] Section 4.3.3
[37] Section 4.3.3
[38] Section 4.4.2
[39] Section 4.4.2
[40] Section 4.4.2
[41] Section 5.5 Figure 5.3 and Box 5.1
[42] Section 2.4
[43] Section 7.8
[44] Section 7.8
[45] Section 4.3.2
[46] Section 4.3.2
[47] Section 2.4
[48] Reference to the table of countries in the full report.
[49] Reference to the table of countries in the full report.
[50] Richter D.D. & Markewitz D. 2001. 'Understanding soil change.' Cambridge, Cambridge University Press.
[51] The five pillars of the Global Soil Partnership are as follows:

- Pillar 1: Promote sustainable management of soil resources for soil protection, conservation and sustainable productivity
- Pillar 2: Encourage investment, technical cooperation, policy, education awareness and extension in soil
- Pillar 3: Promote targeted soil research and development focusing on identified gaps and priorities and synergies with related productive, environmental and social development actions
- Pillar 4: Enhance the quantity and quality of soil data and information: data collection (generation), analysis, validation, reporting, monitoring and integration with other disciplines
- Pillar 5: Harmonize methods, measurements and indicators for the sustainable management and protection of soil resources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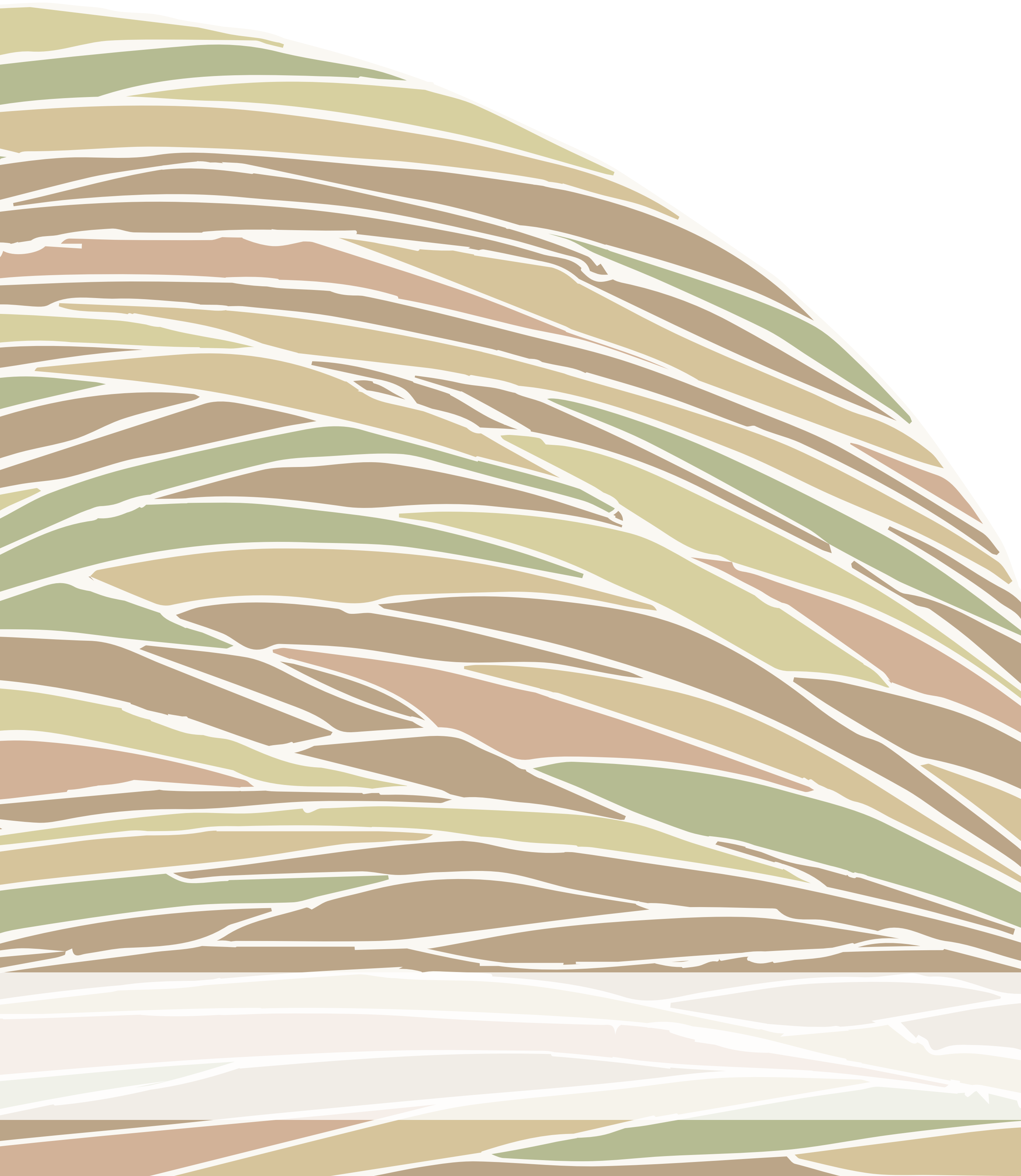

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