Voluntary Guidelines for Sustainable Soil Management

Zero Draft
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Note: Throughout the document italicized text is quoted from other sources and hence cannot be edited

1.0 Sustainable Soil Management

1.1 Introduction

The United Nations designated 2015 as the International Year of Soil and the many activities held throughout the year highlighted the central importance of soils to human wellbeing and ecosystem health. The heightened public awareness of the contributions of soil complemented the institutional frameworks developed under the Global Soil Partnership (established in 2012) and its scientific advisory body, the Intergovernmental Technical Panel on Soils (ITPS, established in 2013).

The major objective of the Global Soil Partnership is to promote and support the global adoption of sustainable soil management practices. This objective is integral to the five Pillars of Actions of the Global Soil Partnership.

To support the work of the Pillars, the ITPS developed two key documents. The revised World Soil Charter [1] is a statement of principles that defines sustainable soil management and specifies a series of actions to be undertaken by stakeholders to facilitate its adoption.

Of greatest relevance to these guidelines, the World Soil Charter states that:

> *The overarching goal for all parties is to ensure that soils are managed sustainably and that degraded soils are rehabilitated or restored.*

The current state of soil degradation was examined in The Status of the World's Soil Resources report [2,3], which provided a comprehensive summary of the current state of the global soil resource relative to ten major threats to soil functioning. The regional summaries (Appendix 2) contained within the Status of the World's Soil Resources report present a generally worrying picture of the current state of global soil resources – threats such as soil erosion and organic matter loss continue to degrade soil functions in most regions. Hence accelerated efforts must be made to facilitate the adoption of sustainable soil management at all levels.

Sustainable soil management will be especially relevant to the achievement of Sustainable Development Goals 2 and 15.

> ***Goal 2. End hunger, achieve food security and improved nutrition, and promote sustainable agriculture***
>
> *2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters, and that progressively improve land and soil quality.*
>
> ***Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss***
>
> *15.3 By 2030, combat desertification, and restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land-degradation neutral world.*

Goal 2 recognizes that food security and nutrition requires establishment of effective sustainable agricultural production, which, in turn, is impossible without maintenance of soil functions. The latter can be provided only under sustainable soil management practices that would ensure stable or increasing production from arable lands, pastures and forestry systems (including agroforestry). Combating soil degradation requires introduction of sustainable soil management systems that reflects the challenges of Goal 15.

1.2 Scope of the Guidelines

In its December 2015 session, the FAO Council noted with satisfaction the process underway for the development of Voluntary Guidelines for Sustainable Soil Management and encouraged the Global Soil Partnership to pursue its work on the proposed way forward for the finalization of draft voluntary guidelines.

The (proposed) scope of the VGSSM is:

- The guidelines will be of voluntary nature and will not be legally binding.

- The guidelines will focus on technical and biological aspects, while facilitating eventual strategic choices.

- The guidelines will address sustainable management of soils in all types of agricultural systems and the maintenance or enhancement of the ecosystem services they provide.

- The voluntary guidelines for SSM will be globally relevant without entering into details of specific actions at the local scale – principle 6 of the World Soil Charter clearly indicates that the development of specific measures appropriate for adoption by decision makers requires multi-level, interdisciplinary initiatives by many stakeholders.

- The global scope of the proposed guidelines will complement the Status of the World's Soil Resources report, which provides a source of locally-specific examples of soil management and information. It also complements existing regionally focused documents such as TerraAfrica's (2011) guidelines and best practises for sustainable land management in Sub-Saharan Africa [4].

Thus, the guidelines will be, as far as possible, an easily accessed and readily understood document that provides guidance and informs decision-making at higher levels and encourages implementation of SSM at local levels. A wide variety of stakeholders – ranging from policy developers, government officials, extension officers, farmer associations, private investors and others – will be able to appropriately use these guidelines.

1.3 Objectives

The objectives of the voluntary guidelines are:

- to compile generally accepted and scientifically grounded principles of sustainable soil management;
- to provide guidance to governments and all stakeholders on how to apply the World Soil Charter principles for implementing sustainable soil management practices;

2. Scientific Basis for Sustainable Soil Management

2.1 Definition of sustainable soil management

The definition of sustainable soil management used in these guidelines is drawn from the revised World Soil Charter:

> *Principle 3: 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. The balance between the supporting and provisioning services for plant production and the regulating services the soil provides for water quality and availability and for atmospheric greenhouse gas composition is a particular concern.*

The range of soil functions and ecosystem services of greatest relevance to agriculture are shown in Table 1.1:

Table 1.1: Ecosystem services provided by the soil of greatest relevance to agriculture and the soil functions that support these services [3].

Ecosystem service	Soil functions
Supporting services : Services that are necessary for the production of all other ecosystem services; their impacts on people are often indirect or occur over a very long time	
Soil formation	• Weathering of primary minerals and release of nutrients; modification of soil texture • Transformation and accumulation of organic matter • Creation of structures (aggregates, horizons) for gas and water flow and root growth • Creation of charged surfaces for ion retention and exchange
Primary production	• Medium for seed germination and root growth • Retention and supply of nutrients and water for plants
Nutrient cycling	• Transformation and mineralization of organic materials by soil organisms • Retention and release of nutrients on charged surfaces
Regulating services: benefits obtained from the regulation of ecosystem processes	
Water quality regulation	• Filtering and buffering of substances in soil water • Transformation of contaminants
Water supply regulation	• Regulation of water infiltration into soil and water flow within the soil • Drainage of excess water out of soil and into groundwater and surface water
Climate regulation	• Regulation of CO_2, N_2O, and CH_4 emissions • Carbon sequestration
Erosion regulation	• Retention of soil on the landsurface
Provisioning Services: products (“goods”) obtained from ecosystems of direct benefit to people.	
Food supply	• Providing water, nutrients, and physical support for growth of plants for human and animal consumption
Water supply	• Retention and purification of water
Fibre and fuel supply	• Providing water, nutrients, and physical support for plant development for bioenergy and fibre
Refugia	• Providing habitat for soil animals, birds etc.
Genetic resources	• Source of unique biological materials

Cultural services: nonmaterial benefits people obtain from ecosystems through spiritual enrichment, aesthetic experiences, and heritage preservation, and recreation.	
Aesthetic and spiritual	• Preservation of natural and cultural landscape diversity

2.2 Management impacts on soil functions and ecosystem services

Soils differ widely in their inherent ability to deliver ecosystem services, their response to management, their ability to resist disturbance (i.e., soil resistance), and their ability to recover after a disturbance has occurred (i.e., soil resilience).

The diversity of soil is captured in two principles of the World Soil Charter:

> *Principle 2: Soils result from complex actions and interactions of processes in time and space and hence are themselves diverse in form and properties and the level of ecosystems services they provide. Good soil governance requires that these differing soil capabilities be understood and that land use that respects the range of capabilities be encouraged with a view to eradicating poverty and achieving food security.*

> *Principle 5: The specific functions provided by a soil are governed, in large part, by the suite of chemical, biological, and physical properties present in that soil. Knowledge of the actual state of those properties, their role in soil functions, and the effect of change – both natural and human-induced—on them is essential to achieve sustainability.*

Achievement of good soil governance requires both that information about the capability of the soil be available and that decisions on land use options consider that information.

Given the global diversity of soils and of agricultural management practices there are many pathways to achieving sustainable soil management; however at the end of each pathway, agricultural soils with a common set of characteristics can be found.

1) They have a stable soil surface.
2) They have sufficient organic cover (from growing plants including crops, pastures and forests and their residues) to stabilize the soil surface and provide organic materials for creation and build-up of soil organic matter and nutrient cycling.
3) The flow of nutrients within these soils is sufficient and efficient – sufficient for high rates of biomass production relative to the limits set by climate and supplementary water sources, and efficient insofar as leakage of nutrients by leaching, gaseous emissions, erosion etc. is low.
4) The organisms in these soils provide the full range of biological functions required for nutrient cycling and material transformations.
5) They efficiently capture precipitation and supplementary water (i.e., through irrigation) and balance retention of sufficient plant-available water and drainage of excess water.

6) They neutralize any added pollutants such that they do not reach levels that affect plant productivity, groundwater quality or compromise food safety.

A final, overarching characteristic of a sustainably managed agricultural soil is that the soil is not wholly transformed to another use – for example, through its surface being sealed by asphalt to construct a roadway or parking lot or stripping of the soil and sub-soil for resource extraction. In these cases the ability of the soil to function and provide ecosystem services of relevance to agriculture and water cycling is essentially eliminated.

In a sustainably managed soil all of these characteristics must be present simultaneously – the absence of any one of them will undermine essential soil functions and reduce the ecosystem services provided by soil. Since the VGSSM are designed to be a stand-alone document, it is important to briefly review each of these characteristics and the effect of management on them; this forms a preface for the guidelines in the following section.

Surface Soil Stability

A stable soil surface indicates that the rates of soil erosion by water, wind, and tillage have been reduced by sustainable management to the minimum possible under the soil, terrain, and climatic conditions in which the soil occurs.

The harmful effects of soil erosion on soil functions and the ecosystem service provided by the soil are well documented.

- Erosion removes the organically enriched surface soil layers (the "topsoil") and truncates soil horizons, reducing the depth of soil that plants can exploit and bringing potentially growth-limiting subsoil into the rooting zone.
- The removal of materials from the soil surface reduces the organic and mineral nutrient pool available for microbial processing and plant uptake and reduces the soil organic carbon store of the soil.
- Sedimentation of soil within the field causes crop burial and over-thickening of surface soil layers in depositional areas of the field.
- Transport of eroded soil and associated nutrients into surface waterways causes major problems with sedimentation, turbidity, and harmful nutrient enrichment leading to eutrophication.

Sufficient Organic Cover

An organic cover can be provided by growing plants or by plant and other organic residues.

The contribution of an organic cover to ecosystem services is multi-faceted:

- It is well established that a sufficient organic cover reduces the erosive power of raindrops and of wind on the soil surface and hence substantially reduces soil erosion rates.
- Surface residues reduce the flow velocity of surface water, reducing its erosive power and enabling infiltration of water into the soil.
- The residues left behind after harvest, both above- and below-ground, are the essential precursors to soil organic matter. Microbial decomposition of residues provides energy for microbial growth and converts organic compounds to plant-available nutrients. The microbial biomass and transformed organic materials are key elements of the soil organic carbon stores and the regulation of CO_2 emissions to the atmosphere.
- Fresh and partially decomposed residues and plant roots contribute to formation of soil aggregation and hence to the flow of water and gases within the soil and the creation of a supportive rooting medium.
- Residues moderate soil temperature extremes that otherwise may affect plant growth and cause excessive mineralization of soil organic matter and evaporation of soil water

Flow of nutrients within the soil is sufficient and efficient

The concepts of sufficiency and efficiency address both sides of the problem of nutrient dynamics in the soil-water-plant roots continuum. In some regions there is a gap between the yields presently being achieved and the optimum yields that would be possible to achieve if nutrient limitations and imbalances were removed. In other regions, yields are at or close to the climatically imposed maximum but nutrients are being added at rates beyond what can be efficiently utilized by plants, and a series of environmental problems results.

The benefits of a sufficient and balanced flow of nutrients to meet plant demands are well established:

- Production of food, fibre, and fodder at levels at or close to the climatically preconditioned maximum for the region.
- Production of sufficient surface residue cover for surface protection and stabilization.
- Production of sufficient above- and below-ground organic residues for maintenance and enhancement of the internal nutrient cycle within the soil.

The consequences of excess nutrient additions have been widely documented:

- Transfer of excess nutrients (especially nitrogen and phosphorus) from agricultural fields to surface waterways and subsequent widespread deterioration of surface water quality due to eutrophication and related water quality issues.
- Enhanced release of the potent greenhouse gas, nitrous oxide, from agricultural soils to the atmosphere. Emissions of nitrous oxide from

agricultural soils are estimated to have increased 10-fold from 1961 to 2010.

- Transfer of mobile forms of nitrogen to groundwater by leaching from the soil, contributing to human health issues, especially in infants.
- Acidification of soils and related productivity decreases associated both with additions of acidic N fertilizers to agricultural soils, uptake of base nutrients by plants, and use of the N-fixing crops in crop rotations.
- Significant release of carbon dioxide is associated with the energy-intensive fixation of atmospheric nitrogen in the production of synthetic nitrogen fertilizers.

The organisms in the soil provide the full range of functions required for nutrient cycling and material transformations.

Soil organisms (e.g. bacteria, fungi, protozoa, insects, worms, other invertebrates and mammals) make up one of the largest reservoirs of biodiversity on earth. Essential services provided by soil biota include: regulating nutrient cycles and the dynamics of soil organic matter; supporting soil carbon sequestration; regulating greenhouse gas emissions; modifying soil physical structure and soil water regimes; enhancing the efficiency of nutrient uptake by plants through symbiotic associations and both nitrogen fixation and solubilization of phosphorus ; and influencing plant and animal health through the interaction of pathogens and pests with their natural predators and parasites.

Our understanding of the relationships between biodiversity and specific soil functions is limited but the availability of a variety of new tools suggests that significant progress in this area may be imminent. Given the significant public concerns about the possible linkage between pesticide use and biodiversity, a focus in this area is to draw attention of users to existing international codes for pesticide use.

The soil efficiently captures precipitation and supplementary water (i.e., through irrigation) and balances retention of sufficient plant-available water and drainage of excess water.

Optimum growth of most plants occurs when roots can access both oxygen and water in the soil. A sustainably managed soil must therefore allow adequate water infiltration, efficient drainage when saturated to allow air to reach plant roots, and optimum retention and redistribution of water for plant use. Rapid water infiltration also minimizes surface runoff, thereby reducing the risk of water erosion and associated off-field transport of agricultural chemicals. At a catchment and basin scale, the capacity of the soil to infiltrate water attenuates stream and river flows and can prevent flooding, while water that percolates through soil replenishes groundwater and maintains river discharge.

The beneficial contributions to the water cycle provided by soil functions are affected by several major threats.

- Soil compaction (i.e., the loss of soil pore space due to pressure at the soil surface or dispersion of soil particles caused by sodicity development) reduces the infiltration capacity of the soil and gas and water flow within the soil.
- Sub-soil compaction or the development of a rock-like layer of calcium minerals can also contribute to soil waterlogging, where the absence of oxygen in the soil pore space causes reductions in plant growth and can lead to higher emissions of potent greenhouse gases such as nitrous oxide and methane.
- Waterlogging also results from poorly implemented drainage programs where the addition of water exceeds the capacity of the soil to efficiently drain the excess water from the rooting zone.
- The addition of salts from irrigation water is also one of the major causes of human-induced salinization of soils.
- Finally soil sealing can fundamentally change the soil surface and eliminate any water infiltration into the soil whatsoever.

Physical soil deterioration due to soil compaction is not limited to cropland but is also prevalent in rangelands and grazing fields, and even in natural non-disturbed systems. Soil compaction occurs when sensitive soils are subjected to pressure—e.g. in forest harvesting, amenity land use, pipeline installation, land restoration, wildlife trampling or over-grazing. Trampling by animals disrupts soil aggregates and reduces aggregate stability, and its effect increases with stocking intensity.

Human modifications to the water cycle can aid soil function. In dry climate conditions, inadequate soil moisture can be mitigated through supplementary irrigation, and where excessive precipitation causes problems, waterlogging can be relieved by land drainage. However, irrigation and drainage can have consequences for water regulation services. Irrigation that enables a shift to intensive land use can increase the sediment and contaminant load of runoff, the contaminant load of drainage water and can also result in salinization of the soil. Furthermore, drainage of wetland soils has been shown to reduce water, sediment and contaminant storage capacity in the landscape and can increase the potential for downstream flooding and upstream vulnerability to drought.

Poor management of land and water resources is also the main factor responsible for the development of human-induced saline soils. The main causes are as follows:

- Inadequate (or lack of) drainage systems associated with irrigation schemes, which can cause a rise of the groundwater table until it intersects the root zone of plants. This causes waterlogging in the rooting zone and, where sufficient salts are present in the water, contributes to salinization of soils.

- The use of brackish water for irrigation, especially where continuous irrigation has occurred over very long periods such as in the Near East and North Africa.
- The intrusion of seawater into coastal areas due to over-extraction of freshwater from coastal aquifers with the absence of induced recharge.
- Replacement of deep-rooted perennial vegetation with shallower rooted annual crops and pastures that use less water, leading to the rise of saline groundwater (i.e., dryland salinity).

The soil filters and neutralizes any added pollutants so they do not reach levels that affect plant productivity or compromise food safety.

Soil contamination reduces food security both by reducing yields of crops due to toxic levels of contaminants and produce crops that are unsafe to consume. The importance of action on this issue is highlighted in Target 12.4 of the Sustainable Development Goals:

By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment.

Local soil contamination occurs from point sources where intensive industrial activities, inadequate waste disposal, mining, industrial and commercial activities, military activities or accidents such as transport spills on land introduce excessive amounts of contaminants.

Diffuse soil contamination is the presence of a substance or agent in the soil as a result of human activity and emitted from dispersed sources. The three major pathways responsible for the introduction of diffuse contaminants into soil are atmospheric deposition, agriculture, and flood events (through deposition of sediments). Diffuse soil contamination is harder to manage than local contamination: in many instances it is not directly apparent but it may cover very large areas and represent a substantial threat.

The area of current agricultural soils is maintained.

The continued availability of productive land for agricultural production should be a high priority in land use planning. Land take and soil sealing are growing threats to the continued availability of land for agriculture. Soil sealing and land take cause a largely irreversible loss of some or all soil functions and the ecosystem services they provide.

Land take covers all forms of conversion for the purpose of settlement including the development of scattered settlements in rural areas, the expansion of urban areas around an urban core, the conversion of land within an urban area (densification), and the expansion of transport infrastructure such as roads, highways and railways.

Some proportion of the land taken will be subjected to soil sealing. Soil sealing is the permanent covering of an area of land and its soil by impermeable artificial material such as asphalt or concrete, for example through buildings and roads.

3. Guidelines for Sustainable Soil Management

The guidelines for sustainable soil management are informed by two key principles from the World Soil Charter that directly relate to the maintenance and, if necessary, restoration of soil functions in agricultural soils:

> *Principle 8: Soil degradation inherently reduces or eliminates soil functions and their ability to support ecosystem services essential for human well-being. Minimizing or eliminating significant soil degradation is essential to maintain the services provided by all soils and is substantially more cost-effective than rehabilitating soils after degradation has occurred.*
>
> *Principle 9: Soils that have experienced degradation can, in some cases, have their core functions and their contributions to ecosystem services restored through the application of appropriate rehabilitation techniques. This increases the area available for the provision of services without necessitating land use conversion.*

<u>3.1 Guidelines for the preservation of agricultural soils</u>

- Governments and policy makers need to review and adapt existing policies for development of settlements and infrastructure to take account of the value of soils, particularly where subsidies or other incentives are driving unplanned land take and soil. Wherever possible, preservation of productive agricultural land should be a priority.

- Where policy aims to minimize land take, measures should be implemented by decision makers to encourage re-use of existing urban areas such as derelict areas, brownfields and upgrading of degraded neighborhoods after appropriate reclamation measures have been implemented. Measures promoting densification of existing urban areas can also contribute to the reduction of land take.

<u>3.2 Guidelines for creation of a stable soil surface through control of soil erosion</u>

- At the field scale, tillage and residue management techniques (e.g. conservation tillage and no-till) that provide sufficient organic cover to protect the soil surface and minimize direct movement of soil by tillage implements should be adopted by soil users.

- In grazing lands, especially on steep slopes, minimizing the creation of bare soil and ensuring sufficient organic cover by reducing stocking rates on vulnerable land.

- At the watershed scale, soil erosion control measures that reduce the volume and velocity of runoff and/or reduce the slope of the land surface itself such as terracing or construction of mini-catchments should be implemented. These measures should be coupled with field-scale measures to improve soil cover through residue management or use of cover crops. Annual cropping should be discouraged on soils that are particularly vulnerable to erosion.

3.3 Guidelines for maintenance and enhancement of a sufficient organic cover

- Plant growth on the field should produce enough growing plants and plant residues for a sufficient cover to exist.

- Sufficient crop and other organic residues must be left on the field and not removed for other purposes (e.g. fodder, fuel, infrastructure etc.).
- When clearing of vegetation for land use conversion occurs, ensuring that the method used maintain an organic cover on the soil.

- When mechanized tillage is used for field operations, the implements used must leave a proportion of the plant residues on the soil surface (i.e., conservation tillage or no-till).

3.4 Guidelines for addressing nutrient imbalance

- In all agricultural soils, the efficiency of plant uptake of nutrients should be increased. The scope for improvement in nutrient-use efficiency is great—for example, a recent study indicates global nitrogen use efficiency is only 38% for crop production and 11% for animal production when N inputs from all sources are considered [5].

- In regions where persistent nutrient limitations to crop growth occur, enhanced plant nutrition should be adopted through balanced measures that include precise and judicious use of organic amendments (i.e., liquid, semi-solid or solid manures, crop residues, biochar, compost, feces dropped by animals, and household refuse), inorganic fertilizers and crop rotations with N-fixing plants.

- In regions where excess nutrient loads have been or continue to be added to the land surface, measures should be undertaken to assess the available nutrient pool relative to crop demand, retain these nutrients in the soil and prevent their release to waterways and the atmosphere. The restoration of riparian buffers and of wetlands plays an important role in this, as does the use of cover crops where appropriate.

- Soils that have low resistance to acidification (i.e., inherently low-pH soils such as ancient, highly weathered soils) should have sufficient lime and or gypsum added to offset the acidification from fertilizers, product removal, and other sources.

3.5 Guideline for maintenance or enhancement of soil biodiversity

- The authorization and use of pesticides in agricultural systems should follow the recommendations included in the International Code of Conduct on Pesticide Management [6].
- Maintenance or enhancement of soil organic matter levels through the provision of a sufficient organic cover, optimum nutrient additions, addition of diverse organic amendments, and minimization of surface disturbance should be practiced.

3.6 Guideline for maintenance or enhancement of soil physical properties

Managing soil compaction can be achieved through appropriate application of some or all of the following techniques:

- An adequate amount of soil organic matter should be maintained to improve and stabilize soil structure.

- Vehicular traffic should be minimized to the absolutely essential by reducing the number and frequency of operations, and by performing farm operations only when the soil moisture content is suitable.

- Surface disturbance and destruction of aggregation by tillage operations should be minimized through adoption of reduced tillage or no-till.

- Rotations should be selected that include crops, pasture plants and, where appropriate, agroforestry crops with strong tap roots able to penetrate and break down compacted soils.

- In grazing systems, a sufficient cover of growing plants should be maintained to protect the soil from trampling and erosion; cattle stocking is a key factor to be managed.

- Macrofauna and microbial (especially fungal) activity should be promoted to create of pores and channels for water infiltration and root growth.

- Mechanical loosening such as deep ripping should be applied where soils have been previously compacted to growth-limiting levels.

3.7 Guidelines for efficient use of irrigation water and minimization of soil salinization

- Efficiency of irrigation water use by plants should be increased through improved conveyance, distribution, and field application methods.

- Surface and sub-surface drainage systems should be installed and maintained to control rising groundwater tables and control soil salinity. The design of these systems needs to be based on a thorough understanding of the water balance in these areas.

- Reclamation of saline soils can be achieved using a variety of techniques. These include: (1) direct leaching of salts; (2) planting salt tolerant varieties; (3) domestication of native wild halophytes for use in agro-pastoral systems; (4) phytoremediation (bioremediation); (5) chemical amelioration; and (6) the use of organic amendments.

3.8 Guidelines for neutralization of soil contamination

- *Governments should establish and implement regulations to limit the accumulation of contaminants beyond established levels to safeguard human health and well-being and facilitate remediation of contaminated soils that exceed these levels where they pose a threat to humans, plants, and animals* (*Action VII for Governments from World Soil Charter*).

- Management of local soil contamination requires surveys to seek out sites that are likely to be contaminated, site investigations where the actual extent of contamination and its human and environmental impacts are defined, and implementation of remedial and after-care measures.

- Soils that are the most susceptible to the harmful effects of diffuse pollutants (e.g. acidification due to atmospheric deposition on highly weathered ancient soils) should be identified and special measures undertaken to reduce atmospheric deposition of pollutants onto these soils.

Successful achievement of sustainable soil management requires that the specific management approaches selected for a given soil are well adapted to the inherent properties of the soil and its likely response to management. This requirement is consistent with principles 2 and 5 from the World Soil Charter. Therefore a final guideline is required:

3.9 Guideline for the creation and application of soil information

- The selection of specific sustainable management techniques to be applied to a soil should be informed by the highest level of knowledge available about the current state of the soil and its likely response to changes in management. This knowledge should be drawn from many sources including national soil survey programs, the soil science research community, and, most importantly, from local users of the soil. The compilation and dissemination of this information is a critical task for extension specialists.

4.0 Sustainable Soil Management for Sustainable Crop Production Intensification

In 2011 the FAO set out a blueprint for farming systems suitable for sustainable crop production intensification [7]. These systems offer a range of productivity, socio-economic and environmental benefits, including high and stable production and profitability; adaptation and reduced vulnerability to climate change; enhanced ecosystem functioning and services; and reductions in agriculture's greenhouse gas emissions and "carbon footprint".

The farming systems they outline are based on three technical principles:

- simultaneous achievement of increased agricultural productivity and enhancement of natural capital and ecosystem services;
- higher rates of efficiency in the use of key inputs, including water, nutrients, pesticides, energy, land and labour;
- use of managed and natural biodiversity to increase the resistance of the system to stresses.

The farming practices required to implement those principles will differ according to local conditions and needs. However, in all cases they will need to use three important practices:

1. minimize soil disturbance by minimizing mechanical tillage, which maintains soil organic matter, soil structure and overall soil health;

2. enhance and maintain a protective organic cover on the soil surface, using crops, cover crops or crop residues, which protects the soil surface, conserves water and nutrients, promotes soil biological activity and contributes to integrated weed and pest management;

3. cultivate a wider range of annual and perennial plant species (including trees, shrubs, pastures and crops) in associations, sequences and rotations that can include, which enhances crop nutrition and improves the ability of the system to recover from disturbances.

In order to achieve the sustainable intensification necessary for increased food production, these three practices need to be supported by four additional management practices [8]:

4. enhanced crop nutrition based on healthy soils, through crop rotations and judicious use of organic and inorganic fertilizer;

5. the use of well adapted, high-yielding varieties with resistance to biotic and abiotic stresses and improved nutritional quality;

6. integrated management of pests, diseases and weeds using appropriate practices, biodiversity and selective, low risk pesticides when needed;

7. efficient water management, by obtaining "more crops from fewer drops" while maintaining soil health and minimizing off-farm externalities.

These practices are entirely consistent with the guidelines for sustainable soil management presented above.

Ideally these field-scale measures are coupled with relevant practices at other scales [8], including:

8. farm-scale management of diversified annual and perennial vegetation, and of water resources including natural water bodies, wetlands, wells, and water harvesting structures; and

9. community- to landscape-scale management of cultivated areas in relation to water resources and associated non-cultivated land areas such as private or community forests, woodlots, grazing areas, and protected areas.

Although some farming systems have successfully adopted some or all of the requirements for Conservation Agriculture, significant impediments exist in many regions to their adoption. Recent reviews [8,9] have suggested that the issue of a sufficient organic cover to protect the surface and provide the precursors of a robust internal nutrient cycle is the greatest impediment to adoption.

Insufficient production of plant material for a protective cover occurs for many specific reasons, but two broad categories exist. In the first, plant growth is chronically insufficient due to a soil-related deficiency – for example, insufficient or imbalanced plant nutrients, chronic water deficiency, or a limiting soil chemical condition such as salinity or high acidity. In this case the lack of plant production can be addressed by enhancing productivity as discussed above.

In the second category, plant growth is limited due to unpredictable event or events – for example, drought, flooding or storms, insect infestation, or plant disease. In some cases it may be possible to adopt targeted measures to address the specific causes of limited organic cover, but more often the response of the soil will depend on its inherent resistance to disturbance. Limiting cropping on soils that have inherently low resistance to disturbance or that lack the ability to recover after disturbance is one way of minimizing the effect of these catastrophic events.

The major constraint to leaving organic residues on the soil surface is the competing uses for residues and other organic material, including their use as fodder for livestock, as fuel, and as building materials [8,9]. These competing uses contribute in obvious ways to human well-being, whereas the benefits of residue cover in erosion control and the creation of soil organic matter are largely invisible and occur over a long term. Residue retention will occur only if alternative sources of fodder, fuel, or building materials are made available and affordable to users.

Conservation tillage or no-till systems have been widely adopted in some cropping systems but conventional tillage (i.e., where crop residues are incorporated into the soil) remains dominant in others. Concerns about yield reductions under no-till systems account for some of the lack of adoption – a recent meta-analysis found that yields under no-till are close to or slightly above those under conventional tillage for oilseeds, cotton, legumes, and some cereals but are substantially lower for maize and root crops [10]. The loss of yield under no-till compared to conventional tillage is greater in subtropical and tropical areas than in drier regions. Adoption of reduced tillage in these regions will be limited unless means can be found to minimize the yield losses associated with them. Assessment of the suitability of soils for reduced tillage and the identification of constraints to adoption is a useful starting point in regions where adoption has been limited.

5.0 Communication, Outreach, Advocacy, Promotion, Monitoring and Evaluation

The major mechanism for dissemination and implementation of these guidelines is through the Global Soil Partnership. The five GSP pillars of action and associated implementation plans constitute a platform for promoting these guidelines.

6.0 Citations

[1] Food and Agriculture Organization. 2014. Revised World Soil Charter. Available at http://www.fao.org/fileadmin/user_upload/GSP/docs/ITPS_Pillars/annexVII_WSC.pdf.

[2] Food and Agriculture Organization and Intergovernmental Technical Panel on Soils. Status of the World's Soil Resources. Technical Summary. 94 pp. Available at http://www.fao.org/documents/card/en/c/39bc9f2b-7493-4ab6-b024-feeaf49d4d01/.

[3] Food and Agriculture Organization and Intergovernmental Technical Panel on Soils. Status of the World's Soil Resources. Main Report. 650 pp. Available at http://www.fao.org/documents/card/en/c/c6814873-efc3-41db-b7d3-2081a10ede50/.

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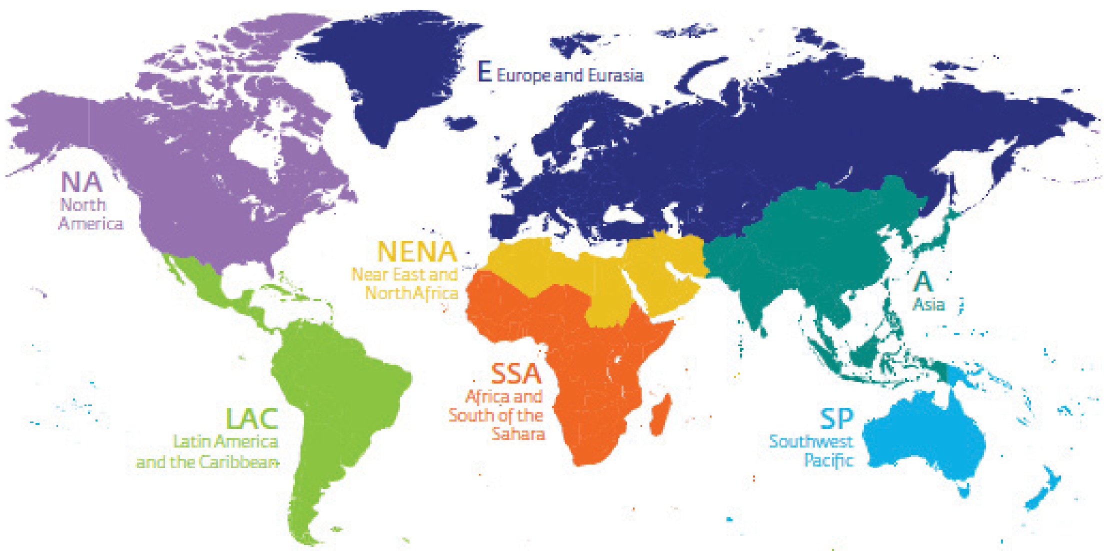
Appendix 1: Glossary

Appendix 2: Regional Summaries of Threats to Soil Functions

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 ↙