B7 Sustainable soil and land management for CSA

Overview

This module looks at sustainable soil and land management in the context of climate change. It provides technical knowledge on the concepts of sustainable soil management and examines how wide-scale implementation of climate-smart soil and land management practices could enhance climate change adaptation and mitigation. The module also highlights the types of institutions and policies that are important for supporting the broader adoption of sustainable soil and land management practices.

Chapter B7-1 provides an overview of the benefits that can be gained from the successful implementation of sustainable soil and land management practices by increasing the contribution soils can make to building resilient agricultural ecosystems capable of coping with the impacts of climate change and mitigating these impacts. Chapter B7-2 describes the modalities for the adaptive planning of soil and land resources, and how to select the most appropriate practices for a given context based on the assessment of soil and land resources; provides examples of sources of technical information for decision-makers at different levels; and presents tools to enhance the effectiveness of measure to implement and scale up sustainable soil and land management practices. Chapter B7-3 looks at soil and land management practices that support climate change adaptation and mitigation by sequestering carbon sequestration in the soil, reducing greenhouse gas emissions and intensifying production. Expanding the uptake of climate-smart sustainable soil and land management practices requires not only technical knowledge, but also a supportive enabling environment. Chapter B7-4 offers some thoughts on how to create this enabling environment and remove the barriers to the expansion of climate-smart sustainable soil and land management.

Key messages

- Knowing the status and the potential of soil and land resources is fundamental for making decisions about sustainable soil and land management practices that can contribute to climate-smart land use.
- Soils that have been degraded are at much greater risk from the damaging impacts of climate change. Land degradation itself is a driver of climate change and exacerbates its impacts. The rehabilitation of degraded soils, which can be achieved by enhancing soil organic carbon and soil biodiversity, avoiding soil compaction and reducing soil erosion, provides a major opportunity for mitigating climate change.
- The proper selection of sustainable soil and land management options for a given agricultural production system provides an opportunity to implement measures that strengthen climate change adaptation and mitigation and build the resilience of the agricultural ecosystem.
- Integrated soil and land management practices can create optimal conditions for the sustainable production of food, fibre, fodder, bio-energy, tree crops, and livestock, and safeguard or enhance the ecosystem services agricultural production systems depend on.
- The successful implementation of sustainable soil and land management measures requires a supportive enabling environment that can increase the availability of technical expertise and address the barriers that hinder the wider adoption of these measures.
- Support is needed by all stakeholders to implement the *Voluntary Guidelines on Sustainable Soil Management* and increase the contribution the management of soil and land resources makes to building climate-smart agricultural systems.

Sustainable soil and land management and climate change

As a result of climate change, land degradation and losses in biodiversity, soil has become one of the world's most vulnerable resources (FAO and ITPS, 2015a and 2015b). Addressing soil and land degradation is a core challenge for sustainable development. Soil and land degradation has adverse impacts on ecosystem services that help safeguard food security, maintain water quality and availability, protect human health and establish the basis for a range of socio-economic activities. Sustainable soil and land management practices that are adapted to the local biophysical and socio-economic conditions can provide options for enhancing the interactions among soil, water, livestock and plants, which can prevent, slow or stop soil degradation and mitigate the impacts of climate change (Lal, 2013).

Sustainable land management refers to:

the use of land resources, including soil, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions (United Nations Earth Summit, 1992).

Sustainable land management includes measures that are suited to the specific biophysical and socio-economic conditions in a given area for the protection; promote the conservation and sustainable use of soil, water and and genetic diversity; and restore or rehabilitate degraded natural resources and revitalize the ecosystem functions.

Soil management is considered 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 of the soil *provides for water quality and availability and for atmospheric greenhouse gas composition is a particular concern (FAO, 2015a, p.4).*

Further definitions of relevant concepts are provided in Box B7.1.

Chapter B7-1.1 looks at the challenges that climate change presents for the sustainable management of soil and land resources. Chapter B7-1.2 considers the opportunities that sustainable soil and land management offers for fostering climate change adaptation and mitigation.

Box B7.1 Key concepts in sustainable soil and land management

Soil[i] is the foundation on which plants establish themselves and grow, and the basis for crop, forest and livestock production. Soil provides nutrients and water that are taken up through plant roots and contribute to the hydrological cycle and atmospheric gases. The diversity of life and abundance of biological activity that exist within the soil are greater than those in any other terrestrial ecosystem.

Soil health is a precondition that enables the soil to provide the basic services for supporting plant growth and contributing to the regulation of nutrient, water, carbon and gaseous cycles. Soil health, and hence soil's productivity, are inextricably linked to its physical, chemical and biological properties. Of particular importance are its mineral composition, organic matter content, soil biodiversity and associated biological activity.

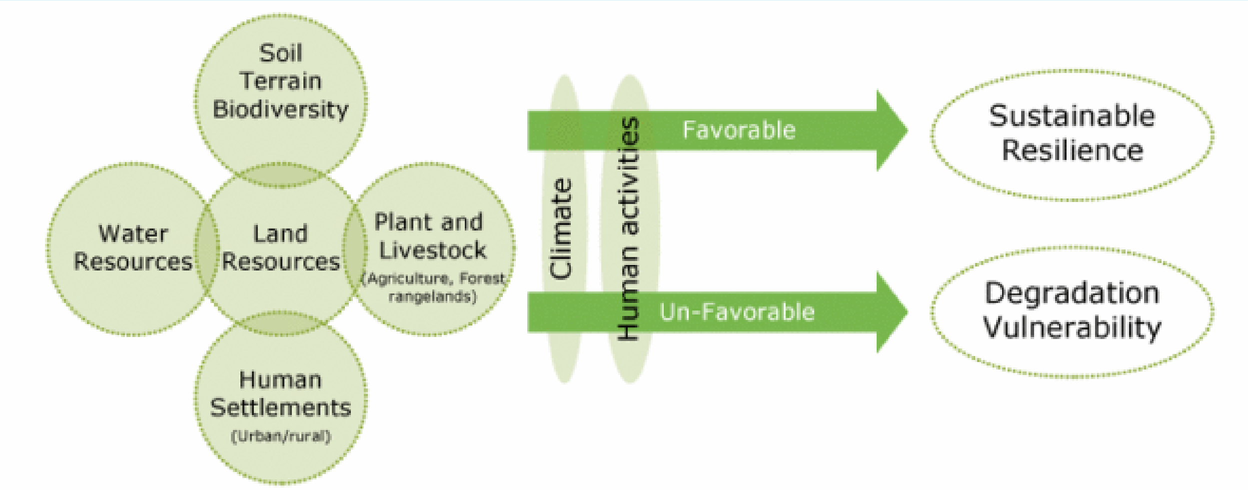
Land as defined by the United Nations:

is a delineable area of the earth's terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface including those of the near-surface climate, the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes, and swamps), the near-surface sedimentary layers and associated groundwater reserve, the plant and animal populations, the human settlement pattern and physical results of past and present human activity, such as terracing, water storage or drainage structures, infrastructure, buildings (UN, 1994).

The interaction between the different components of land resources determines the productivity and sustainability of any land-use system (Ziadat and Bayu, 2015). Land productivity depends directly on soil productivity and health. Healthy soils provide plants with the support and nutrients they need to grow and provide the foundation for agricultural production systems. A favourable climate and suitable management are needed to sustain production and help withstand the impacts of climate change. An imbalance in one or more of the components of land resources and their interactions will reduce the production capacity of the agricultural ecosystem and increase its vulnerability to climate change (Figure B7.1).

Sustainable soil and land management practices provide options to manage soil, water, and plants, and their interactions under a specific set of biophysical and socio-economic conditions. Unfavourable climatic conditions, which may result from climate change and variability, coupled with the mismanagement or misuse of resources lead to degradation and vulnerability. Human activities can have a positive impact. For example, making a sound initial determination about how the land will be used and implementing sustainable land management practices will enhance sustainability and build resilience to change (Figure 7.1). Understanding which components of the land resources are at risk is vital for selecting and putting into practice the most efficient and affordable measures for reducing these risks. Land resources planning, which helps ensure that initial choices about land use are appropriate and subsequent soil and land management practices are sustainable, is an entry point for helping decision-makers and communities to achieve climate-smart land use.

Figure B7.1 - Land resource components



Source: Authors

B7-1.1 The impacts of climate change impact on soil and land resources - the need for sustainable management

In cropping, grazing and forest systems, climate change and variability may affect soil health and its effects on plant growth in a number of ways.

- Reduced or erratic rainfall, and more frequent and severe periods of drought lower the capacity of soils to make water and nutrients available to plants.
- More intense extreme weather events, along with higher evaporation and transpiration rates, will lead to increased erosion by water and wind, and accelerated runoff; reduce groundwater recharge; and reduce the availability of soil moisture for plant growth.
- Higher soil surface temperatures will increase the rates of mineralization of soil organic matter and impair the soil's capacity to sequester carbon and retain water, which will ultimately limit plant growth.
- Higher temperatures cause soil salinization and increase the evaporation rates and the accumulation of salts (e.g sodium chloride, calcium and magnesium sulfate and chloride) in the soil surface layers. Salinization can hinder plant growth and reduce yields on productive agricultural lands. High levels of soil salinity can be tolerated only if salt-tolerant (halophytic) plants are grown with properly managed irrigation and drainage systems. In almost every irrigated area in the world, the groundwater is affected to some extent by salinity (Palaniappan and Gleick, 2009; FAO, 2011). When there is a predominance of sodium ions, soils can become sodic. This presents particular challenges, as sodic soils tend to have very poor structure that limits or prevents water infiltration and drainage, and exacerbates the risk of water stagnation and erosion (see Chapter B7-3.2).

Some soil properties, such as soil texture[ii], are more resistant to change, or change very slowly over time. Other properties and functions, such as soil organic matter and soil organic carbon content (see Chapter B7-3.3), soil structure[iii], base saturation and nutrient availability, soil organism populations, and pH[iv], are more easily affected by environment changes, including those associated with climate, and prevailing land management. Soil organic carbon and carbon stocks above and below ground are included in the monitoring of Sustainable Development Goal indicator 15.3.1 for determining the proportion of land that is degraded out of the total land area. The physical properties of the soil affect how the soil will respond to climate change. These properties determine the proper management practices that need to be adopted to to maintain the delivery of soil ecosystem services, such as storing water, supplying nutrients to plants, sequestering carbon and reducing greenhouse gas emissions. Understanding these properties will enable agricultural producers and other land users to adapt to climate change and mitigate its impacts.

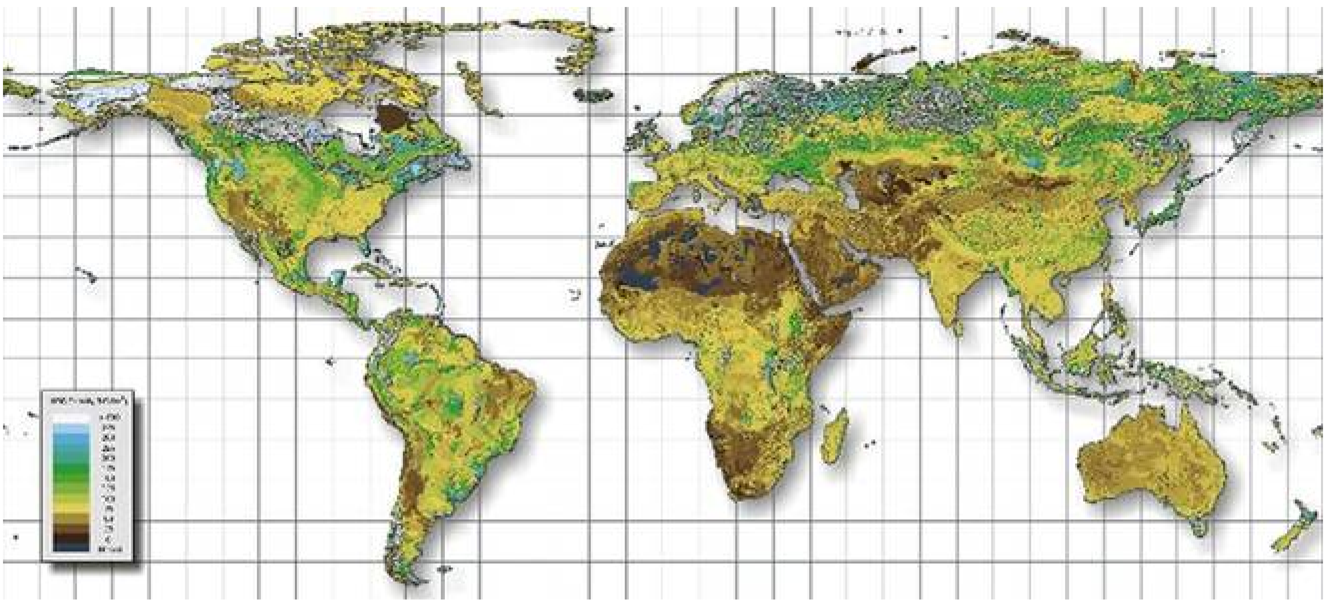
B7-1.2 The impacts of soil and land resources on climate change - the need for sustainable management

Soil hosts the largest terrestrial carbon pool, and the biogeochemical processes that take place in the soil regulate the exchange of greenhouse gases with the atmosphere (Scharlemann *et al*., 2014). These processes and emissions are strongly affected by land use, land-use change, vegetation cover and soil management (Chapter B7-2.1). The stocks of soil organic carbon in the upper soil layers are particularly responsive to these influences, and their careful management provides an opportunity to reduce the concentration of greenhouse gases in the atmosphere.

Sustainable crop, grazing and forest systems can sequester substantial amounts of carbon from the atmosphere and store it in soils and vegetation (Figure B7.2). The mechanisms underpinning terrestrial carbon sequestration are described in Box B7.3.

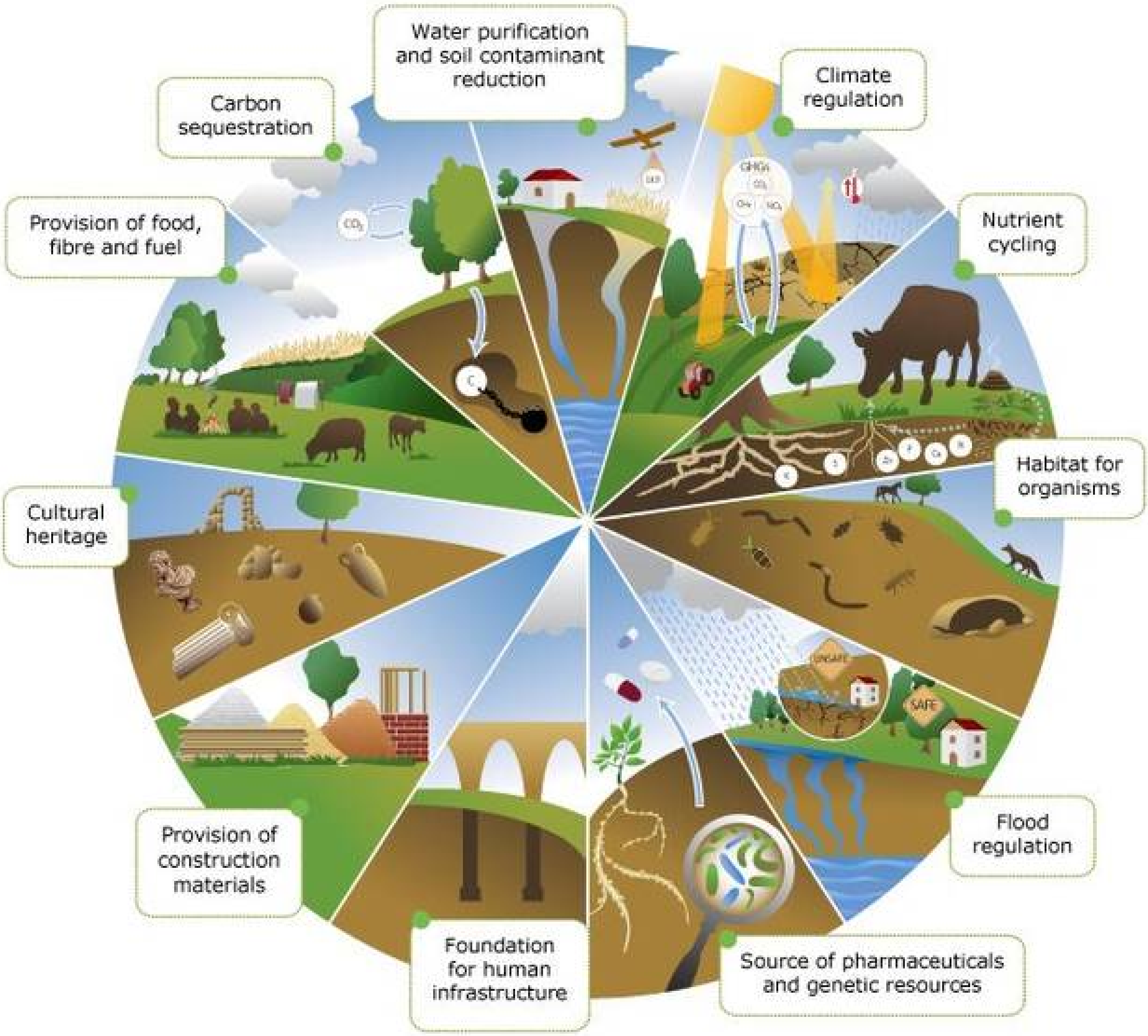
Sustainable soil and land management interventions that are designed to increase soil organic matter should be accompanied by actions that address the drivers of degradation and help preserve existing soil carbon stocks, particularly in soils with high soil organic carbon content (see Box B7.2) (Smith *et al*., 2014).

Figure B7.2. Estimates of global soil organic carbon (tonnes/ha of carbon) from the amended Harmonized World Soil Database.



Source: Hiederer and Kocky, 2011

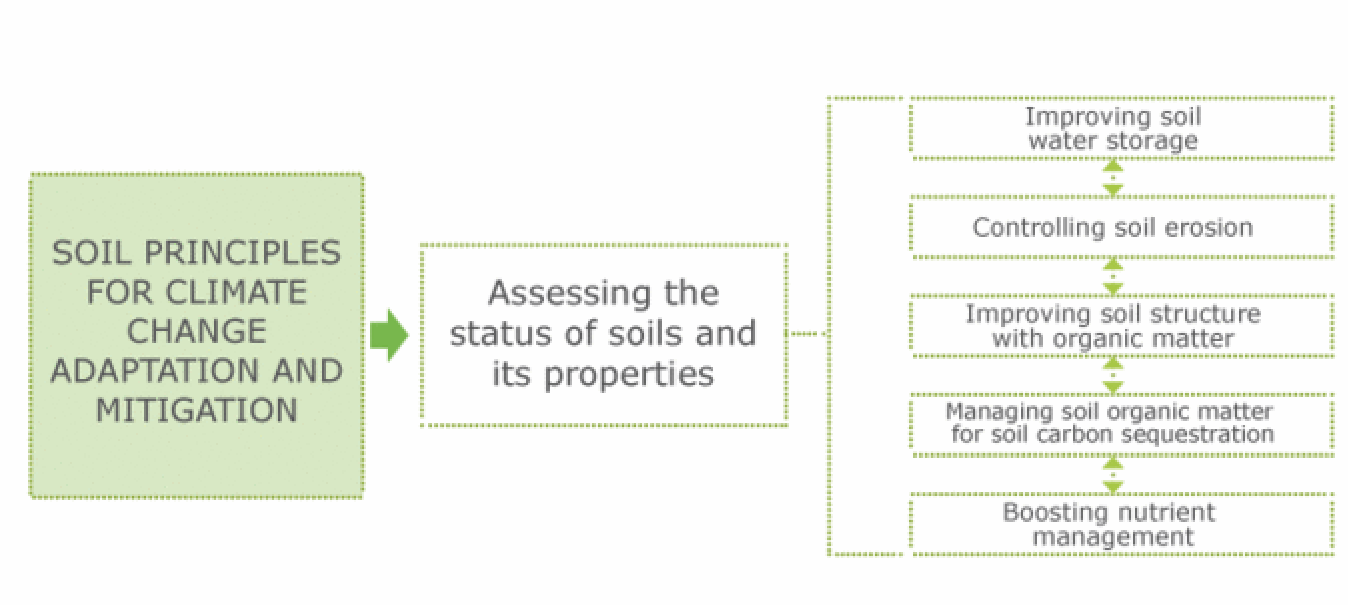
Carbon sequestration in soils will contribute to climate change adaptation and mitigation. It will also make agricultural production systems more sustainable; increase the overall resilience of agricultural ecosystems; and maintain the ecosystem services that are supported by soils (FAO and ITPS, 2015a; FAO, 2016a). The ecosystem services that the soil can provide and the soil functions that support these services are listed in the image below.



Source: FAO, 2015b

There are many already proven soil management practices that can help farmers adapt to the likely adverse effects of increasing weather variability and climate change, and that can, in many cases, also reduce agricultural greenhouse gas emissions (see case study B7.1). The widespread adoption of these practices has the potential to make a major contribution to the achievement of national food security and development goals. Chapter B7-3 provides a summary of these practices. Figure B7.3 outlines the principles for climate change adaptation and mitigation on which these practices are based. Chapter B7-3 looks at the importance of assessing the needs and vulnerabilities of farming communities, and providing incentives for the adoption of sustainable agricultural systems with the greatest production, mitigation and adaptation potential.

Figure B7.3. Soil management to enhance climate change adaptation, mitigation and resilience.



Source: Vargas, 2013

Strategies for sustainable soil and land management for climate-smart agriculture

Land resources planning should help producers, policy makers and other stakeholders select the most appropriate land uses for a given area. It should also help create conditions that allow for the adoption of sustainable soil and land management practices that promote the conservation of soil and land in healthy landscapes and ecosystems, and restore degraded land (FAO, 2017b). See module A3 on integrated landscape management.

Chapter B7-2.1 looks at the use of systematic assessments of land potential as a means of identifying optimal land uses suitable for a specific set of economic and social conditions that can contribute to climate change adaptation and mitigation. Chapter B7-2.2 presents databases of practices that have been identified for major land-use systems that can help agricultural producers and other land users select adapted management practices for particular environmental conditions and problems that can enhance agricultural resilience and support climate-smart agriculture. These tools can also provide guidance to decision-makers who are looking to ensure that the use of land resources is based on its natural potential, avoids overexploitation and prevents any further degradation. Chapter B7-2.3 describes tools that can support the implementation and scaling up of sustainable soil and land management practices for climate-smart agriculture. Chapter B7-3 describes the sustainable soil and land management practices that are most pertinent in this regard.

B7-2.1 Assessment of the status of soil and land resources

The assessment of the status of soil and land resources helps decision-makers understand the extent and effectiveness of existing or potential sustainable land management measures on soil conservation and land recovery; trends in land conversion and alternatives for optimal land use; and the type, extent and severity of various land degradation processes.

There are various types of assessments that are suited to different purposes.

Soil assessments

Knowing the status and condition of soils and their properties is fundamental for making sound decisions about sustainable soil management practices that can contribute to climate-smart land use. It is crucial to carry out soil assessments, including on-site visual assessments and soil surveys, analyse the data and information, and make soil maps (FAO, 2008). Participatory field observations need to be backed up by laboratory testing for specific properties. Various conventional and digital mapping tools should be used to extrapolate the findings across a range of soil and terrains, vegetation types, and/or agro-ecological zones. Ideally, soil information will be made available as continuous maps that emphasise the soil's geographic position and attributes. Visual soil assessments should also involve land users and be supported by technical experts to assess the soil's physical properties (e.g. texture, structure, water holding capacity and dispersion) and chemical properties (e.g. pH, nutrients and salinity). Soil test kits for quantitative chemical characterizations are available in many countries or can be ordered online. FAO has developed Visual Soil Assessment Field Guides for annual crops, olive orchards, orchards, vineyards and wheat. The United Sates Department of Agriculture has also developed a soil quality test kit for nine soil parameters (USDA and NRSC, 1998). However, the kit does not include any facility to analyse the labile soil organic carbon fraction, which are the parts of soil organic carbon that are the most rapidly oxidized by microbial activity, and which release carbon dioxide into the atmosphere. These labile fractions of soil organic carbon are important to study in their own right, as they drive the soil food web and greatly influence nutrient cycles and biologically-related soil properties. The use of dilute, slightly alkaline potassium permanganate and calcium chloride and a colorimeter represents a simple method of estimating changes in biologically active soil organic carbon. This procedure can be conducted in the field and may provide an early indication of soil degradation or how management practices are affecting soil quality (Weil *et al*., 2003).

Regional assessments of soil change

The Status of the World's Soil Resources (SWSR) is a reference document that provides global and regional assessments of soil change. It includes, for example, the hazards posed by the thawing of permafrost soils and their connection with climate change. The status report looks at the ten major soil threats to ecosystem functions, goods and services: soil erosion, soil organic carbon loss, nutrient imbalance, soil acidification, soil contamination, waterlogging, soil compaction, soil sealing, salinization, and loss of soil biodiversity. It also describes direct and indirect pressures on soils and the ways and means to combat soil degradation. A synthesis report for policy makers summarizes the major findings, conclusions and recommendations (FAO and ITPS, 2015a).

Assessment of land use, land degradation and land management practices

Slowing or stopping soil and land degradation is a core challenge for sustainable development. The degradation of soil and land has adverse impacts on food security, water quality and availability, human health, and social and economic activities (FAO and ITPS, 2015b). Addressing soil and land degradation through the sustainable management of soil and land and building up soil organic matter offers tremendous potential for climate change adaptation and mitigation.

The Land Degradation Assessment in Drylands (LADA) and The World Overview of Conservation Approaches and Technologies (WOCAT) toolset facilitates a participatory process with land users and experts for carrying out national and local assessment of land degradation and existing land management practices; selecting the most suitable practices for the given local context; and assessing, documenting and sharing results through the WOCAT database (FAO, 2012). A harmonized set of methodologies for the assessment of land use, land degradation and land management practices have been developed at global, national, subnational and local levels.

At the national and regional level, the assessment of the status, causes and impacts of land degradation, as well as the status and impacts of conservation measures and sustainable land management practices are assessed by major land-use systems. The toolset includes the production of land-use system maps and a multidisciplinary, participatory expert assessment of these maps, which is guided by the questionnaire for mapping.

The main purpose of LADA-Local level assessment manual is to provide a standard methodological approach and a toolkit for assessing, in collaboration with local stakeholders and communities, local land degradation processes, their causes and impacts. The LADA approach also assesses the extent to which natural resources, such as soil, water and vegetation, and landscapes and ecosystems are being conserved and/or improved through sustainable land management practices. The approach can also be used to assess the impact of implementing sustainable land management in improving the status of land resources. The methodology is documented in the two interlinked parts of the LADA-Local level assessment manual:

Part 1 - Planning and Methodological Approach, Analysis and Reporting (available in English, Chinese, French and Spanish)

Part 2 - Field Methodology and Tools (available in English and French)

B7-2.2 Information systems that support the selection of sustainable soil and land management practices

The selection of suitable sustainable soil and land management practices is a clearly a critical element for the success of any implementation programme designed to foster climate-smart agriculture. For a given set of biophysical and socio-economic conditions, the key question is: what are the potential technologies or practices that the farmers and other land users could adopt that would enable them to better adapt to the impacts of climate change and mitigate these impacts? Practitioners need information to facilitate the selection of suitable practices from a variety of alternatives that have been developed locally and globally. Listed below are three examples of information systems that can provide guidance in this area.

- The World Overview of Conservation Approaches and Technologies (WOCAT) is an established global network that supports innovation and decision-making processes in sustainable land management. The overall goal of the WOCAT Network is to unite international efforts in knowledge management and decision support for scaling up sustainable land management among all stakeholders, including national governmental and non-governmental institutions and international and regional organizations and programmes. The network provides tools that allow sustainable land management specialists to identify what actions are needed and where, and share their knowledge in land management. These tools assist specialists in their search for appropriate sustainable land management technologies and approaches; support them in making decisions in the field; help them in planning measures to promote the adoption and scaling up of identified best practices. WOCAT provides the users with over 500 technologies and approaches that have been documented around the world and in various agricultural ecosystems and socio-economic settings. This also provides assistance to agricultural producers and other land users in choosing the most appropriate sustainable land management practices. WOCAT has also prepared a questionnaire on climate change adaptation. The questionnaire can be used to assess experienced and projected exposure of a given technology or practice to gradual climate changes and climate-related disasters (see module C5 on the synergies between disaster risk reduction and climate-smart agriculture); define and assess the experienced and projected risks and potentials, and the sensitivity of the technology or practice; and determine the experienced and projected adaptive capacity to gradual climate changes and climate-related disasters. The results can provide assistance to agricultural producers and other land users in selecting a sustainable land management technology that will enhance their adaptability under the current prevailing conditions and under various climate change scenarios.

- Technologies and Practices for Small Agricultural Producers (TECA) is a platform where users can find practical information on agricultural technologies and practices that can help small-scale producers in the field. The platform includes technologies and practices in crop and livestock production, forestry, fisheries and aquaculture, marketing and other areas. All the TECA technologies and practices have been tested and/or adopted by small-scale producers, are easy to replicate, and can be expected to increase production in a sustainable way. A number of these technologies and practices can also help small-scale agricultural producers adapt to climate change. The TECA Exchange Groups are online forums where the members can ask questions and connect with experts, practitioners and producers, share experiences in the field, and learn how to implement technologies and practices. The TECA platform facilitates the sharing and exchange of knowledge to support small-scale producers in selecting and adopting practical and sustainable management practices.
- As part of the Global Soil Partnership (GSP), the Eurasian Soil Partnership Secretariat has established initiatives to facilitate targeted research and partnerships between scientists and local and national beneficiaries. These partnerships form a stable basis for long-term collaborative engagement to scale up the implementation sustainable soil management practices. Thematic areas for sustainable soil management practices are: the assessment of soil salinity; innovations for soil salinity management; practices and methods for the restoration of saline soils; guidelines and training modules for soil salinity management; the economic assessment of ecosystem services provided by soils in saline ecosystems; and the environmental impact assessment of sustainable soil management practices on soil ecosystem services in salt-affected landscapes.

B7-2.3 Tools to support implementation and scaling out of sustainable soil and land management

A substantial amount of experience has been gained about technical practices that have been tested and fine tuned for the optimal management of soil, water and land resources. These practices can reduce land degradation and enhance adaptation to climate change. However, the adoption of these technologies by farmers is remains less than what is needed to achieve tangible impacts. This is partially due to the lack of a proper enabling environment to support the uptake of technical solutions (see Chapter B7-4), and a lack of tools to ensure the selection and proper implementation of techniques and technologies suitable for the specific set of biophysical and socio-economic conditions under consideration. Identifying potential areas where specific technologies can be implemented with high chance of success significantly facilitates the scaling up of these technologies (Ziadat *et al*., 2015).

In many cases, the selection and implementation of improved technologies do not usually take into consideration the specificities of the agricultural ecosystem. Consequently, the efficiency of the technology transfer programmes remain low. The concept of 'benchmarking' has been proposed as an approach that can help identify areas that are similar to those where the improved technologies were developed (Ziadat *et al*., 2014). This approach starts with the selection and characterization of a benchmark site in an agricultural ecosystem. Improved technologies are then developed and evaluated at this site. After the evaluation, similar areas to the benchmark site are selected within a targeted area for scaling up the technologies.

Similarity analyses are used to find areas with characteristics that match those of the area where farmers tested, fine tuned or implemented a particular set sustainable soil and land management technologies. The generation of 'similarity maps' requires the formulation of an agreed 'expert similarity criteria', which is defined by an interdisciplinary team using the available datasets. These criteria are specific for certain area. Among the factors used to develop these criteria are the soil, climate, land use, and water resources. Land ownership type and size must be also included in the criteria. Suitability analyses are used within the similar areas to identify areas where the water and land management packages that have been developed can be applied with a high probability of success. The professionals, planners, and decision-makers can use the information and products generated from these analyses to identify suitable technologies for the targeted areas and/or communities. A follow up socio-economic analysis would be needed at the community level before implementing the interventions. The interventions should be abetted by a proper enabling environment that can provide incentives to communities to adopt the proposed changes. The results of these efforts should help decision-makers, planners, and donors identify areas for scaling up sustainable water and land management interventions.

Sustainable soil and land management for climate-smart agriculture in practice

This chapter provides examples of sustainable soil and land management practices that are designed to protect and restore soils and soil biodiversiy, control soil erosion control, sequester soil carbon and optimize water management in the soil.

B7-3.1 Preventing and mitigating land degradation

The world's soils are seen as having a high potential for carbon sequestration because soil organic carbon content can be conserved, restored and increased through appropriate land uses and agricultural management practices that can be applied at the landscape level (Corsi *et al*., 2012). However, initiating the carbon sequestration process on degraded soils is a slower process as the soil microbial population that drives the soil organic carbon and nutrient cycling requires specific nutrient ratios that take time to achieve (Stevenson, 1986). In addition, degraded soils are at much greater risk from the damaging impacts of mismanagement and climate change. Their vulnerability is a result of serious losses in soil organic matter and soil biodiversity, which undermine soil resilience; greater soil compaction; and increased rates of soil erosion and a higher incidence of landslides. Land degradation is itself a major cause of climate change (Scherr and Sthapit, 2009b).

Unsustainable land management practices that degrade soils include tillage-based crop production systems; simplified crop rotations that lead to soil nutrient mining; the improper application of fertilizers; inappropriate irrigation practices; overstocking, overgrazing and burning of rangelands; inefficient grazing methods; and the overexploitation or clearance of wooded and forest lands.

The widespread restoration of degraded soils is crucial for sequestering carbon and supporting the productive capacities of the world's croplands, rangelands and forests. Soil organic carbon sequestration can be achieved by reducing erosion (Chapter B7-3.2) and preserving and increasing soil organic matter in the soil (Chapter B7-3.3).

Equally important is the prevention of the conversion of vulnerable land for unsustainable uses. Intensive land uses are expanding into areas where soil organic carbon stocks are less resilient.

- Semi-arid savannas and grasslands, tropical rainforests and peatlands are being converted to arable land at an increasing rate.
- Temperate humid grasslands release about 30 percent of their soil organic carbon after 60 years of cultivation (Tiessen and Stewart, 1983; Guo and Gifford, 2002).
- In semi-arid environments, the cultivation of tropical forest soils causes more than 60 percent of original soil organic carbon stocks to be lost in only a few years (Brown and Lugo, 1990). Converting native vegetation or pastures to cropland depletes soil carbon stocks by 30 percent in less than five years (Zach *et al*., 2006;

Noellemeyer *et al*., 2008). In the Amazon rainforest, establishing pastures on cleared forest emits between 8 and 12 tonnes of carbon dioxide per hectare (Fearnside and Barbosa, 1998; Cerri *et al.*, 2007).
- In arid and semi-arid areas, soil organic carbon is undergoing significant changes in the aftermath of series of different combinations and sequences of land-use changes.

Changes in soil organic carbon depend on the management practices associated with land use and the time since the current land-use system was established (Mohawesh *et al*., 2015). Assessments of land resources (Chapter B7-2.1) are needed to help identify the effects of land-use changes and associated management practices on the dynamics of soil organic carbon and support the formulation of sustainable land management plans. Such assessments will identify hotspots in terms of the degradation of soil, water and biodiversity) and climate change, and bright spots where sustainable land management practices are generating multiple ecosystem benefits. Land-use planning can then be used to determine the most suitable land uses and provide policy support or incentives to reduce land conversion and promote the adoption of sustainable practices, with particular attention given to peatlands (Box B7.2 and drylands that are more vulnerable to human intervention and climate change. See also module C3 on policy and programmes for climate-smart agriculture.

Box B7.2 Peatlands as climate change mitigation hotspots - towards wiser management

Peatlands are ecosystems where greenhouse gas emissions can often be reduced in a cost-effective manner. Peatlands or 'organic soils' have a substantial layer of organic matter near the surface. Unlike mineral soils, most pristine peatlands are wet during most of the year. Peatlands, which are found in almost every country in the world, contain 30 percent of the world's soil carbon but cover only three percent of the global land area (Joosten, 2009; Victoria *et al*., 2012). Draining a part of a peat dome or excessive irrigation lowers the water table in the entire peatland area and causes greenhouse gas emissions. Drained peatlands and fires in drained peatlands are responsible for almost one-quarter of the carbon dioxide emissions from the land-use sector (Joosten, 2009; Victoria *et al*., 2012).

There has been a rapid growth in emissions from peatlands as they have been drained for forestry, food crops and cash crops, such as oil palm. In many cases, for example in Ukraine and Southeast Asia, the cultivation of peatlands has led to their serious degradation, subsidence and abandonment. Abandoning peatlands significantly increases the risk of fires.

To reduce greenhouse gas emissions from peatlands, it is essential to determine their status; whether they are pristine, drained, abandoned or in productive use. The main approaches for reducing emissions from peatlands include:

- conserving undrained peatlands;
- rewetting drained peatlands using blocking canals and grids;
- increasing the productivity on the existing farmland to reduce the pressure to drain peatlands for agriculture or forestry; and channelling the expansion of agricultural land to areas with mineral soils; and
- managing peatlands, if they cannot be rewetted, in ways that maintain soil carbon. (FAO, 2014)

Rewetted peatlands (Figure B7.4) can provide income and other benefits to local communities by supporting forestry and agricultural cultivation under wet conditions, a practice known as paludiculture. Paludiculture, which can be carried out wherever there are marketable plants and animals living in wet conditions, can produce biomass for bioenergy, feed for livestock, fibre, building materials and food, such as nuts and berries. In Southeast Asia, natural rubber is collected from *Jelutung* paludiculture. Local communities are earning up to half of their income from raising fish in the blocked grids alongside the rubber production (FAO and Wetlands International, 2012). Paludiculture represent the only sustainable mode of agricultural production on peatlands. There are, however, technical and socio-economic constraints that can prevent drained peatlands from being rewetted. In such cases, the negative environmental and socio-economic impacts of peatland use can be limited, for example, by choosing crops that are adapted to high soil moisture; minimizing drainage as much as possible to reduce peat oxidation and land degradation; and reducing the use of fertilizers.

Source: Hans Joosten and Maria Nuutinen

Figure B7.4. Raising the water levels on drained peatlands by blocking ditches can be done with low-cost techniques and local materials. Dam in a channel in Mentangai, Indonesia

Source: Marcel Silvius, Wetlands International

B7-3.2 Controlling soil erosion

Soil erosion is process that is causing widespread and serious environmental degradation. Erosion removes a field's original topsoil, reducing the thickness of the soil surface, which is the most productive part of the soil profile, and causing losses of soil organic matter (Mohawesh *et al*., 2015).

Tillage-induced soil erosion is a major cause of the severe soil carbon loss and soil translocation in upland landscapes (Lobb *et al*., 1995; Lobb and Lindstrom, 1999; Reicosky *et al.*, 2005). Even on gradual slopes, alkaline soils for example, may suffer from dispersion or crusting that will increase surface runoff and the risk of soil erosion. The redistribution of soil within fields caused by tillage erosion may lead to high erosion rates on knolls, exceeding 30 tonnes per hectare per year and to deposition rates in hollows and at downslope field borders, exceeding 100 tonnes per hectare per year. These rates are not directly comparable to wind or water erosion rates, as soil eroded by tillage will not leave the field. However, tillage erosion may significantly reduce crop productivity on knolls and near downslope field or terrace borders (FAO and ITPS, 2015b).

Intense rains can cause devastating soil erosion on cultivated lands on moderate to steep slopes where runoff rates are high and the ground has inadequate vegetative cover. Increased incidences of windstorms accelerate the loss of fertile soil by blowing soil particles off the fields or onto other fields.

Soil erosion by rainfall and surface runoff, and wind can be prevented or substantially reduced with conservation agriculture, and minimum- or no-tillage farming, combined with a range of soil and water conservation measures that include optimizing vegetative cover with adapted species; using rotational grazing to sustain the quality of rangeland vegetation; enhancing the roughness of the soil surface with clods and tied ridges; contour farming using bunds and diversion ditches; and planting windbreaks perpendicular to the prevailing winds.

On steeper slopes, soil erosion control requires additional measures, including reducing the degree and length of slopes with progressive and bench terracing; planting cross-slope vegetation; using soil and water conservation structures, such as terraces, earth bunds and tied ridges to optimize water capture and infiltration; and creating grassed waterways to convey excess water safely off the slopes. Erosion control mats and blankets (geotextiles), preferably biodegradable ones, offer immediate soil protection, and in some cases, these products may be an economic option for erosion control. In different parts of the world, biological geotextiles have proven to be highly effective for controlling soil erosion and supporting above-ground biomass production (Bhattacharyya *et al*., 2009; Bhattacharyya *et al*., 2011; Bhattacharyya *et al*., 2012a; Ghosh *et al*., 2016).

B7-3.3 Managing Soil Organic Matter for soil carbon sequestration

Organic matter in the soil is made up of dead plant and animal materials in various stages of decomposition. It does not include fresh and undecomposed plant material lying on the soil surface, which is known as litter. As explained in Box B7.3, soil organisms break down the organic matter so they can use it as food. In doing so, they release excess nutrients into the soil in forms that plants can use. The organic matter that these organisms cannot digest is reorganized into soil organic matter, which is less decomposable than the original plant and animal material (Figure B7.5). Soil organic matter primarily contains organic carbon (on average 58 percent), but also nutrients that are essential for plant growth, and some inorganic carbon. Soil organic matter acts as a sink for atmospheric carbon, in that it sequesters carbon from the atmosphere. Soil organic matter also enhances soil structure by binding the soil particles together as stable aggregates, which influence the soil’s physical properties (e.g. aggregation, water holding capacity, water infiltration and aeration) and chemical fertility (e.g. nutrient availability). The characteristics of soil organic matter have an impact on the overall biological resilience of agricultural ecosystems. The greater the soil organic matter content, the greater the soil biodiversity. Higher levels of biodiversity in the soil accelerate the processes involved in breaking down dead and decaying organic matter into humus and making nutrients available for plant growth (Charman and Roper, 2000; Bot and Benites, 2005; Bhattacharyya *et al*., 2012b; Bhattacharyya *et al*., 2012c).

Soil carbon stocks and the mitigation potential they provide depend on the agro-climatic zone, the type of land use and the intensity of use (Figure B7.2). The rate of soil organic matter decomposition and turnover depends primarily on the combined effects of the soil organisms, temperature, moisture and the soil's chemical and physical composition. It is also affected by the previous land use and natural resource management practices, particularly the mechanical disturbance of the soil. When assessing carbon sequestration, rates should always refer to the specific association of soil and vegetation and definite carbon pools, as each carbon category has a very different turnover rate. For instance, carbon accumulated in the first ten years is young and highly oxidizable, but becomes more stable over time. To assess the effects of management practices on soils, it is also necessary to use a reference base for similar soil types under the same climatic conditions. Undisturbed soils under natural vegetation should be used as a benchmark and used when making a comparison with the soils affected by human activities. In this context, it is important to emphasise that only data from similar agro-ecological zones can be compared because the rate of conversion of the carbon content in crop residues into soil organic matter is strongly related to the climate, and the rates achieved under different climatic conditions are not directly comparable (Corsi *et al.*, 2012).

Box B7.3 Nutrient turnover and terrestrial carbon sequestration

Terrestrial carbon sequestration occurs in standing biomass (e.g. trees), long-term harvested products (e.g. lumber), living biomass in soil (e.g. perennial roots and microorganisms), recalcitrant soil organic matter in soil (e.g. humus), and inorganic carbon in the subsoil (e.g. carbonates) (Johnson *et al.*, 2007). Organic and inorganic carbon pools in soils are generally the most long-lived terrestrial reservoirs for sequestering carbon (Figure B7.5).

Photosynthesis represents the largest transfer of carbon (through carbon dioxide) in the carbon cycle. Through photosynthesis, plants draw carbon dioxide out of the air to form plant tissues (carbohydrates). When dead plant and animal material (i.e. organic matter) is returned to the soil, it decomposes. The decomposition of organic matter is a biological process carried out by soil organisms that involves a series of steps that lead to the mechanical breakdown (comminution), the chemical breakdown (mineralization), and the biochemical reorganization of complex structures and molecules (polymers). Only the indigestible fraction of carbon (i.e. carbohydrates, lignins, tannins, aromatic amino acids and waxes) enters into the formation of stable soil organic matter (humification).

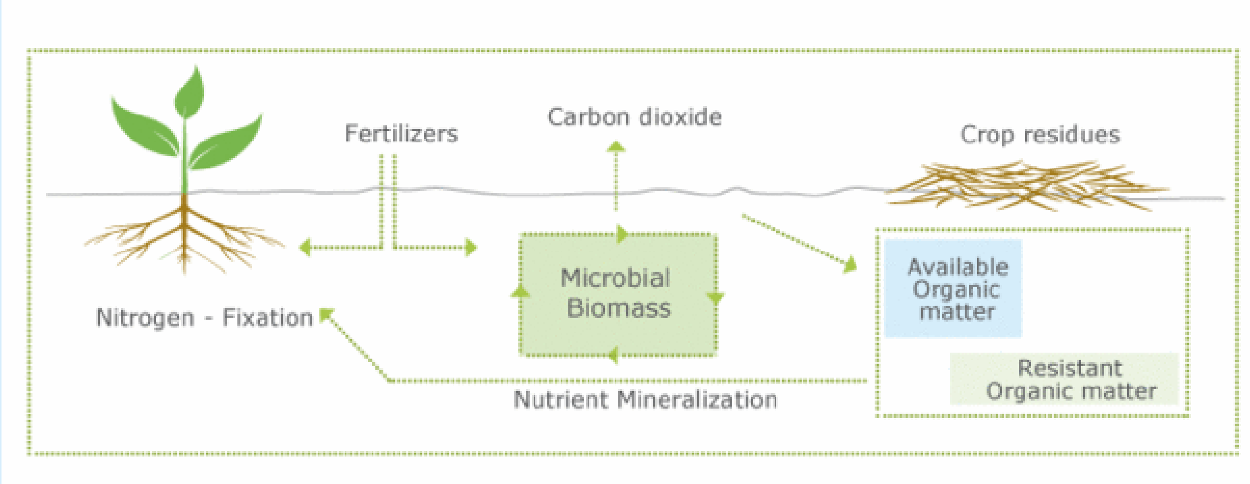
By transforming organic compounds into inorganic compounds, and breaking down carbon structures and rebuilding new ones or storing carbon into their own biomass, the microbial population acts as functional engine for the turnover of organic matter and the release of nutrients to the soil. It is this microbial population that is responsible for enabling the soil to provide crops with nutrients.

When decomposing soil organic matter, the soil organisms release nitrogen in the form of ammonium ions, potassium, calcium, magnesium and a range of other nutrients necessary for plant growth and the organisms' activities. Plants obtain many of their nutrients from soil by ‘cation exchange’, whereby root hairs exchange hydrogen ions with the cations (positively charged ions) adsorbed in the soil particles. Clay soils have a higher cation exchange capacity and a structurally greater potential chemical fertility than silty soil and sandy soils.

Nitrogen is a nutrient that deserves special attention. It plays a key role in plant metabolism and growth, but it can also be a cause of pollution when it leaches in the form of nitrates into the water table. Nitrogen can also be released from the agricultural ecosystem in the form of nitrous oxide - a potent greenhouse gas.

Source: Sandra Corsi, Feras Ziadat

Figure B7.5. Organic matter turnover



Source: Gupta et al., 1997

Mainstream agricultural production systems that do not rely on biogechemical cycles do not ensure the sustained productivity of soils.

- Over the past 50 to 100 years, tillage-based agricultural practices have caused soil organic carbon levels in many regions to decline by one to three percent, which has caused soil degradation. As shown in Table B7.1, a three percent loss in soil organic carbon not only represents a significant loss of water storage (432 000 litres per hectare), but also represents nearly 400 tonnes of extra carbon dioxide per hectare emitted into the atmosphere. The loss of soil organic carbon and water holding capacity is associated with a range of practices, including the elimination of perennial groundcover, repetitive cultivation and tillage, continuous grazing, bare fallows, the removal of crop residues and grassland burning.
- Intensive monoculture, in combination with the high use of external inputs, has been an approach farmers have adopted to achieve the highest possible yields with minimal labour. However, the production of energy-intensive mineral fertilizers and pesticides is a major source of greenhouse gas emissions. Moreover, when incorrectly applied, these inputs leach into water resources, and the resulting water contamination has seriously harmful effects on ecosystems and human health.

With agricultural intensification, farmers are increasingly supplementing organic fertilizers (e.g. manure, compost and plant residues) with inorganic or synthetic fertilizers, which deliver the required crop macronutrients (e.g. nitrogen, phosphorus, potassium, calcium, magnesium and sulphur) and micronutrients (e.g. boron, chlorine, copper, iron, manganese, molybdenum, zinc and nickel). Nitrogen fertilizers are the most widely used fertilizers and deliver huge benefits in terms of productivity, especially in nutrient-depleted soils. However, as indicated in Table B7.1, these fertilizers can cause environmental damage in the form of greenhouse gas emissions and nitrate pollution (Scherr and Sthapit, 2009b).

Table B7.1. Capacity of a soil with a bulk density of 1.2 g/cm^3 to store water as affected by soil organic carbon content to 30 cm soil depth

The calculation of these figures is based on a conservative estimate that one part of soil organic carbon retains four parts of soil water.Change in soil organic matter content.

Change in soil organic matter content	Extra soil organic matter	Extra water		Carbon dioxide sequestered
[%]	[kg]	[litres/m^2]	[litres/ha]	[t/ha]

Change in soil organic matter content	Extra soil organic matter	Extra water		Carbon dioxide sequestered
1	3.6	14.4	144 000	132
2	7.2	28.8	288 000	264
3	10.8	43.2	432 000	396

Source: Jones, 2006a and 2006b

Integrated soil fertility management practices seek to maximize the efficiency in the use of nutrients and water. They does this by balancing the use of organic matter obtained on the farm or from other sources as a soil amendment with the judicious use of nutrients from mineral fertilizers; and reducing nutrient losses by synchronizing the supply of nitrogen with crop demands through sound agronomic practices, including soil and water conservation measures. Examples of integrated soil fertility management practices include:

- making changes in the rates, timing and type of nitrogen fertilizer applications; and using slow release fertilizers that control the formation of nitrates;
- adding nitrification inhibitors containing ammonium to fertilizer;
- practicing no-tillage farming, while maintaining continuous soil cover and rotating cropping patterns, which provides enough structural carbohydrates (e.g. lignin) along with nitrogen to allow the nitrogen produced from decaying surface residues to be released more slowly and contribute to the growth of the following crop and minimize nutrient losses (Huggins *et al*., 1998; Gregorich *et al*., 2001; Gál *et al*., 2007).

This form of agriculture, known as conservation agriculture, considerably reduces nitrate leaching (Macdonald *et al*., 1989). This is because, unlike mechanical tilling practices, conservation agriculture does not disrupt the stabilization and formation of soil aggregates (Bhattacharyya *et al*., 2013). Soil aggregates protect the nitrogen from microbial enzymes, decreasing mineralization and the subsequent production of nitrates. The cover crops in the rotation take up the nitrogen and keep it from being lost from the soil. At the same time, unused mineralized nitrogen remains distributed within smaller pores and is not washed out of the soil (Gors *et al*., 1993; Bergström, 1995; Davies *et al*., 1996). However, where no-tillage is used without cover crops and with herbicides to manage weeds, the effects on nitrogen uptake and reduced leaching, as well as on yields, may be less evident (Das *et al*., 2014).

Greater efficiency in the management of production inputs reduces wastage and the amounts used, which can lower greenhouse gas emissions. Additional efficiency gains can be achieved through the climate-smart practices presented in module B1 for crop production, module B2 for livestock production and module B5 for integrated systems and summarized in Table B7.2. The use of biochar as a carbon sequestration practice may be an option, but it remains controversial (see Box B7.4).

Box B7.4 Biochar

Biochar is a stable, carbon-rich form of charcoal that can be produced by pyrolysis, a process in which biomass is heated with little or no oxygen (Sparkes and Stoutjesdijk, 2011). Possible biomass sources for biochar include milling residues (e.g. rice husks, sugar cane bagasse); crop and logging residues; biofuel crops; municipal wastes; and animal manure. The suitability of biomass for biochar production depends on its lignin content (Eagle *et al*., 2012).

Biochar, due to its porous nature, high surface area and its ability to absorb soluble organic matter and inorganic nutrients, is thought to offer benefits for sustainable agricultural productivity. It increases biological activity and improves the efficiency of nutrient use, which reduces nitrous oxide emissions and increases carbon sequestration. Prommer *et al*. (2014) found that biochar increased total soil organic carbon but decreased the extractable organic carbon pool and soil nitrate. They concluded that the addition of inorganic nitrogen fertilizer in combination with biochar could compensate for the reduction in organic nitrogen mineralization.

Biochar is a relatively new, and the physical properties of biochar are highly variable. The cost effectiveness of using biochar depends on the biomass source and distance to the pyrolysis plant. In many contexts, it is not an economically viable option. Also, not all soils or crops show the same improvements when biochar is applied, and there may be risks associated with increased soil alkalinity. In the long term, the application of biochar may affect soil fertility, reduce the efficacy of some agricultural chemicals, and inhibit microbial processes due to the production of ethylene. More research is needed on the potential benefits and risks of its use in agricultural soils.

Source: FAO, 2013

B7-3.4 Improving water use and management in agriculture

As climate change has an impact on every element of the water cycle, particular attention should be placed on using water efficiently.

Water storage in the soil depends on many factors, including the amount and intensity of rainfall, soil depth, soil texture (e.g. clay content), soil structure, soil temperature, and the content and type of soil organic carbon. Different soil types, textures and structures have different degrees of water permeability and offer different levels of protection for soil organic matter. Within the soil, stable forms of soil organic carbon, such as humus, can hold up to 7 times their own weight in water. A soil that has a crumbly structure, which breaks easily into separate lumps and clumps, will absorb water more quickly than one that is compacted. Sandy soils are the least productive soils. They have a non-reactive chemical nature and, as they are highly permeable, have a low capacity for retaining water. They also offer limited protection to soil organic matter compared to soils with a higher proportion of silts and clays, which can attract and retain water and nutrients through chemical processes.

Soil management can increase water infiltration, strengthen the capacity of the soil to store water and reduce soil water evaporation.

- Groundcover management can have highly significant effects on soil surface conditions, soil organic matter content, soil structure, porosity, aeration, bulk density. This has a direct influence on infiltration rates, the water storage potential of the soil and water availability to plants.
- Roots, and the organisms that thrive in undisturbed soils create channels that improve soil porosity and the water infiltration rate.
- Minimizing soil compaction increases the effectiveness of rainfall, enhances productivity, reduces erosion and the dispersion of soil particles, and lowers the risks of waterlogging. Compacted soils or soils with a hardpan may waterlog easily and then dry out quickly.
- Sandy soils can be managed productively even in hot, dry climates by adding organic matter (e.g. green manure, animal manure, composted material) and, in irrigated systems, supplying nutrients through drip irrigation.

The good management of soil-crop-water interrelations can maintain and increase soil organic matter, improve the soil's nutrient retention capacity and enhance soil biodiversity. This integrated management can create optimal conditions for crop production, while simultaneously increasing the resilience of production systems to climate change.

In crop production systems, good management practices to increase soil organic matter include:

- direct seeding (no-tillage) in combination with protective soil cover, crop diversification and crop rotation;
- the elimination of the burning of crop residues;
- integrated soil fertility management to increase the soil's nutrient retention capacity and the availability on nutrients to plants;
- the precise management of nitrogen;
- integrated pest management, which includes the sustainable use of herbicides.
- the construction of soil conservation structures, such as stone and earth terraces and bunds, and check dams;
- irrigation or partial irrigation where needed or possible (see module B6 on water management);
- the harvesting and proper use of rainwater;
- the development of reliable sources of information and extension services that are tailored to local conditions; and
- appropriate soil erosion control practices

In grazing systems, soil organic matter can be increased through controlled grazing, which reduces the degradation of vegetation and restores grassland diversity. Reducing burning to the absolute minimum also increases soil organic matter. However, on common property lands, burning is often a preferred strategy to enhance phosphorus and encourage the growth of young plants for grazing animals (also see module B2 on livestock). Case study B5.2 presents details on the ‘Quesungual Slash and Mulch Agroforestry System’, an alternative to slash and burn practices.

Integrated crop and livestock systems can be used to enhance soil fertility. An example of an integrated system on sloping uplands is presented in case study B7.2. Pasture cropping, a practice where an annual crop is grown out-of-phase with perennial pasture, builds soil at higher rates than perennial pastures alone. This is due to the fact that there is a year-round transfer of soluble carbon to the root zone and the humification process is maintained during the period when the perennial crop is not growing (Cluff and Seis, 1997).

To increase the amount of water in the soil, rainwater harvesting and irrigation can be used. These are addressed in module B6 on water management. Case study B7.3 presents an indigenous system of soil and water management for rice production.

Table B7.2. 'Business-as-usual' practices verses climate-smart practices

The following practices and approaches have been selected as good management practices that can contribute to climate change adaptation and mitigation. Progress in this area will require embracing an ecosystem approach that fosters the integrated management of soil and land resources and takes into consideration the interactions among water, crops, forests, livestock and other components of the ecosystem.

<table>
<tr><th>'Business-as-usual' practices</th><th>Climate-smart practices for climate change adaptation</th><th>Climate-smart practices for climate change mitigation</th></tr>
<tr><th>Soil fertility management through synthetic fertilizers</th><th colspan="2">Integrated soil fertility management</th></tr>
<tr><td>- The manufacturing, processing and applying synthetic nitrogen fertilizers emit considerable greenhouse gases. Mechanical incorporation of fertilizers through ploughing, or minimum tillage, for example, disrupts the soil and the formation of new aggregates. It also encourages microbial activity, which contributes to the rapid mineralization of soil organic matter.
- Fertilizers may contain hazardous by-products that can accumulate in the soil and may pollute the soil and groundwater.
- Soil micro-organisms mineralize organically-bound nitrogen and release ammonia, which in turn is transformed into ammonium ions, and further nitrified into nitrates (Jiang and Bakken, 1999). Nitrate ions can be leached from the soil through drainage.
- In oxygen-limited soils, denitrifying organisms will reduce nitrates to nitrous oxide, a greenhouse gas with about 300 times more warming effect than that of carbon dioxide.</td><td>- Maximizing the use of organic matter sources (e.g. compost, animal manure and green manure) is a cost-efficient means to replenish soil organic matter content.
- Enhancing nutrient efficiency through crop rotations or intercropping with nitrogen-fixing crops, and the judicious and precise use of soil amendments and nutrients reduces nutrient inputs and losses.</td><td>- Reducing the input of synthetic nitrogen fertilizers reduces carbon dioxide emissions that result from their production, and nitrous oxide emissions that result from their application of these inputs and consequent ammonia volatilization.
- Using enhanced efficiency fertilizers (e.g. slow-release fertilizers or fertilizers with urease or nitrification inhibitors) reduces ammonia volatilization and nitrous oxide emissions.
- Using appropriate placement of nitrogen fertilizer near the zone of active root uptake, and synchronizing the timing of nitrogen fertilizer application with plant nitrogen demand reduces inputs, decreases nutrient losses and lowers greenhouse gas emissions.
- Improving methods and rates of manure application (e.g. applying solid rather than liquid manure, applying manure to dry rather than wet soils and when air temperatures are low) reduces greenhouse gas emissions.</td></tr>
<tr><td>Soil tillage for annual crops</td><td colspan="2">Conservation agriculture</td></tr>
<tr><td>Tillage is done to control weeds and loosen the soil. However, when loose soil is left under the impact of rain, wind and heat, the topsoil gets eroded. This lowers the natural content of soil organic matter, reducing soil fertility and releasing carbon dioxide. It also reduces the presence of soil organisms (e.g. earthworms, fungi), which limits the soil's capacity to regain its fertility.
Tillage also typically develops a compacted layer (hardpan), which impedes plant root growth and rainwater infiltration.</td><td>Conservation agriculture increases the resilience of the farming systems in a number of ways.

- Soil is kept fertile and protected from erosion and evaporation.
- Water and nutrients are used efficiently. Ground cover slows down the flow of water on the surface, allowing it to soak and infiltrate into the soil, where it remains available for the crop.
- The elimination of pre-seeding operations allows maximum timeliness and flexibility in planting to accommodate weather conditions. Pre-seeding operations can be avoided by sowing seeds directly into the standing stubble of the previously harvested crop, or seeding while mechanically terminating the previous cover crop.</td><td>Conservation agriculture reduces:

- carbon dioxide emissions from tractor use, as the farm power requirements are lower and fewer passes across the field are needed.
- carbon dioxide emission from the production of farm machinery, as the required equipment is smaller and has a longer life;
- carbon dioxide emissions from the soil relative to those released by tillage.
These 'carbon savings' exceed the carbon costs related to the use of chemical herbicides for weed control.
Conservation agriculture also has the potential to sequester soil organic carbon. Maximum rates of sequestration are achieved in the first 5 to 20 years after carbon-enhancing changes in land management have been implemented. Sequestration rates then decrease until soil organic carbon stocks reach a new equilibrium after 20 to 30 years (Lal, 2004; IPCC, 2007; FAO, 2017). The point at which equilibrium is reached depends on soil texture and composition. Until this point is reached, an exponential relationship between the application and accumulation of soil organic matter can be expected in most soils (Jacinthe et al., 2002; Six et al., 2002).</td></tr>
<tr><td>Soil puddling in rice paddy systems</td><td colspan="2">Systems of Rice Intensification</td></tr>
</table>

'Business-as-usual' practices	Climate-smart practices for climate change adaptation	Climate-smart practices for climate change mitigation
Soil fertility management through synthetic fertilizers	**Integrated soil fertility management**	
Flooded rice fields represent one of the main sources of methane emissions.	Systems of Rice Intensification, which reduce the use of water, also bring benefits in terms of productivity and adaptation.	Systems of Rice Intensification reduce greenhouse gas emissions in rice cultivation. Also the timely flooding of rice paddies, or the cultivation of rainfed lowland rice in flooded fields with periods of non-submergence can help save water and reduce methane emissions. However, this practice also may have the potential to increase nitrous oxide emissions.
Extensive grazing	**Improved grazing management** *(see module B2 for more details)*	
Many extensive grazing systems are suffering from overgrazing and serious reductions in the biodiversity of above-ground vegetation. This is a result of declining land availability and overstocking due to inadequate livestock management. This is leading to a decline of soil quality in rangelands, which is marked by a depletion of biomass, the erosion of topsoil by water and wind, the loss of soil organic carbon and a reduction of ecosystem services. This is accompanied by a decline in soil structure and resilience (e.g. through loss of deep rooting species that can cycle nutrients and water from deep in the soil profile). Excessive trampling of the soil by livestock, particularly around watering points, further damages the soil structure and inhibits its ecosystem functions.	- Improved grazing management on pastures or rangelands may involve reducing stocking rates; avoiding grazing during drought periods; and improving the duration and timing of grazing and its frequency. This increases the protection of the soil surface by living and decomposing vegetation; increases soil organic carbon; and supports wider soil ecosystem services. Applying fertilizer or other inputs can also increase annual net primary productivity. - The practice of rotational grazing, which involves regularly moving livestock between paddocks, intensifies grazing pressure for a relatively short period of time (e.g. 1 to 3 days for ultra-high stocking density or 3 to 14 days for typical rotational grazing), but leaves a rest period for regrowth in between rotations.	Compared with more highly productive pasture, rangelands have low carbon sequestration rates when measured on a per unit of production basis. However, because of the vast areas they cover, their carbon sequestration potential remains high.
Livestock waste management	**Sustainable mixed farming systems**	
When conventional stockless arable farms become dependent on the input of synthetic nitrogen fertilizers, manure and slurry from livestock become an environmental problem. In these livestock operations, the availability of nutrients becomes excessive and over-fertilization may occur. In this situation leaching is likely to lead to water pollution and high emissions of carbon dioxide, nitrous oxide and methane.	Mixed farms or close cooperation between crop and livestock operations—a common practice in most forms of sustainable farming, especially organic ones— can contribute considerably to climate change mitigation and adaptation. Different forms of compost, especially composted manure, are also particularly useful in stimulating soil microbial processes and building up stable forms of soil organic matter (Fließbach and Mäder, 2000). On-farm use of farmyard manure, which is a practice that has been increasingly abandoned in conventional production, needs to be reconsidered in light of climate change.	

Creating an enabling context and removing barriers for adoption of sustainable soil and land management

Fostering the uptake of sustainable soil and land management is a complex process. It involves not only providing technical options suitable for different conditions, but also managing barriers to adoption and establishing supporting policies and institutions to ensure successful scaling up of successful practices. It also requires investments in identifying and promoting appropriate production systems that can simultaneously reverse or minimize degradation, conserve above- and below-ground biodiversity, sequester carbon, reduce greenhouse gas emissions and ensure sustained productivity.

To promote the principles and guidelines on sustainable soil and land management and support their transition into sound policies and activities at all levels, the 39th Session of the FAO Conference adopted the revised World Soil Charter as a normative measure. The principles contained in the revised Status of the World's Soil Resources were elaborated on in the Voluntary Guidelines for Sustainable Soil Management under the Global Soil Partnership (FAO and ITPS, 2015a and 2015b; FAO, 2016a). The Voluntary Guidelines for Sustainable Soil Management, which take into account evidence provided in the Status of the World's Soil Resources report, recognize that sustaining soil biodiversity and ecosystem services provides many benefits to people and the environment, including strengthening climate change adaptation and mitigation. The Guidelines highlight the importance of soils as a non-renewable natural resource and the importance of sustainable soil management as an integral part of sustainable land management. They provide a reference document for generally accepted, practically proven and scientifically based principles to promote sustainable soil management; and offer guidance to all stakeholders on how to translate the principles into practice. They also include the core characteristics of sustainably managed soils, key challenges and potential solutions to address them.

The technical guidelines address in particular the main soil threats that hamper sustainable soil management. They highlight the need to minimize soil erosion; enhance soil organic matter content; foster soil nutrient balance and cycles; prevent, minimize and mitigate soil salinization and alkalinization, soil contamination, soil acidification and soil compaction; preserve and enhance soil biodiversity; minimize soil sealing; and improve soil water management to prevent waterlogging.

The impacts of climate change are complex and will affect natural resources and ecosystems in different ways in different places. It is important that communities understand the implications of these potential impacts in their own areas and can adapt to them. There is a need to enhance farmers' knowledge and innovations and develop the capacity of local agricultural producers and other land users to manage their soil systems in ways that build resilience and allow them to continually innovate and adapt to changing climatic conditions and changes in production systems. This will involve building on practical farming skills through observation, personal experiences and knowledge sharing. Examples of potential climate-smart practices include breeding locally adapted seeds and livestock, using organic fertilizers, such as compost, manure, and green manures, and managing soil moisture.

To scale up climate smart sustainable soil and land management practices it is vital to understand and analyse the various barriers that hinder farmers from adopting these practices. The barriers for sustainable soil and land management adoption vary from one area to another, and most importantly, from one agricultural ecosystem to another.

Some of the common barriers are the lack of sufficient technical information on sustainable soil and land management technologies; the poor quality of agricultural extension, including forecasting systems; an absence of a multidisciplinary, integrated landscape approach to land resource management and land-use planning; inadequate financial resources and access to credit; insufficient technical and management capacities; lack of promotion of crop diversification, including inadequate seed supplies and limited dissemination of information about market conditions; and institutional disconnection at various levels on issues related to land, soil and water management.

Specific barriers for the adoption of sustainable soil and land management in irrigated agroecosystems are the lack of developed input and output market institutions, and the lack of farmer awareness or training in the use of appropriate soil and water management practices.

In rainfed agricultural ecosystems, farmers are also generally unaware or untrained in the use of appropriate soil conservation practices. Other barriers to adoption include the lack of land resources and land-use planning and monitoring; a lack of mechanisms to implement laws and legislations; and the shortage of labour, working capital and capital assets, such as machinery.

In rangelands, common barriers to adoption are the absence of policies and mechanisms to regulate land management (e.g. pasture leasing mechanisms or agreements between land users); lack of economic and management capacities, particularly among individual household pastoralists; and the limited public awareness of rangeland degradation issues and approaches. This module as considered the tools and approaches to tackle some of these barriers. Barriers related to institutions and capacity development are addressed in module C1; extension services in module C2; and policies in module C3.

Conclusions

Healthy soils are fundamental for sustained agricultural productivity and the maintenance of vital ecosystem processes and services. To cope with climate change, the different types of crop, livestock and forest production systems, and the specific practices used to manage them, need to be adapted to take into account the diversity and current status of soils, terrain and climatic conditions.

Diversified production systems and land uses will conserve the diversity of plant and animal species and varieties in the agricultural ecosystem; provide diverse habitats for beneficial predators and pollinators; and reduce farmers' risk and vulnerability in situations where one or more crops fail or other farming enterprises collapse. Practices that maintain or increase soil organic carbon from year to year through the management of soil organic matter will bring 'triple win' benefits. They will create productive soils that are richer in carbon, require fewer chemical inputs, maintain vital ecosystem functions, and mitigate climate change. There is a need to shift away from specialized high-input systems towards an ecosystem approach for the management of land, soil, water and living resources ¬– an approach that promotes conservation and sustainable use in an equitable way, lowers the need for external production inputs and cuts down on the greenhouse gas emissions that are linked to these inputs. Integrated production systems reduce the use of inorganic fertilizers and their associated greenhouse gas emissions, diversify farm outputs, sustain yields and reduce vulnerability to the impacts of climate change and other shocks.

A variety of sustainable soil and land management practices are available to enhance climate change adaptation and mitigation. Planning tools are needed to help land users select the most appropriate practices for their particular conditions. Policies and financial mechanisms that establish a conducive enabling environment will foster a greater uptake of sustainable soil and land management practices, and ensure that they have a wider impact on building resilient agricultural systems.

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