Ecosystem Soil

Bringing nature-based solutions on climate change and biodiversity conservation down to earth

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List of Abbreviations

CBD	Convention on Biological Diversity
CCA	Climate Change Adaptation
CSA	Climate-Smart Agriculture
EbA	Ecosystem-based adaptation
ELD	Economics of Land Degradation
FAO	Food and Agriculture Organization of the United Nations
FLR	Forest Landscape Restoration
GBF	Global Biodiversity Framework
GDP	Gross Domestic Product
GSP	Global Soil Partnership
IPBES	Inter-governmental Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
KJWA	Koronivia Joint Work on Agriculture
LDCs	Least Developed Countries
LDN	Land Degradation Neutrality
NAPs	National Adaptation Plans
NbS	Nature-based Solutions
NBSAPs	National Biodiversity Strategies and Action Plans
NDCs	Nationally Determined Contributions
SDGs	United Nations Sustainable Development Goals
SLM	Sustainable Land Management
SPI	Science-Policy Interface
SSM	Sustainable Soil Management
UNCCD	United Nations Convention to Combat Desertification
UNFCCC	United Nations Framework Convention on Climate Change
VGSSM	Voluntary Guidelines for Sustainable Soil Management

Table of Contents

The multiple roles of soils often go unnoticed. Soils don't have a voice, and few people speak out for them. They are our silent ally in food production.

José Graziano da Silva, former Director-General of FAO, 2014[1]

1. Introduction

There is an unprecedented interest in nature-based solutions for climate change mitigation and adaptation. But something very important is often missing from discussions of such solutions: the role of healthy soils. As habitats for plants and animals, as regulators of climate and water, and as the foundation of terrestrial ecosystems and the vast majority of our food production, soils are critical to all ecosystem services – including those that humans depend on for survival.

Yet soil health is in jeopardy in many parts of the world, depleted by decades of industrial agriculture and land degradation, and further threatened by climate change. One third of the earth's land is already degraded. This degraded land is home to about 3 billion people.[2] At the same time, healthy soils can boost resilience to climate shocks and increase species diversity both above- and below-ground, making them a critical element of policies and practices for climate change adaptation and mitigation, biodiversity conservation, water resource management and sustainable development.

But while soils are clearly relevant to many areas of international concern, they have been invisible until recently. For decades, soil degradation and the importance of sustainable soil and land management received little attention. Only in the last few years has the importance of soil quality become increasingly acknowledged by practitioners and policymakers. During the International Year of Soils (2015), the Food and Agriculture Organization of the United Nations (FAO) and the Intergovernmental Technical Panel on Soils released an important report on the status of soils.[3] More recently, awareness of the connection between sustainable development, food security, climate change, biodiversity and soil has started to gain ground, as seen in a growing number of international strategies, policies and initiatives. However, there is still a lack of attention to the critical role healthy soils play in almost any terrestrial ecosystem-based approach. There is also a need to make the connections between soil health, biodiversity and climate change more explicit, and to develop integrated policies at national, regional and international levels.

Now is a critical time to examine the intersection between healthy soils and other global goals, as well as relevant nature-based solutions that can create 'triple wins' for people, climate and nature. With less than a decade to meet the United Nations Sustainable Development Goals (SDGs), governments must scale up efforts to improve both the state of the environment and human well-being.

Agricultural systems play a key role in the implementation of the SDGs and other international agreements on climate change, biodiversity and many other topics. But they are also severely affected by the increasing impact of climate change. The need to adapt farming systems to make them more resilient is paramount to achieving global food security and sustainable food systems. Ecosystem-based approaches can significantly contribute to this. But in order to leverage the potential of ecosystem-based adaptation (EbA) in agriculture, we need to look below the surface – into the soil.

The goal of sustainable agriculture is to significantly reduce negative impacts on ecosystems and make agricultural systems more resilient to climate change, while meeting the growing demand for healthy food. Soil management is the central factor that determines whether agroecosystems can continue to deliver sustainable yields for future generations or whether their resources will be overexploited, disrupting ecosystem services and generating immense downstream societal costs. But not all sustainable farming approaches promote soil health – and thus ecosystem health – equally.

This guidebook aims to demonstrate the importance of sustainable soil management (SSM) for adaptation to climate change, biodiversity conservation and the achievement of long-term food security. By adopting nature-based solutions such as ecosystem-based adaptation (EbA), farmers can dramatically increase their productivity while adapting to climate risks.

But what does EbA mean in relation to soil? Which techniques are truly sustainable and how can they be implemented? These and other questions are addressed in the following chapters.

Chapter 2 describes the key functions of soils, highlighting the importance of soil health to various ecosystem services. Chapter 3 examines the linkages between soil and climate change, looking at both the impacts of climate change on soils, as well the potentials of soils for climate change mitigation and adaptation. Chapter 4 explores different land and soil management approaches and their capacity to make agriculture more climate resilient. Chapter 5 turns to the political sphere, providing an overview of current initiatives to raise the profile of soils in international and national arenas. And finally, Chapter 6 discusses the importance of soil governance, including challenges and what is needed to enable sustainable soil management at scale.

Box 1. Nature-based solutions and ecosystem-based adaptation

The International Union for Conservation of Nature defines nature-based solutions (NbS) as: *“actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits. They are underpinned by benefits that flow from healthy ecosystems and target major challenges like climate change, disaster risk reduction, food and water security, health and are critical to economic development”.*[4]

NbS encompasses a broad spectrum of ecosystem-based approaches that hold the potential to address the interlinked multifaceted environmental crises and broader societal challenges affecting humanity today. ‘NbS for adaptation’ focus on building resilience to the impacts of a changing climate, including drought, floods and extreme weather events. Another term for NbS for adaptation is ecosystem-based adaptation (EbA), which entails the conservation, sustainable management and restoration of ecosystems as part of an overall strategy to help people adapt to climate change.

According to the United Nations Environment Programme, EbA is: *“a strategy for adapting to climate change that harnesses nature-based solutions and ecosystem services. For instance, protecting coastal habitats like mangroves provides natural flood defences; reforestation can hold back desertification and recharge groundwater supplies in times of drought; and water bodies like rivers and lakes provide natural drainage to reduce flooding”.*[5]

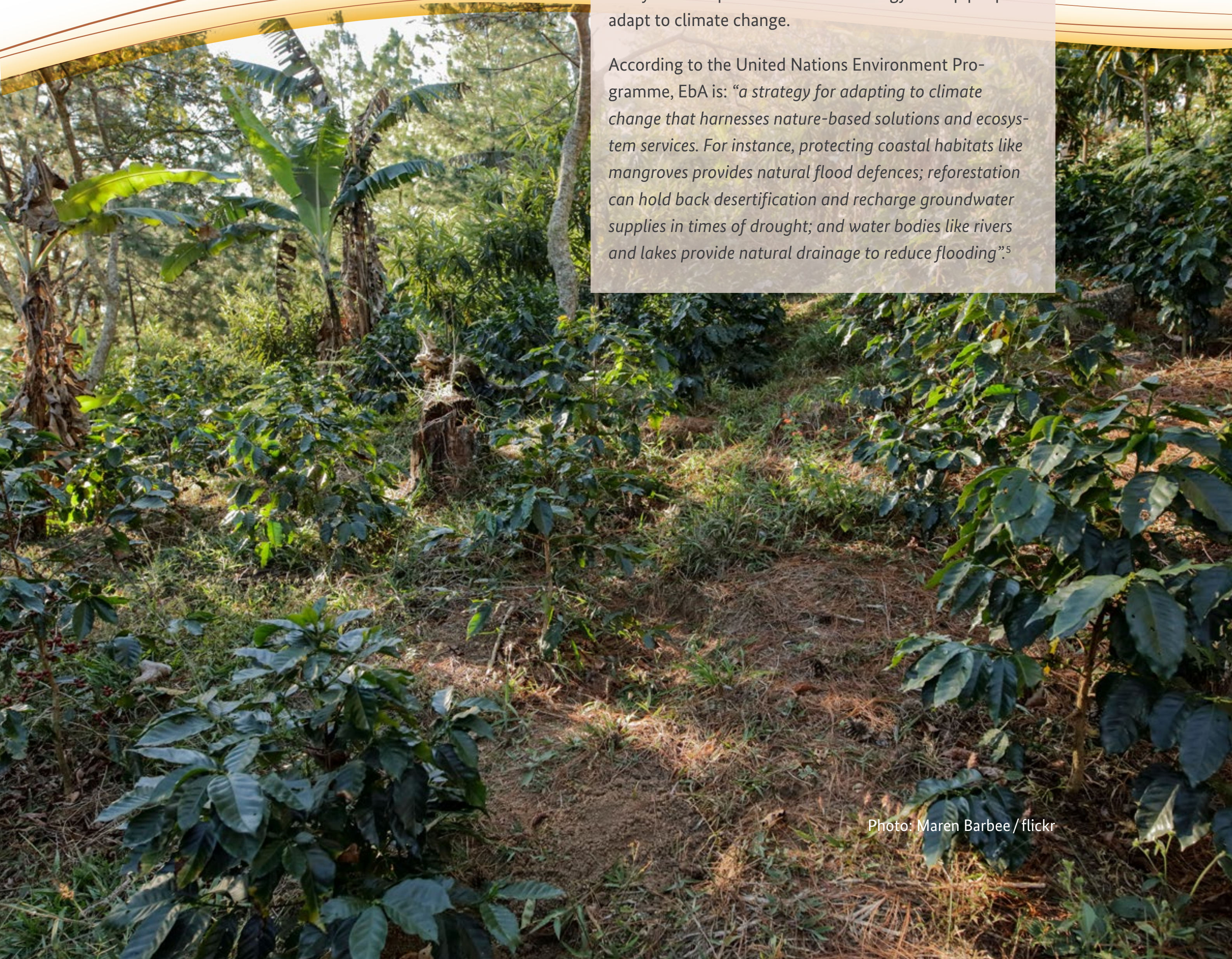

Photo: Maren Barbee / flickr

2. Soils as ecosystems

As highly complex ecosystems, soils are biodiversity hotspots. They represent an essential resource for life, both plant and animal. As the second largest carbon sink after oceans, soils store more carbon dioxide than all biomass above ground, including forests.[6] They strongly influence the local climate by enabling the growth of vegetation, which in turn has a major influence on evaporation, local temperature and rainwater retention. Soils provide us with some of the most important elements for survival – food and fodder – as well as the raw materials required for a wide array of other products. Without soils' purification function, we would not have clean drinking water.

Soils are not static but dynamic, formed when rocks are transformed by the climate and by plants, animals and microorganisms. Processes like weathering, new mineral formation, decomposition, accumulation of humus, formation of soil structure, and the movement and transformation of soil substances take place over long periods of time; most of Earth's soils developed in the last hundred million years. Depending on the parent rock and conditions (such as temperature and humidity), it can take between 20,000 and 200,000 years for one metre of soil to form. On a human timescale, soil cannot be considered a renewable resource; in fact, it is scarce. Only 12% of the planet's land surface is suitable for intensive farming, with a further 22% being suitable for limited agricultural use; the rest is desert, tundra or wetland (Figure 1). The percentage of arable land cannot be increased, which is why soil degradation poses such a major threat. Each year, 12 million hectares of land are degraded due to unsustainable use, adding to the 2 billion ha that are already degraded.[7] Wherever soils are eroded, they are lost forever. Thus, it is critical to halt the loss of productive soil by avoiding and reducing land degradation, as this is more cost-effective than trying to reverse it.[8] This goal, known as Land Degradation Neutrality (LDN), is anchored in SDG 15 and aligns with the broader definition of restoration adopted by the UN Decade on Ecosystem Restoration 2021–2030, which includes halting, preventing and reversing the degradation of ecosystems (see also Chapter 5.1). Whether climate change will make additional land available for cultivation cannot yet be estimated.

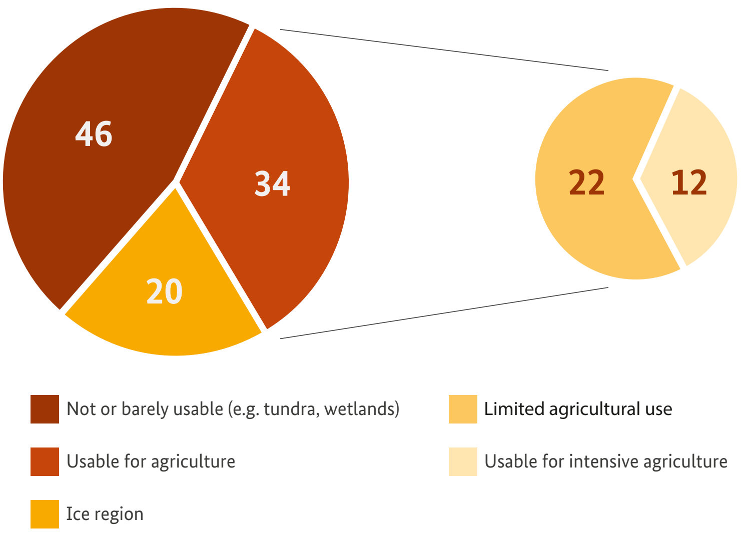

Figure 1: Percentage of the Earth's land surface that can be used for agriculture. Source: Wissenschaftlicher Beirat Bodenschutz (2002)[9]

2.1 Soil functions and soil health

Internationally, scientists have agreed on the definition of three ecological functions of soils considered essential for a balanced ecosystem. Only when soils are able to perform all three of the following functions are they considered to be healthy:

- → **Provision of habitat** for both plants and animals
- → **Regulation** of water, organic and inorganic matter through filtering, buffering, transformation and storage
- → **Production** of food, feed and biomass.

These soil functions, together with other ecosystem functions, enable the provision of certain essential ecosystem services (Figure 2). For example, flood regulation depends on water infiltration into the soil, which reduces surface run-off (regulation function). In addition, the vegetation that grows in the soil (production function) also attenuates run-off, namely through interception, roughness and transpiration. Soils thus form the basis for all ecosystem services that are essential to keeping terrestrial ecosystems intact. They are also critical to human survival: after food production, the most important function of soils is the replenishment and purification of groundwater, which supplies our drinking water.

Habitat	Regulation and storage	Production
Habitat and means of subsistence for plants and animals	Filtering, buffering, storage and transformation of water and organic and inorganic matter	Production of food, fodder and renewable raw materials

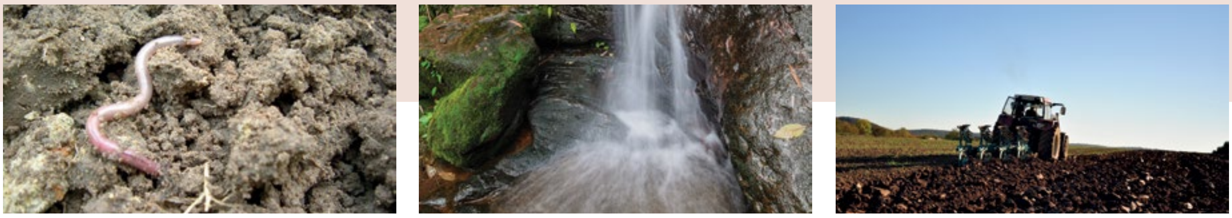

Figure 2: The three ecological functions of healthy soils. Source: Beste (2015)[10]

2.1.1 Soil as habitat

One gram of healthy soil can contain up to 600 million bacteria of various species, not to mention fungi, algae, single-celled organisms, pinworms, earthworms, mites, woodlice, springtails, insect larvae, and so on. If one projects this across an area of one hectare, the live weight of all the organisms in the soil would be around 15 tonnes, or the weight of 20 cows[11] (Figure 3). Microorganisms and soil-dwelling animals are part of a complex food web: they break down organic matter and form new substances that serve as food for other soil organisms and plants, or which positively influence the soil structure and facilitate the exchange of nutrients.[12 13] All this, whether it is living or not, is called soil organic matter, and it is the basis of soil fertility (Box 2).

Soil organisms actively loosen soil or create larger soil particles with their mucous secretions. Vital to the formation of soil structure, they encourage soil aeration and enhance the soil's capacity to absorb and store water. Their ability to break down organic pollutants, such as engine oil and pesticides, help boost the soil's own ability to self-purify. Further, the symbiotic relationship between some soil organisms (mostly fungi and bacteria) and plants enhances plants' uptake of nutrients and protects them from disease. Mycorrhizal fungi are the best-known example of this.[14]

TEEMING SOILS

Number of living organisms in 1 cubic metre of topsoil in temperate climates, logarithmic scale

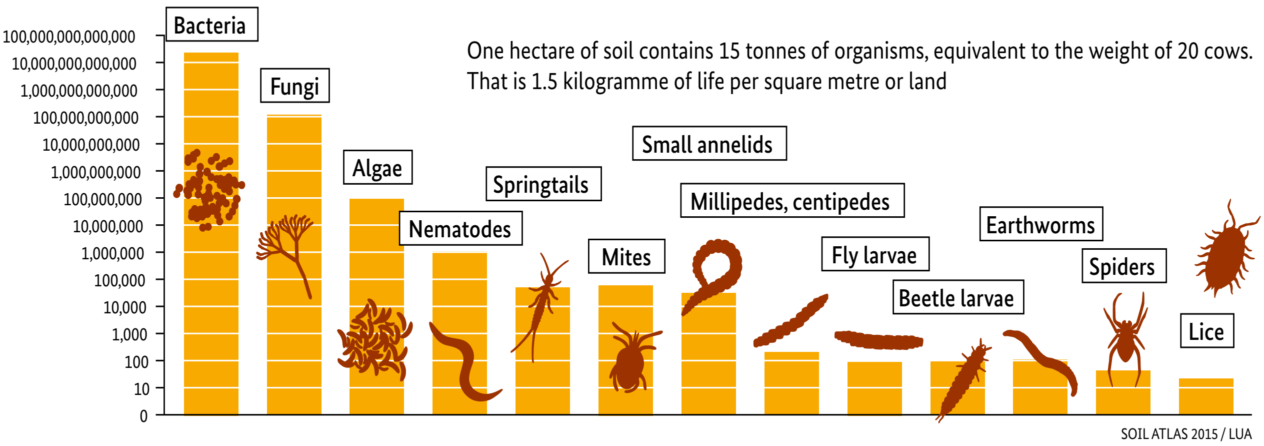

Figure 3: Living organisms in soils. Source: Chemnitz & Weigelt (2015)[15]

2.1.2 Soil as a regulator

Soil's regulation function comes from its ability to absorb, sequester, convert or break down materials, including pollutants. Water supply and quality, carbon sequestration, climate regulation, and control of flooding and erosion relate to this function. If soil is in good condition – i.e. not sealed, crusted or compacted – then most of the rainwater that falls on it will infiltrate into it. A portion of it is naturally stored and remains available to plants and soil-dwelling animals, while the rest seeps further down to the groundwater level, becoming purified in the process. Sustainable soil management is therefore essential for our drinking water supply. **According to one estimate, it takes about 256 m^3 of unsealed, non-compacted, unpolluted soil to produce enough water to meet the average daily water consumption of a European citizen (140 L).**[16]

If soil is compacted, it has less capacity to absorb and drain water, and this affects groundwater replenishment. Water runs off at surface level, causing erosion (loss of fertile soil matter) and flooding, along with loss of housing, transport infrastructure and human life. Further, surface waters suffer from contamination: soil particles, nutrients and pollutants are carried into lakes, streams and rivers, interfering with their functions. **However, the compaction that occurs in intensively farmed agricultural soils still receives little attention from scientists, policymakers and practitioners, nor is there much focus on adapted soil management to improve infiltration.** Compaction results from the use of heavy equipment, but it can also occur along with structural degradation from the loss of soil life caused by non-sustainable farming methods such as cultivation of monocultures and use of synthetic inputs, even without heavy machinery.[17,18]

Soil first filters, then buffers and finally transforms pollutants, regardless of their origin. But its ability to perform this function is contingent upon the soil type, the microorganisms present in the soil, the soil's humus content and the soil structure.[19,20,21,22,23] A high humus content enhances soils' capacity to absorb and purify substances, including pollutants. While this is good news for groundwater quality (filtration), it can lead to a build-up of pollutants in the soil over time. Thus, while filtration might be good for clean groundwater (buffering), it can cause accumulation of pollutants if the soil must absorb high amounts of chemical inputs. The third process, transformation, involves organisms living in the soil that convert organic substances in plants into available nutrients; they can also transform organic pollutants into other compounds that are either less toxic or more toxic, depending on the source material. The biological purification process performed by soil is far more effective than its physical and chemical purification processes, and thus soil life is crucial for our drinking water supply.[24] Any reduction in biological activity in soil has a decisive impact on its ability to purify water. However, it is precisely this biological diversity and activity that is disturbed by common agricultural practices such as the use of pesticides and intensive mineral fertilization.[25,26]

Photo: Britta Radike / GIZ

2.1.3 Soil as biomass producer

Soil's production function also has a major role in maintaining the natural balance across a landscape. Healthy plant growth is an essential precondition for the vast majority of ecosystems. The nutrients and water stored in soil produce varied vegetation, which facilitates evaporation, air purification and CO_2 absorption. In conjunction with climatic conditions, different soils can produce a broad variety of animals and plants – a genetically limitless reservoir that holds vast potential for human use. However, due to both climate change and human practices, this diversity is threatened.

The effects of decreased soil fertility is the main driver of desertification; as soils become less able to sustain plant growth, the resulting loss of vegetation loss leads to erosion, a disrupted water cycle (no evaporation) and drought. Throughout the world, soil degradation through overexploitation is driving desertification at an alarming rate.[27 28]

This threat extends beyond ecosystem degradation to food security. Studies have reported yield stagnation in the world's major cereal crops, including maize, rice and wheat.[29 30 31] Experts warn that failure to identify and remedy the causes of yield stagnation or reduction will have a major impact on the future of global food security.[32] If we do not fundamentally change our current soil and land management, we put our very survival in danger.[33 34]

→ A note on tropical soils

The soils of the humid tropics are predominantly washed out and nutrient poor. Their profound degradation is a result of intensive weathering. Unlike mid-latitude soils, the proportion of clay minerals with low nutrient exchange capacity in tropical soils is very high (predominantly kaolinite). Nutrient exchange in these soils is therefore much more dependent on humus content and the transforming processes of soil life than in mid-latitude soils. However, humic substances have 25 times the exchange capacity of the main clay minerals in tropical soils,[35] allowing them to compensate for this deficit. Thus, encouraging humus accumulation and supporting soil life is crucial to enhancing production conditions in tropical soils (Box 2).[36]

Box 2. Soil organic matter, soil organic carbon and humus

There is a standard conversion factor to determine the humus content in soil: multiplying the measured amount of soil organic carbon by 1.72 provides the humus content. As soils and humus composition are very site-specific and diverse, using this general calculation for all soils without regard for site-specific factors and soil management can lead to inaccurate values.[37] For the sake of simplicity, this guide does not make any distinction between soil organic carbon, soil organic matter and humus. However, it should be taken into account that, strictly speaking, soil organic matter and humus consist of carbon for the most part, but also oxygen, hydrogen, nitrogen, phosphorus and sulphur in variable proportions, whereas soil organic carbon is just carbon that is organically bound.

Key messages

- → Soils are biodiversity hotspots and the second-largest carbon store on the planet.
- → Soils form the basis of ecosystem functions; climate and water regulation depend on them.
- → Soils are a prerequisite for the production of biomass of any kind.
- → Soils have an important influence on ecosystem services that are important to humans, such as water purification and storage.

3. Climate change and soils: Impacts and potential for mitigation and adaptation

As shown in Chapter 2, soils play a key role not only in food production, but also as a habitat and a provider of ecosystem services. This makes them extremely relevant for both climate change mitigation, where soil organic carbon is plays a key role, and adaptation, where regulatory functions turn out to be key (e.g. for the water cycle). In general, agriculture is both a driver and a victim of climate change. During the 20th century, the world's cultivated soils lost between 25% and 75% of their original carbon stock[38 39] – released into the atmosphere in the form of CO_2 – mainly due to unsustainable land management practices. These losses of soil carbon not only contribute to accelerating climate change, they also make soils more vulnerable to its effects through crucial impacts on the fertility of soil, its capacity to retain water, and its resilience to extreme weather conditions. This increased vulnerability in turn has a negative impact on harvest yields and their stability, furthering the destructive cycle. The loss of ecosystem services due to soil degradation is estimated at 6.3–10.6 trillion USD a year.[40]

Therefore, in order to break this cycle, agricultural strategies must become 'climate-smart' to reduce greenhouse gas emissions, while at the same time integrating adaptation mechanisms to maintain productivity under increasingly variable and extreme weather conditions. Sustainable soil management (SSM, see below) is a core element of such mechanisms.

3.1 Soil under climate stress

Soils are affected by climate change in a multitude of ways but most of all by fundamentally altering water cycles around the world. On the local and regional scale, there is greater variation in rainfall – heavier in some years and much less than usual in others – as well as increased evaporation in many areas, which in turn raises the risk and severity of droughts. Years of drought are more and more often followed by extreme rainfall events, causing abrupt flooding, soil loss and crop failure. In many areas, rainfall has become either increasingly abundant or in desperately short supply, compared with long-term averages. Increased rainfall can lead to run-off and erosion if the soil is not able to absorb precipitation at the rate it falls. In the most extreme cases, when a heavy rainfall occurs over sloped land without adequate vegetation cover, landslides can occur. Decreased rainfall on the other hand, along with less regular precipitation (especially in combination with increased heat and evaporation) can accelerate desertification and even lead to a complete loss of food production in some areas. Frequent droughts and enhanced evaporation are not only killing off the vital soil organisms needed to grow healthy crops, they also leave less water to dilute even relatively common pollutants in reservoirs, streams and rivers, lakes and wells.[41] From a global, long-term perspective, climate change is predicted to lead to larger-scale variations in precipitation, triggering seasonal or even permanent shifts in entire ecosystem zones due to long-term changes in temperature and rainfall regimes, which would also significantly alter soil life in many areas.

A recent study on land use and climate change impacts on global soil erosion by water predicts an increase in soil erosion of 30–66% by 2070 compared to 2015, depending on land use and climate change impacts. If agricultural practices do not change and measures to slow global warming fail to materialize, the study projects an additional loss of soil of over 28 billion tons annually.[42 43 44] A study from the European Commission's Joint Research Centre found that soil erosion might lead to a loss of USD 8 billion from global gross domestic product (GDP).[45] Soil degradation and compaction further increase the risk of flooding through increased run-off. These impacts can lead to crop failure and, in some places, hunger, displacement and migration, sometimes fuelling armed conflicts.[46]

Soil health is also susceptible to heat. Increased average temperatures and more frequent extreme temperatures, can also directly affect and alter soil life, especially for soils with limited vegetation cover.

However, the water cycle and local microclimate are impacted not just by climate change: they are also affected by land use and vegetation. The less diverse the vegetation at a site, the less water evaporates and the less rain falls in one location.[47 48] The less diverse the roots in the soil, the less water it can hold and the more likely flood events will occur.[49] Areas with intact vegetation cover often are not only cooler, but also have a far more stable microclimate and are far less affected by extreme temperature changes. Yet **far too often the links among soil, vegetation and climate are not properly appreciated**.[50]

The good news is that sustainable and adaptation-oriented land use management can partly offset the extreme effects of drought or heavy rainfall and thus prevent soil and crop losses. Yet due to the unpredictability of these impacts, there is no one-size-fits-all solution for adaptation measures – they must be adapted to the local context. However, some general measures can make agroecosystems more resilient to both drought and heavy rainfall, while also promoting soil fertility, improving drinking water supply, and increasing biodiversity, which protects against pests.

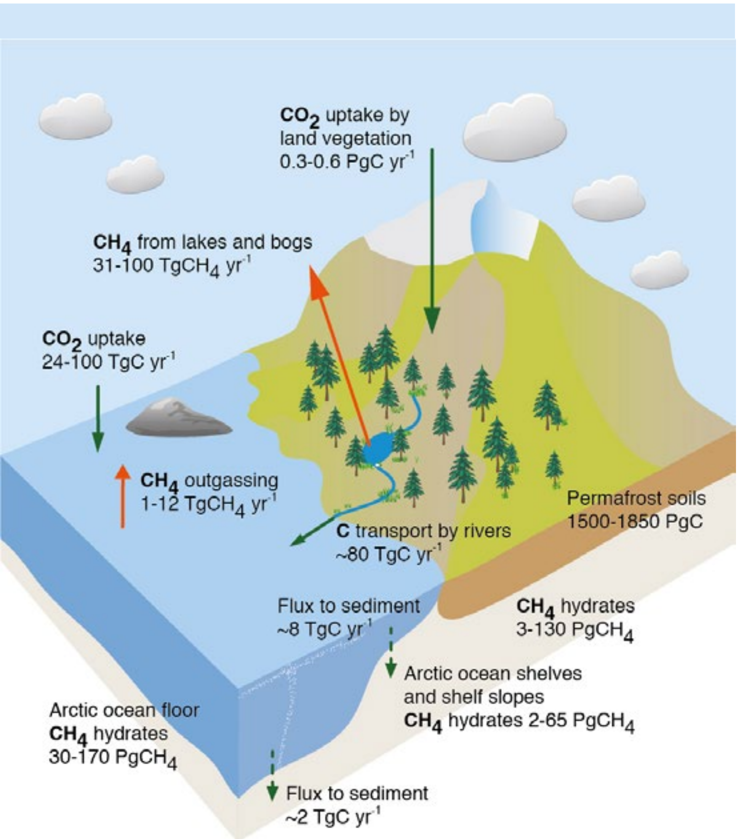

Figure 4: The global carbon cycle. Source: IPCC (2013)[60]

TgC = 10^{12} gC, 1 Petagram of carbon = 1 PgC = 10^{15} grams of carbon = 1 Gigatonne of carbon = 1 GtC. This corresponds to 3.667 GtCO_2.

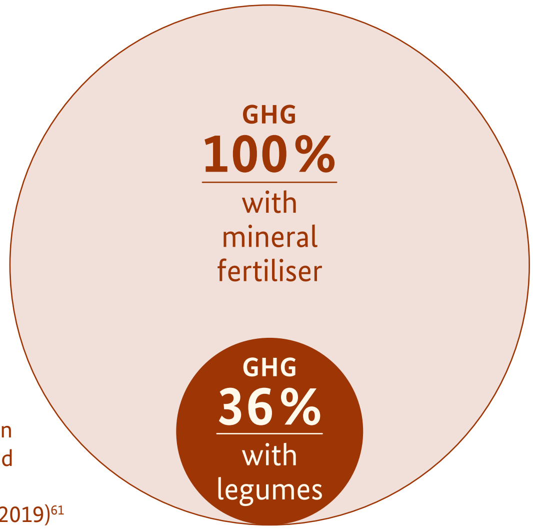

Figure 5: Emission saving potential in a legume-based rotation versus a rotation based on mineral fertilizer. Source: Beste & Idel (2019)[61]

3.2 Relevance of soils for climate change mitigation

Soils as carbon sinks, and thus as an aid to climate mitigation, are currently the subject of much debate. The largest amount of soil carbon on the planet (25%) is stored in the soils of permafrost regions (Arctica, Antarctica, Alps), which amount to a quarter of the Earth's land surface.[51] This is followed by wetlands, grasslands and forests, which also contain a large portion of the carbon stored in soils. Figure 4 illustrates the global carbon cycle.

Wetlands are a major carbon store, but 85% of them are considered destroyed.[52] When wetlands are converted into arable land or (short) rotation plantations, or if peat is extracted, large amounts of greenhouse gases are released. The same is true for the conversion of grasslands and forests.[53] Thus, controlling land use change holds by far the greatest potential when it comes to global soil carbon stocks – much greater than agricultural and soil management practices. This must be taken into account when evaluating the relevance of carbon storage in soils.

Agriculture's largest contribution to climate change is the production and application of synthetic nitrogen fertilizer.[54] Thus, limiting its use in favour of high-quality organic fertilizers could prevent the release of large volumes of greenhouse gas emissions. Nitrogen fertilization using legumes is the most energy-efficient and climate-friendly option. Through its ability to fix atmospheric nitrogen in the soil, a yield of four tons per hectare of beans can supply the equivalent of 180 kg of mineral nitrogen. This is equivalent to an energy saving of the 180 L of fuel (480 kg of CO_2) needed to produce this amount of mineral fertilizer.[55 56 57]

The total avoided emissions potential (carbon dioxide, nitrous oxide and methane emissions) in a legume-based rotation versus a rotation based on mineral fertilizer has a ratio of 36 to 100 (Figure 5),[58 59] and legumes have many other positive effects.

In contrast, storing carbon in the soil as a way to sequester it from the atmosphere has limited potential, increases slowly and is reversible.[62 63] This is because almost all indicators of carbon sequestration can also be influenced by external factors, such as weather extremes.[64 65] Therefore, many figures describing the theoretical carbon-sequestration potential in soil are significantly inflated.

According to the Intergovernmental Panel on Climate Change (IPCC), better management of soils could offset 5–20% of global anthropogenic greenhouse gas emissions,[66 67 68] but as mentioned above, avoiding conversion of wetlands, grasslands and forests plays the biggest role in this assessment. Thus, protecting wetlands and promoting pasture grazing has more mitigation potential than agriculture, because of the huge humus content stored in those soils.

Key messages

- → Soils are heavily impacted by climate change.
- → Drought kills soil organisms, and heavy rains can trigger erosion and soil loss.
- → The capacity of arable soils to sequester carbon is very limited.
- → The largest potential for climate change mitigation is in preventing land-use change and protecting peatlands, wetlands, grasslands and forests.
- → Humus accumulates very slowly and can be removed when soil management or external influences change.

3.3 Potential of soils for climate change adaptation

Soil is a key factor for any agroecosystem. While there is no doubt that agricultural systems around the world need to adapt to climate change, the potential contribution of nature-based solutions to climate change adaptation in agriculture is often overlooked. In industrialized countries, the benefits of intensive use of technology and synthetic inputs for soil fertility and agroecosystem performance are increasingly coming under scrutiny. There is growing recognition that more holistic approaches such as ecosystem-based adaptation (see Box 1) better support the long-term viability of soils and ecosystems – as well as economic sustainability.[69] Such approaches require a more holistic understanding of ecosystems and their sustainable use. While a uniform definition and a binding set of rules for the implementation of this concept are still being developed, many existing agricultural management practices already meet these requirements.

Sustainable land management (SLM) and sustainable soil management (SSM; Box 3) are two NbS that provide multiple ecologic and economic advantages, such as more reliable crop yields, greater conservation of biodiversity, and avoided costs related to the need to protect groundwater and drinking water from over-fertilization and use of pesticides.[70] Research shows that SSM can achieve yields up to 10–120% compared with high-external-input agriculture. They also provide better protection against erosion, flooding and mudslides, and improve local microclimates.[71] However, there are several barriers to the uptake of such approaches at scale. NbS does not imply a return to ancestral forms of agriculture – it is based on current evidence of how soil ecosystems function and knowledge on optimal soil management. Applying this knowledge requires clear and consistent knowledge transfer, which is currently insufficient. Some NbS practices require time for positive effects to materialize, and thus projects and funding need to be planned over longer timeframes. Finally, many types NbS are rooted in Indigenous or traditional local knowledge and experience, leading to some resistance in expert circles even when their effectiveness has been shown under scientific study.

There are many examples around the world that demonstrate the viability of agroecological approaches (see Annex 2).

Box 3. Managing land – and soil – sustainably

Sustainable land management (SLM), as defined at the 1992 UN Earth Summit, is: *"the use of land resources, including soils, 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"*.[72 73 74 75 76] Sustainable land management is strongly influenced by the land market, environmental laws, support from local authorities and agricultural subsidies. But education at universities and agricultural schools also plays a role. SLM is also about deciding what type of approach makes the best use of local resources.

The Voluntary Guidelines for Sustainable Soil Management (VGSSM), endorsed by the FAO Council in December 2016, complement the World Soil Charter by further elaborating principles and practices for incorporation into policies and decision-making. The VGSSM define sustainable soil management (SSM) as: *"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."*[77 78]

SSM therefore depends on producers' knowledge and experience of the basic functions of the soil and local ecosystem. SSM involves deciding what to grow in which location, where the best conditions are for both forage and cash crops, and how soil fertility for plants and animals can be used efficiently and maintained over time.

Adaptation to climate change, biodiversity protection and sustainable soil management require an integrated strategy that goes beyond isolated solutions for specific impacts, addressing all causes of degradation, increased greenhouse gas emissions and biodiversity loss. For example, replacing mineral fertilizers with organic fertilizers can support biodiversity and improve soil function, while simultaneously making a major contribution to climate mitigation and making ecosystems more resilient to weather extremes.

SSM comprises three essential elements that aim to support interactions in the soil ecosystem, leading to a healthy, resilient and fertile soil. These are regarded by international science as essential to soil ecology and soil functions:

- → Increasing soil organic matter
- → Promoting soil life
- → Promoting diversity (both below and above ground).

These elements enable the following benefits to be achieved, regardless of the ecosystem, soil or climate:

- → Humus accumulates.
- → All soil functions – habitat, regulation and production function – are protected and improved.
- → Soil structure in particular, and thus water infiltration and storage capacity, are improved.
- → This stabilizes the local water cycle and thus the supply of water to plants – even in droughts.
- → Cooling of the system through evaporation is optimized.
- → Improved water infiltration reduces erosion and the risk of flooding.

As a result of all these benefits, ecosystem services are improved overall.

Since extreme events such as heavy rainfall and droughts will continue to increase in frequency and magnitude, and are often unpredictable, a flexible, comprehensive design of ecosystem-based approaches is needed that can be continuously adapted over time.

Promoting these three elements can reduce emissions, support biodiversity and stabilize the land-use system as a whole against climate shocks and other stressors. Therefore, SSM is a type of EbA for climate change. Most of these practices are rooted in indigenous and/or local knowledge, and their positive effects are increasingly proven through basic research and empirically confirmed in many projects worldwide (see Chapter 4).

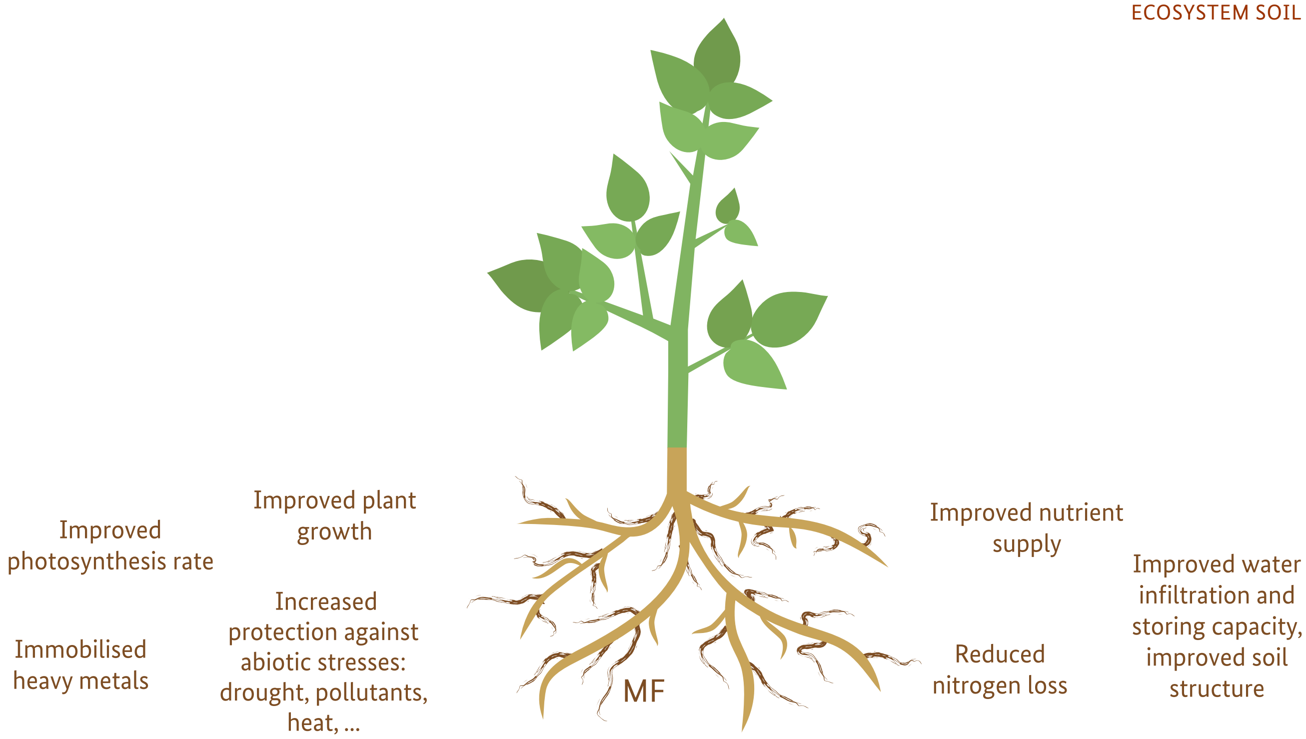

Figure 6: Ecosystem services by mycorrhiza funghi (MF). Source: Beste (2022)[87]

The first element: Increasing soil organic matter

Enhancing organic carbon and humus in soils improves their health and fertility, water and nutrient retention capacity, food production potential, and resilience to drought and heavy rain. The ability of carbon-rich manure to support humus accumulation is highly dependent on the form in which the carbon is introduced into the soil; not all organic manure is suitable for soil life (e.g. untreated slurry or large amounts of fresh matter (green mulching) are not beneficial to soil organisms). Compost is particularly well suited to improve soil as it increases humus content, microbial biodiversity and soil fertility (Figure 6). Mulching has benefits for soil life and, perhaps more significantly, protects the soil surface from erosion.

The following positive effects of compost on soil have been confirmed by research:[79]

- → Increased aggregate stability, improved soil structure
- → Increased pore volume
- → Improvement in water storage and filtration capacities
- → Increased biological activity
- → Increased humus content
- → Reduced risk of erosion and increased flood protection
- → Increased mycorrhization and improved nutrient supply
- → Reduced nitrogen leaching
- → Improved disease resistance in crops
- → Improved nutrient exchange capacity.

Compost can hold 3–5 times its weight in water. This allows rainwater that would normally be lost through evaporation or run-off to remain and replenish ecosystems.

Long undervalued, roots and the substances they release into the surrounding soil (exudates) are now known to be the largest promoters of humus accumulation – even more so than compost. Therefore, they can be considered part of 'organic manure' both in terms of their definition and usage. A diverse root system increases biological activity, stabilizing the soil structure and improving water retention and filtration capacity. First, roots bind soil fragments; second, they supply food for soil life, whose biological activity structures and stabilizes the soil fabric; and third they are important humus builders. Thus, they support the water cycle in three ways.[80 81 82]

Biochar – the introduction of carbon into soils by means of pyrolysis (thermal decomposition) to increase soil organic matter – is another widely discussed approach. However, in 2019 the German Federal Thünen Institute states that the use of biochar is considered to be in dispute, due to inconsistent results regarding the effects on soil functions and soil fertility and the potential risks for soil caused by pollutants arising from pyrolysis.[83 84 85 86]

The second element: Promotion of soil life

Whether composed of manure or plant matter, organic fertilizer is preferable to mineral fertilizers, which disturb the balance of soil biology, particularly mycorrhizal fungi. Mycorrhiza constitute a major component of the agroecosystem, as they establish a symbiotic relationship with the roots of 80% of all plant families. Mycorrhizal colonization benefits plants by improving their nutrient status, and it subsequently enhances ecosystem services through, for example, enhanced soil structure formation (Figure 6).[88] Mycorrhiza stabilizes soil aggregations, prevents soil erosion, and inhibits the colonization of pathogens.[89 90] In contrast, disturbing soil life through the use of agrochemicals, mineral fertilizers and tillage causes soil compaction, which leads to erosion, loss of fertility and emissions of nitrous oxide.[91 92 93]

In a complex food web[94], microorganisms and soil animals decompose organic material and form new substances. These, in turn, serve as nutrients for other soil organisms and plants or as humic substances, which have a favourable influence on soil structure and material exchange. Soil organisms loosen the soil or cause soil particles to stick together. They contribute decisively to the formation of soil structure, promote aeration and increase water infiltration and storage capacity (see Figure 3). Thus, it is better able to absorb most of the rainwater that falls, storing part of this water for a longer period of time and making it available to plants and soil animals; the remaining rainwater is purified as it seeps downwards, contributing to groundwater accumulation. This is deeply dependent on the creation of biological soil structure, as mid-sized pores must be built by microorganisms – they cannot be created through technical loosening.[95 96 97]

The third element: Promoting ecosystem services and diversity

Biodiversity stabilizes ecosystems. It enhances the capacity of ecosystems to respond to stress and maintains the water cycle through structure stabilization and increasing pore volume. It also provides important ecosystem services, e.g. by balancing food cycles and competing species. Thus is also crucial for food production.

For example, pollinators contribute USD 217 billion to the global economy,[98 99 100] and honeybees alone are responsible for USD 15 billion dollars in agricultural productivity in the United States through their vital role in fruit, nut and vegetable production.[101]

Diverse agricultural systems are less vulnerable to extreme climatic events, climate variability, and cumulative agro-climatic changes,[102] including both above- and below-ground diversity.

The ideal way to promote belowground diversity is through crop rotations or planting of different crops on the field at the same time (under sowing, mixed crops), and perennial crops, as these measures promote root diversity and density, which stimulates soil biota. Crop rotation is part and parcel of good agricultural practice. Traditional knowledge, educational textbooks and experiential knowledge all underline the importance of alternating 'humus-sapping' crops with humus-building crops – a principle that comes up frequently in training courses and university curricula. **However, the practice of crop rotation has been waning in the last 20 years and is virtually non-existent in intensive farming across Central Europe and North and South America. This is having devastating impacts on soil health.**[103 104]

Intercropping protects soil from erosion and dehydration. It promotes root system development and increases biological activity, thus stabilizing the soil structure and improving its ability to retain and filter water.[105] This is especially true when an extensive, network-like root system forms throughout the entire soil profile. Such root system development can even loosen damp clay soils, improve soil structure and increase pore volume.[106] Further, diversified farming systems reduce the risk of harvest and livestock losses in cases of extreme climatic events or pest outbreaks, while also supporting economic diversification as an effective risk-reducing strategy for both smallholder farmers and large-scale operations. Since they have a positive effect on the water balance, they also contribute to yield security.

Increasing the amount of vegetation on land will boost soil fertility and groundwater recharge, increasing evapotranspiration and in turn leading to greater cloud cover and higher rainfall. More cloud cover causes an increase in atmospheric cooling through additional reflectance of incoming solar radiation.

Globally, 40–60% of the rain falling over land comes from moisture generated through upwind land evapotranspiration, mostly by transpiring trees. In some regions of the world, this share amounts to 70% of the rainfall. Thus, diverse vegetation cover makes its own microclimate and improves resilience against drought as it can convert heavy rainfall into a cooling effect, and increased water storage and groundwater replenishment.[107]

→ A note on no-tillage agriculture

Conservation tillage, or 'no-tillage agriculture' is credited with conserving moisture, minimizing the disturbance of soil life and protecting soils from erosion. It has also been long considered to increase soil organic matter. However, a 2010 global meta-analysis and other subsequent studies have concluded that no-tillage techniques do not accumulate more carbo across the soil depth profile (Figure 7).[108 109] Since most studies that measure soil organic matter content only examined soil at a depth of 7–15 cm, this remained unobserved for several years.

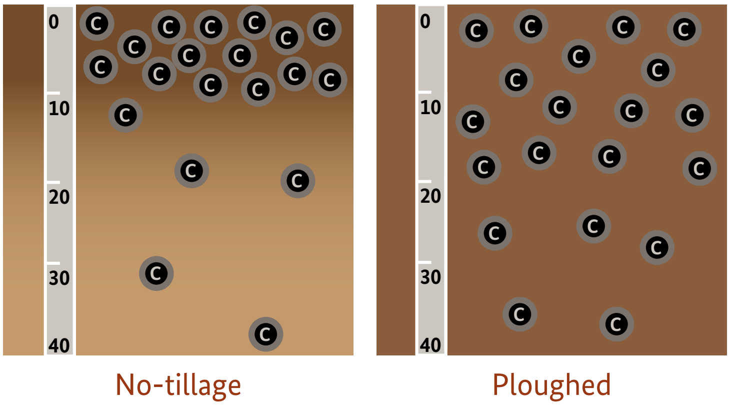

Figure 7: Carbon distribution in no-tillage agriculture vs. ploughed soil. Source: Beste 2016[122]

The claimed higher infiltration and retention of water with no-tillage is also complicated by the fact that large earthworm tunnels in unploughed soils are surrounded by compacted soil, not by the 'spongy' structure that has mid-sized pores capable of holding water. Rather than keeping water near the surface and thus available to plants during dry spells, these tunnels may increase the risk of water percolating into the groundwater before it can be filtered.[110 111] Proper water retention is only possible in biogenic soil, where microorganisms and roots from diverse crop rotations create the 'spongy' structure needed to hold moisture. If avoiding ploughing is the goal for less soil disturbance, root diversity and organic manure must be part of the solution.

In terms of climate mitigation, no-tillage farming can also be counterproductive if done under intensive management with low root diversity, as nitrous oxide emissions (which are 300 times more harmful to the climate than CO_2) can increase if the soil structure is not loosened either technically or biologically.[112]

With respect to biodiversity, the no-tillage approach is often claimed to protect diversity as soil organisms are not disturbed by ploughing. However, as weed control is an issue with unploughed soil, the majority of no-tillage techniques worldwide are implemented in conjunction with total herbicides such as glyphosate. Glyphosate and its by-products have a negative impact on earthworms and other soil organisms, leading to a strong decline in both above- and below-ground diversity over the past 20 years.[113 114] The increasing use of glyphosate – from less than 1 million lbs in 1974 to 80 million lbs in 2010 in the USA alone[115 116 117 118 119] – is a major cause of species extinction in agricultural areas, as cash-crop monocultures and the elimination of all weeds across large areas deprive insects and birds of habitat and food.

If conservation tillage is to contribute to sustainable soil management, enhancing biodiversity is a crucial precondition. It is only feasible in highly diverse agroecosystems, where a network of roots and a mixture of diverse crops loosens soil, stabilizes 'crumbly' soil particles (aggregates) and suppresses weeds. Protection against erosion and promotion of humus accumulation can only be achieved through increased diversity across the ecosystem and below ground.[120 121]

Key messages

- → Sustainable Soil Management (SSM) is a key strategy for ecosystem-based adaptation (EbA) to climate change; it relies mostly on Indigenous knowledge and current evidence of how soil ecosystems function.
- → SSM aims to create healthy, resilient and fertile soils by supporting interactions in the soil ecosystem and thus stabilizing the land-use system as a whole against climate shocks and other stressors.
- → Compost and diverse root systems are the best tools to increase soil organic matter, as well as to promote humus accumulation and diverse soil life, as they support soil structure, nutrient exchange, water infiltration and cleaning capacity, and reduce the risk of erosion.
- → Promoting soil life also brings benefits in terms of better nutrient supply for plants and resilience against biological and climate stressors and is thus the basic condition for climate-resilient agriculture.
- → Diversity above and below ground is by far the most important means of stabilizing soils and agricultural systems.

4. Sustainable farming systems for adaptation to climate change

The following well-known practices are examples of farming systems that apply the three elements of SSM (see Chapter 3) in a particularly comprehensive way; these are therefore recommended as holistic approaches to sustainable agriculture and climate adaptation.

4.1 Agroecology

Agroecology is a complex concept that goes far beyond farming practices. It can be understood as a scientific discipline, a set of farming practices (including some of the practices mentioned later in this chapter), as well as a social movement.

As a farming practice, the basic features of agroecology are very similar to certified organic farming. However, many smallholder farmers who produce agroecologically are not 'certified organic', as certification is often too expensive. This is particularly true for poor rural communities without access to markets via developed infrastructure. Due to their inability to engage in the certification process, these producers cannot benefit from the price premiums that buyers are willing to pay in Europe (where organic farming is subsidized), North America, and parts of Asia and Brazil. They may lack the financial means to join the cooperatives that facilitate this process or the distance may be simply too far to transport products for certification. For these reasons, there is little interest in certification and labelling among smallholders who produce goods for local markets.

As 'agroecologic' is not defined as a controlled production standard or for trade, in theory anyone can claim to produce agroecologically; thus there is a potential risk of greenwashing. In response to this risk, the FAO compiled 10 elements of agroecology, along with 13 principles that should be followed; however, these are not legally binding or controlled in national and international markets.[123]

Emerging evidence shows that agroecology can be an innovative approach to climate change adaptation for food security and rural livelihoods.[124 125 126] A background paper commissioned by the Global Commission on Adaptation (GCA) demonstrates the positive contribution of agroecological approaches to climate-resilient agriculture.[127] This refers not only to a greater variety of crops (species and varieties) on one farm, but also to the integration of crop-livestock systems or agroforestry (see the GIZ Factsheet on Agroecology).[128]

4.2 Agroforestry

According to World Agroforestry, agroforestry is defined as "land-use systems and practices where woody perennials are deliberately integrated with crops and/or animals within the same land management unit.[129] Agroforestry can be applied in both conventional and organic systems, as it focuses on how to design the arrangement of plants, not on avoiding special inputs. However, many traditional agroforestry projects work without mineral fertilizers and pesticides. This is partly to reduce costs, but also because the farming system itself produces organic fertilizer and keeps pests at bay. In agroforestry, perennial plants such as trees and shrubs are specifically combined with cropping systems and/or livestock (agrosilvopastoral systems; see Figure 8), resulting in both ecological and economic benefits.[130]

Agroforestry systems range from grazing livestock under orchards to adding rows of trees in fields to forest farms interspersed with trees and shrubs. Short rotation coppices for energy wood production are also often described as 'agroforestry systems', but as they lack diversity they are not included in the above definition.

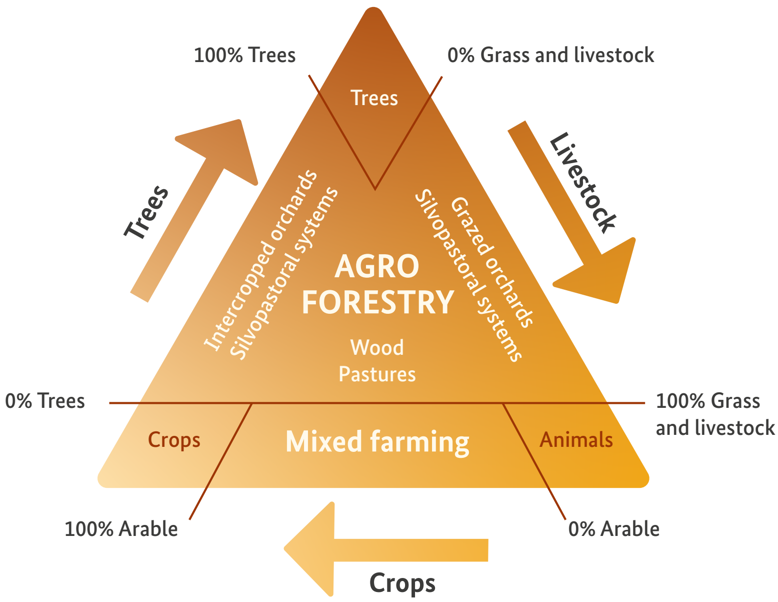

Figure 8: Characteristics of agroforestry systems. Source: From Burgess' et al. lecture[131]

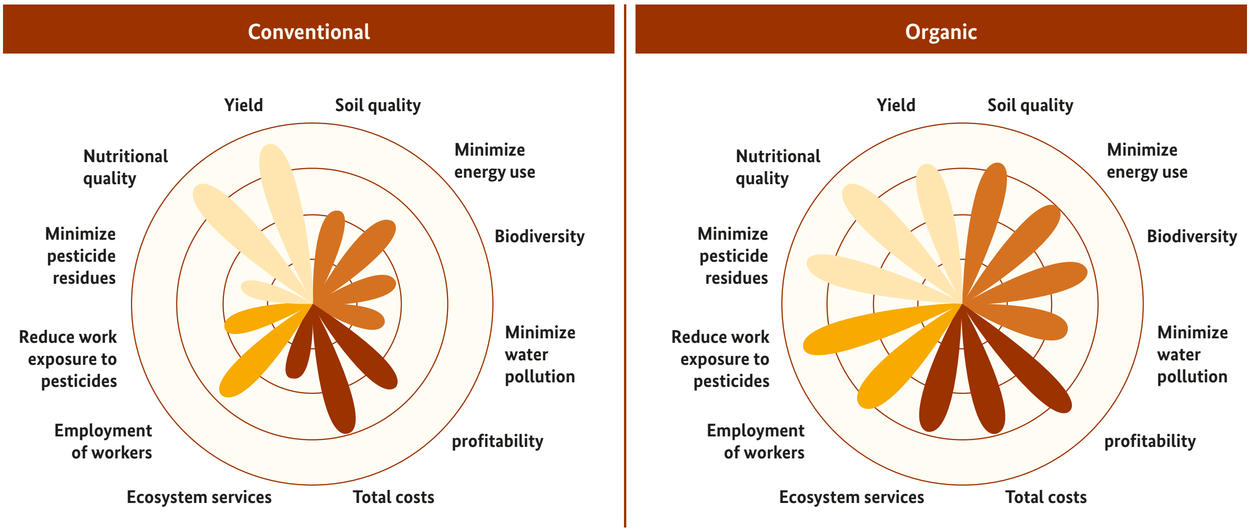

Figure 9: Sustainability of conventional and organic agriculture. Source: Reganold & Watcher (2016)[149]

An example from the Quesungual system in Honduras highlights key elements of agroforestry systems and their benefits. The agricultural measures include:

- → integration of crops and the preservation of trees, shrubs and grasses;
- → maintenance of vegetation cover and clearance of vegetation by hand instead of with fire;
- → increased organic matter in soils and minimum soil tillage.

These measures almost doubled the yields, increased soil organic matter content, and led to an increase in soil moisture. All these effects enhanced local communities' resilience to landslides and extreme weather events.[132 133]

Agroforestry is a promising land management system that can improve farmers' livelihoods while reducing pressure on forests. It has positive effects on biodiversity, improves water management and provides many tree-related ecosystem services such as increased soil fertility. The approach also contributes to reduced erosion and carbon sequestration.[134]

Since tropical soils are much more susceptible to erosion, and because rainfall is becoming more erratic and extreme, protection of the land surface is of particular importance. Therefore, while the use of intercropping and 'rainforest structure' – as practiced in agroforestry and permaculture systems – is particularly well adapted for the tropics, these approaches can also contribute to climate change adaptation in the mid-latitudes.

4.3 Organic farming

By definition, organic farming follows three main principles: no synthetic fertilizers, no synthetic pesticides, and diversity as a fundamental component. Together, these principles also offer a succinct summary of the abovementioned SSM measures.. Findings from both trials and comparative studies demonstrate that organic farming is superior to conventional agriculture across all measures of sustainability (Figure 9).[135] Organically farmed soils can absorb and retain twice as much water as conventionally manged soils on average,[136 137] and they can have twice as much humus build up, particularly in livestock-based systems. When it comes to climate change mitigation, organic agriculture stands out, with 48–60% less CO_2 and 40% less N_2O emissions[138] compared to conventional farming.

Despite lower yields in the short-term, organic farming leads to considerable environmental and socio-economic advantages compared to conventional agriculture.[139 140 141] While intensive conventional agriculture produces higher yields in the short term, soil depletion and overuse of ecosystem services results in dwindling harvests and high social costs over the long term. However, some studies in tropical environments show that organic farming and higher crop diversity can achieve yields up to double-digit percentage ranges compared with conventional agriculture.[142]

One benefit of organic farming is that its principles and rules are now clearly defined internationally, both scientifically and in legal and trade terms.[143 144 145 146 147 148] Therefore, it is the only precisely defined farming system for which equivalent sustainability rules must be applied worldwide.

→ A note on climate-smart agriculture

Launched by the Food and Agriculture Organization of the United Nations (FAO) in 2010 at The Hague Conference on Agriculture, Food Security, and Climate Change, 'climate-smart agriculture' (CSA) mainly employs precision farming and no-tillage approaches (see above). However, CSA lacks a consistent definition of proven climate-friendly techniques, and this has led to a variety of different practices operating under the same name. For example, genetic engineering is included in some projects, and agroforestry is mentioned in others, but overall the approach appears arbitrary. This lack of clarity and the use of the CSA label by global players to promote industrial high-input farming methods led to criticism by more than 300 civil society organizations, which released a joint statement ahead of the 2015 Paris climate summit rejecting the rhetoric of CSA and urging support for agroecology.[150 151]

However, if the sustainability elements described in this section become required practice in CSA, the term can meaningfully represent sustainable adaptation to climate change.

4.4 Regenerative agriculture

The objectives of regenerative agriculture are similar to those of organic farming and agroecology, but with a clear focus on the fight against climate change. The term was coined during research initiatives at the Rodale Institute in the early 2000s.

Regenerative agriculture can – similar to the internationally defined principles of organic farming[152] – be understood as aiming to *improve the regeneration of the topsoil, biodiversity and the water cycle without the use of pesticides and synthetic fertilizers.[153] Other more specific definitions include that of Christine Jones, the author of a Australian study on rangelands: regenerative agriculture focuses on the improvement of soils, water cycles, vegetation and productivity through agriculture and emphasises the interlinkage between the diversity, quality, vitality and health of soil, plants, animals and people.[154] This shifts the focus to soil building and humus enrichment.*

Proponents of regenerative agriculture are primarily concerned with building up and improving the soil. In addition, farmers often practice special forms of intercrop grazing by sheep or cattle. As agroforestry and agropastoral systems are currently in the international spotlight, regenerative agriculture can be a novel approach to organic farming in industrialized countries, where such techniques have not been widely practised.

As with agroecology, since the term 'regenerative agriculture' is not yet officially defined on an international or even national level, greenwashing is always a risk.

4.5 Permaculture

Permaculture, like organic farming, avoids mineral fertilizers and synthetic pesticides and works with diversity. However, it also specifies a particular arrangement of crops and primarily uses perennial varieties. Most permaculture cultivation practices are rooted in traditional Indigenous knowledge. The term was coined in the 1970s by the Australian ecologist Bill Mollison and is defined as follows: "Permaculture (permanent agriculture) is the conscious design and maintenance of economical, agriculturally productive ecosystems that have the diversity, stability, and resilience of natural ecosystems".[155]

With regard to climate change adaptation, permaculture promotes high resilience under changing external influences and in particular extreme weather events. Its practice involves farming based on natural cycles and ecosystems. Elements of this type of farming can be found in rice paddies in Asia, terraced systems developed by Berber peoples in Morocco, and in traditional cropping systems in Brazil and Mexico (variously called 'rainforest structure', '*sistemas agroflorestais', and 'paisajes bioculturales'). Farmers in Morocco have worked with such methods for millennia.[156] The focus is not only on individual elements of the farm, but on how they relate to and support each other to make up a highly productive farming system.*

Permaculture in Brazil; Photo: Beste

Examples include:

- Grain cultivation: Undersowing clover, radishes, salad and medicinal herbs once the cereal crop has flowered ensures a (feed) crop after the cereal harvest.
- Mixed cropping: A mixture of corn, sunflowers and hemp are grown together with peas or beans; the tall plants provide support for the legumes, which in turn supply the plants with nitrogen.
- Horticulture: Different plants of different heights are cultivated together to create a 'rainforest structure', similar to agroforestry.
- Cocoa production: Tall trees are planted around cocoa plants to provide needed shade, with ground cover crops planted beneath for a third harvest option, for nitrogen fixation or simply to provide mulch as soil cover.

Permaculture is particularly effective at protecting against erosion through its rainforest structure, shading (via cooling, reduced evaporation and lessening the intensity of rainfall on soil), efficient water use, high output of carbohydrates and proteins from the same plot, and by providing a source of income at different times of the year. Perennial plants are more resilient overall to yearly fluctuations of water availability because of their established root systems, especially if those trees, shrubs, herbs and grasses are climatically appropriate species. The efficiency of a permaculture system cannot be measured solely by tallying the yields of each of its components; the total biomass production per area and the positive effects on ecosystem services must also be taken into account. However, it must be noted that permaculture is not an extensive system but a very intensive one.[157]

Key messages

- Agricultural and soil management systems that promote biodiversity above and below ground are climate resilient and highly productive, without polluting water and soil or overstressing natural ecosystems.
- Farming systems, particularly agroecology and agroforestry have gained a lot of attention over the last years and build on the traditional and Indigenous knowledge of small-scale farmers.
- Farming systems like regenerative agriculture and permaculture put a particular focus on the interplay within the farming systems to protect soil, biodiversity and the health and livelihoods of people.
- With the exception of organic agriculture, the above-mentioned concepts lack a uniform and protected definition, increasing the risk of 'greenwashing'. It is therefore crucial to take a closer look at the concrete measures that are promoted.

5. Soil policies and politics

As shown in the preceding chapters, healthy soils play a key role in maintaining the critical ecosystem services that support life on Earth. While the state of soils is relevant to several areas of international concern, including biodiversity conservation and climate change adaptation and mitigation, soil degradation and the need for sustainable soil and land management have historically received little attention from international agencies, aside from the United Nations Convention to Combat Desertification (UNCCD).

However, soils have emerged in international, regional and national arenas in recent years, as reflected in a growing number of international strategies, policies and initiatives. While these have focused primarily on agriculture, there is momentum to shift the focus towards the importance of soils to climate change adaptation and mitigation, biodiversity conservation, water resource management, and sustainable development in general. Efforts are being made to make interlinkages more explicit and to develop integrative policies at the national level. The year 2021, in particular, provided an opportunity to highlight the links between healthy soils and other global goals, as well as relevant nature-based solutions that can respond to the needs of both people and the planet.

The next two chapters investigate the ways in which soil degradation and soil health are considered in international and national politics and policies.

5.1 Soil in international strategies, guidelines and initiatives

In the sustainable development arena, the importance of healthy soil is reflected in the United Nations 2030 Agenda for Sustainable Development through the Sustainable Development Goals (SDGs). The SDGs address the need to protect soil quality in order to enable an increase in the quantity and quality of food as well as to guarantee ecological resilience. SDG target 15.3, in particular, aims for "Achieving land degradation neutrality – by preventing land degradation and rehabilitating already degraded land, scaling up sustainable land management and accelerating restoration initiatives […]".[158]

Initially, the concept of Land Degradation Neutrality (LDN) was introduced in international discussions by the Secretariat of the UNCCD,[159], defining it as: "a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems".[160] As a result, in the Rio+20 final document 'The Future We Want', the international community agreed to work towards a "land degradation neutral world".[161] Even though LDN is not a comprehensive soil policy and includes other aspects related to land degradation, in this context soil degradation also means land degradation; in contrast to other policies, the LDN target includes all soil threats (and other drivers of land degradation).[162] While the SDGs are not a binding treaty, they are still seen as the only global political reference point specifically on land and soil, and thus as a strong political commitment.[163]

→ A note on national LDN targets

The Science-Policy Interface (SPI) under the auspices of the UNCCD published a Conceptual Framework for Land Degradation Neutrality, which provides a scientific basis for understanding and implementing LDN, as well as guidance for UNCCD Parties that choose to pursue a LDN target at the national level.[164] It defines appropriate steps and measures to be taken based on a "response hierarchy" and lists actions to achieve LDN, including land management approaches that avoid or reduce degradation, coupled with efforts to reverse degradation through restoration or rehabilitation.[165]

In 2012, the UN General Assembly also decided to create the Global Soil Partnership (GSP), managed by the FAO, promoting, among other things, sustainable soil management for increased protection, conservation and productivity. Important achievements were the revision of the World Soil Charter and the development of Voluntary Guidelines for Soil Sustainable Management (VGSSM) as the first attempt to define sustainable soil management practices at the global level (see Box 3). The principles of the VGSSM are closely related to the concepts of agroecology, organic farming or permaculture (see Chapter 4), which are receiving increasing attention at the global level. Both the Global Soil Charter and the VGSSM are being adopted and integrated into national policies and programmes by many countries.[166] Also led by the FAO is the UN Decade on Ecosystem Restoration (2021–2030), which was announced by the UN General Assembly in 2019 following a proposal for action by over 70 countries from all latitudes.[167] As land degradation lowers a soil's ability to maintain soil functions and fertility, thereby contributing to global threats such as climate change and costing trillions of dollars every year[168], the decade is an appeal to halt this degradation and restore ecosystems in order to achieve global goals. The decade is building political momentum for restoration and for thousands of initiatives on the ground. Restoration initiatives can have co-benefits for soil even if this is not their main focus. For example, the Bonn Challenge was launched by the Government of Germany and the International Union for Conservation of Nature (IUCN) in 2011 with the goal of having 150 million hectares of deforested and degraded land under restoration by 2020. The initiative focuses on forest landscape restoration (FLR), which entails more than just planting trees; FLR implements a variety of interventions, from agroforestry and natural regeneration to soil management and rainfall harvesting in order to help forests perform the ecosystem functions that provide goods and services such as food, fuel and clean water.[169]

As shown in chapters 3 and 4, there are also strong linkages between soil and climate change adaptation and mitigation and the conservation of biodiversity that are addressed by the other Rio Conventions. The United Nations Framework Convention on Climate Change (UNFCCC) refers to sustainable agriculture and food security, more than to soil, specifically. For example, its founding documents refer to stabilizing greenhouse gas concentrations in order to "ensure[s] that food production is not threatened"[170] and committing Parties to prepare for adaptation by developing "integrated plans for coastal zone management, water resources and agriculture, and for the protection and rehabilitation of areas affected by drought and desertification, as well as floods" (Article 4 [1][e]). Yet, until 2017, agriculture was excluded from UNFCCC negotiations and progress to effectively address the sector remains slow.[171]

Nevertheless, there are some noteworthy initiatives related to soil, such as the 4p1000 initiative launched by France at the twenty-first UNFCCC Conference of the Parties (COP21) in 2015 that aims to increase soil carbon sequestration by 4‰ per year. Even if this target might not be realistic, the initiative will contribute to climate change adaptation and food security through increases in soil organic matter.[172] The Koronivia Joint Work on Agriculture (KJWA), which was adopted at COP23 (decision 4/CP.23) addresses issues related to agriculture, including "improved soil carbon, soil health and soil fertility under grassland and cropland as well as integrated systems, including water management" and "improved nutrient use and manure management towards sustainable and resilient agricultural systems". Despite these initiatives, the Paris Agreement itself as the guiding framework for climate policy only makes a reference to food security in its preamble – it does not specifically refer to soil or other related topics. It thus fails to encourage the introduction and implementation of approaches that make use of the abovementioned synergies between SSM and climate change adaptation and mitigation. Yet, due to heightened awareness, inter alia through initiatives and (scientific) publications such as the IPCC special report on Climate Change and Land,[173] the importance placed on soil in the international climate agenda is likely to increase further.

In the framework of the Convention on Biological Diversity (CBD), the topic of soil was discussed from the very beginning and the link between biodiversity and healthy soils is usually taken into account, even if it is not always referred to explicitly. Healthy soil biodiversity is a precondition for the achievement of many biodiversity targets (within both the CBD's expiring framework and the upcoming one). There are related decisions and a Programme of Work on Agricultural Biodiversity,[174] and the focus of COP 13 on mainstreaming biodiversity into productive sectors, including agriculture, as well as the global assessment of land by the Inter-governmental Platform on Biodiversity and Ecosystem Services (IPBES) have given the topic new momentum. Still, policies and programmes that focus on specific aspects of soil biodiversity and which promote its conservation and sustainable use are generally lacking.[175]

Much of the work on agricultural biodiversity under the CBD to date has been undertaken in cooperation with the FAO. The FAO and other relevant organizations were also invited to facilitate and coordinate the ongoing International Initiative for the Conservation and Sustainable Use of Soil Biodiversity. A recent review of the initiative's implementation stresses the importance of soil biodiversity for human well-being and for the implementation of the new Global Biodiversity Framework (GBF). While the first draft of the GBF does not (so far) include a target directly related to soil biodiversity, it does include goals on the integrity of ecosystems, biodiversity-inclusive spatial planning, restoration, area-based conservation, the reduction of pollution, the contribution to climate change mitigation and adaptation through ecosystem-based approaches as well as on ensuring benefits for people (including nutrition and food security), sustainable agricultural management, and nature's contributions to the regulation of the quality and quantity of water – all of which are relevant for, or rely on, healthy soils.

In order to further increase the specific focus on soils and their sustainable management, the International Initiative for the Conservation and Sustainable Use of Soil Biodiversity urges the international community to strengthen the integration of soil biodiversity into broader policy agendas for food security, ecosystem restoration, climate change adaptation and mitigation, the sustainable development agenda, the GBF and all other relevant areas.[176]

Alignment of international strategies and guidelines

Despite the many globally recognized connections between climate change, biodiversity and human well-being, synergies between the three UN Rio Conventions (UNFCCC, CBD and UNCCD) and the agricultural community are not fully exploited.[177] The various international strategies and policies need to be aligned with each other, and their implementation at regional, national and local levels needs to be promoted. Regarding soil health, this will require the mainstreaming of aspects related to both climate change and biodiversity when designing soil policies, as well as the integration of soil into national climate change and biodiversity policies to overcome silo thinking (see Chapter 5.2). Strategic alliances, for instance between the three Rio Conventions and the agricultural sector, need to be strengthened to further promote the role of soil for climate change adaptation and mitigation, biodiversity conservation, ecosystem restoration, and food security.[178]

Key messages

→ Through their habitat, regulation and production functions, soils play a crucial role for many areas of international concern, including climate change adaptation and mitigation, biodiversity, water resource management and sustainable development.

→ Soils and their sustainable management are reflected in international strategies and initiatives, but in many areas the focus on the interlinkages is weak and not made explicit.

→ Specific targets related to healthy soils are often lacking in international strategies on climate change and biodiversity. Policies and programmes focusing on specific aspects of soil for climate change adaptation should be strengthened.

→ There is good cooperation between important international institutions and organizations that could further promote the integration of healthy soils and SSM, e.g. between FAO and CBD. However, strategic alliances could be strengthened even further.

→ A two-way mainstreaming is required: aspects related to climate change and biodiversity need to be integrated into soil policies and soil matters need to be integrated into other policy areas, including biodiversity and climate change, to overcome silo thinking.

5.2 Soil in national policies

National climate change and biodiversity policies, such as the Nationally Determined Contributions (NDCs) and National Adaptation Plans (NAPs) under the UNFCCC, as well as the National Biodiversity Strategies and Action Plans (NBSAPs) under the CBD, can be used as vehicles for simultaneously addressing soil health, climate change and the conservation of biodiversity through the inclusion of NbS or EbA measures (as mentioned above). But are they currently used in this way?

Nationally Determined Contributions (NDCs)

One hundred and sixty-seven Parties note in their first NDCs the vulnerability of ecosystems to the effects of climate change. A similar number recognize that ecosystems need to be preserved and have included general NbS into their NDCs and adaptation planning efforts, without necessarily focusing on soil.[179] While unfortunately few industrialized and high-income countries included NbS in their NDCs, the topic is referred to by all low-income countries and almost all least developed countries (LDCs).[180]

Despite the slow progress within the UNFCCC to address agriculture and soil, agriculture in general is included in many NDCs.[181] Soil and land management measures are often mentioned as priority actions for climate change mitigation and, in some NDCs, for adaptation.[182] For adaptation, reference is also made to climate-smart agriculture or agro-ecological and other approaches that embrace food security and social and environmental concerns (see Chapter 4). For mitigation, Parties plan to reduce agricultural emissions, e.g. through the implementation of conservation or organic agriculture, the reduction of tillage, or by increasing carbon storage through tree plantations – whereby these techniques are effective at very different intensities, as discussed in Chapter 3. While such actions will all have impacts on soils, these effects could be referred to more explicitly. As mentioned above, some approaches such as CSA lack an internationally consistent definition, and there is room for improvement regarding the number of actions specifically focusing on soil. Most targets concerning soils are related to the field of agriculture.

Box 4: Nature-based solutions Policy Platform

The Nature-based solutions Policy Platform[183] hosted by Oxford University allows users to explore and compare how countries are planning for the impacts of climate change, and to link this to climate change adaptation outcomes based on a systematic review of the peer-reviewed literature. This can support countries in the revision of their NDCs. However, in order to reach farmers and other land managers on the ground to strengthen the application of NbS and ecosystem-based adaptation related to soil, it will be key to also enhance education, dissemination and advisory services.

Examples for NbS-related targets in the NDCs of Morocco and Tunisia

Many goals and intended actions in Morocco's and Tunisia's first NDCs are related to the three areas of NbS defined in Chapter 1: to protect, sustainably manage and restore ecosystems.

Examples from Morocco

- → Protection of upstream river basins against silting and water erosion;
- → Development of rangelands in a way that will combat desertification, enhance livestock farmers' income and protect biodiversity;
- → Planting of 447,000 hectares of olive trees in areas that are unfit for year-round crops to limit soil erosion and improve smallholder farmers' income;
- → Planting of argan trees on 38,000 hectares to enhance vulnerable communities' resilience to climate change, increase carbon storage in biomass and soils, and indirectly reduce the industrial and anthropogenic pressure on natural argan tree forests.

Examples from Tunisia

- → Conservation of the ecological functions of low-lying coastal areas;
- → Consolidation of water and soil conservation works through forestry, olive and fruit tree plantations;
- → Promotion and development of conservation agriculture to store carbon in soil and limit the use of synthetic fertilizers;
- → Promotion of organic agriculture in order to limit N_2O emissions due to the use of fertilizers;
- → Biological consolidation of work to combat silting in the south of Tunisia and support the implementation of regional action plans to counter desertification.

National Adaptation Plans (NAPs)

Many developing countries are in the process of developing their national adaptation plans, but as of June 2021 only 22 had finalized their first NAP.[184] Most countries have identified threats to ecosystems and vulnerabilities in their NAPs and have included EbA measures to address them.[185] Very few NAPs mention the mitigation co-benefits of EbA measures.[186] In Latin American countries, the focus on ecosystem services and EbA is generally stronger than in other regions, and in the NAPs reference is also made to national biodiversity strategies.[187]

However, while many countries include EbA measures, in the majority of NAPs the term itself is not mentioned explicitly.[188] This is particularly the case regarding proposed measures for climate change adaptation in the agricultural sector such as agroforestry, sustainable land management, or the use of organic matter to improve soil quality. According to Seddon et al., there seems to be a lack of understanding on how best to integrate NbS into adaptation planning; therefore, they highlight "the need for policymakers and practitioners to be better supported as they translate theoretical NbS approaches into locally relevant actions".[189]

In a large number of NAPs, reference is made to soil-related EbA measures that focus specifically on sustainable ecosystem management, but also on ecosystem protection and restoration.

Examples for soil-related EbA targets in the NAPs of Fiji and Sri Lanka

Some projects and intended actions in Fiji's and Sri Lanka's NAPs are related to the three areas of EbA defined in Chapter 1: conservation, sustainable management and restoration of ecosystems as part of an overall strategy to help people adapt to climate change.

Examples from Fiji

- → Integrating the management of natural resources relevant to agriculture in land use so as to meet the needs of society without undermining the long-term sustainability of ecosystems;
- → Adoption of sustainable soil and land management techniques to address soil erosion, desertification and increased soil salination, as well as to improve soil fertility, nutrient management, arability and soil restoration;
- → Developing and applying practical on-farm approaches (demonstration sites); developing teaching materials; strengthening land-use planning across soil and climate zones that involves the participation of communities and land users; integrating pest management, controlled livestock grazing, cover crops, soil health, water-run off controls, integrated crop-livestock farming and agroforestry into farm practices; and providing user-friendly guidelines and incentives for investing in organic farming.

Examples from Sri Lanka

- Improvement of farm water management: development of water-efficient farming methods, promotion of on-farm rainwater harvesting, and promotion of wastewater reuse;
- Improvement of farm and nursery management practices: improvement of cropping systems and conservation farming practices; increase in the use organic matter to improve soil quality (integrated plan nutrient management); improvement in the management of shade trees as a climate change adaptation measure; and improvement of soil organic matter through biofertilizer development, agroforestry, and soil and moisture conservation practices.

Soil-related ecosystem-based adaptation in Fiji's NAP

Fiji's NAP, submitted to the UNFCCC in 2018, emphasizes the importance of biodiversity and the natural environment for society and economic growth. It includes EbA as one of four approaches underpinning the NAP process, stressing social, economic and environmental co-benefits, as well as opportunities for alignment with other national sustainable development efforts and obligations.[190] The NAP includes explicit links to biodiversity conservation and is seen as an additional vehicle supporting the implementation of Fiji's NBSAP. It emphasizes that EbA can "provide a link between the United Nations Framework Conventions for climate change, biological diversity, and desertification".[191]

Soil is addressed in relation to agriculture, which plays an important part in the Fijian economy and is highly vulnerable to the effects of climate change. Fiji will thus aim to reduce vulnerability in the sector "by integrating the management of natural resources relevant to agriculture in land use so as to meet the needs of society without undermining the long-term sustainability of ecosystems".[192] Envisioned adaptation measures in the agricultural sector include an increased "adoption of sustainable soil and land management techniques to address soil erosion, desertification, increased soil salination and to improve soil fertility, nutrient management, arability and soil restoration." This is to be supported by developing and applying practical on-farm approaches (demonstration sites); developing teaching materials; strengthening land-use planning across soil and climate zones that involves the participation of communities and land users; integrating pest management, controlled livestock grazing, cover crops, soil health, water-run off controls, integrated crop-livestock farming and agroforestry into farm practices; and providing user-friendly guidelines and incentives for investing in organic farming. Where possible, nature-based and urban solutions are to be adopted.

National Biodiversity Strategies and Action Plans (NBSAPs)

Under the CBD, parties have an obligation for national biodiversity planning. It was decided to continue using NBSAPs as a vehicle for biodiversity planning once the global biodiversity framework is adopted. Countries will therefore be asked to update their NBSAPs, providing an important opportunity to strengthen synergies and linkages with other national policies[193] and to facilitate the integration of soil-related climate change concerns into biodiversity policies, programmes and activities – something that is currently not widely applied.

In some countries' NBSAPs, one can already find direct and indirect references to soil, with some countries also starting to integrate soil biodiversity in other areas, including food security and agriculture. However, generally there is a lack of policies and programmes that focus on the specific aspects of soil biodiversity and that promote its conservation and sustainable use.[194] In a recent review of the International Initiative for the Conservation and Sustainable Use of Soil Biodiversity, the current level of integration of measures related to the conservation and sustainable use of soil biodiversity into NBSAPs and relevant policies, plans and programmes was assessed.

Box 5: Soil-related measures in NBSAPs can include:

- The improvement of soil quality
- The conservation of soil biodiversity
- The promotion of sustainable land and soil management.

Of the 170 NBSAPs that were reviewed, a large number of Parties implemented actions related to improving soil quality in general, of which only a small number recognized the importance of conserving soil biodiversity. Even fewer Parties considered the conservation of soil biodiversity by promoting sustainable agricultural management practices (including crop rotation, crop diversification, and use of organic fertilizers) and an even smaller number prioritized the conservation of soil biodiversity in order to maintain soil health and fertility. Despite the lack of direct reference to soil biodiversity, many Parties reported the promotion of sustainable use and management of soils, mainly in agricultural systems. This included practices such as crop diversification, erosion-minimizing irrigation technologies, crop rotations, and agroforestry – all of which promote one or more of the three functions of soil (habitat, regulation and production). Many Parties developed incentives or compensation programmes to offset the extra costs associated with sustainable practices, or reformed subsidy schemes that encouraged the use of harmful agricultural chemicals.[195] However, some Parties also refer to techniques such as conservation agriculture and no-tillage farming, the effect of which on biodiversity conservation is debatable (see Chapter 3.3 above).

Sustainable land/soil management in Pakistan's NBSAP

The agricultural sector plays a significant role for Pakistan's economy, "contributing approximately 22% to the country's GDP, accounting for over 60% of exports, and employing more than 60% of the rural labour force".[196] Nearly 35% of the total land area is used for agriculture. Due to local conditions, this mostly relies on rainfed lands that are prone to desertification, degradation, drought, flood and severe climate change impacts. Obsolete agricultural practices and associated chemical pollution, along with the introduction of high-yielding varieties, are exacerbating the situation. One of the overall goals of Pakistan's NBSAP is therefore "to mainstream biodiversity as an essential element of human development. This goal aims to increase awareness of how biodiversity and ecosystem goods and services contribute to human well-being, sustain development outcomes, and promote integration with key sectors",[197] including agriculture and climate change. While the interlinkages between biodiversity and climate change are generally referred to in the NBSAP, the relationship between the targeted actions and the protection of soil biodiversity and climate change is not addressed specifically.

Two of the five strategies for the agricultural sector include explicit reference to soils:

- "Developing and promoting models of sustainable agriculture for major crops by managing organic matter, enhancing soil biotic activity, minimizing water losses and use of agro-chemicals";
- "Restoring the bio diversification of agro ecosystems through crop rotations, cover crops, intercropping, crop/livestock mixtures, conservation of pollinators, and soil biodiversity".[198]

One of its targets is: *"the considerations of sustainable agriculture, bio diversification of agro ecosystems, conservation of pollinators and soil biodiversity, wise use of transgenic organisms, and climate change will be incorporated in agriculture policies and plans."*[199]

Alignment of national strategies and guidelines

As for the international level, countries would also benefit from better alignment of national plans submitted to the three Rio Conventions. In order to facilitate reporting and tracking of NbS-related actions in these plans, the development of common frameworks and indicators would be beneficial.[200] Moreover, in order to truly promote soil-related EbA, countries also need to integrate relevant climate and biodiversity issues into sectoral policies and practices. The degree to which climate change is integrated into national sectoral policies varies significantly. In some cases, the increase in SSM practices in some areas is counteracted by an increase in harmful activities such as land-use change in other areas. As long as harmful sectoral practices are subsidized, the support for NbS is but a drop in the ocean.

Key messages

- NDCs, NAPs and NBSAPs can be and in some cases are already used as vehicles for simultaneously addressing soil health, climate change and biodiversity conservation through the inclusion of NbS or EbA measures.
- While national climate and biodiversity policies also mention soil in relation to other areas (e.g. water management), most specific targets are formulated for the agricultural sector.
- Soil-related adaptation measures in NDCs include water protection, agricultural management practices such as sustainable land and soil management (SLM/SSM), climate-smart agriculture (CSA), agroecology and the restoration and protection of trees and forest areas.
- Soil-related mitigation measure in NDCs include conservation/organic agriculture to reduce emissions and store carbon, and the restoration and protection of tree plantations to increase carbon storage.
- Soil-related measures in NAPs include water and soil conservation, and the promotion of drought-preventing cropping systems and management practices such as SLM/SSM, CSA, organic/conservation agriculture and integrated soil fertility management.
- Soil-related measures in NBSAPs include the improvement of soil quality, the conservation of soil biodiversity, and the promotion of sustainable land and soil management.
- As at the international level, countries would also benefit from better alignment of national plans submitted to the three Rio Conventions and an integration of climate and biodiversity issues into other 'mainstream' sectoral policies and practices.

6. Soil governance

Having soil-related international strategies in place and translating them into national policies is important, but equally important are governance processes that determine the way soil is actually used and protected.

According to the IUCN Environmental Law Centre, "Governance is the means through which society defines its goals, priorities and moves towards decision-making at a global, national, or local level. It includes the:

- → legal and policy frameworks;
- → institutions; and
- → processes and mechanisms,

through which citizens and other interested actors express their interests, exercise their rights, fulfil their obligations and resolve their differences."[201]

The purpose of soil governance is to achieve SSM and to avoid soil degradation and conflict between different users. It therefore requires:

- → "international and national collaboration between governments, local authorities, industries and citizens to ensure implementation of coherent policies";[202]
- → effective and fair formal and informal institutions;
- → involvement and clear roles and mandates of all relevant actors from government, civil society and the private sector.

According to IPBES, both the effectiveness of adaptation planning as well as socioeconomic outcomes of restoration projects highly depend on governance structures.[203] Therefore, social principles, including governance and equity, are seen as equally important as biophysical aspects for SSM approaches.[204]

6.1 What are common challenges regarding soil governance?

There are many challenges that impede smooth governance processes related to soil. These include:

1. **Fragmentation – No 'Ministry of Soil'**
   Given the range of ecosystem services delivered by soil and the many land use activities that are related to soil, it is inevitable that many government departments, agencies and stakeholders have an interest in participating in soil governance and policy development, or have a role in delivering outcomes. In many countries, soil governance is therefore highly fragmented.[205] One of the results is that many interventions focus on one specific driver of land degradation in a given sector, despite the fact that degradation is rarely caused by a single factor.[206] Further, insufficient collaboration between relevant ministries that are often dominated by very different interest groups and lobbyists can lead to the development of conflicting regulations.[207]

   → **Example: Multilevel soil policies in Colombia**
   Colombia aims to address the importance of soils by promoting the implementation of soil policies at different levels, by encouraging regional and national decision-makers to provide technical, human and financial support. Yet as three different ministries are responsible for soil policies and activities, the result is fragmentation. In order to include soil considerations in environmental protection and the activities of productive sectors, awareness of soil biodiversity and the implications of its loss need to be raised. But while there are regulations and policies related to soil biodiversity in place in Colombia, the integration of the topic into inter-sectoral and inter-institutional policies and processes could be strengthened further.[208]

2. **Public good vs. private property**
   Soil can be seen as both private property and a common good. On the one hand, it is attached to land, which is often privately owned and seen as a private concern, e.g. by farmers. In addition, more and more land is owned as an investment by non-agricultural investors or by global agribusinesses. On the other hand, soil is a natural resource and part of wider biogeochemical cycles and it provides crucial ecosystem services (see Chapters 2 and 4), making it a public good.[209] These interlinkages can also have economic consequences, as the Sustainable Soils Alliance highlights: " Effective soil governance must address these tensions".[210]

3. **Long timescales involved in soil change**
   The impact various activities have on soils often becomes evident only after a long period of time; this can hinder a timely response by communities and institutions before critical and irreversible thresholds for some species or ecosystem services are exceeded.[211] This aspect is usually not covered by environmental law, and thus 'soil offenders' often cannot be held accountable once degradation becomes apparent. However, the impacts of SSM or restoration measures can also be associated with considerable time lags[212] (see Chapter 4) and potential successes cannot be communicated in the short term.

4. Intergenerational equity
   Human population growth, the intensification of agriculture and other land use, unsustainable land and soil management practices, climate change and other drivers lead to more and more pressure on soil resources, rendering the achievement of intergenerational equity a difficult challenge. When taking intergenerational equity into account, attention should be paid to three interlinked key dimensions: (i) distribution of benefits and costs between different actors/generations; (ii) equity regarding procedures such as participation, accountability and dispute resolution – this is at times impeded by differences in capacity or power between different actors, which also applies to different generations, some of which are not yet able to defend their rights and interests; and (iii) recognition of relevant actors and their rights, knowledge and values, including future generations.[213]

Beyond these considerations, there is a multitude of other challenges such as tenure rights; reactive processes; weak enforcement of existing policies, laws and regulations; a weak information base (both on status of soils and on governmental plans); unclear assignment of responsibilities; and international trade policies that render sustainable production less competitive.

Key messages

- → Having soil-related international strategies in place and translating them into national policies is not enough, as the way soil is used and protected also heavily depends on governance processes.
- → Soil governance requires: (i) international and national collaboration between all relevant stakeholders from government, civil society and the private sector; (ii) effective and fair formal and informal institutions; and (iii) the involvement and clear roles and mandates of all relevant stakeholders.
- → Of the many challenges characterizing the weak institutional contexts that persist in many countries, the fragmentation of responsibility, public vs. private ownership and long timescales for soil change and intergenerational equity pose particular challenges for smooth governance processes related to soil.

6.2 What is needed for sustainable soil governance and management?

In its report 'Creating an Enabling Environment for Land Degradation Neutrality and its Potential Contribution to Enhancing Well-being, Livelihoods and the Environment', the Science-Policy Interface (SPI) of the UNCCD argues that the achievement of Land Degradation Neutrality depends on: (i) an appropriate enabling environment, which includes institutional, policy-regulatory, financial and science-policy dimensions; and (ii) on measures that provide multiple benefits, i.e. for the environment, livelihoods and human well-being. As this also applies to other objectives of sustainable soil governance and management, the following section will look at these dimensions in more detail.

1. Policy-regulatory dimension
   Coherence is crucial for effective soil governance and management. This can be achieved through vertical and horizontal coordination and collaboration.

   Horizontal integration concerns the collaboration across countries, for example through international, regional or bilateral legally binding and non-binding agreements, and across relevant governmental departments within one country. The latter can materialize in, for instance, policies from one sector taking into account and referring to another sector's objectives and policies. Since soil-related matters do not halt at national borders, cross-boundary collaboration, such as for water management and disaster risk reduction, is key. Trade policies must be revised in order to counteract the fact that products are less competitive on the world market due to SSM.

   Vertical integration concerns collaboration between different levels, i.e. from international, regional and bilateral agreements over national legislation, institutions and processes down to the local level of implementation. According to the FAO, "International agreements on soil and land resources are helpful but they are all to no avail unless there are complementary policies and coordinated activities at regional, national, district and local levels. Appropriate and effective policies need to reflect the local context in terms of the natural resource issues, cultural acceptability and economic feasibility."[214] At the national level, international agreements should thus be translated into appropriate national policies, laws and regulations, taking the specific country context and local conditions into account. In order to create an enabling environment for SSM, a range of legal and regulatory, rights-based, economic and financial, social and cultural policy instruments could be applied such as: the inclusion of customary norms and support for Indigenous and local knowledge;

strengthening human capacity, including through academic education and development of well-educated advisory services, research and technology development, and institutional reform[215] (see also the institutional, financial and science-policy dimensions, below).

Local implementation efforts rely on a sound national framework, which provides farmers and other land managers with the necessary means, commitment and control to restore, maintain or improve the quality of land, including appropriate tenure rights.[216] As large investors are usually not interested in SSM or in participatory approaches, countries would benefit from implementing the Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security[217] in order to attempt to combat land grabbing.

→ Example: Securing farmer commitment through tenure in the Philippines

Effective soil conservation in the Philippines has been attributed to improved land tenure. As this also helps maintain productivity and thereby income, it provides a two-fold security to farmers. Scientific evidence shows that farmers are more inclined to invest in sustainable soil and land management practices if they know they will profit from long-term benefits.[218] In contrast, insecure land tenure, involving family and communal land, is believed to lead to an increase in unsustainable land use.[219]

2. Institutional dimension

Inclusive local governance could be strengthened through the active participation of civil society, local communities and the private sector, e.g. by supporting the institutionalization and strengthening of farmers' organizations and networks,[220] by including rights holders that are identified as the beneficiaries of soil management measures from the outset of projects,[221] and by engaging the private sector through, inter alia, information sharing, clear, stable and inclusive institutions, policies and regulations, and capacity building to develop selected adaptation activities.[222] In order to achieve SSM, the various interests must be thoroughly balanced against each other, which will especially require closer collaboration between agriculture and environment communities.[223] The development and revision of national climate and biodiversity policies can be used to initiate such processes.

A strong coordinating mechanism and institution can help increase communication, coordination and collaboration when developing strategies, policies and processes on soil use and protection that also contribute to climate change mitigation and adaptation and the conservation of biodiversity. The often limited influence and oversight of sectoral ministries such as the Ministry of Environment might lead to weak coordination. Therefore, providing the Planning or Finance Ministry with the task of coordinating the development of strategies policies and processes related to soil can be more successful. However, other relevant ministries, such as the Ministries of Agriculture and Environment, still need to play a key role in this process.[224]

Box 6: The 'Tara Bandu' regime as an important entry point for facilitating community-led climate change adaptation in Timor-Leste[225]

Tara Bandu is a Timorese customary rule that focuses on peace and reconciliation through public agreements, covering aspects of reducing or preventing community conflict, protecting the environment, managing natural resources and improving community well-being. Regulating the use of natural resources through Tara Bandu dates back to pre-colonial times and has regained importance since independence in 2002, when the regime was protected in the country's Constitution.

Tara Bandu is an important starting point for increasing the involvement of local communities in efforts to build resilience to environmental challenges. Communities throughout Timor-Leste have introduced new Tara Bandu resource management regulations that include forest conservation areas, no-fishing zones, and bans on certain destructive fishing methods and on harvesting certain species. The NAP process will continue to use existing and future Tara Bandu mechanisms to encourage communities to plan and implement locally appropriate measures for climate change adaptation. This includes EbA measures that provide co-benefits, such as regarding sustainability of harvests and ecosystem service provision. In addition, through Tara Bandu the NAP process can contribute to peace building and reconciliation at the local level.

3. Financial dimension

The availability of financing from various sources is seen as another important factor for an enabling environment for sustainable soil governance and management. A lack of finance is seen as a major obstacle for implementing SSM and reaching related targets.[226] Only a fraction of climate finance promotes NbS. In 2018, merely 1.5% of all public international climate finance was used to fund NbS for adaptation in developing countries.[227]

The proportion that also benefitted soils was probably minimal. A first step needs to be the assessment of actual financing needs for SSM, including medium- to long-term operational, monitoring and enforcement costs.[228]

Further, assessing the economic value of soil ecosystem services can deliver the rationale for an increase in investments in soil protection and sustainable use. If the value of land and soils, including for climate change adaptation and mitigation, is understood more broadly, appropriate incentives for its protection could be developed; this must, however, be part of an enabling environment that also takes the equitable distribution of the benefits into account.[229]

→ Example: Economic assessment of land degradation

The Economics of Land Degradation (ELD) Initiative aims to "transform global understanding of the value of land and to create awareness of the economic case for sustainable land management in preventing the loss of natural capital, preserving ecosystem services, combatting climate change, and in addressing food, energy, and water security". It is "an international collaboration that provides a global assessment of the economics of land degradation, and highlights the benefits of sustainable land management. Working with a team of scientists, practitioners, policy-/decisionmakers, and all interested stakeholders, the initiative endeavours to provide a scientifically robust, politically relevant, and socio-economically considerate approach that is economically viable and rewarding. […] Understanding the cost of inaction and benefits of action are important in order for stakeholders to be able to make sound, informed decisions about the amount and type of investments in land they make. […] If the full value of land is not understood by all stakeholders, it may not be sustainably managed, leaving future generations with diminished choices and options to secure human and environmental well-being." In contrast, knowing the economic value of land enables communication between actors and allows them to decide between alternative land uses.[230]

4. Science-policy dimension

In order to strengthen the sustainable use and protection of soils, it is essential to understand barriers to soil governance. These, along with potential policy and governance elements to develop incentives, coordinate between sectors and handle resistance, need to be assessed and the results presented to policymakers and decision makers.[231]

Knowledge of, and capacities to implement, SSM methods need to be increased in many countries. The SPI suggests fostering research to develop context-specific governance instruments that contribute to avoiding, reducing and reversing land (and soil) degradation.[232]

There is a need not only for science at government level, but also for community learning processes in which local populations (including farmers, Indigenous Peoples and pastoralists) are involved and can contribute their knowledge of land management and learn new techniques (co-learning). Countries can support each other by exchanging their experiences related to laws, policies and implementation.

→ Example: Database on soils-related legal and policy instruments

SoiLEX is a new online platform launched by FAO, which enables access to existing legal and policy instruments related to soils and connection between relevant stakeholders. It is a further development or rather spin-off from the already existing FAOLEX platform, a large database of legal frameworks and instruments related to natural resource management, food and agriculture more generally. Creating a sub-database on soil enables more precise searches for legal instruments specifically related to soil, an understanding of relevant legal areas, and the exchange of experiences in soil governance between countries and regions. Results can be sorted by country profiles or by soil-related keywords. The database can be accessed under the following link: http://www.fao.org/soils-portal/soilex/en.

Key messages

- Enabling effective soil governance and management will require:
  - coherence, which can be achieved through vertical and horizontal coordination and collaboration;
  - a sound national framework, providing farmers and other land managers with the necessary means, commitment and control to restore, maintain or improve the quality of land, including appropriate tenure rights;
  - inclusive local governance strengthened by the active participation of civil society, local communities and the private sector;
  - a strong coordinating mechanism and institution, improving communication, coordination and collaboration when developing soil strategies, policies and processes;
  - the availability of financial means from various sources;
  - an understanding of the barriers for soil governance; and
  - knowledge and capacities to implement SSM methods.
- The development and revision of national and local climate and biodiversity policies can be used to initiate inclusive processes.

6.3 An enabling environment for sustainable soil governance and management

As shown in the previous chapter, policy interventions to integrate the topic of SSM are needed on various levels: on the one hand, climate change adaptation through SSM can be incorporated into broader development plans and activities at the national and project levels. However, since vulnerability and response options are highly sector-specific, important steps and decisions on adaptation also need to be taken at the sectoral level. Mainstreaming climate change impacts and adaptation options, including NbS, is of particular importance for those areas and sectors that are inherently vulnerable to climate risks, including the management of soil.

To reduce complexity, it is helpful to identify basic areas (or dimensions) in which mainstreaming becomes evident. For example, the degree of mainstreaming is detectable in the degree to which institutional arrangements allow for multi-sectoral collaboration. It also becomes evident in the degree to which policies are coherent, and corresponding instruments are in place, e.g. to solve conflicts of interest between those agencies aiming to increase adaptive capacities and those aiming to achieve other development objectives. The degree of mainstreaming of soil-related adaptation is also reflected in the variety of adaptation options considered, as well as in the amount and variety of financial resources available. And it is observable in the social sphere, e.g. when assessing the importance the public attaches to climate risks and adaptation options.

In order to assess the environment for sustainable soil governance and management, including its multiple benefits and how well related topics are integrated into a country's or a region's political and governance processes, policies and programmes, the tool 'Five Dimensions of Mainstreaming Climate Change Adaptation' can be applied.

See framework on next page →

The five dimensions of mainstreaming climate change adaptation

The five dimensions framework of mainstreaming climate change adaptation (CCA) tool aims at providing practitioners and policy-makers with a structured and easy-to-use approach to reflect on mainstreaming in their specific working contexts. Due to its basic nature, it is applicable in different contexts and can be used with varying depths of information (ranging from a rough assessment to an in-depth analysis) according to the specific demand and time budget.

The framework describes five dimensions on a continuum:

1. Institutional arrangements
2. Policies and regulations
3. Scope of adaptation options
4. Financial and human resources
5. Public awareness and participation.

On the one side of the continuum, there is a low degree of CCA mainstreaming, while on the other there is a high degree of mainstreaming CCA into a given sector. The framework allows for a relative assessment along each dimension. The resulting profile describes the status quo of CCA mainstreaming in the sector of a given country or region. It provides a starting point for a more systematic discussion about the integration of climate change adaptation, helping to form a common understanding among different stakeholders of where progress has been achieved and where it can realistically be made in the future. Exemplary for the agricultural sector, the figure below shows a more detailed description of the two sides of the continuum. The tool can, however, be applied to any sector.

Box 7: The five dimensions of mainstreaming climate change adaptation, in the context of soil management

Low degree of mainstreaming ⟵	⟶ High degree of mainstreaming
1. Institutional arrangements	
CCA is taking shape as an area of action only for the Ministry of Environment (MoE).	All relevant soil related agencies are concerned with climate change impacts on soil resources and adaption options.
There is no focal point institution coordinating CCA integration among different governmental agencies related to soil and no coordination mechanisms in place.	There is a strong focal point institution coordinating CCA integration among different agencies related to CCA in the area of soil and coordination mechanisms are in place.
The multilateral environmental agreements are only implemented by the Ministry of Environment.	The multilateral environmental agreements are implemented in an integrated, synergetic manner.
2. Policies and regulations	
There is a tendency towards “soft” instruments (informative and voluntary) to raise awareness for soil related CCA.	There is a coherent legal framework for integrating CCA into soil related policies and processes.
The development of soil policies and projects is not informed by up-to-date climate risks and vulnerability assessments and projections.	The development of soil policies and projects is informed by up-to-date climate risk and vulnerability assessments and projections.
Relevant standards and regulations are rigid and cannot be adapted when more detailed information on climate risks become available.	There is a high degree of flexibility of relevant standards and regulations to facilitate the eventual consideration of climate risks as they become available.

Low degree of mainstreaming ⟵	⟶ High degree of mainstreaming
3. Scope of adaptation options	
Soil policies and programmes do not consider climate change impacts and adaptation options.	All relevant soil policies and programmes consider climate change impacts and adaptation is a key objective.
There are no cross-sectoral policies and measures to adapt to climate change.	There are cross-sectoral policies and measures to adapt to climate change.
There is a narrow focus on a few soil related adaptation options.	A variety of adaptation options related to soil are applied, including ecosystem-based adaptation (EbA).
4. Financial and human resources	
There is an emerging (small) budget for implementation of soil related CCA within the MoE.	There is a large budget from a variety of sources for soil related CCA through a variety of instruments.
Soil related investments are not informed by climate risk scenarios.	Soil related investments take climate risk scenarios into account at an early stage.
Research, knowledge and competencies to integrate considerations of CCA into the area of soil are lacking.	There is sufficient research, knowledge and competencies to integrate considerations of CCA into the area of soil.
5. Public awareness and participation	
The general public does not know about climate change-induced risks for soil resources and about adaptation options.	There is strong awareness of climate change impacts on soil resources and various adaptation options, including EbA.
Only a limited number of actors participates in the implementation of soil related adaptation measures.	Many stakeholders, including the scientific community and the private sector, participate actively.

Beste and Lorentz 2022, adapted from GIZ (2016)[233]

Key messages

→ Similar to other sectors linked to climate change adaptation, an enabling environment for soil management depends on institutional arrangements; policies and regulations; the scope of adaptation options; and financial and human resources and public awareness and participation.

→ The Five Dimensions Framework of Mainstreaming Climate Change Adaptation is a tool that can be used to assess the enabling environment for sustainable soil governance and management in a given sector for a particular country or region. It provides a starting point for a more systematic discussion about the integration of climate change adaptation and helps form a common understanding among different stakeholders of where progress has been achieved and where it can realistically be made in the future.

7. Conclusions

As this guidebook has shown, sustainable soil management (SSM) is critical to ecosystem-based adaptation approaches in agricultural systems. Farming systems that integrate SSM are able to stabilize agroecosystems and lead to higher and more stable yields over the long term, compared with intensive agriculture. They require fewer external inputs, help to make better use of fertile land, and can improve less fertile land. They also reduce the pressure on natural ecosystems that would otherwise continue to be converted for agriculture.

Healthy soils can be a critical aspect of EbA Following the elements of SSM described above can create more resilient ecosystems by protecting essential ecosystem services and resources, thereby increasing food security and livelihoods in rural regions while reducing pressure on natural ecosystems. By adopting nature-based solutions (NbS) such as ecosystem-based adaptation (EbA), farmers can significantly increase their productivity while adapting to climate risks. The three core soil functions are key to this: **provision of habitat** for both plants and animals; **regulation** of water, organic and inorganic matter through filtering, buffering, transformation and storage; and **production** of food, feed and biomass. These soil functions, together with other ecosystem functions, enable the provision of certain essential ecosystem services. Only when soils are able to perform all three functions are they considered to be healthy.

Soils are affected by climate change in a multitude of different ways, but most of all by a fundamentally altered water cycle around the world. This leads to increased drought that destroys soil organisms, often in combination with extreme rainfall events that trigger erosion and soil loss. Areas with intact vegetation cover usually are not only cooler but also have a far more stable microclimate and are less affected by extreme temperature changes. Yet too often the links among soil, vegetation and climate are not properly appreciated.

Soils as carbon sinks – and thus as contributors to climate change mitigation – is currently a subject of much debate. Wetlands and peatlands are a major carbon store and it is crucial to protect and restore these biomes. As far as farming on mineral soils is concerned, the largest contribution to climate change is the production and application of synthetic nitrogen fertilizer. Legumes should play a decisive role here, with the potential to save more than half of the greenhouse gas emissions produced by fertilisation. Storing carbon in the soil as a form of sequestering it from the atmosphere has limited climate protective potential, increases slowly and is reversible.

The potential **contribution of soils to climate change adaptation** is often overlooked. SLM and SSM are two NbS in agriculture that offer huge potential for climate adaptation. They provide multiple ecologic and economic advantages such as more reliable crop yields, greater conservation of biodiversity, and avoided costs from the need to protect groundwater and drinking water from over-fertilization and use of pesticides. The three essential elements of SSM are:

- → increasing soil organic matter,
- → promoting soil life, and
- → promoting diversity above and below the ground.

These three elements aim to support interactions in the soil ecosystem, leading to a healthy, resilient and fertile soil. Following these elements can support biodiversity and stabilize the land-use system as a whole against climate shocks and other stressors – which is crucial for adaptation to climate change.

Most SSM practices are rooted in Indigenous and/or local knowledge of small-scale farmers. **Farming systems** – particularly organic farming, agroecology and agroforestry – have gained a lot of attention over the last years. Their positive effects are increasingly proven through basic research and are being empirically confirmed in many projects worldwide. These farming systems put a particular focus on the interplay within different farming elements to protect soil, biodiversity and the health and livelihoods of people. Agricultural and soil management systems that promote biodiversity above and below ground can be climate resilient and highly productive without polluting water and soil or overstressing natural ecosystems.

Sustainable soil management needs a coherent policy framework

Soils and their sustainable management have long been neglected in **international and national policy frameworks**. The growing number of international strategies, policies and initiatives in recent years shows that they are gaining more attention. Still, in many areas the focus on the interlinkages is weak and not made explicit through soil-specific targets. For two-way mainstreaming, aspects related to climate change and biodiversity need to be integrated into soil and agricultural policies, while soil matters need to be integrated into other policy areas, including biodiversity and climate change.

The **national strategies for climate change and biodiversity conservation** (NDC, NAP and NBSAP) show the importance of soil management in practice. Soil-related adaptation measures include water and soil conservation and agricultural management practices such as sustainable land and soil management (SLM/SSM). While climate policies put a more general emphasis on agricultural systems such as agroecology and organic farming, which have benefits for soils,, biodiversity conservation strategies mention soil quality and soil biodiversity more explicitly.

The way soil is used and protected also depends heavily on governance processes, which are still weak in many contexts. **Soil governance** requires:

- international and national collaboration between all relevant stakeholders from government, civil society and the private sector;
- effective and fair formal and informal institutions;
- the involvement and clear roles and mandates of all relevant stakeholders.

This needs to address soil-specific challenges like the fragmentation of responsibility, public vs. private ownership and the long time scales needed for soil change. Supporting an **enabling environment for soil management** also means strengthening institutional arrangements, policies and regulations, as well as enhancing the scope of adaptation options, financial and human resources, public awareness and participation. The development and revision of national and local climate and biodiversity policies can be used to initiate inclusive processes to enhance soil management in the areas of climate change and biodiversity conservation.

Lessons learned for practice and policy development

As this guidebook has shown, healthy soils and the ecosystem services they sustain deserve greater attention in practical implementation and political frameworks. However, the connections between soil health, biodiversity and climate change mitigation and adaptation must be better understood by both practitioners and policymakers. Greater effort is needed to integrate the principles of EbA and SSM into national, regional and international policies, in order to build momentum for the achievement of global goals.

See recommendations on next page →


Photo: GreenForce Staffing / unsplash.com

Recommendations for practitioners

1. Explicitly adopt and implement sustainable soil management practices as part of NbS and EbA projects to reduce the risk of climate-related impacts (e.g. through erosion and reduced soil quality, which impact biodiversity and food security):

   → Increasing soil organic matter through compost and diverse root systems brings multiple benefits, e.g. by supporting soil structure, nutrient exchange, water infiltration and cleaning capacity.

   → Compost and diverse root systems also promote soil life, which increases nutrient supply for plants and resilience against biological and climate stressors; it is thus the basic condition for climate-resilient agriculture.

   → Intercropping and crop rotation promote diversity above and below ground through extensive, network-like roots systems.

2. Enhance farming systems adopting agroecological approaches that build on the Indigenous and local knowledge of small-scale farmers, in particular organic agriculture, agroforestry, permaculture, and regenerative agriculture. These systems put an emphasis on creating benefits for food production and biodiversity by enhancing agrobiodiversity, building on mixed systems and explicitly stabilizing and enhancing soil health.

Recommendations for policymakers

1. Set specific targets related to healthy soils in international strategies on climate change and biodiversity, and further strengthen strategic alliances between international institutions working under the three Rio Conventions (UNFCCC, CBD, UNCCD).

2. At the national level, countries should enhance soil management at different levels:

   → Elaborate policies and programmes at national level focusing on specific aspects of soil for climate change adaptation. Rather than stating general farming systems, they should specify which measures are understood and promoted as SSM to avoid 'greenwashing'.

   → Use the elaboration and revision of NDCs, NAPs and NBSAPs as an opportunity to further integrate soil health, climate change and biodiversity conservation through the inclusion of NbS or EbA measures.

   → Support the integration of climate and biodiversity issues into other 'mainstream' sectoral policies and practices such as agriculture, water and tourism.

3. Enable effective soil governance and management through, inter alia, the following measures:

   → Increase vertical and horizontal coordination and collaboration between political actors to strengthen coherence.

   → Provide farmers and other land managers with the necessary means, commitment and control to restore, maintain or improve the quality of soil, including appropriate land tenure rights.

   → Strengthen inclusive local governance through the active participation of civil society, local communities and the private sector.

   → Strengthen coordinating mechanisms and institutions to improve communication, coordination and collaboration when developing soil strategies, policies and processes.

4. Systematically assess the different elements of an enabling environment for soil management in a given sector for a particular country or region, e.g. through tools like the 'Five Dimensions Framework of Mainstreaming Climate Change Adaptation'. This enables a structured discussion and the evolution of a common understanding among different stakeholders on past progress and future steps to enhance soil governance.

Annex 1 – Glossary

Aggregate stability – Aggregate stability refers to the ability of soil aggregates to resist disintegration when disruptive forces associated with tillage and water or wind erosion are applied.

Ecosystem-based adaptation (EbA) – A strategy for adapting to climate change that harnesses nature-based solutions and ecosystem services.

Exchange capacity – Ability of soil particles to react with molecules. If the exchange capacity is low, not many molecules are able to bind (react) to the particle surface. If it is high, a larger number of molecules can bind to the particle's surface. This is important for nutrient storage and exchange.

Ecosystem services – The direct and indirect contributions of ecosystems to human well-being.

Land Degradation Neutrality (LDN) – A state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems.

Mycorrhiza – A mycorrhiza is a mutual symbiotic association between a fungus and a plant. The term mycorrhiza refers to the role of the fungus in the plant's rhizosphere, its root system. Mycorrhizae play important roles in plant nutrition, soil biology, and soil chemistry.

National Adaptation Plan (NAP) – The NAP Process is meant to help countries reduce vulnerability, build adaptive capacity and mainstream adaptation in development planning by identifying key medium and long-term adaptation needs and set strategic goals, which can include identifying and prioritizing the role of nature in adaptation. The NAP process should serve as a concrete process for achieving adaptation goals set out in a country's NDCs.

National Biodiversity Strategy and Action Plan (NBSAP) – A national biodiversity strategy will reflect how the country intends to fulfil the objectives of the Convention on Biological Diversity (CBD) in light of specific national circumstances, and the related action plan will constitute the sequence of steps to be taken to meet these goals.

Nature-based solutions (NbS) – Actions to protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human well-being and biodiversity benefits.

Plant root exudates – Are fluids emitted through the roots of plants. These secretion influence the rhizosphere around the roots to inhibit harmful microbes and promote the grow of self and kin plants.

Soil fabric – The physical arrangement of particles and particle groups in different patterns is known as soil fabric. Soil structure includes soil fabric as well as the intra- and inter-particle forces of attraction and repulsion.

Annex 2 – Selected case studies

Following are just a few case studies that highlight work on issues covered in this guideline.

→ Region: Philippines

Institutions: World Agroforestry (ICRAF), Integrated Natural Resources and Environmental Management Project (INREMP)

Main focus: agroforestry, soil conservation, improving income of farmers

The project has established learning sites in a commercial forestry area, that show examples for the combination of conservation farming, agroforestry and commercial tree plantations. This is accompanied by the development of a teaching concept, so that farmers can more easily understand the 'science, art and businesses of agroforestry and sustainable land management as a whole.

Of note: The concept encourages farmer-to-farmer sharing of knowledge, which has been proven more effective than other kinds of teaching methods.

More Information:
https://worldagroforestry.org/blog/2021/06/23/power-proof-how-model-farms-philippines-encouraged-expansion-scale-agroforestry

→ Region: Brazil

Institutions: International Centre for Research in Agroforestry (ICRAF), Renova Foundation, WRI Brazil, Fazenda Ecológic

Main focus: agroforestry, climate change adaptation, land rehabilitation

Farmers affected by the collapse of the Samarco dam four years ago in Mariana (MG) are receiving advice to diversify their production through Agroforestry Systems (AFS), a model that seeks to merge in a single area different agricultural crops and forest species capable of establishing a harmonious relationship. For example, the banana tree is used to exemplify how to integrate species. Pruned, it serves as organic fertilizer for other species. In addition, it retains water in its roots, which can contribute to the development of certain plants in its vicinity. The plantations are combined with ecological pasture management models due to the predominance of milk production in the region.

Of note: Model open to the community, which will serve as an example for others. Evaluation through a systemic approach based on 21 indicators of social, economic and environmental elements.

More Information:
https://worldagroforestry.org/blog/2019/11/21/agricultural-areas-affected-mariana-bet-diversifying-production

→ Region: Egypt

Institutions: SEKEM

Main focus: developing intensive agroecological farming under difficult natural conditions

A nearly 30-year old project with an extraordinarily diverse commitment in the areas of ecology, economy and culture. Holistic approach focusing on sustainable, organic agriculture to restore and maintain the vitality of the soil and food as well as fostering biodiversity. Reclaimed 684 hectares of desert land, all of which were 100% operated by biodynamic and sustainable agriculture methods.

Of note: Support of social and cultural development by enabling and promoting knowledge transfer and education.

More Information:
https://www.agroecology-pool.org/portfolio/sekem_initiative

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References

1 Da Silva, H.G. (2014). Soils are the foundations of family farming. Food and Agriculture Organization of the United Nations (FAO). http://www.fao.org/soils-2015/news/news-detail/en/c/271795/

2 IPBES. (2018). The IPBES assessment report on land degradation and restoration. Montanarella, L., Scholes, R. and Brainich, A. (eds.). Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). https://doi.org/10.5281/zenodo.3237392

3 FAO & ITPS. (2015). Status of the world's soil resources: Main report. Food and Agriculture Organization of the United Nations (FAO) & Intergovernmental Technical Panel on Soils (ITPS). https://www.fao.org/documents/card/en/c/c6814873-efc3-41db-b7d3-2081a10ede50/

4 IUCN. (2022). 'Nature-based solutions'. International Union for Conservation of Nature (IUCN). https://www.iucn.org/theme/nature-based-solutions/about

5 IUCN (2022)

6 Prentice, I.C., Farquhar, G.D., Fasham, M.J.R., Goulden, M.L., Heimann, M., Jaramillo, V.J., Kheshgi, H.S., Le Quéré C., Scholes, R.J. & Wallace, D.W.R. (2001). The carbon cycle and atmospheric carbon dioxide. In: Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. https://www.ipcc.ch/report/ar3/wg1/the-carbon-cycle-and-atmospheric-carbon-dioxide/

7 Ding, H., Faruqi, S., Wu, A., Altamirano, J-C., Ortega, A.A., Zamora-Cristales, R., et al. (2018). Roots of prosperity: The economics and finance of restoring land. https://www.wri.org/research/roots-prosperity-economics-and-finance-restoring-land

8 UNCCD Science-Policy Interface (2016). Land in balance. The scientific conceptual framework for land degradation neutrality (LDN). Science-Policy Brief 02. United Nations Convention to Combat Desertification (UNCCD). https://www.unccd.int/sites/default/files/documents/18102016_Spi_pb_multipage_ENG_1.pdf

9 Wissenschaftlicher Beirat Bodenschutz (WBB). (2002). Ohne Boden bodenlos – eine Denkschrift zum Bodenbewusstsein. https://www.umweltbundesamt.de/sites/default/files/medien/421/dokumente/denkschrift_ohne_boden_bodenlos.pdf

10 Beste, A.(2015): Down to Earth – The soil we live off. Study on the state of soil in Europeans agriculture. https://www.gesunde-erde.net/media/bodenstudie_beste_english_2015.pdf

11 Chemnitz, C. & Weigelt, J. (Eds). (2015). Soil Atlas 2015 – Facts and figures about earth, land and fields. Heinrich Böll Foundation and the Institute for Advanced Sustainability Studies. https://www.boell.de/sites/default/files/soilatlas2015_ii.pdf

12 Dion, P. (2010). Soil biology and agriculture in the tropics. Springer eBooks. https://www.worldcat.org/title/soil-biology-and-agriculture-in-the-tropics/oclc/462921767

13 Vorney, R.P. (2007). The soil habitat. In: Paul, E. (Ed). Soil microbiology, ecology and biochemistry (Third Edition). https://www.elsevier.com/books/soil-microbiology-ecology-and-biochemistry/paul/978-0-08-047514-1

14 Vorney (2007)

15 Chemnitz & Weigelt (2015): Soil Atlas. Facts and figures about earth, land and fields. https://www.boell.de/sites/default/files/soilatlas2015_ii.pdf

16 Wissenschaftlicher Beirat Bodenschutz (WBB) (2002)

17 Nortcliff, S. (2006). Soil 1. Definition, function, and utilization of soil. In: Ullmann's Encyclopedia of Industrial Chemistry. Wiley. https://doi.org/10.1002/14356007.b07_613.pub3

18 Gisi, U., Shenker R. & Schulin, A. (1997). Bodenökologie. Stuttgart, New York.

19 Schnug, E. & Haneklaus, S. (2002). Landwirtschaftliche Produktionstechnik und Infiltration von Böden: Beitrag des ökologischen Landbaus zum vorbeugenden Hochwasserschutz. FAL, Landbauforschung Völkenrode 52.

20 Hamza, M.A. & Anderson, W.K. (2005). Soil compaction in cropping systems: A review of the nature, causes and possible solutions. Soil and Tillage Research 82:121–145. https://doi.org/10.1016/j.still.2004.08.009

21 Hamza & Anderson (2005)

22 Beste, A. (2016). Down to Earth – The soil we live off. On the state of soil in Europe's agriculture. The Greens in the European Parliament & European Free Alliance. https://www.martin-haeusling.eu/images/Boden_Englisch_Web_Mail.pdf

23 Gupta R.K. et al. (2008). Soil biology. In: Chesworth W. (eds) Encyclopedia of soil science. Encyclopedia of Earth Sciences Series. Springer. https://doi.org/10.1007/978-1-4020-3995-9_531
24 Preetz, H. (2003). Bewertung von Bodenfunktionen für die praktische Umsetzung des Bodenschutzes. Dissertation Martin-Luther-Universität Halle-Wittenberg.
25 Gisi, Shenker & Schulin (1997)
26 SOILSERVICE (2012). Conflicting demands of land use, soil biodiversity and the sustainable delivery of ecosystem goods and services in Europe. Lund University. https://cordis.europa.eu/project/id/211779
27 Solanki, M.K. (2020). Mycorrhizal fungi and its importance in plant health amelioration. In: Solanki, M.K., Kashyap, P., Ansari, R. & Kumari, B. (Eds). Microbiomes and plant health. https://doi.org/10.1016/C2019-0-00466-9
28 FAO & ITPS (2015)
29 UNEP. (2004). UNEP's Strategy on Land Use Management and Soil Conservation. A strengthened functional approach. United Nations Environment Programme (UNEP).
30 UNEP. (1990). The extent of human-induced soil degradation. Annex 5. United Nations Environment Programme (UNEP) & World Soil Information (ISRIC).
31 Ray, D., Ramankutty, N., Mueller, N. et al. (2012). Recent patterns of crop yield growth and stagnation. Nat Commun 3. https://doi.org/10.1038/ncomms2296
32 Gomiero, T. (2016). Soil degradation, land scarcity and food security: Reviewing a complex challenge. Sustainability 8(3):281. https://doi.org/10.3390/su8030281
33 IPCC. (2019). Climate change and land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. Intergovernmental Panel on Climate Change (IPCC). https://www.ipcc.ch/srccl/
34 IAASTD. (2009). Agriculture at a crossroads. International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). https://wedocs.unep.org/20.500.11822/8590
35 Müller-Sämann, K.M. (1986). Bodenfruchtbarkeit und standortgerechte Landwirtschaft – Eine Studie über Maßnahmen und Methoden im Tropischen Pflanzenbau. (o.A.)
36 Finkl C.W. (1999). Tropical soils. In: Environmental geology. Encyclopedia of earth science. Springer.
37 LfL (no date). Bestandteile von Humus und Humusqualität. https://www.lfl.bayern.de/iab/boden/031122/index.php
38 Lehmann, J. & Kleber, M. (2015). The contentious nature of soil organic matter. Nature 528:60–68. https://doi.org/10.1038/nature16069
39 Lal, R. (2018). Digging deeper: A holistic perspective of factors affecting soil organic carbon sequestration in agroecosystems. Global Change Biology 1–17. https://doi.org/10.1111/gcb.14054
40 Stewart, N. (Ed). (2015). The value of land: Prosperous lands and positive rewards through sustainable land management. The Economics of Land Degradation (ELD). https://www.eld-initiative.org/fileadmin/pdf/ELD-main-report_08_web-72dpi_01.pdf
41 The Climate Reality Project (2017). Right under your feet: Soil health and the climate crisis. https://www.climaterealityproject.org/sites/climaterealityproject.org/files/Soil%20Health%20and%20Climate%20Change.pdf
42 Blankinship, J.C., Niklaus, P.A. & Hungate, B.A. (2011). A meta-analysis of responses of soil biota to global change. Oecologia 165:553–565. https://doi.org/10.1007/s00442-011-1909-0
43 Classen AT., Maja K. Sundqvist, Jeremiah A. Henning, Gregory S. Newman, Jessica A. M. Moore, Melissa A. Cregger, Leigh C. Moorhead, Courtney M. Patterson (2015). Direct and indirect effects of climate change on soil microbial and soil microbial-plant interactions: What lies ahead? Ecosphere 6(8): 1–21. https://doi.org/10.1890/ES15-00217.1
44 Borelli, P. David A. Robinson Panos Panagos, Emanuele Lugato, Jae E. Yang, Christine Alewell, David Wuepper, Luca Montanarella, and Cristiano Ballabio (2020). Land use and climate change impacts on global soil erosion by water (2015–2070). PNAS 117. https://doi.org/10.1073/pnas.2001403117
45 Martina Sartori, George Philippidis, Emanuele Ferraria, Pasquale Borrellic, Emanuele Lugatod, Luca Montanarella, PanosPanagos (2019). A linkage between the biophysical and the economic: Assessing the global market impacts of soil erosion. Land Use Policy 86. https://doi.org/10.1016/j.landusepol.2019.05.014
46 IPCC (2019)
47 IPBES (2018)
48 Live Science Staff (2012). Less forest, less rain: Deforestation reduces tropical rainfall. Live Science. https://www.livescience.com/23017-deforestation-reduces-rainfall.html

49 Gould, I.J., Quinton, J.N., Weigelt, A., De Deyn, G.B. & Bardgett, R.D. (2016). Plant diversity and root traits benefit physical properties key to soil function in grasslands. Ecology Letters 19(9):1140–1149. https://ec.europa.eu/environment/integration/research/newsalert/pdf/diverse_plant_communities_improve_soil_structure_ecosystem_services_481na3_en.pdf

50 Schwarzer, S. (2021). Working with plants, soils and water to cool the climate and rehydrate Earth's landscapes. UNEP Foresight Brief. United Nations Environment Programme (UNEP). https://wedocs.unep.org/bitstream/handle/20.500.11822/36619/FB025.pdf

51 University of Washington. (2005). Warming could free far more carbon from high arctic soil than earlier thought. NewsWise. https://www.newswise.com/articles/warming-could-free-far-more-carbon-from-high-arctic-soil-than-earlier-thought

52 IPBES (2018)

53 Canadell, J.G. (2002). Land use effects on terrestrial carbon sources and sinks. Science in China, Vol. 45. https://www.globalcarbonproject.org/global/pdf/landuse_Canadell_Zhou_Noble2003/Canadell_yc0001.pdf

54 Tian, H., Xu, R., Canadell, J.G. et al. (2020). A comprehensive quantification of global nitrous oxide sources and sinks. Nature 586:248–256. https://doi.org/10.1038/s41586-020-2780-0

55 Sutton, M., Howard, C. lare M. Howard, Jan Willem Erisman, Gilles Billen and Albert Bleeker (Eds.) (2011). The European Nitrogen Assessment: Sources, effects and policy perspectives. Cambridge University Press. https://assets.cambridge.org/97811070/06126/frontmatter/9781107006126_frontmatter.pdf

56 Del Grosso, S.J. & Cavigelli, M.A. (2012). Climate stabilization wedges revisited: Can agricultural production and greenhouse-gas reduction goals be accomplished? Frontiers in Ecology and the Environment 10(10):571–578. https://doi.org/10.2307/41811871

57 Köpke, U. & Nemecek, Th. (2010). Ecological services of faba bean. Field Crops Research 115(3):217–233. https://doi.org/10.1016/j.fcr.2009.10.012

58 Igiehon, N.O. & Babalola, O.O. (2018). Rhizosphere microbiome modulators: Contributions of nitrogen fixing bacteria towards sustainable agriculture. International Journal of Environmental Research and Public Health. https://doi.org/10.3390/ijerph15040574.

59 Köpke & Nemecek (2010)

60 IPCC. (2013). Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press. https://www.ipcc.ch/report/ar5/wg1/

61 Beste, A. & Idel, A. (2019). The belief in technology and big data. The myth of climate smart agriculture – why less bad isn't good. https://www.arc2020.eu/the-myth-of-climate-smart-agriculture-why-less-bad-isnt-good/

62 Igiehon & Babalola (2018)

63 Powlson, D.S., A. P. Whitmore, K. W. T. Goulding (2011). Soil carbon sequestration to mitigate climate change: a critical re-examination to identify the true and the false. European Journal of Soil Science 62(1):42–55. https://doi.org/10.1111/j.1365-2389.2010.01342.x

64 Wiesmeier, M, Livia Urbanski, Eleanor Hobley, Birgit Lang, Margit von Lützow, Erika Marin-Spiotta, Basvan Wesemael, Eva Rabot, Mareike Ließ, Noelia Garcia-Franco, Ute Wollschläger et al. (2019): Soil organic carbon storage as a key function of soils – A review of drivers and indicators at various scales. Geoderma 333:149–162. https://doi.org/10.1016/j.geoderma.2018.07.026

65 Paustian, K., Lehmann, J., Ogle, S. et al. (2016). Climate-smart soils. Nature 532:49–57. https://doi.org/10.1038/nature17174

66 Wiesmeier et al. (2019)

67 European Commission (2021). Technical Guidance Handbook. Setting up and implementing result-based carbon farming mechanisms in the EU. https://op.europa.eu/en/publication-detail/-/publication/10acfd66-a740-11eb-9585-01aa75ed71a1/language-en

68 IPCC (2019)

69 TMG Research & Partners (2020). Systemic challenges, systemic responses: innovating adaptation to climate change through agroecology. TMG. https://tmg-thinktank.com/220202

70 FAO. (no date). What are the environmental benefits of organic agriculture? Food and Agriculture Organization of the United Nations (FAO). http://www.fao.org/organicag/oa-faq/oa-faq6/en/

71 Chen, J., Engbersen, N., Stefan, L., Schmid, B., Sun, H. & Schöb, C. (2021). Diversity increases yield but reduces harvest index in crop mixtures. Nature Plants 7(7):893–898. https://doi.org/10.1038/s41477-021-00948-4

72 Gurbir S., David Bautze, Noah Adamtey, Laura Armengot, Harun Cicek, Eva Goldmann, Amritbir Riar, Johanna Rüegg, Monika Schneider, Beate Huber (2021). What is the contribution of organic agriculture to sustainable development? A synthesis of twelve years (2007-2019) of the "long-term farming systems comparisonsin the tropics (SysCom)". Research Institute of Organic Agriculture, Frick, Switzerland. https://systems-comparison.fibl.org/results/reports.html

73 Thomas, S., Jayne, Nicole M. Mason, William J. Burke, Joshua Ariga, (2018). Review: Taking stock of Africa's second-generation agricultural input subsidy programs. Food Policy 75:1–14. https://doi.org/10.1016/j.foodpol.2018.01.003

74 De Shutter (2011)

75 UN Human Rights, Office of the United Nations High Commissioner. (2011). Eco-farming can double food production in 10 years, says new UN report. News Release. http://www.srfood.org/images/stories/pdf/press_releases/20110308_agroecology-report-pr_en.pdf

76 FAO. (no date). What are the environmental benefits of organic agriculture? Food and Agriculture Organization of the United Nations (FAO). http://www.fao.org/organicag/oa-faq/oa-faq6/en/

77 FAO. (no date). Sustainable land management. Food and Agriculture Organization of the United Nations (FAO). https://www.fao.org/land-water/land/sustainable-land-management/en/

78 FAO & ITPS. (2020). Protocol for the assessment of sustainable soil management. Food and Agriculture Organization of the United Nations (FAO) & Intergovernmental Technical Panel on Soils (ITPS). http://www.fao.org/fileadmin/user_upload/GSP/SSM/SSM_Protocol_EN_006.pdf

79 ECN. (2010). Sustainable compost application in agriculture. English Version of the German Report Summary. European Compost Network (ECN). https://www.compostnetwork.info/wordpress/wp-content/uploads/ECN-INFO-02-2010_Sustainable_Use_of_Compost_in_Agriculture_LTZ-Project.pdf

80 ECN (2020)

81 ECN (2017)

82 Gentsch, N., Boy, J., Batalla, J.D.K. et al. (2020). Catch crop diversity increases rhizosphere carbon input and soil microbial biomass. Biol Fertil Soils 56, 943–957. https://doi.org/10.1007/s00374-020-01475-8

83 Beste (2016)

84 Thünen/BMEL (2019). Humus in landwirtschaftlich genutzten Böden Deutschlands. Ausgewählte Ergebnisse der Bodenzustandserhebung. https://www.thuenen.de/media/institute/ak/Allgemein/news/Bodenzustandserhebung_Landwirtschaft_Kurzfassung.pdf

85 Bucheli T., Hilber-Schöb I. & Schmidt H.P. (2015); Polycyclic aromatic hydrocarbons and polychlorinated aromatic compounds in biochar. In: Lehmann J. & Joseph S. (Eds.) Biochar for environmental management. Earthscan. https://www.taylorfrancis.com/chapters/edit/10.4324/9780203762264-28/polycyclic-aromatic-hydrocarbons-polychlorinated-aromatic-compounds-biochar-thomas-bucheli-isabel-hilber-hans-peter-schmidt

86 De la Rosa J.M. Águeda M., Sánchez-Martín, Paloma Campos, Ana Z. Miller (2019). Effect of pyrolysis conditions on the total contents of polycyclic aromatic hydrocarbons in biochars produced from organic residues: assessment of their hazard potential. Sci Total Environ 667:578–585. https://doi.org/10.1016/j.scitotenv.2019.02.421

87 Beste, A. (2022): GREENWASHING & HIGH TECH – Faking it: (un-)sustainable solutions for agriculture. https://www.gesunde-erde.net/media/fakesustainability_end_english_1.pdf

88 Sumbul A. Mahmood, I., Rizvi, R., Ansari, R.A., Safiuddin (2017). Mycorrhiza: an alliance for the nutrient management in plants. In: Kumar, V. et al. (Eds). Probiotics in Agroecosystem. https://doi.org/10.1007/978-981-10-4059-7_19

89 Saia, S., Tamayo, E., Schillaci, C., De Vita, P. (2020). Arbuscular mycorrhizal fungi and nutrient cycling in cropping systems. In: Carbon and nitrogen cycling in soil. Springer. https://doi.org/10.1007/978-981-13-7264-3_4

90 Smith, S.E. & Read, D.J. (2008). Mycorrhizal symbiosis, 3rd edn. Academic Press. https://www.elsevier.com/books/mycorrhizal-symbiosis/smith/978-0-12-370526-6

91 Ravnskov, S., Carmina Cabral, John Larsen (2020). Mycorrhiza induced tolerance in Cucumis sativus against root rot caused by Pythium ultimum depends on fungal species in the arbuscular mycorrhizal symbiosis. Biological Control 141. https://doi.org/10.1016/j.biocontrol.2019.104133.

92 Solanki (2020)

93 Oehl, F., Ewald Sieverding, Kurt Ineichen, Elisabeth-Anne Ris, Thomas Boller, Andres Wiemken (2005). Community structure of arbuscular mycorrhizal fungi at different soil depths in extensively and intensively managed agroecosystems. New Phytol. 65(1):273–283. https://doi.org/10.1111/j.1469-8137.2004.01235.x

94 Eldor A.P. (2007). Soil Microbiology, Ecology and Biochemistry. https://doi.org/10.1016/C2009-0-02816-5

95 SOILSERVICE (2012). Conflicting demands of land use, soil biodiversity and the sustainable delivery of ecosystem goods and services in Europe. Lund University. https://cordis.europa.eu/project/id/211779

96 Solanki (2020)

97 Vorney (2007)

98 Beste, A. (2020). 5th edition: Improvement of soil functions and soil fertility with the help of Qualitative Soil Analysis. https://www.gesunde-erde.net/en/publications/publications-on-soil-management-analysis/
99 Beste (2021). Flood protection – Let's start with soil. ARC2020. https://www.arc2020.eu/flood-protection-lets-start-with-soil/
100 Gallai, N., Salles, J.M., Settele, J., Vaissiere, B.E. (2009). Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. Ecological Economics 68(3): 810–821. https://doi.org/10.1016/j.ecolecon.2008.06.014
101 The White House. (2014). Fact Sheet: The economic challenge posed by declining pollinator populations. https://obamawhitehouse.archives.gov/the-press-office/2014/06/20/fact-sheet-economic-challenge-posed-declining-pollinator-populations
102 TMG Research & Partners (2020)
103 Dawson, I.K., Attwood, S.J., Park, S.E., et al. (2019). Contributions of biodiversity to the sustainable intensification of food production – Thematic Study for The State of the World's Biodiversity for Food and Agriculture. FAO. https://www.fao.org/documents/card/en/c/ca4003en/
104 IPES FOOD. (2016). From uniformity to diversity: A paradigm shift from industrial agriculture to diversified agroecological systems. International Panel of Experts on Sustainable Food systems (IPES FOOD). https://www.ipes-food.org/_img/upload/files/UniformityToDiversity_FULL.pdf
105 Beste (2016)
106 Beste (2020)
107 Oregon State University (no date). Permaculture design: Tools for climate resilience. 8 drought, heat, and erratic rainfall. https://open.oregonstate.education/permaculturedesign/chapter/drought-heat-and-erratic-rainfall/
108 Schwarzer (2021)
109 Luoa et al. (2010). Can no-tillage stimulate carbon sequestration in agricultural soils? A meta-analysis of paired experiments. Agriculture, Ecosystems and Environment 139 (2010) 224–231. https://agris.fao.org/agris-search/search.do?recordID=US201301897852
110 Titi, Adel El (Ed). (2003). Soil tillage in agroecosystems. Routledge. https://www.routledge.com/Soil-Tillage-in-Agroecosystems/Titi/p/book/9780849312281
111 Beven, K. & Germann, P. (1982). Macropores and water flow in soils. Water Ressour. Res. 18.
112 Holland, J.M. (2004). The environmental consequences of adopting conservation tillage in Europe: Reviewing the evidence. Agriculture, Ecosystems and Environment 103(1):1–25. https://doi.org/10.1016/j.agee.2003.12.018
113 Catch-C. (2014). Compatibility of Agricultural Management Practices and Types of Farming in the EU to enhance Climate Change Mitigation and Soil Health. https://cordis.europa.eu/project/id/289782
114 Gaupp-Berghausen, M., Hofer, M., Rewald, B. et al. Glyphosate-based herbicides reduce the activity and reproduction of earthworms and lead to increased soil nutrient concentrations. Sci Rep 5, 12886 (2015). https://doi.org/10.1038/srep12886
115 Philpott, T. (2011). USDA scientist: Monsanto's roundup herbicide damages soil. Mother Jones. www.motherjones.com/tom-philpott/2011/08/monsantos-roundup-herbicide-soil-damage
116 Sailaja, K.K. & Satyaprasad, K. (2006). Degradation of glyphosate in soil and its effect on fungal population. Journal of Environmental Science and Engineering 48 (2006):189–190. https://pubmed.ncbi.nlm.nih.gov/17915782/
117 Van Bruggen, M.M. He, K. Shin, V. Mai, K.C. Jeong, M.R. Finckh, J.G. Morris (2018). Environmental and health effects of the herbicide glyphosate. Science of the Total Environment. 616-617:255–268. https://doi.org/10.1016/j.scitotenv.2017.10.309
118 Zaller et al. (2018). Herbicides in vineyards reduce grapevine root mycorrhizationand alter soil microorganisms and the nutrient composition in grapevine roots, leaves, xylem sap and grape juice. Environmental Science and Pollution Research 25:23215–23226. https://doi.org/10.1007/s11356-018-2422-3
119 Dobberstein, J. (2017). Is glyphosate harming your no-tilled soils? No-Till Farmer. https://www.no-tillfarmer.com/articles/7169-is-glyphosate-harming-your-no-tilled-soils?v=preview
120 UNCCD Science Policy Interface (2017). Sustainable land management contribution to successful land-based climate change adaption and mitigation. A Report of the Science-Policy Interface. United Nations Convention to Combat Desertification (UNCCD). https://knowledge.unccd.int/sites/default/files/2018-09/UNCCD_Report_SLM_web_v2.pdf
121 Beste, A. (2015). Organic farming: Feeding crops by feeding the soil. In: Chemnitz, C. & Weigelt, J. (Eds). Soil Atlas 2015 – Facts and figures about earth, land and fields. Heinrich Böll Foundation and the Institute for Advanced Sustainability Studies. https://www.boell.de/sites/default/files/soilatlas2015_ii.pdf
122 Beste, A. (2016). Down to Earth – The soil we live off. On the state of soil in Europe's agriculture. The Greens in the European Parliament & European Free Alliance. https://www.martin-haeusling.eu/images/Boden_Englisch_Web_Mail.pdf

123 Barrios, E. Barbara Gemmill-Herren, Abram Bicksler, Emma Siliprandi, Ronnie Brathwaite, Soren Moller, Caterina Batello & Pablo Tittonell (2020). The 10 elements of agroecology: Enabling transitions towards sustainable agriculture and food systems through visual narratives. Ecosystems and People 16(1):230–247. https://doi.org/10.1080/26395916.2020.1808705
124 FAO (2018). The 10 elements of agroecology: Guiding the transition to sustainable food and agricultural systems. the Food and Agriculture Organization of the United Nations (FAO). http://www.fao.org/3/i9037en/i9037en.pdf
125 TMG Research & Partners (2020)
126 TMG Research & Partners (2020)
127 Sinclair, F. Wezel, A. & Mbow, Cheikh & Chomba, Susan (2019). The Contribution of Agroecological Approaches to Realizing Climate-Resilient Agriculture. Technical Report. https://www.researchgate.net/publication/341406604_The_Contribution_of_Agroecological_Approaches_to_Realizing_Climate-Resilient_Agriculture
128 GIZ (2020). Agroecology. Factsheet. https://www.giz.de/en/downloads/giz2020_en_Agroecology_SV%20Nachhaltige%20Landwirtschaft_05-2020.pdf
129 UNCCD Science Policy Interface (2017)
130 UNCCD Science Policy Interface (2017)
131 Plieninger T. et al. (2018). Chancen von Agroforstwirtschaft für die ländliche Entwicklung: Ergebnisse aus dem AGFORWARD-Projekt. https://agroforst-info.de/wp-content/uploads/2018/11/2_Plieninger.pdf
132 Beste & Idel (2019)
133 FAO (2019). Recarbonization of global soils: A dynamic response to offset global emissions. FAO and Global Soils Partnership. http://www.fao.org/3/i7235en/I7235EN.pdf
134 Agroforestry Network (2018). Scaling up agroforestry: Potential, challenges and barriers. https://viagroforestry.org/app/uploads/2018/11/Scaling-up-Agroforestry-Potential-Challenges-and-Barriers_FINAL.pdf
135 FAO. (no date). 'Organic agriculture FAQ'. Food and Agriculture Organization of the United Nations (FAO). http://www.fao.org/organicag/oa-faq/en/
136 Reganold, J. & Wachter, J. (2016). Organic agriculture in the twenty-first century. Nature Plants 2:15221. https://doi.org/10.1038/nplants.2015.221
137 KBU/UBA (2016): Böden als Wasserspeicher. https://www.umweltbundesamt.de/sites/default/files/medien/377/publikationen/kbu_erhohung_und_sicherung_der_infiltr_ationsleistung_von_boden_juli_2016.pdf
138 FAO. (no date). 'Organic agriculture FAQ'. Food and Agriculture Organization of the United Nations (FAO). http://www.fao.org/organicag/oa-faq/en/
139 FAO. (2007). Report on the International Conference on Organic Agriculture and Food Security, Rome, 3–5 May 2007. Food and Agriculture Organization of the United Nations (FAO). https://www.fao.org/organicag/ofs/docs_en.htm
140 Skinner, C. et al. (20019). The impact of long-term organic farming on soil-derived greenhouse gas emissions. Scientific Reports 9(1):1702. https://doi.org/10.1038/s41598-018-38207-w
141 De Shutter (2011)
142 Chen et al. (2021)
143 GMWatch (2021). Mixed cultures for a greater yield. https://www.gmwatch.org/en/news/latest-news/19830
144 Gurbir et al. (2021)
145 De Shutter (2011)
146 UN Human Rights, Office of the United Nations High Commissioner. (2011). Eco-farming can double food production in 10 years, says new UN report. News Release. http://www.srfood.org/images/stories/pdf/press_releases/20110308_agroecology-report-pr_en.pdf
147 Gurbir et al. (2021)
148 IFOAM (2020). Principles of organic farming. IFOAM Organics International. https://www.ifoam.bio/sites/default/files/poa_english_web.pdf
149 Reganold, J. & Wachter, J. (2016). Organic agriculture in the twenty-first century. Nature Plants 2:15221. https://doi.org/10.1038/nplants.2015.221
150 FAO & WHO (2007). Codex Alimentarius. Organically produced foods. Third edition. Food and Agriculture Organization of the United Nations (FAO) and World Health Organization (WHO). https://www.fao.org/3/a1385e/a1385e00.pdf
151 Climate Smart Agriculture Concerns signatories. (2015). Don't be fooled! Civil society says NO to "Climate Smart Agriculture" and urges decision-makers to support agroecology. http://www.climatesmartagconcerns.info/cop21-statement.html
152 IFOAM (2020)
153 Christen, O., Squires, V., Lal, R. & Hudson R.J. (Eds). (2010). Interdisciplinary and sustainability issues in food and agriculture. EOLSS Publishers Co. Ltd. https://www.eolss.net/ebooklib/bookinfo/interdisciplinary-sustainability-issues-food-agriculture.aspx

154 Jones (2003). Recognise, relate, innovate. Department of Land & Water Conservation, New South Wales Government. https://www.amazingcarbon.com/PDF/JONES-RecogniseRelateInnovate.pdf

155 Mollison, B.C. (1990). Permaculture: A practical guide for a sustainable future. Island Press. (p. 8). https://www.worldcat.org/title/permaculture-a-practical-guide-for-a-substainable-future/oclc/1131430610?referer=di&ht=edition

156 Mollison (1990)

157 Millison, A. (Ed). (no date). Drought, heat, and erratic rainfall. In: Permaculture design: Tools for climate resilience. Oregon State University. https://open.oregonstate.education/permaculturedesign/chapter/drought-heat-and-erratic-rainfall/

158 UN DESA. (no date). Sustainable Development Goal 15. UN Department of Economic and Social Affairs (UN DESA). https://sdgs.un.org/goals/goal15.

159 Lal, R., Safriel, U., Boer, B. (2012). Zero Net Land Degradation. A sustainable development goal for Rio +20. UNCCD Secretariat policy brief. United Nations Convention to Combat Desertification (UNCCD). https://catalogue.unccd.int/991_Zero_Net_Land_Degradation_Report_UNCCD_May_2012.pdf

160 UNCCD. (2015). Decision 3/COP.12. United Nations Convention to Combat Desertification (UNCCD). https://www.unccd.int/sites/default/files/relevant-links/2017-03/Decision_3_COP_12_GM.pdf

161 UN General Assembly. (2012). The future we want. A/RES/66/288. http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/66/288&Lang=E

162 Bodle, R. & Stockhaus, H. (2020). Improving international soil governance – Analysis and recommendations. Umweltbundesamt. https://www.umweltbundesamt.de/sites/default/files/medien/479/publikationen/texte_75-2020_3716_71_2100_uba_endbericht_internationaler_bodenschutz.pdf

163 Bodle & Stockhaus (2020)

164 UNCCD. (2017). Scientific conceptual framework for Land Degradation Neutrality. A report of the Science-Policy Interface. United Nations Convention to Combat Desertification (UNCCD) https://www.unccd.int/sites/default/files/documents/2019-06/LDN_CF_report_web-english.pdf

165 Bodle & Stockhaus (2020

166 CBD. (2020). Review of the International Initiative for the Conservation and Sustainable Use of Soil Biodiversity and updated plan of action. CBD/SBSTTA/24/L7/REV1. Convention on Biological Diversity (CBD). https://www.cbd.int/meetings/SBSTTA-24

167 UN General Assembly (2019). Resolution adopted by the General Assembly on 1 March 2019. A/RES/73/284. https://undocs.org/A/RES/73/284

168 Davies, J. (2017). The business case for soil. Nature 543:309–311. https://doi.org/10.1038/543309a

169 IUCN (2016). The Bonn Challenge for forest restoration. International Union for Conservation of Nature (IUCN). https://2016congress.iucn.org/news/20160316/bonn-challenge-forest-restoration.html

170 UNFCCC (1992). Article 2. United Nations Framework Convention on Climate Change (UNFCCC). https://unfccc.int/resource/docs/convkp/conveng.pdf.

171 Richards, M. ; Richards, Meryl B. ; Bruun, T.B. ; Campbell, B. M. ; Gregersen, LE. ; Huyer, S.; Kuntze, V.; Madsen, STN; Oldvig MB. ; Vasileiou, Ioannis (2015). How countries plan to address agricultural adaptation and mitigation. CCAFS Info Note. https://cgspace.cgiar.org/handle/10568/69115.

172 FAO, ITPS, GSBI, CBD and EC. (2020). State of knowledge of soil biodiversity – Status, challenges and potentialities. https://doi.org/10.4060/cb1928en.

173 IPCC (2019)

174 CBD (2008). Biodiversity and agriculture: Safeguarding biodiversity and securing food for the world. Convention on Biological Diversity (CBD). https://www.cbd.int/doc/bioday/2008/ibd-2008-booklet-en.pdf

175 FAO, ITPS, GSBI, CBD and EC (2020)

176 CBD (2020)

177 TMG Research & Partners (2020)

178 TMG Research & Partners (2020)

179 Seddon, N. (2018). Nature-based solutions: Delivering national-level adaptation and global goals. International Institute for Environment and Development (IIED). https://pubs.iied.org/17484iied.

180 Seddon (2018)

181 Richards et al. (2015)

182 Richards et al. (2015)

183 Nature-based Solutions Policy Platform. (no date). A global policy platform for climate change adaptation. University of Oxford. https://www.nbspolicyplatform.org/

184 UNFCCC. (2021). National Adaptation Plans 2020: Progress in the formulation and implementation of NAPs. United Nations Framework Convention on Climate Change (UNFCCC). https://unfccc.int/documents/273920.

185 Terton, A. & Greenwalt, J. (2020). Building resilience with nature: Ecosystem-based adaptation in National Adaptation Plan processes. International Institute for Sustainable Development (IISD). https://napglobalnetwork.org/resource/building-resilience-with-nature-eba-in-nap-processes.

186 Seddon (2018)

187 Seddon (2018)

188 Author's assessment

189 Seddon (2018)

190 Terton, A., Ledwell, C. & Kumar, A. (2021). How Fiji is using the National Adaptation Plan (NAP) process to scale up ecosystem-based adaptation (EbA). NAP Global Network. https://napglobalnetwork.org/wp-content/uploads/2021/06/napgn-en-2021-snapshot-fiji-using-nap-to-scale-up-eba.pdf.

191 Government of the Republic of Fiji. (2018). Republic of Fiji National Adaptation Plan – A pathway towards climate resilience. https://www4.unfccc.int/sites/NAPC/Documents/Parties/National%20Adaptation%20Plan_Fiji.pdf

192 Government of the Republic of Fiji (2018)

193 Terton & Greenwalt (2020)

194 FAO, ITPS, GSBI, CBD and EC (2020)

195 Government of Pakistan. (2018). National Biodiversity Strategy and Action Plan for achieving Aichi Biodiversity Targets and Sustainable Development Goals. https://www.cbd.int/doc/world/pk/pk-nbsap-01-en.pdf

196 Government of Pakistan. (2018)

197 Government of Pakistan (2018)

198 Government of Pakistan (2018)

199 Government of Pakistan (2018)

200 Seddon, N.; Sengupta, S.; Garcia Espinosa, M.; Hauler, I.; Herr, D.; Rizvi, A.R.(2019). Nature-based solutions in Nationally Determined Contributions: Synthesis and recommendations for enhancing climate ambition and action by 2020. IUCN and University of Oxford. https://portals.iucn.org/library/node/48525

201 Burhenne-Guilmin and Scanlong (2004), cited in GIZ (2019). Amend, T. Governance for Ecosystem-based Adaptation: Understanding the diversity of actors and quality of arrangements. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. https://www.adaptationcommunity.net/wp-content/uploads/2019/09/giz2019-en-eba-governance-study-low-res.pdf

202 FAO. (2021). Soil governance. Food and Agriculture Organization of the United Nations (FAO). http://www.fao.org/global-soil-partnership/areas-of-work/soil-governance/en/

203 IPBES (2018)

204 TMG Research & Partners (2020)

205 Mansur, E. (2021). Webinar on soil governance. Food and Agriculture Organization of the United Nations (FAO). Video. 13 January 2021. https://www.youtube.com/watch?v=zEpTtbT3s6M.

206 IPBES (2018)

207 Debonne, N., J. van Vliet, G. Metternicht, and P. Verburg. (2021). Agency shifts in agricultural land governance and their implications for land degradation neutrality. Global Environmental Change 66: 102221. https://doi.org/10.1016/j.gloenvcha.2020.102221.

208 FAO, ITPS, GSBI, CBD and EC (2020)

209 Krzywoszynska, A. (2018). Soil: Private asset or public good? Sustainable Soils Alliance. https://www.sustainablesoils.org/about-soils/third-party-articles/2-uncategorised/508-3rd-party-articles-anna-krzywoszynska

210 Sustainable Soils Alliance (2019). The Economics of soil: Private asset or public good? https://static1.squarespace.com/static/58cff61c414fb598d9e947ca/t/5ca4b8eda4222f9623b1a94f/1554299118256/Economics+of+Soil+Event+Report.pdf

211 FAO & ITPS (2015)

212 IPBES (2018)

213 GIZ (2019). Amend, T. Governance for Ecosystem-based Adaptation: Understanding the diversity of actors and quality of arrangements. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. https://www.adaptationcommunity.net/wp-content/uploads/2019/09/giz2019-en-eba-governance-study-low-res.pdf

214 FAO & ITPS (2015)

215 IPBES (2018)

216 Stewart (2015)

217 FAO. (2012). Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security. Food and Agriculture Organization of the United Nations (FAO).PSIT www.fao.org/docrep/016/i2801e/i2801e.pdf.
218 Debonne, N., J. van Vliet, G. Metternicht, and P. Verburg. (op. cit.)
219 IPBES (2018)
220 TMG Research & Partners (2020)
221 GIZ (2019)”
222 GIZ (2019)
223 UNIQUE Forestry and Land Use GmbH. (2018). Sustainable land management for upscaled climate action. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. https://www.desertifikation.de/fileadmin/user_upload/downloads/2018/2018-12-21_Positioning_SLM_to_support_upscaled_climate_action.pdf
224 Government of the Democratic Republic of Timor-Leste. (2021). Timor-Leste’s National Adaptation Plan – Addressing climate risks and building climate resilience. https://www4.unfccc.int/sites/NAPC/Documents/Parties/Timor%20Leste%20NAP.pdf
225 GIZ (2019b). Emerging lessons for mainstreaming Ecosystem-based Adaptation – Strategic entry points and processes. Authors: Lili Ilieva and Thora Amend. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Bonn. https://www.adaptationcommunity.net/wp-content/uploads/2019/04/giz2019-en-study_Emerging-lessons-for-EbA-mainstreaming_web.pdf
226 Debonne et al.. (2021)
227 Swann, S. ; Blandford, L. ; Cheng, S.; Cook, J.; Miller, A.; Barr, R. (2021). Public international funding of nature-based solutions for adaptation: A landscape assessment. World Resources Institute. https://doi.org/10.46830/wriwp.20.00065
228 Debonne N., J. van Vliet, G. Metternicht, and P. Verburg. .. (2021)
229 Stewart (2015)
230 Stewart (2015)
231 GIZ (2019)
232 GIZ (2019b). Five Dimensions of Mainstreaming Climate Change Adaptation. Author: Lorentz Noemi. https://panorama.solutions/sites/default/files/5df_factsheet_building_block1.pdf
233 Debonne N., J. van Vliet, G. Metternicht, and P. Verburg. .. (2021)