Common ground

Restoring land health for sustainable agriculture

Ludovic Larbodière, Jonathan Davies, Ruth Schmidt, Chris Magero, Alain Vidal, Alberto Arroyo Schnell, Peter Bucher, Stewart Maginnis, Neil Cox, Olivier Hasinger, P.C. Abhilash, Nicholas Conner, Vanja Westerberg, Luis Costa

INTERNATIONAL UNION FOR CONSERVATION OF NATURE

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Foreword

Climate change, unprecedented biodiversity loss and the spread of devastating disease send us a clear message: the time has come to reconsider our relationship to nature. Few economic sectors are as central to humanity's relationship with nature as agriculture. Farming provides livelihoods for billions and harnesses nature's resources to give us food, feed, fibre and energy. Yet, excessive expansion and intensification of agriculture are also drivers of soil and biodiversity degradation and contribute to climate change, undermining the agricultural sector's own future.

It is perhaps not surprising that the dialogue between the conservation and agricultural sectors is too often antagonistic, focusing on seemingly irreconcilable aims and competition for space. While acknowledging this situation, this report attempts to reframe the dialogue between the agricultural sector and the conservation community around the 'common ground' of shared solutions.

In recent decades, the agricultural sector has significantly increased productivity and drastically reduced the number of food insecure people worldwide. This is an immense achievement. However, it has at times come at a high cost. The impact of agriculture on its own viability calls for vigilance. In many parts of the world, the only option for farmers is to search for new land to continue production or to use soil as a substrate with massive synthetic inputs. Most production growth has been achieved through intensification – getting more out of the same land area – but there are still major concerns over habitat loss to agriculture threatening biodiversity and natural ecosystems such as forests, grasslands or peatlands in many developing countries. While the harmful effects of some agricultural inputs are becoming evident, many policies and incentives are emerging that promote sustainable farming. They encourage environmentally sound practices that conserve healthy, biodiverse, productive landscapes and soils, retain moisture, benefit nutrient cycling, decomposition and soil structure and help control pests and diseases.

This report highlights the immense potential of a widespread adoption of sustainable agricultural practices for the secure, long-term production of food, feed, fibre and energy. It also emphasises that ecosystem services derived from healthy soils are not limited to the farm. When farmers work the land sustainably, they do not just feed us; they transform agriculture into a genuine nature-based solution to our most pressing societal challenges, contributing to regulating the climate, enhancing water security and providing habitats to countless species. Society enjoys these added services, though it seldom pays for them, nor does it sufficiently incentivise farmers to safeguard them. This report for the first time estimates the significant potential monetary value of these additional benefits and lays out concrete steps to achieve them.

It is now more evident than ever that we need to make our food production systems more sustainable and resilient if we are to tackle the interlinked challenges of climate change, accelerating biodiversity loss and global food and nutrition insecurity.

It is our hope that this report will help conservationists and farmers to work together towards a more sustainable agricultural sector, promoting agro-ecological approaches and healthy landscapes that can feed society into the future while conserving the rich diversity of life on our planet.

Julien Denormandie

French Minister of Agriculture and Food

Dr Bruno Oberle

Director General

IUCN, International Union for Conservation of Nature

Executive summary

Why the search for common ground?

Recent major international reports have highlighted the alarming impact of food production systems on climate change, land and biodiversity. The COVID-19 pandemic provides another illustration of the need for more sustainable food systems that work with, and not against nature, while ensuring food security and decent livelihoods for a rapidly growing population.

Achieving greater sustainability depends on reaching consensus between diverse actors, over goals as well as approaches. It requires increased coordination and the development of synergy between a variety of stakeholders in the agriculture and conservation sectors.

This report shows that common ground between the agriculture and conservation sectors for mutually beneficial action exists, and that there is great potential for widespread adoption of sustainable agricultural practices that can meet our needs for food, feed, fibre, and energy. More widely, sustainable agriculture can contribute to food, water security, climate regulation and other objectives, supporting progress towards the Sustainable Development Goals and other international targets for climate change, biodiversity and land degradation.

Conserving soil biodiversity improves agricultural land health

Farms are modified ecosystems that depend on nature in many ways, for nutrient supply, water supply, pest control, pollination and other services. Soil biodiversity conservation is at the heart of most sustainable farming practices, but scientific knowledge is weak: 90-95% of soil biota remains unidentified and less than 1% of some groups has been described. A close correlation is observed between the diversity and abundance of soil species and soil ecosystem function. Management of this biota by farmers should be better informed by science as to how species interact in the soil and how positive interactions can be enhanced or restored by farming practices.

Improved agricultural land health can bring massive benefits for society

The 'four per thousand' (or '4‰') initiative aims to increase soil organic carbon annually by 0.4% of its current stock within the first 30-40 cm of soil, through the implementation of economically viable and environmentally sound agronomic practices. This report shows that meeting the 4‰ target on all the world's agricultural land can bring major potential benefits in mitigating climate change, increasing food production and improving green water stocks. **Achieving the goals of 4‰ on the world's agricultural lands could increase carbon capture** by croplands and grasslands **by approximately 1 Gt per year** over the next 30 years, **equivalent to 10% of global anthropogenic emissions** based on 2017 emissions. The **avoided social cost** implied by this contribution to climate change mitigation over the 2020-2050 time horizon is in the order of **US$ 600 billion per** year in present value terms.

Crop production could also benefit from achieving the goals of 4‰. **Production of three major crops – maize, wheat and rice – is estimated to increase by 23.4%, 22.9% and 41.9% respectively with an estimated value of US$ 135.2 billion per year between 2020 and 2050**. The benefits of production increases will differ by region but would be highest in developing countries, and particularly in Africa. Meanwhile, the reduced reliance on inorganic fertiliser can reduce pollution of watercourses while increased land productivity could offset the demand for further conversion of land for agriculture.

Hydrological cycles also benefit from increased soil carbon and the **capacity of soils to store water could increase by up** to 37 billion m^3. The increase in soil moisture from 4‰ has the potential to reduce reliance on irrigation, with estimated global savings of US$ 44 billion per year. The benefits of 4% could result in increased resilience for vulnerable farming communities, and reduced exposure to projected risks associated with climate change, such as floods, droughts and storms.

Solutions for restoring and maintaining agricultural land health are well established

Many sustainable agricultural approaches and practices are known and documented, and they have proven to be effective in conserving and enhancing soil and above-ground biodiversity on farms. Farming systems are closely linked to the wider landscape through many ecological interactions that can also be managed. Landscape management practices also have a direct impact on agriculture and landscape productivity and on the level of provision of ecosystem services. Sound farming and landscape management practices can have a direct positive impact for farmers, especially the most vulnerable, for consumers' health and nutrition, and for society as a whole.

Incentives are needed to accelerate the transition

For land health to be fully mainstreamed in institutions, markets and policies, the true values of agricultural landscapes must be better understood, and rewarded, and ways found to incentivise and de-risk the transition to more sustainable farming. However, farmers must overcome numerous **hurdles to adopt sustainable practices**, such as insufficient awareness, high transition costs, unreliable markets, and aversion to change due to a range of risks and uncertainties. Many farmers are tied to existing unsustainable management systems through trade policies, legal frameworks and public incentives. This report highlights **three priority areas for progress** to address these hurdles:

1. Understanding and rewarding the diverse values of agricultural land and landscapes
2. Developing incentives and regulations that encourage or enable transformative action, while relaxing disincentives
3. Reducing risks associated with the transition towards agriculture and food production that conserves land health

Conditions are favourable for rapid progress

Restoring land health is one element of wider changes needed in the food system. Countries that are food-deficient, or whose economies depend heavily on the agriculture sector, are likely to continue prioritising overall agricultural production. Managing land health should be central to achieving production goals while safeguarding sustainability and strengthening the resilience of farmers. Improvements are also needed in equitable access to natural resources (especially land and water) and access to food, to reduce unhealthy diets, and to mitigate food loss and waste. This will require unprecedented coordination between many actors in food supply chains and beyond, guided by bold political leadership.

The coming decade offers a unique window of opportunity to orientate agriculture towards a more ambitious set of goals that balance needs for food, feed, fibre and for a variety of ecosystem services that will contribute globally to more sustainable and resilient societies. **Public policies should aim to achieve net-positive impact of agriculture on key indicators of biodiversity by 2030 as well as stabilisation of the land area under agriculture, in order to increase biodiversity and resilience in agricultural landscapes and to reduce land degradation, pollution and greenhouse gas emissions**.

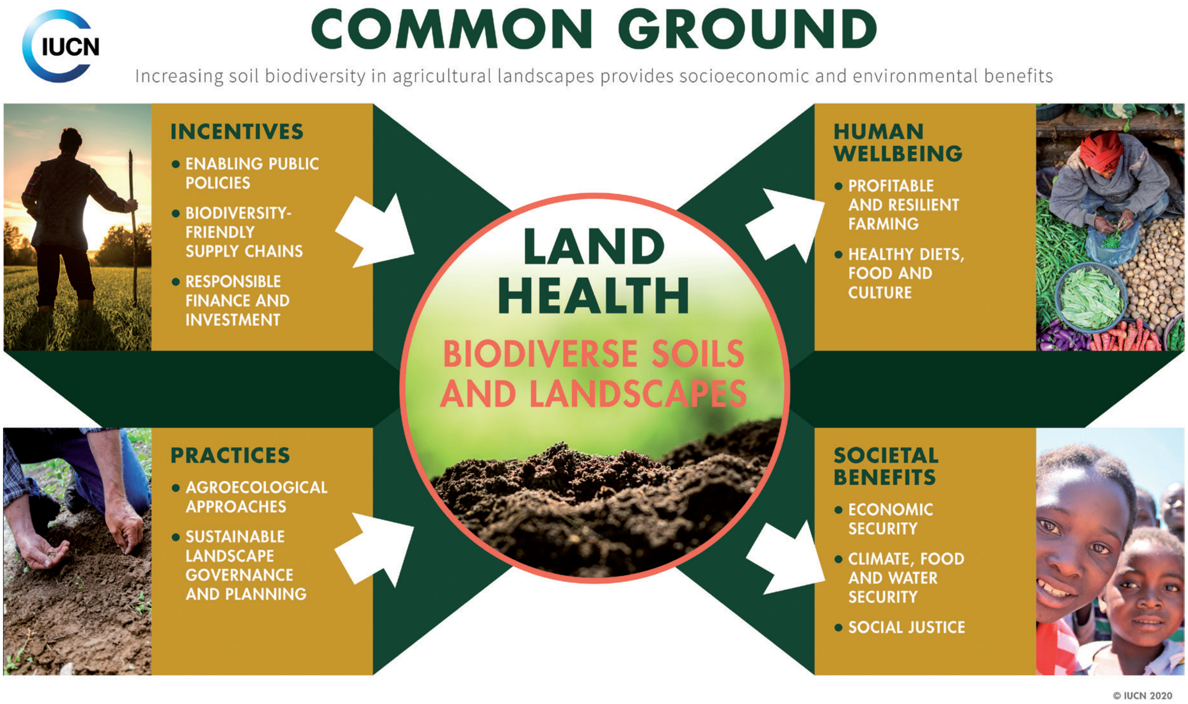

Figure 1 Land health as a common ground

Recommendations

1. **Prioritise soil and landscape biodiversity for food and nature**

Sustainable agriculture depends on maintaining land health and conserving biodiversity in agriculture soils and landscapes. Land health must therefore be a central goal for the agriculture sector to contribute to ending hunger, achieving food security and improved nutrition, and promote sustainability without expanding the overall area of agriculture land. In doing so, agriculture can become a **Nature-based Solution** that contributes to some of the most pressing societal challenges. **Farmers and the agriculture sector should urgently adopt ambitious targets for land health, and the conservation sector should strengthen the scientific foundation for monitoring progress.**

2. **Mainstream agroecological approaches for managing agricultural landscapes**

Agroecological approaches that foster synergies between agriculture and biodiversity are already available and should be scaled up and mainstreamed in all relevant policies, instruments and institutions. This should be done in close partnership with farmer communities and organisations. **Emphasis should be placed on creating conditions that enable farmers to achieve sustainability at both the farm and the landscape level, and reduce the risks they face during the transition**. While rapid progress is already possible based on existing knowledge, as demonstrated in a number of countries, deeper analysis is needed on behavioural, organisational, social, political, financial and economic barriers to adoption.

3. Establish targets and indicators at national and global levels for sustainable agriculture
Adoption of sustainable agriculture approaches should be up-scaled by establishing clear targets for sustainability metrics. More specifically, the agriculture sector should aim for a net-positive impact on key indicators of biodiversity by 2030, including the stabilisation of the total land area under agriculture, increase of biodiversity in agricultural landscapes, and reduced pollution and greenhouse gas emission. These indicators should complement socioeconomic data on incomes, employment, poverty reduction, and livelihood resilience, especially for those most in need, including youth and women.

4. Reward ecosystem services to incentivise sustainable farming
The global transition to sustainable agriculture requires a shift from thinking of agriculture in terms of 'food, fibre and fuel' (and other products), to thinking in terms of 'production, water, climate and nature' (and other services). The agriculture sector's overriding policy goal should be to enhance the overall value of farming, **promoting all values of agricultural soil, land and landscapes and the services provided to society, and putting in place relevant regulations and incentives.** Innovative incentives and de-risking measures need to be designed and tested, which requires creative and coherent policy frameworks.

5. Promote change throughout the global food system to enhance sustainability
Restoring and conserving soil and land health must be promoted as an integral part of wider system transformation, focusing on national and international **policy convergence to connect soils and land health with sustainable and healthy diets**. Public subsidies and private financial flows should be redirected from conventional to more sustainable agriculture, while unlocking factors that block the transformation, such as input subsidies, specialisation of systems, standardised supply chains, and power asymmetries. Greater attention should be given to responsible landscape and supply chain investments that protect healthy soils and reward sustainable farming practices.

6. Build consensus on environmental stewardship in the agricultural sector
Dialogue between the agriculture and conservation communities must be intensified at local, national and international levels. The agriculture sector need improved information on the ecological and living nature of soils as natural capital. Conservation actors need greater appreciation of sustainable agriculture as a solution for increasing biodiversity, and agricultural landscapes as an opportunity to expand global conservation area coverage. New or adapted institutions may be required to incentivise action and secure sustainability outcomes at the agroecosystem or landscape level.

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Acronyms and abbreviations

AMF	Arbuscular mycorrhizal fungi
BNF	Biological nitrogen fixation
C	Carbon
CBD	Convention on Biological Diversity
CFS	United Nations Committee on World Food Security
CO_2	Carbon dioxide
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FMNR	Farmer Managed Natural Regeneration
FOLU	Food and Land Use Coalition
GAIN	Global Alliance for Improved Nutrition
GHG	Greenhouse gas
GIZ	Gesellschaft fur Internationale Zusammenarbeit
HLPE	High Level Panel of Experts on Food Security and Nutrition
IDDRI	Institut du développement durable et des relations
IUCN	International Union for Conservation of Nature
LDN	Land degradation neutrality
MAA	Ministère français de l'agriculture et de l'alimentation
N	Nitrogen
NbS	Nature-based Solution
NDC	Nationally Determined Contribution
NBSAP	National Biodiversity Strategy and Action Plan
N_2O	Nitrous Oxide
OECD	Organisation for Economic Co-operation and Development
OECM	Other effective area-based conservation measure
OFB	Office français de la Biodiversité
P	Phosphorus
SDG	Sustainable Development Goal
SLM	Sustainable Land Management
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environment Programme
WHO	World Health Organization

Chapter 1

Introducing the search for common ground: feeding nine billion people while protecting nature

1.1 Feeding the future

There has been a surge of interest in the environmental impact of the food and agriculture sector in recent years. Several influential reports have highlighted the scale of damage caused by agriculture, through its contribution to climate change, deforestation, pollution and other hazards (HLPE on Food Security and Nutrition, 2017; Willett et al., 2019). While the concerns are fully justified, public discourse can be highly polemical and often overlooks the evidence of potential environmental benefits from agriculture. This report shows that, by reorienting agriculture towards responsible use and protection of the natural environment through sustainable practices – what we refer to as environmental stewardship – we can incentivise a transition from net biodiversity loss to net biodiversity gain, while contributing to food security and farmers' livelihoods.

The global population reached 7.7 billion at the end of 2019 and is projected to increase by a further 25% by the year 2050, approaching 10 billion people. Those 10 billion people will probably have greater per capita wealth than previous generations and will demand more food, and more environmentally costly food, as well as other agricultural products. This demand must be satisfied under changing climatic conditions, which will affect the quality and quantity of agricultural produce (Ebi & Loladze, 2019). Agriculture already has a large environmental footprint, to the extent that, without radical change, the long-term viability of food production may be jeopardised. Land degradation is a growing concern, and a senior UN official has warned that the world's soil could be depleted in as little as 60 years.[1]

Nevertheless, considering the growing global demand for food and the persistent inequity in food distribution around the world, a discourse that focuses exclusively on the harmful effects of agriculture is unlikely to yield practical solutions for sustainable development. If we are to reconcile nable Development Goals on zero poverty (SDG 2) and life on land (SDG 15), not to mention several others, the world must pay much greater attention to the opportunities for environmental stewardship by the food and agriculture sector.

There are stark differences of opinion over how best to feed the population of the future. A recent study by the Food and Agriculture Organisation (FAO) sugges that "to meet demand, agriculture in 2050 will need to produce almost 50% more food, feed and biofuel than it did in 2012."[2] (FAO, 2018a). However, other sources, including the High Level Panel of Experts on Food Security and Nutrition (HLPE, 2017), under the United Nations Committee on World Food Security (CFS), find that the challenge is not total production but inequality in food distribution combined with over-consumption. The World Health Organization (WHO) reported in 2014 that, while approximately 462 million adults worldwide were underweight, 1.9 billion were either overweight or obese.[3]Additionally, FAO estimates that one-third of all food produced is wasted.[4] The HLPE has estimated that the world already produces more than enough food to give everybody on the planet a healthy diet (HLPE, 2017).

Reducing food loss and waste globally could have a major impact on the total environmental impact of agriculture. FAO differentiates between food loss – decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retail, food service providers and consumers – and food waste – decrease in the quantity or quality of food resulting from decisions and actions by retailers, food services and consumers.

About 30% of the world's agricultural land is used to produce food that is lost or wasted, with the highest levels of waste in Europe and North America (95-115 kg per person per year) and lowest waste in sub-Saharan Africa, southern and south-eastern Asia (6-11kg per person per year) (Gustavsson et al., 2011). The global pattern for food loss is quite different, with the highest levels in central and southern Asia (21%) and lowest levels in Australia and New Zealand (6%). Globally, around 14% of food produced is lost from the post-harvest stage up to, but excluding, the retail stage. (FAO, 2019).

[1] https://www.scientificamerican.com/article/only-60-years-of-farming-left-if-soil-degradation-continues/
[2] http://www.fao.org/3/a-i6583e.pdf
[3] https://www.who.int/en/news-room/fact-sheets/detail/malnutrition
[4] http://www.fao.org/food-loss-and-food-waste/en/

Recent reports, including those of the HLPE and the EAT-Lancet Commission (Willett et al., 2019) argue for transformation of the food system, away from inefficient production, over-consumption and inequitable distribution. The EAT-Lancet report finds that feeding the projected future population depends on transforming eating habits, improving food production and reducing food waste. The following chapters show that, by reorienting agriculture towards environmental stewardship we can incentivise this transformation.

The authors have been guided by a vision of a food and agriculture system that protects ecosystems and conserves biodiversity, and is a net contributor to conservation goals. In our vision, agricultural landscapes throughout the world provide food, fuel and fibre, regulate water supply, store carbon (C) and contribute to climate change mitigation, and conserve biodiversity, while supporting the livelihoods of farming communities. While this is an ambitious and far-reaching vision, it is grounded in solutions that are already widely practised today, and has been shown to be economically viable. The Food and Land Use Coalition, 2019 suggests that the benefits of more sustainable agriculture could far outweigh the costs, potentially unlocking US$ 4.5 trillion in new business opportunities each year by 2030 while saving US$ 5.7 trillion a year in damage to people and the planet by 2030. This is more than 15 times the estimated investment cost of US$ 350 billion a year.

1.2 Balancing sustainability goals

The 2030 Agenda for Sustainable Development includes several environmental ambitions through its targets for responsible consumption and production (SDG 12), climate action (SDG 13), life below water (SDG 14) and life on land (SDG 15). At the same time, many conservation actors explicitly work towards development goals including no poverty (SDG 1) and zero hunger (SDG 2). Balancing social and economic development with environmental goals is implicit in the vision of IUCN (International Union for Conservation of Nature) of 'A just world that values and conserves nature'.

Balancing the achievement of the SDGs requires a deep understanding of potential trade-offs between them. The dominant agricultural development paradigm still mostly focuses on producing food and less on environmental impacts. Furthermore, the greatest increases in production are not taking place in the regions with the greatest food deficits. These inconsistencies need to be addressed to achieve the SDGs. This report examines pragmatic solutions that capitalise on potential synergies between agriculture and conservation. Achieving transformative change towards sustainable agriculture requires a deeper understanding of the positive as well as the negative impacts of agriculture on the environment.

The Convention on Biological Diversity (CBD) adopted a revised and updated Strategic Plan for Biodiversity, including the Aichi Biodiversity Targets, for the 2011–2020 period. These 20 targets were ambitious and comprehensive, and included two targets of direct relevance to agriculture:[5]

- Target 7: "By 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity";
- Target 13: "By 2020, the genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socio-economically as well as culturally valuable species, is maintained, and strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity."

While many National Biodiversity Strategies and Action Plans (NBSAPs) refer to Targets 7 and 13, only 30% include details of actions for agrobiodiversity conservation and sustainable use.

Very few NBSAPs include plans to use genetic resources for food and agriculture or for diversified diets and improved nutrition (Lapena et al., 2016).
The Paris Agreement adopted under the United Nations Framework Convention on Climate Change (UNFCC) in 2015 has also acknowledged the role that the agricultural sector can play in preserving food security and contributing to the adaptation and the mitigation targets:

[5] https://www.cbd.int/sp/targets/

- "Recognizing the fundamental priority of safeguarding food security and ending hunger, and the particular vulnerabilities of food production systems to the adverse impacts of climate change" (Preamble);
- Requesting Parties to take action to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases in order to achieve the long-term objective to hold the increase in the global average temperature well below 2°C above pre-industrial levels (Art. 4.1 and 5.1).

The vast majority of Parties to the Paris Agreement have also included agriculture in their Nationally Determined Contributions (NDCs) to the global response to climate change, as a priority area for adaptation (78% of NDCs submitted) or mitigation (86% of NDCs submitted) (FAO, 2016).

Our report takes a fresh look at the role of biodiversity in agriculture, paying particular attention to the foundational role of soil biodiversity and the different farming practices that contribute to its protection and ability to provide a variety of ecosystem services, including a direct contribution to climate change adaptation and mitigation. The report is framed around the concern of declining land health, the impacts that this can have – on productivity as well as on locally and globally important societal challenges – and the consequences for rural livelihoods.

The concept of Nature-based Solutions (NbS) opens the door to a new approach to balancing environmental and agricultural development goals. IUCN defines NbS as "actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits."[6] A better analyses of the way agriculture can better manage biodiversity to qualify as NbS can renew our analysis framework for examining and managing potential synergies and trade-offs.

1.3 Managing nature for improved agricultural sustainability

Agriculture depends on biodiversity in numerous ways, from the genetic diversity in crops and livestock to the organisms that play a role in pollination or pest control. However, mainstream agriculture and conservation alike pay little attention to many of these roles. An area of particular neglect is soil biodiversity, and its role in maintaining soil fertility and moisture, and therefore determining land productivity as well as controlling a number of other ecosystem functions. For example, soil biodiversity moderates soil pH, fertility, moisture and structure, through its influence on the C, nitrogen (N) and water cycles. It contributes to ecosystem services such as soil stabilisation, flood and drought mitigation (Brussaard et al., 2007), and the creation of microclimates that assist agricultural production. A diverse community of vertebrate and invertebrate organisms plays an important role in the biological control of pests and nutrient cycling (see Figure 1) (Laban et al., 2018).

Data on the status of soil biodiversity is scarce and scientific understanding of the relationship between soil biota and ecosystem function is still limited. However, this report shows that ecosystem function and soil biodiversity are closely correlated, and that agricultural productivity can be enhanced by healthy soils and improved ecosystem function.

The concept of land health will be used as a point of common interest between agriculture and conservation actors, defined as "the capacity of land, relative to its potential, to sustain delivery of ecosystem services" (Shepherd et al., 2015). Despite the knowledge gaps, considerable areas of land are already under agricultural practices that are considered as sustainable land management (SLM).

[6] IUCN (International Union for Conservation of Nature) (2016). Resolution 69 on Defining Nature-based Solutions (WCC-2016-Res-069). IUCN Resolutions, Recommendations and Other Decisions 6–10 September 2016. World Conservation Congress Honolulu, Hawai'i, USA. https://portals.iucn.org/library/sites/library/files/resrecfiles/WCC_2016_RES_069_EN.pdf

Agricultural landscapes are managed with different degrees of intensity and FAO estimates that two-fifths of the world's croplands include at least 10% tree cover (Zomer et al., 2009). Accelerated adoption of sustainable practices at the farm and landscape level is possible immediately, provided downstream blocking factors and lock-in effects in the food-system are removed. There are signs that many actors in agriculture are concerned about the sector's sustainability – including the risk of exhausting soils – and this is creating new opportunities for action on more environmentally responsible production.

One fundamental constraint is the lack of consensus over the goals, targets and indicators of progress. The lack of consensus over what constitutes sustainable agriculture is a major impediment to agreeing on desired farming practices or approaches, and the polarisation of the debate between agriculture and conservation on those issues means that important commonalities and opportunities are overlooked or ignored.

This report shows that farming practices that conserve soil biodiversity are likely to generate multiple benefits by improving the quality and quantity of ecosystem services. Another major constraint is that in many cases, farmers and land managers have little incentive to protect the ecosystem assets from which ecosystem services are derived. The underlying ecological mechanisms of sustainable agriculture receive limited attention from many actors in the agriculture sector and in society as a whole. Establishing rewards and other incentives for these ecosystem services may be one of the keys to catalysing the transition to global agri-environmental stewardship.

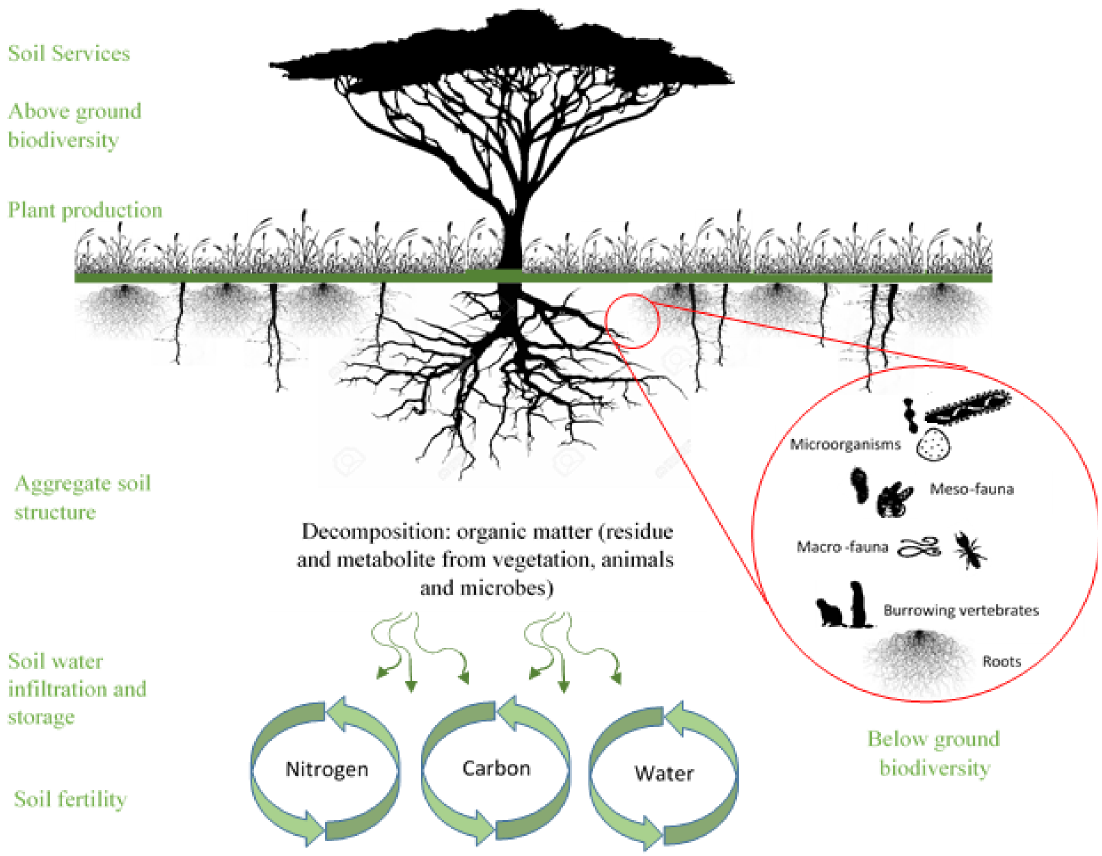


Figure 2 Soil biodiversity and ecosystem functions that determine agricultural performance

1.4 Towards system change

A multitude of policies and incentives currently promote unsustainable farming and discourage environmentally sound practices, obscuring the full environmental potential of agriculture. Many countries have promoted dependence on costly, environmentally harmful and non-renewable farm inputs for decades. However, there is growing interest from actors in the agriculture sector to adopt methods of food production that protect the ecosystem services upon which they depend. This includes protecting soil fertility and soil moisture, protecting insect pollinators and biological control organisms, and conserving on-farm genetic diversity.

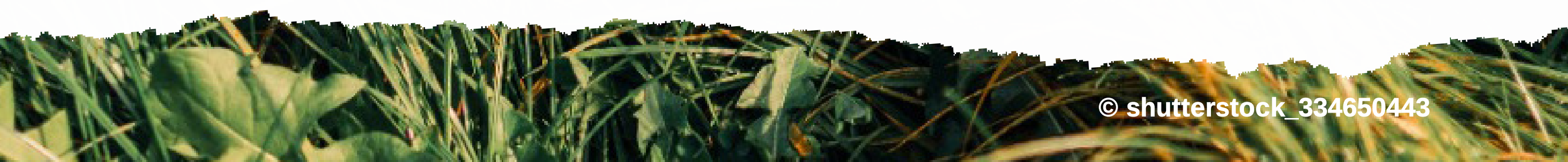
This report shows that increasing land health creates a platform for improved sustainability in agriculture and can provide a doorway to other improvements in sustainability, and other environmental goals. It demonstrates the common ground between the agriculture and conservation sectors for mutually beneficial action, emphasising the importance of soil biodiversity for land health and the system-wide interventions and incentives to enhance its restoration and management. The report shows that widespread adoption of sustainable agricultural practices can contribute to food production, water security, climate regulation and other benefits.

Chapter 2 examines data on global trends in agriculture to show how unsustainable agricultural practices have managed to feed a growing population while threatening the future of farming, particularly by compromising land health. Chapter 3 explores biodiversity in agriculture, with particular focus on the ecosystem services that drive production and the soil biodiversity that underpins those services. Chapter 4 models potential outcomes from global improvements in land health, simulating the multiple benefits that could be generated by adopting the strategy of increasing soil organic carbon (SOC) by 0.4% per annum. Chapter 5 presents a number of concepts and approaches for sustainable agriculture that are already practised on a significant scale, and which have the potential to be further scaled up. Chapter 6 provides insights into reshaping the narrative for system change in the food and agriculture sector, with emphasis on incentivising SLM through investments and policies that influence agricultural production and supply chains. Finally, lessons from the report are summarised in a series of key messages in Chapter 7.

The report is intended to provide a constructive, science- and knowledge-based contribution to the reconciliation of agriculture and conservation. It aims to convince actors in the conservation and agriculture sectors to advance a common agenda and take a more constructive approach to dialogue, focusing on a common vision of sustainability and agreed goals for SLM and biodiversity conservation. The primary audience therefore includes conservation and agriculture actors in governments and non-governmental organisations, as well as farmers' groups and agribusinesses. The report challenges the antagonistic portrayal of the relationship between biodiversity and agricultural productivity as a zero-sum game. It provides evidence of the potential for genuine convergence and synergy through promoting sustainable approaches that can enhance land health and qualify as NbS to provide multiple benefits to society and nature.

Chapter 2

Unsustainable agricultural practices and the future of farming



2.1 Land as a finite resource

As illustrated in Chapter 1, in the coming decades, one of the biggest challenges faced by humanity will be to balance the need to feed 9 billion people with the need to restore and protect natural resources. Land is one of the most fundamental of natural resources: something so commonplace that we routinely ignore how human actions are harming it. Land is territory, property, a resource, our heritage, and much more. Land has economic, social and environmental value and, even when privately owned, it provides many benefits to society, including provision of fresh water and climate regulation. Land is part of the foundation for human life, yet we take it for granted and we are rapidly degrading it.

In their 2009 paper, Rockström et al. define what they refer to as a safe operating space for humanity, beyond which we may incur "deleterious or even catastrophic" risk. The authors identify nine planetary boundaries, and estimate that three of these boundaries have already been transgressed by humanity: climate change, biodiversity loss, and changes to the global N cycle (Rockström et al., 2009). A later study estimates that a fourth boundary – land conversion – is also being transgressed, and proposes a generic planetary boundary to encompass human influence on biogeochemical flows in general, rather than just focus on phosphorus (P) and N (Steffen et al., 2015).

Achieving the SDGs adopted by UN member states in 2015 would help to address these planetary boundaries. However, the SDGs include economic and social development goals that potentially involve tradeoffs with environmental sustainability. In particular, Zero Hunger (SDG 2) can be considered as in direct competition with Life on Land (SDG 15). One of society's most urgent challenges is thus to satisfy the rights of people to a 'good life,' including adequate food and nutrition, while remaining within the planetary boundaries. In other words, we need to reconcile agriculture and the environment: to "end hunger, achieve food security and improved nutrition and promote sustainable agriculture" Zero Hunger (SDG 2) and also "protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss" Life on Land (SDG 15).

A more recent framework has been put forward to balance planetary boundaries with social development (Raworth, 2017). The "doughnut economics" model adds twelve dimensions of social development, drawn from the SDGs, to the nine planetary boundaries. This model puts forward a vision of a just and sustainable society, in which humanity occupies the safe space between the upper limits of our planetary boundaries and the minimum requirements of social development for all people everywhere, referred to as the "social foundation." This model highlights the challenge of improving our delivery of social benefits such as food, water, health, and education, while remaining within planetary limits.

Basic economic development remains an urgent priority for many people, with approximately three-quarters of a billion people currently living in extreme poverty. However, that number has halved since the late 1980s while the population has grown, bringing the portion of the world population in extreme poverty down from 42% to 10% since 1987 (Roser & Ortiz-Ospina, 2017). Population continues to grow rapidly and is projected to rise from approximately 7.7 billion people at the end of 2019 to about 9.7 billion by 2050.[7]

As the world makes significant progress on the social dimensions of sustainable development, rising population and growing per capita wealth are placing increasing demands on nature, particularly through the food sector.

[7] http://www.un.org/en/sections/issues-depth/population/

2.1.1 The contribution of agriculture to the transgression of ecological boundaries

Agriculture is currently one of the major threats to planetary boundaries. It is the main source of risk to biosphere integrity, biogeochemical flows, land-system change and freshwater use, and a major contributor to climate change (Campbell et al., 2017). While some forms of agriculture protect the biosphere and even create new habitat, harmful practices have compromised biosphere integrity by destroying habitat and contributing to species extinctions.

Agri-food systems are the leading contributor to biogeochemical flows, most notably through N and P leaching, which impacts water quality and contributes to ocean pollution. Agriculture is also the key driver of land use change, responsible for the conversion of forests and grassland into cultivated areas.

Offtake of freshwater to serve agricultural production has negatively affected ecosystems in many watersheds. It reduces water bodies, threatens biodiversity and compromises ecosystem function. The scale of impact can be large, with localised use of water having consequences at great distance, through fragmentation of ecosystems and eutrophication caused by N and P leaching (Falkenmark, 2013). Agriculture is considered the largest non-point source of pollution (Evans et al., 2019).

Agriculture contributes to climate change through the release of greenhouse gases (GHGs) such as methane from enteric fermentation in ruminant livestock and rice cultivation, and nitrous oxide from soil, fertiliser application and manure management (Blanco et al., 2014). In all, an estimated 23% of anthropogenic GHG emissions derive from Agriculture, Forestry and other Land Use (IPCC, 2019).

The impact of agriculture on nature is far-reaching. Unsustainable farming practices can compromise land productivity and water availability, and frequently undermine the long-term viability of agriculture. As a result, unsustainable farming has a knock-on effect on resilience and human security, and can contribute to conflict and migration. The unsustainability of our global food system ultimately undermines the world economy and political stability.

Agriculture is a central component of the highly complex global food system, but farming practices are not the only factor affecting its sustainability. The choices and behaviour of billions of consumers, along with a multitude of actors in inputs supply chains, food processing, marketing and distribution, ultimately determine the sustainability of the food system. As Figure 3 illustrates, powerful underlying forces, including population growth and rising per capita income, are driving growing demand for agricultural products (food, fibre, biofuel and biomaterial) and intensifying the pressure on land. The agriculture sector responds by stepping up output through increased production on existing farmland and bringing more land into production. Both responses can have serious harmful consequences for nature. However, Figure 3 includes a third response: increasing efficiency in the food system. This response is consistent with the view that global food production is already sufficient and the challenge is to ensure this food is distributed equitably and consumed responsibly.

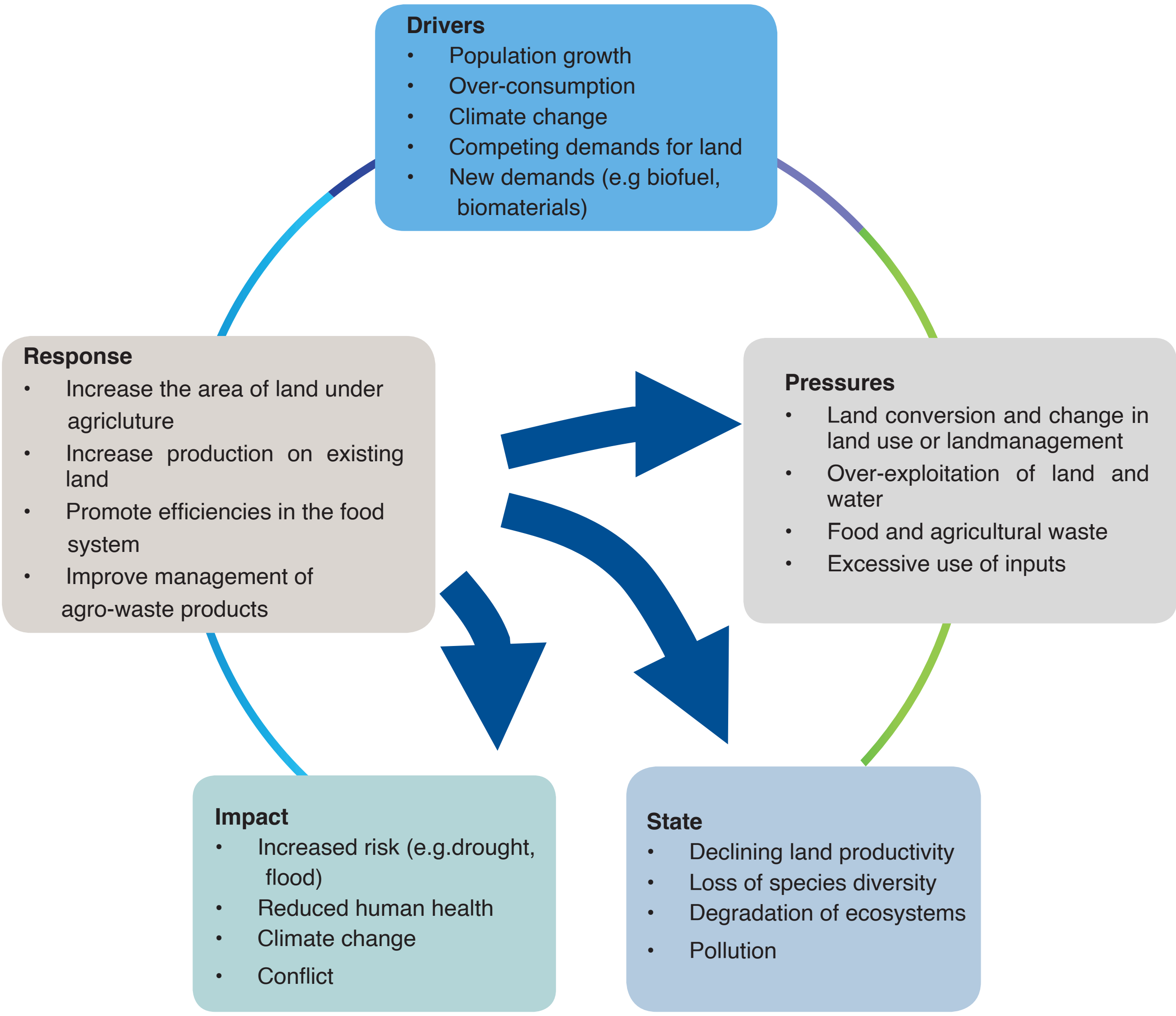


Figure 3 Environmental effects of agriculture: drivers, pressures, state, impact and response

Figure 3 shows how agriculture and other factors contribute to the increasing pressure on land, underscoring the complexity of the challenge. Addressing this complexity demands far-sighted strategies and integrated, multi-actor responses. Understanding the feedback between responses and drivers, pressures and the state of the land is essential for identifying and promoting options for positive feedback. This positive relationship can be developed through a focus on environmental stewardship and balanced investment in the multiple values of agricultural land.

2.2 Agricultural development: a high performer?

Food is a fundamental human need, essential for healthy, productive lives and for peaceful, prosperous societies. Food insecurity has led to immeasurable suffering during the course of human history and, even in recent years, has been at the root of political revolutions and social upheavals. It is unsurprising if governments place food security ahead of many competing development priorities.

In the last 50 years, the agriculture sector has made remarkable progress in feeding a rapidly growing global population. While the human population increased by more than 170% since 1962, global agricultural output rose by over 270% (Figure 3). This jump in output is largely attributed to an increase in productivity, rather than an expansion of agricultural land: during the same period the cultivated area grew by around 12%.

As an illustration, per capita cereal production rose from 0.29 to 0.39 tonnes between 1961 and 2014.
Higher yields are attributed to four major areas of technological development: higher-yielding crop varieties, irrigation, synthetic fertilisers and pesticides, and mechanisation, coupled with low-cost (often subsidised) energy from fossil fuels (Ramankutty et al., 2018).

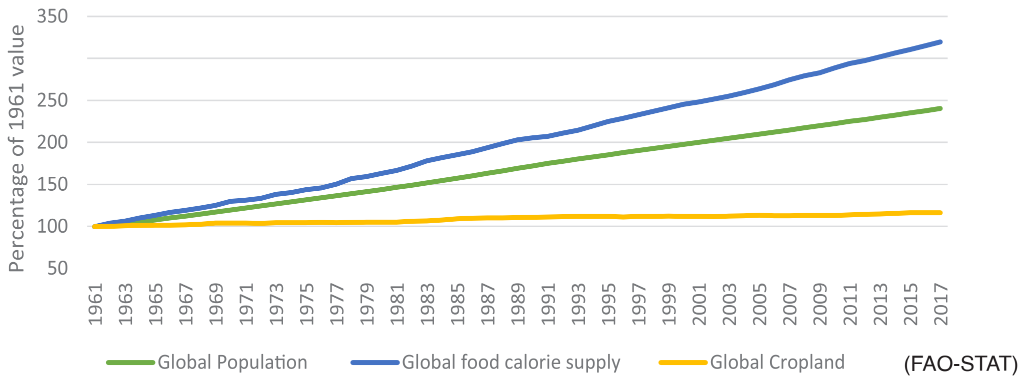


Figure 4 Global change in population, area of cropland and calorie production since 1961

Irrigation has played a significant role in agricultural growth. Irrigated land accounted for approximately 19.7% of cultivated land in 2006 but the increase in irrigation accounts for an estimated 40% of the total rise in agricultural output (Food and Agriculture Organisation, 2011).

Although the rate of expansion of irrigation is declining, irrigated food production has been projected to increase by 15–17 percent from 2015 to 2050 according to one estimate (Tubiello & Van der Velde, 2010).

Agrochemicals have also played a major role in agricultural development. Global artificial fertiliser use was expected to exceed 200 million tonnes per year by 2018: an increase of 25% on 2008 levels (Food and Agriculture Organisation, 2015).[8]

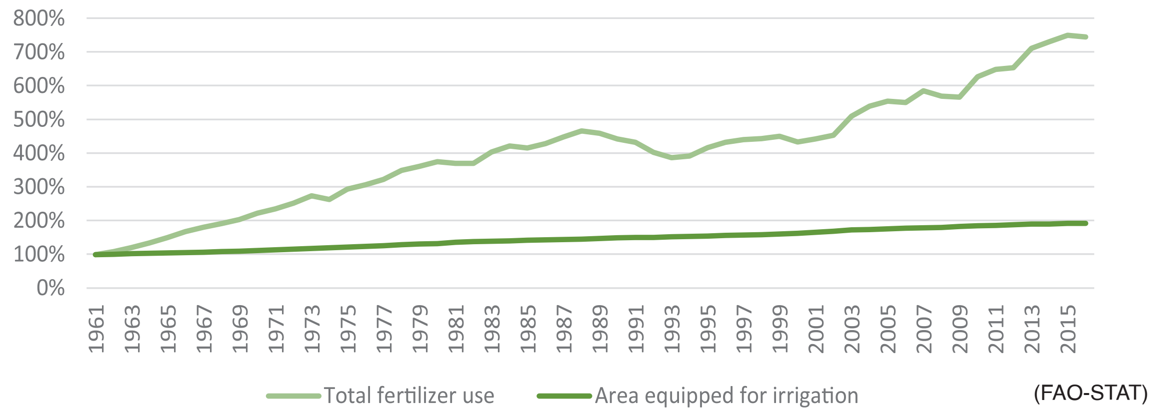


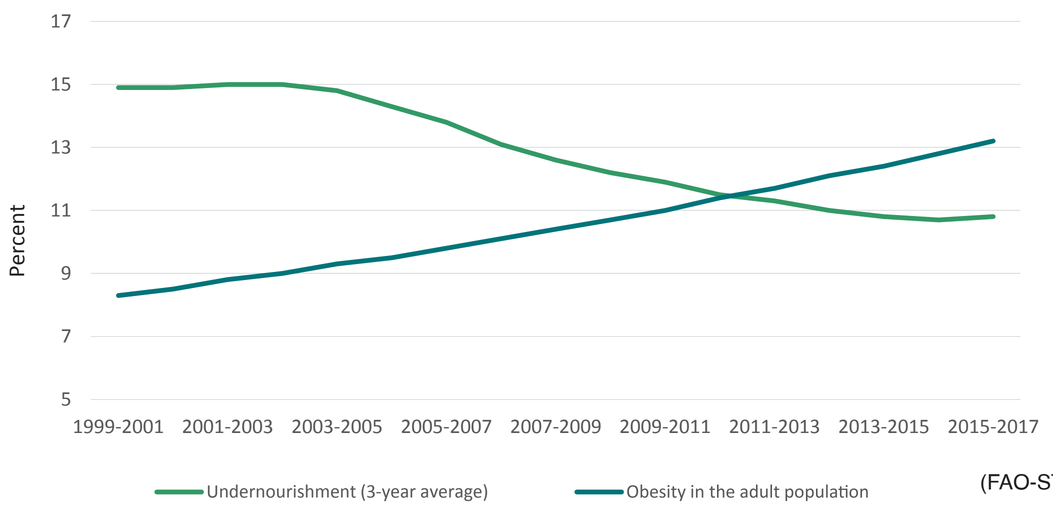
Figure 5 Change in fertiliser use and irrigation since 1961

[8] It should be noted that this projection is based on projections of agricultural productivity that assume no change in business as usual regarding efficiency in the food and agriculture sector.

Although progress in agricultural production has been remarkable, the global picture can disguise major challenges that remain in some countries and regions. The increases in crop yields have helped to reduce hunger, improve life expectancy, reduce infant and child mortality rates, and decrease global poverty (Whitmee et al., 2015). The prevalence of under-nourishment has declined over the past 20 years, although it is still currently close to 11% of the global population, or 800 million people, and at least 51 countries faced food insecurity in 2017 (Network, 2018). Nevertheless, the figures for prevalence of food insecurity have increased between 2015 and 2018. In a context of climate change and multiple humanitarian crises, uncertainty has increased and higher global food production may not be sufficient to ensure food security unless food production systems become more resilient and people have more stable access to food (FAO, 2019d).

At the same time, a combination of rapid urbanisation, increasing incomes, and inadequate access to nutritious foods is driving a growing phenomenon of over-consumption and unhealthy diets (Global Panel on Agriculture and Food Systems for Nutrition, 2016; Willett et al., 2019). Rising consumption of meat, refined fats, refined sugars, alcohols, and oils is contributing to unhealthy diets and leads to a competition for resources with basic food commodities (Ramankutty et al., 2018). One study estimates that between 2005-07 and 2050, global production of meat will increase by 76% and cereal production will rise by 46% (Alexandratos & Bruinsma, 2012).

While there are major concerns about the level of global undernutrition, 2 billion people worldwide are estimated to be overweight (WHO, 2019). The prevalence of obesity is steadily increasing (Figure 5) and in 2011 overtook undernourishment as the leading cause of malnutrition globally. Agriculture policies contribute to these negative health outcomes: improvements in agricultural productivity, combined with subsidised access to saturated fats and sugar, have facilitated a massive increase in dietary energy intake (Willett et al., 2019).



(FAO-STAT)

Figure 6 Change in prevalence of undernourishment and adult obesity over time

In addition to feeding the world, agriculture is still the leading employer and makes many contributions to rural livelihoods. The World Bank estimates estimated that agriculture employs employed 278% of the global workforce in 2019, down from 43% in 1991,[9] and 33 countries have more than half of their labour force working in agriculture, 24 of them in Africa.[10] In South Asia, one-third of employment growth since 1999 has been in agriculture, whereas agricultural employment is declining in developed economies, East Asia and Latin America and the Caribbean. Women are more active in agriculture sector than men globally (38% versus 33%). The sector also employs the highest proportion of child labour globally: around 60% of all child labourers, or 129 million girls and boys (FAO, 2014b).

2.2.1 Land under agriculture

Based on 2015 data from the FAO Statistics Division, (FAO-STAT),[11] 12% of all land on the planet is under crop cultivation and a further 25% is under permanent meadows and pastures. (Figure 6). Together, these figures indicate that 37% of the total land area is under agriculture. However, such data can be misleading, since large areas of permanent meadow and pasture are semi-natural habitats in which wildlife is conserved alongside livestock production (Davies et al., 2012). These areas could potentially be considered as subject to 'other effective area-based conservation measures' (OECMs) and contribute alongside more strictly protected areas to Aichi Biodiversity Target 11.

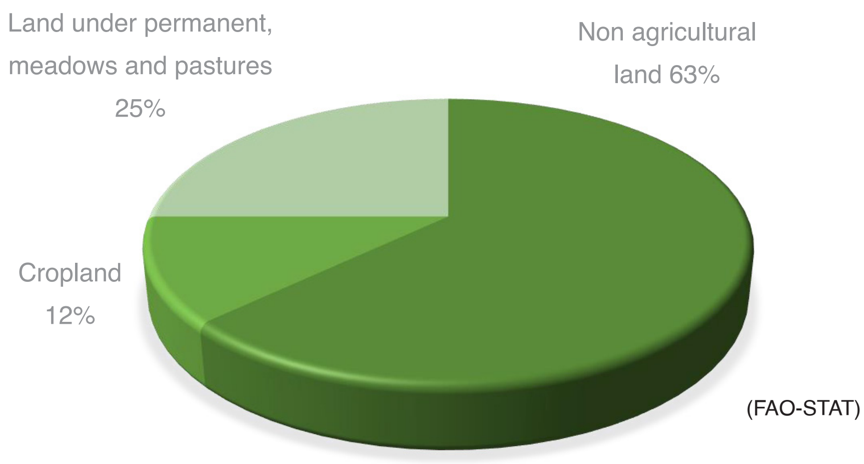


Figure 7 Global agricultural land area 2015

[9] https://data.worldbank.org/indicator/sl.agr.empl.zs
[10] https://www.theglobaleconomy.com/rankings/employment_in_agriculture/
[11] http://www.fao.org/faostat/en/#home

A number of attempts have been made to estimate when the global area of cropland will stabilise, a point known as 'peak cropland.' Models used in these projections are susceptible to uncertainty in parameters such as population growth, dietary preferences, and new demands, such as that for biofuel. One study predicted that the total area under cultivation would begin to decline after 2010 (Ausubel et al., 2013), although recent data indicates that the peak may be reached between 2020 and 2040 for all agricultural land, and around 2050 for cropland (Roser & Ortiz-Ospina, 2017). FAO has estimated that peak cropland may not be reached until 2080 (Alexandratos & Bruinsma, 2012).

Large areas of land are unsuitable for cultivation, based on current technologies, but significant areas of potential cropland remain. It has been estimated that 80% of the world's remaining potential agricultural land lies in Africa (580 million ha) and South America (369 million ha). However, a significant proportion of this land is already managed for livestock and other purposes and the estimate of available cropland may be inflated (Cotula et al., 2008). Land that has been identified for conversion to cropland has often proven to come at a high environmental cost, for example through destruction of grasslands, grazing lands or forest. Additionally, suggestions to expand cropland into marginal or degraded lands face several problems. There are ongoing challenges in reaching agreement over how to define degraded land and identify where such land can be found. Marginal or degraded lands are seldom vacant and are already providing benefits to existing users, and yet are simultaneously sought for competing uses, such as food production, wood production, bioenergy, and conservation. Finally, much land that is classified as degraded is already agricultural land and therefore is suitable for rehabilitation through sustainable agriculture, but cannot be 'converted' to agriculture (Hanson & Searchinger, 2015).

With the expansion of total cropland slowing, the majority of future production growth – as much as 80% – is predicted to come from improved yields. This reflects a shift towards increasing efficiency since 1990, whereby rising global agricultural output is driven less by the use of inputs (land, irrigation, labour, machinery etc.) and more by "total factor productivity," which measures the output per unit of input (Ramankutty et al., 2018).

Changes in productivity and land use have implications for land tenure and the resource rights of agrarian communities. Changes in farm size can give an insight into how resource rights are evolving, with marked differences between regions. Average farm size in Africa and Asia declined from 1950 to 2000, but in recent years the trend has reversed in Asia. Farm size continues to decrease in Africa, although most land-abundant African countries have shown an increase in average farm size. At the same time, farm size in Europe and North America has increased (Lowder et al., 2016).

The majority of the world's farmers farms (84%) are managed by smallholders, farming less than 2 hectares and collectively managing about 12% of the world's agricultural land (Lowder et al., 2016). The contribution of these farms to global calorie production has been estimated at between 18% and 34% (Herrero et al., 2017; Ricciardi et al., 2018). Most agricultural land is managed by family farmers that are not classified as smallholders because they have more than 2 hectares of land. Based on Lowder et al. (2016), these family farmers (that are not classified as smallholders) manage 6% of the world's individual farms, but 63% of the agricultural land. The remaining 10% of farms manage the other 25% of the land: this includes land controlled by state farms and private companies.

Concerns have been raised in the past decade over agricultural land deals between developing countries and foreign companies, often ignoring the customary rights of indigenous and local communities to access and use the land. According to one study, the water rights alone acquired through these deals would be sufficient to improve food security and abate malnourishment in the affected countries (Rulli et al., 2013). The study estimates that around 47 million hectares of land have been acquired worldwide and consume an estimated 310 billion m^3 per year of green water (water from soil and vegetation) and up to 140 billion m^3 per year of blue water (water from lakes, rivers and groundwater).

Although the relationship between agricultural development and the structure of land holdings is difficult to discern, changes in land tenure raise concerns about potential inequalities that could result. In Many societies have discriminatory attitudes towards land ownership and access to knowledge or financial capital are still happening that and lead to inequitable outcomes in agricultural development. Of particular concern are inequalities between men and women in land tenure and resource rights. Women are disadvantaged relative to men with regard to all dimensions of land rights associated with agricultural land: ownership, management, transfer and economic rights. Less than 15% of all landholders worldwide are women, dropping to as low as 5% in the Middle East (FAO, 2018b).

Women are often excluded from participation in processes related to land tenure and land governance and may have limited capacity to influence decision-making. Land tenure often reflects power relations between different groups and can be abused to assert authority over poor and socially marginalised groups. This may be the outcome where state control and influence are weak and local elites are able to take control of land and resources (Borelli et al., 2019).

Considering the importance of women's labour in agriculture in many countries, their exclusion from decision-making can have significant implications for the adoption of SLM practices. This may be due to different motives and priorities that drive their decision-making, different capacity to respond to opportunities, or a lack of access to relevant information (Ragassa, 2014).

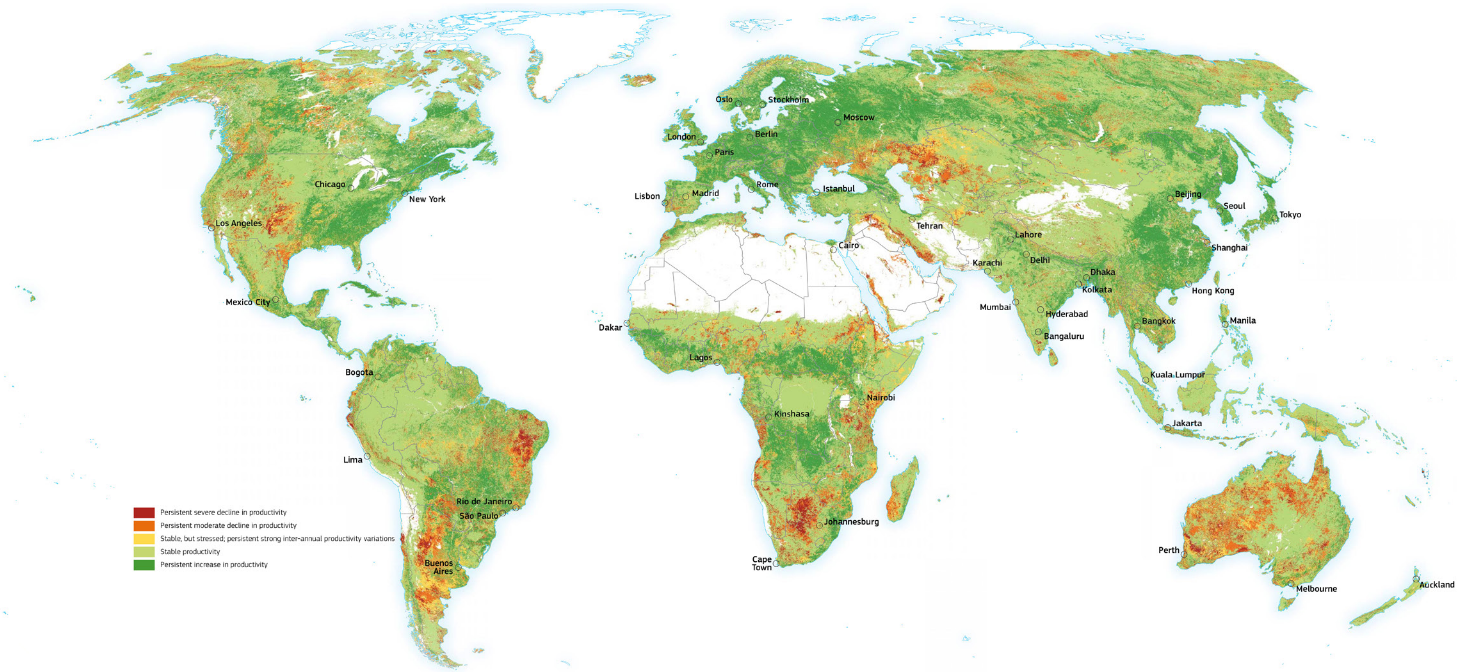
2.3 Environmental impacts on agricultural land

The rapid increase in agricultural production over the past half-century has come at a significant environmental cost and there are signs that unsustainable farming practices are undermining the long-term viability of the sector. Advances in agricultural technology, including the selection of crop varieties and livestock breeds that require more demanding production factors to deliver their potential (fertilisers, pesticides, and mechanisation), have been significant drivers of environmentally unsustainable farming practices. However, further technological developments can play an important role in achieving sustainability in future and the challenge is to redirect the development of agricultural technology to support more sustainable production.

2.3.1 Land degradation

The United Nations defines land degradation as "reduction or loss … of the biological or economic productivity and complexity of … land resulting from land uses ..." Land degradation can occur as the result of soil erosion caused by wind or water, deterioration of the physical, chemical and biological or economic properties of soil, or long-term loss of natural vegetation (United Nations, 1994). The prolonged, intensive and indiscriminate use of agrochemicals adversely affects soil biodiversity, agricultural sustainability, and food safety and is a major contributor to land degradation (Meena et al., 2020). Symptoms of land degradation can include loss of soil, nutrient depletion, salinity, water scarcity, pollution, disruption of biological cycles, and loss of biodiversity (Bai et al., 2008).

Agriculture contributes to the degradation of agricultural land and other land cover types, for instance through deforestation or conversion of natural grasslands. Land degradation affects approximately 29% of the total global land area and occurs across all agroecosystems. Human-induced decline in biomass productivity is observed on 25% of croplands and vegetation-crop mosaics, 29% of mosaics of forests with shrub and grasslands, 25% of shrublands, and 33% of grasslands. Land degradation in crop lands may be masked by the application of fertiliser to boost land productivity (Le et al., 2014). Land degradation is observed on agricultural land in all regions, although it is most prevalent in North Africa and the Near East, affecting 45% of the land and 52% of grazing land, compared with 19% and 17% respectively in Europe. Globally, 28% of the population is estimated to reside in degrading areas, although this rises to 66% in North Africa and the Near East, whereas in Europe the figure is 10% (Le et al., 2014).



World Atlas of Desertification: https://wad.jrc.ec.europa.eu/landproductivity

Figure 8 Map of Decreasing Land Productivity: one of the 3 agreed indicators of land degradation under the UNCCD

2.3.2 Biodiversity decline

Unsustainable farming practices are associated with a decline in species diversity, driven by conversion of natural habitats for food production as well as by pollution. The impact on biodiversity is amplified along food supply chains through energy use, transport and waste (Dudley & Alexander, 2017). A major contributor to biodiversity loss from the food and agriculture sector is intensification and the increased application of agrochemicals, including pesticides and fertiliser. Ecosystem functions and services frequently decline in parallel with biodiversity loss, including decline in water supply, water quality, clean air, and climate regulation. The global loss of ecosystem services due to land use change has been estimated to cost US$ 4.3-20.2 trillion per year (Costanza et al., 2014).

Conversion of land to agriculture contributes to loss of habitat and fragmentation of landscapes. The global forest area has declined by about 3% from 1990 to 2015, although the rate of net forest loss between 2010 and 2015 was half that in the 1990s (Keenan et al., 2015). Forest loss was greatest in the tropics and in developing countries, whereas the global area of temperate forest has increased. Changes in agricultural land management practices have also adversely affected biodiversity, including conversion of permanent pastures to annual crops, replacement of fallows with permanent cultivation, loss of field boundaries, and numerous other changes (UNEP, 2007). In Europe, for example, agriculture is the most frequently reported factor affecting the state of nature[13].

[13] European Environment Agency. (2015). State of nature in the EU: biodiversity still being eroded, but some local improvements observed. http://www.eea.europa.eu/highlights/state-of-nature-in-the

Agricultural intensification has contributed to a loss of traditional farming methods, which often support higher levels of landscape heterogeneity and biodiversity. This simplification of farming systems reduces the number of natural predators, which in turn leads to an increase in crop-pest infestations and higher reliance on pesticides. One analysis found that natural pest control was 46% lower in homogeneous agricultural landscapes compared with more complex landscapes (Rusch et al., 2016). Furthermore, intensification has led to a decline in the diversity of crops and livestock. While more than 6,000 plant species have been cultivated for food, fewer than 200 make substantial contributions to global food output, with only nine accounting for 66% of total crop production in 2014 (FAO, 2019d)

2.3.3 Water stress

Expansion of irrigated agriculture has led to degradation of wetlands and riparian areas, depletion of aquifers, and disruption of downstream water supply. The agriculture sector uses an estimated 70% of all water that is withdrawn from aquifers, streams and lakes (FAO, 2011). Water availability for agriculture now constrains further intensification in many areas. Additionally, poorly managed or designed irrigation contributes to land degradation in some countries through salinisation of crop lands (IWMI, 2007).

During the second half of the 20th century, 'Green Revolutions' in several countries compromised water security through depletion of river flow and groundwater as well as severe water pollution. Loss of soil moisture (green water) due to land degradation and deforestation threatens terrestrial biomass production, including agricultural yields, and sequestration of C. Changes in water run-off (blue water) volumes and patterns threatens aquatic ecosystems as well as domestic and industrial water supplies. Decline in the moisture feedback of vapour flows (green water) affects local and regional precipitation patterns and impacts on climate regulation (Falkenmark, 2013).

2.4 Drivers of land degradation in agriculture

Population growth is a major driver of environmental pressure from agriculture. Global population is projected to reach 9.7 billion by 2050 and around 11 million people by 2100.[14] Without other changes to improve efficiency in the food and agriculture system, it has been estimated that demand for agricultural produce will increase by at least 50% by 2050 (FAO, 2018a). However, as already noted, food production greatly exceeds current demand. The challenge is not food availability, but more a question of how food is distributed and consumed globally.

Although global agricultural production is projected to slow down, this masks major regional discrepancies. Production in South Asia may double and in sub-Saharan Africa is projected to triple (Alexandratos & Bruinsma, 2012). Meanwhile, rural abandonment is emerging as a new environmental challenge in Europe. The mid-range estimate of farmland abandonment in the European Union (EU) is about 3-4% of total land area by 2030 (Keenleyside & Tucker, 2010).

The EAT-Lancet Commission report on consumption patterns and environmental degradation found a large body of evidence linking diets with human health and environmental sustainability (Willett et al., 2019). The commission found that the way food is produced, consumption choices, and the extent of food loss and waste heavily shapes the health of both people and planet. They conclude that diets rich in plant-based foods and with fewer animal products can provide both improved health and environmental benefits, while recognising that the global pattern can disguise regional discrepancies such as micronutrient deficiencies.

[14] http://www.un.org/en/sections/issues-depth/population/

In addition to a growing demand for calories and protein, our appetite for non-food products from agriculture, such as biofuel and bioplastics is increasing. According to one estimate, the total area of land used for the production of biofuels and by-products could rise to between 35 million and 54 million hectares by 2030, depending on the policy scenario (Cotula et al., 2008).

Meanwhile, the growing global concern over plastic waste is driving new demand for bioplastics manufactured from biomass such as vegetable fats and oils or corn starch. Palm oil, which is used for biofuel, cosmetics and other uses besides food, was produced from 18.7 million hectares of industrial-scale oil palm plantations in 2017. Although this represented less than 10% of the land allocated to oil crops, it accounted for 35% of all vegetable oil, reflecting comparatively high levels of land productivity (Meijaard et al., 2018).

Food waste is another major driver of environmental impacts from the agriculture sector, since it raises the total area of land and inputs needed to produce each unit of food consumed. The majority of food waste in medium- and high-income countries is due to consumer behaviour combined with a lack of coordination between actors in food supply chains. In the EU this costs an estimated 143 billion euros per year,[15] with each tonne of food waste sent to landfill contributing GHG emissions equivalent to 4.2 tonnes of carbon dioxide (CO_2).[16] In developing countries, limitations in harvesting, storage, infrastructure and marketing are the main factors in food waste. Up to one-third of all food produced globally is wasted and cutting waste is one of the most promising ways to reduce the current impact of humanity on the environment while simultaneously achieving food security (Gustavsson et al., 2011).

Economic factors have greatly contributed to unsustainability in agriculture. An OECD evaluation of the 37 OECD countries, the five non-OECD EU Member States, and 12 emerging economies, found that net transfers to the agricultural sectors in these 54 countries amounted to USD 619 billion per year from 2017-19 (Organisation for Economic Cooperation and Development, 2020). The OECD reports that more than USD 500 billion contributes to distorting markets, stifling innovation and harming the environment. In contrast to this, the report finds that very little is spent on securing the long-term performance of the agricultural sector, with only USD 106 billion per year allocated to research and development, infrastructure, biosecurity and other enabling services.

The OECD estimates that more than one of every nine dollars of gross farm receipts globally flows from public policies, although in some countries it is almost half of all farm receipts. Over the past 40 years, producer support in OECD countries has declined as a percentage of gross farm receipts, from about one third in the 1980s to about 17% 2017-19. The trend in emerging economies is currently in the opposite direction, from an average of 4% across the countries examined in 2000-02 to over 8% in 2017-19. While the OECD acknowledges the need for governments to invest in well-functioning food systems, it recognises that "most current support to agriculture is unhelpful or even harmful". Three policy actions are identified that governments can take to make their agriculture sector more productive, sustainable and resilient (Organisation for Economic Cooperation and Development, 2020):

1. Phase out distortive policies, including price support and budgetary support closely linked with agricultural production and input use.
2. Reallocate funds toward key public services to the sector for improving productivity, sustainability and resilience, or to well-targeted support for the provision of public good outcomes such as biodiversity.
3. Focus on more ambitious environmental outcomes through less distortive, more efficient and more targeted policies.

Climate change affects agriculture land productivity both positively and negatively, through increased temperatures, changes in precipitation patterns, increased severity and frequency of climatic shocks, and CO_2 fertilisation. Climate change is exacerbating land degradation processes including through increases in rainfall intensity, flooding, drought frequency and severity, heat stress, dry spells, sea-level and wave action, and permafrost thaw with outcomes being modulated by land

[15] For more information on EU food waste, see: https://ec.europa.eu/food/safety/food_waste_en
[16] Dinamix, Issue No. 2, February 2016. *Policy Report*. A policy mix aimed at reducing impacts of agricultural production and consumption - Synthesis of potential impacts. https://dynamix-project.eu/sites/default/files/Dynamix%20Policyfield_roadmap_land_230316_0.pdf

management. Coastal erosion is intensifying and impinging on more regions with sea-level rise adding to land use pressure in some region.

In drylands, climate change and desertification are projected to reduce crop and livestock productivity, modify the plant species mix and harm biodiversity. Asia and Africa are projected to have the highest number of people vulnerable to increased desertification. The tropics and subtropics are projected to be most vulnerable to crop yield decline. Land degradation resulting from the combination of sea-level rise and more intense cyclones is projected to jeopardise lives and livelihoods in cyclone prone areas (IPCC, 2019).

2.5 Reviving land health to drive sustainability in the food system

The agriculture sector has achieved a remarkable transformation over the past half-century and currently provides enough food for the population of the future. Agricultural intensification has played a major role in reducing the expansion of agricultural land, but has created a number of environmental threats, including land degradation and pollution. Transformation of agriculture has been driven by a narrow policy focus built around one principal goal – producing more food, fibre and fuel – without sufficient regard for other important dimensions of food and farming systems including nutritional variety, rural livelihoods and incomes, environmental sustainability and even economic efficiency.

Agricultural intensification has led to practices been harmful to that harm the very essence of agricultural productivity – the soil – and this has in turn undermined land health, to the extent that land and landscape degradation threatens the future of the current agricultural system. The future sustainability of the world food system depends on restoring and maintaining land health in agriculture, at both the farm and the landscape level, acknowledging simultaneously the need to meet increasing global food demand and to preserve biodiversity.

Agroecosystems provide many benefits besides food production, including water provision, reducing the risks of drought and flood, regulating climate, biodiversity conservation and providing recreational, aesthetic and cultural services. The focus on raising food production from agricultural land has often sacrificed these other values; values that society increasingly demands. Many of the benefits associated with agricultural land are determined by soil biodiversity, which is one of the first casualties of land degradation. The value of soil biodiversity to ecosystem services has been estimated at between US$ 1.5 trillion and US$ 13 trillion annually (van der Putten et al., 2004). The agriculture sector has a major role to play in safeguarding ecosystem services by protecting soil biodiversity.

The amount of land available for agricultural expansion is limited, pushing agriculture into increasingly marginal areas. Land encroachment and habitat loss will remain pressing conservation concerns in some regions – most notably Africa – and for certain critical habitats. To be consistent with the SDGs, agriculture will need to feed everybody without increasing the total area under cultivation. This will depend on increasing efficiency of resource use, and in some regions will almost certainly involve further production increases. It is highly likely that the use of irrigation, synthetic inputs, and improved breeds will continue to increase. Agricultural development therefore urgently needs to emphasise increased efficiency – producing more output per unit of input – in an environmentally sustainable manner (Van Der Esch et al., 2017). Producing more output per unit of input does not necessarily mean producing more output overall: producing the same output with less input is also a legitimate way to improve efficiency. Maintaining production while reducing costs can be an attractive business option for many farmers.

Sustainable agriculture must balance food production with provision of other ecosystem services. This needs to be achieved without compromising output and incomes, particularly in food insecure regions. The sustainability of agriculture has to be assessed at the landscape as well as the farm level. It depends on adoption of sustainable farming practices by individual farmers as well as collective efforts to ensure landscape functionality and integrity, beyond the individual farm. This may include protection of forests and wetlands, or management of woodlands and pastures, within the wider agricultural landscape.Addressing global consumption and distribution patterns and reducing food waste will require cross-sectoral action in countries and intergovernmental action for global change. The scale of the challenge is massive and requires urgent action on a large scale. It requires responses from individual farmers, agricultural investors, and throughout food and agriculture supply chains up to the consumer. It requires responses in policy and legislation and in national political agendas to provide greater support for sustainability in agriculture. However, conservation and agriculture actors alike have a shared interest in protecting and restoring land health and soil biodiversity in agricultural landscapes. Creating incentives for land health through the global food and agriculture system must be an integral part of the transition to sustainability. This will be an important challenge to address during the UN Decade on Ecosystem restoration (2021-2030).[17]

2.6 Conclusion to Chapter 2

The agriculture sector has performed remarkably over the past half-century. Food production has increased dramatically, driving down hunger and contributing to higher life expectancy, lower infant and child mortality rates, and decreased poverty. These impressive changes have largely been attained through intensification, particularly a massive increase in the use of inputs including agrochemicals and mechanisation as well as irrigation and new breeds.

These improvements have come at a high cost to the planet and society. The expansion of farmland and destruction of natural habitat have contributed to massive biodiversity losses, pollution, GHG emissions and land degradation. Easy access to cheap food has contributed to the obesity crisis in some countries, while large numbers of people in developing countries remain food insecure and micronutrient deficient. Global demand could already be met if food was more equitably distributed and waste eliminated.

Land is a finite resource that is greatly over-exploited, jeopardising the future well-being ofhumanity. To achieve the sustainable development goals, and meet international targets on climate change, biodiversity conservation and land degradation, society must urgently adopt more SLM practices together with other far-reaching changes in the food and agriculture system. This must be achieved in the context of a changing climate as well as population growth and declining natural resources.

The cost of these changes may appear daunting, but must be examined in the light of the US$ 60 billion of subsidies and the even greater flows of private investment (mostly by farmers themselves) into the agricultural sector. The challenge is to ensure that financial flows are re-purposed to favour sustainable production practices as well as to promote efficiencies throughout the food and agriculture system.

[17] https://www.decadeonrestoration.org/

Chapter 3

Soil biodiversity and agricultural land health

Biological diversity (or biodiversity) is defined as the variability among living organisms and the ecological complexes of which they are part of. This includes diversity within species, between species and of ecosystems (United Nations, 1992). Agricultural biodiversity includes all components of biological diversity of relevance to food and agriculture and that constitute an agroecosystem: the variety and variability of animals, plants and micro-organisms, at the genetic, species and ecosystem levels, which are necessary to sustain key functions of the agroecosystem, its structure and processes (CBD, 2010).

Agricultural biodiversity can be divided into two main categories. The first category consists of the domesticated species that provide food and other products along with their wild relatives. The second category comprises all those non-harvested components that contribute to, and sustain, agricultural productivity by provisioning, supporting and regulating ecosystem services, including soil biota, pollinators and the enemies of pests and diseases (CBD, 2010). Soil micro-biota are of particularly immense diversity, and perform a number of vital functions that regulate soil fertility and the cycling of nutrients (discussed in detail in the next section). This is particularly true of the ecosystem functions determined primarily by biodiversity in soils: 90-95% of soil biota remains unidentified and less than 1% of some groups has been described.

Pollination for crop production is perhaps the best-known ecosystem service (performed by insects as well as some birds and mammals). Eighty-seven of humanity's major food crops, accounting for 35% of global food production, depend on animal pollination (Klein et al., 2007). The most mportant pollinators for economically important crops are honeybees (Apis mellifera), followed by solitary bees, and flies (Rader et al., 2016). In all, between US$ 235 billion and US$ 577 billion worth of annual global food production relies on direct contributions from pollinators (IPBES, 2018).

Pollinators vary widely for each crop, depending on geographic location, availability of natural habitat, and use of pesticides (Kremen et al., 2002). For example, in contrast to versatile honeybees, solitary bees are specific for certain plant species (Hallmann et al., 2017). Thus, the loss of certain plant species can be directly linked to declines in bees in some parts of the world and is a major concern for biodiversity and ecosystem services in agriculture (Papanikolaou et al., 2017; IPBES, 2018). For example, Biesmeijer et al. (2006) found parallel declines of bees and insect-pollinated plants in Britain and the Netherlands through shifts in species richness (number of species), and Weiner et al. (2014) demonstrated that the effects of land use on pollinators are accelerated by their mutual dependence of plants.

Biological control of pests and diseases is another important ecosystem service for agriculture provided by organisms through direct predation, parasitism or their produced compounds (e.g. toxins). This activity reduces the population density of harmful organisms, including animals, weeds and diseases (Bale et al., 2008). Reducing habitat loss and environmental disturbance associated with intensive crop production can conserve natural enemies and contribute to pest suppression, an approach known as conservation biological control (Begg et al., 2017).

Conservation biological control, involving deployment of various methods to conserve and enhance naturally occurring native herbivores, parasitoids and/or predators, has minimal negative impacts on the environment and ecological services. In contrast, classic biological control, involving the introduction and establishment of specialised non-native natural enemies, can sometimes lead to unexpected ecological consequences in the targeted ecosystem (Jennings et al., 2017).

Many such biopesticides target specific pest species, with less impact on pollinators and soil biodiversity (Chandler et al., 2011) compared to chemical pesticides that often have detrimental effects on non-target organisms, so damaging soil communities and interactions among species (Thiour-Mauprivez et al., 2019). Some organisms can even develop resistance and so require higher inputs of pesticides (Aktar et al., 2009). For this reason, biopesticides have sometimes been considered a safer alternative to chemical pesticides (Bale et al., 2008). A highly successful example is the bacterium Bacillus thuringiensis, an insect pathogen used to combat lepidopteran agricultural pests (Bravo et al., 2005) that accounts for 95% of the world market for microbial pest control agents (Joung & Côté, 2000).

In a more recent review, Siegwart (Siegwart et al., 2015) showed that all widely used biopesticides ultimately select resistant individuals. For example, at least 27 species of insects have been described as resistant to Bacillus thuringiensis toxins. Similarly, it has been demonstrated that biopesticides can have similar impacts as synthetic pesticides on soil biodiversity, especially when used at doses recommended for agriculture (Romdhane et al., 2019, Shao et al. 2017). Other commonly used biopesticides include entomopathogenic nematodes such as Steinernematidae and Heterorhabditidae that have been used effectively against insects (Lacey & Georgis, 2012), as well as species of the fungus Trichoderma that are used against soil-borne plant pathogenic fungi and also produce a variety of compounds that promote plant growth (Verma et al., 2007). By reducing the populations of pests in agriculture, biological control services reduce the need for chemical pesticides (Power, 2010). Some studies suggest that insect predators and parasitoids account for approximately 33% of natural pest control (Hawkins et al., 1999), and the value of pest control services attributed to insects has been estimated at US$ 4.5 billion annually in the United States alone (Losey & Vaughan, 2006).

3.1 The rich biodiversity of soil

Soil biota include bacteria, fungi, algae, protists, viruses, nematodes, Acari (including mites), Collembola (springtails), Annelids (primarily earthworms), macroarthropods (such as spiders, ants and woodlice) and vertebrates (like voles, moles and shrews). They can be beneficial or harmful, according to the specific agroecosystem. Soil biota also include plants whose root exudates provide food for soil organisms in a zone around the roots known as the ’rhizosphere’ (Briones, 2014) the opacity of this world has severely limited our understanding of their functional contributions to soil processes and to ecosystem resilience. Traditional taxonomy, based on morphological and anatomical aspects, is becoming replaced by rapid processing molecular techniques (e.g. with marker gene-based approaches.

Soil organisms are commonly classified into three major groups according to body size: macrofauna (2-20 mm) such as earthworms, ants and termites; mesofauna (0.1-2 mm) including mites and springtails and microfauna and microorganisms (less than 0.1 mm) including nematodes, protists, fungi and bacteria (Swift et al., 1979). The diversity of species in soil is so immense that an estimated 90-95% of soil biota remain to be identified (D H Wall, 2005). The species identified and described so far include 7,000 earthworms (23% of the estimated total number of species). (Table 1, Figure 8).

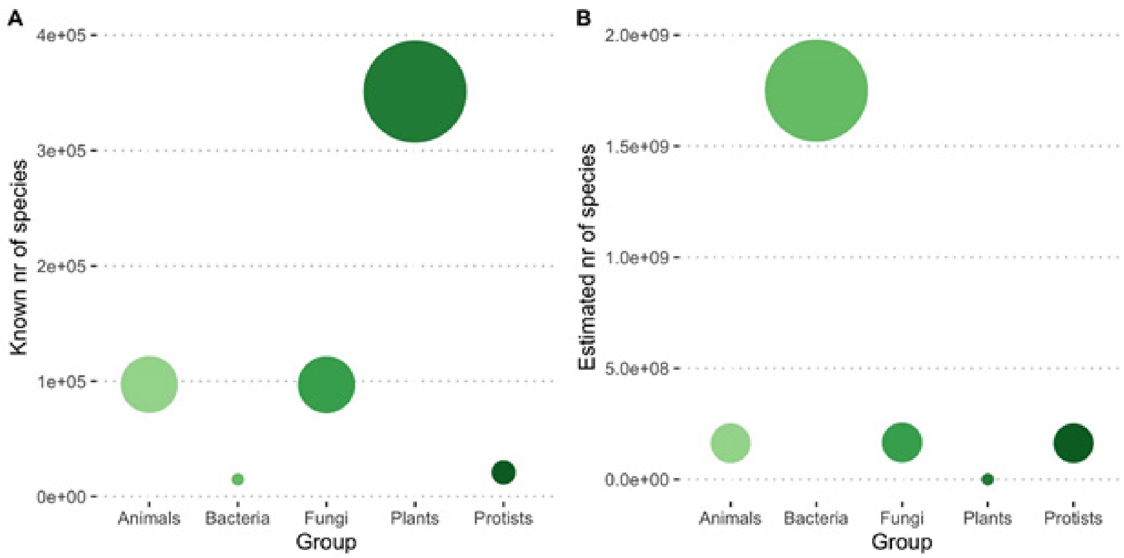
3.1.2 Macrofauna

Macrofauna species help to maintain a good soil structure by ingesting soil organic matter and mineral particles, mixing and aggregating soil, a process also known as bioturbation, burrowing and releasing nutrients to plants (Tate, 2005). Earthworms are usually the most abundant animal group in agricultural soils in terms of biomass and contribute significantly to healthy soil structure (Plaas et al., 2019).

Table 1 Global diversity (species richness) of soil organisms organised according to body size

Group	Sub-groups	Species described	Estimated no. of species existing	Percentage of species described
Vascular plants		350,700	400,000	88
Macrofauna (2-20 mm)				
	Earthworms	7,000*	30,000*	23
	Ants	14,000	25,000 - 30,000	50-60
	Termites	2,700	3,100	87
Mesofauna (0.1-2 mm)				
	Mites	40,000*	100,000	40
	Springtails	8,500	50,000	17
Microfauna and Microorganisms (< 0.1 mm)				
	Nematodes	20,000 - 25,000*	1-10 million*	≤2.5
	Protists	21,000*	7-70 million*	≤0.03
	Fungi	97 000	1.5-5.1 million	≤0.02
	Bacteria	15 000	>1 000 000	<1.5

From De Deyn & Van Der Putten (2005) and Diana Wall et al. (2011)



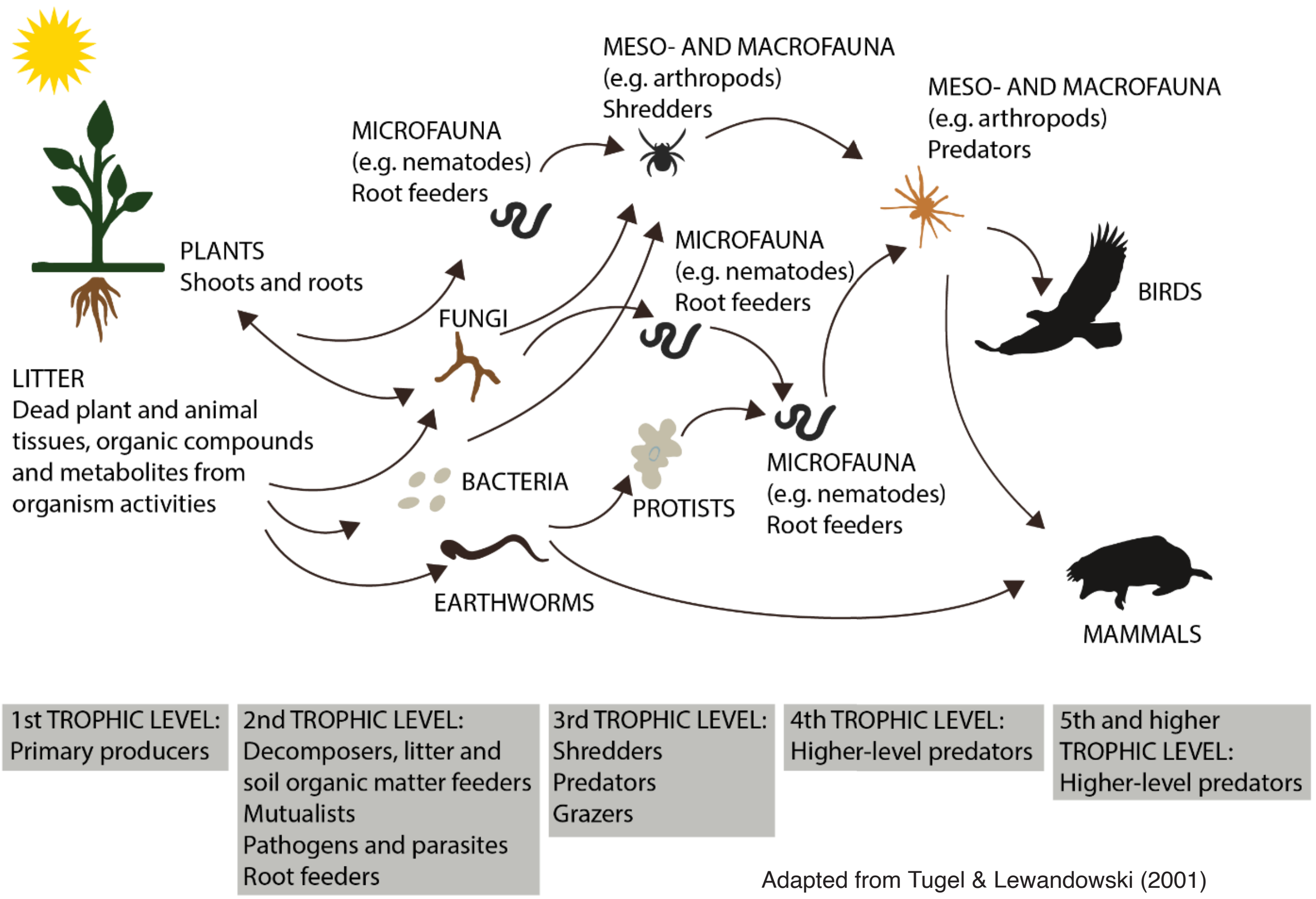
Data from Barrios (2007) and Larsen et al. (2017). Animals include earthworms, ants, termites, mites, springtails.

Microorganisms (bacteria, fungi). Plants = vascular plants.

Figure 9 Known (left) vs. estimated (right) species number (species richness) of major taxonomic groups

3.1.1 Soil biota and ecosystem processes

Soil biota interact and form complex food webs that support a range of ecological processes (Barrios, 2007), as shown in Figure 10. These processes are essential to maintain a functional soil ecosystem and are therefore essential for land health.



Adapted from Tugel & Lewandowski (2001)

Figure 10 Soil biota form complex food webs that sustain ecosystem functions

3.1.3 Mesofauna

Mesofauna species, including many arthropods, break down organic matter and deposit faeces, helping increase soil fertility (Culliney, 2013). Acarines are often the most abundant and the most species-rich group (Culliney, 2013) and are found at different trophic levels of the soil food web: as herbivores (feeding on plants or algae from the first trophic level), bacterivores and fungivores (feeding on bacteria or fungi which belong to the second trophic level), and predators (feeding on small soil-dwelling animals of the second and higher trophic levels) (Mitchell, 2013). The number of known collembolan species is much lower than that of acarines, but they may reach the same abundance. Compared to acarines, most collembolan species feed on fungi and algae, but a few feed on plants or are predators (Petersen & Luxton, 1982).

3.1.4 Microfauna

Microfauna species are an extremely abundant and diverse group of soil organisms, with nematodes (also known as roundworms) and protists (mostly unicellular organisms including amoeboids and ciliates) being the most dominant component of soil biota (Haynes, 2014). Many thousands of microfauna species are known globally, but it is believed that these are only a fraction of the number of species actually present on the globe. For example, a recent study estimated that approximately 4.4 × 1020 nematodes (accounting for a total biomass of approximately 0.3 gigatons) inhabit soils globally (van den Hoogen et al., 2019). Microfauna generally live in the soil-water film and feed on microflora, plant roots, other microfauna (including fungi and bacteria). Entomopathogenic nematodes feed on larger organisms . Nematodes can thus regulate the population size and activity of soil microbes and promote the competitive ability and dispersal of beneficial microbes by selective grazing on harmful soil microorganisms (Bonkowski et al., 2009; Mitchell, 2013). Their activity helps to release nutrients, including N and P that stimulate root growth (Mekonen Ertiban, 2019).

Nematodes are present at all levels in the food web. Based on their feeding strategy, they can be classified into five trophic groups: bacterivores, fungivores, predators, omnivores, and herbivores (Kennedy & de Luna, 2005). Given their pivotal role in processing organic nutrients and control of soil microorganism populations, they play critical parts in regulating C and nutrient dynamics and are a good indicator of biological activity in soils (van den Hoogen et al., 2019). Moreover, entomopathogenic nematodes can contribute to insect pest suppression (Mitchell, 2013).

Protists commonly reach tens of thousands of individuals per gram of soil (Finlay, 2002) and have immense morphological and functional diversity. Autotrophic and heterotrophic protists are of fundamental importance in the food web (Geisen et al., 2018) and photosynthetic protists may provide important C inputs in soils (Bonkowski & Clarholm, 2012). Heterotrophic phagotrophic protists release nutrients via microbial predation, which are then made available to plants and stimulate growth. Protists in soil are the main consumers of bacteria, thereby shaping bacterial communities. Some also feed on fungi, including plant pathogens (Geisen et al., 2018).

Microbial diversity in soil ecosystems is even greater than that of protists. Microbes such as saprotrophic fungi are the primary regulators of soil C and nutrient cycling (Crowther et al., 2012). By making up a major portion of the microbial biomass of soil (Frac et al., 2018), fungi are the primary agents of plant litter decomposition and their hyphal networks represent highly dynamic channels through which nutrients are readily distributed (Crowther et al., 2012).

Over 80% of plant species form root associations with mycorrhizal fungi, symbiotic relationships that help the plant acquire important nutrients such as P from the soil in return for plant sugars (Peterson et al., 1984). In addition, mycorrhizal fungi improve plant stress resistance, tolerance, and fertility as well as soil structure as mycorrhizal mycelia can transport plant-derived C compounds through the soil system (Chen et al., 2018).

Arbuscular mycorrhizal fungi (AMF) are by far the most ubiquitous class, and form arbuscules and sometimes vesicles within the root cells of hosts (S. Smith & Read, 2008). A key mechanism by which AMF increase P acquisition by plants is through the exploration of a large soil volume by hyphal networks (Jakobsen et al., 1992). AMF symbioses are therefore most beneficial in low-fertility soils because the fine fungal hyphae can scavenge more efficiently for essential nutrients than plant roots (Chen et al., 2018).

3.2 Soil as an ecological system

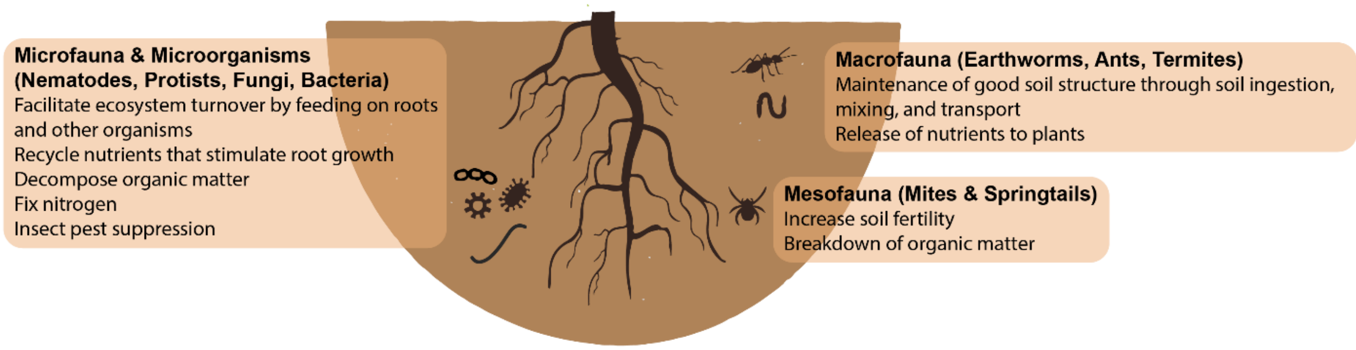


Figure 11 Overview of ecosystem processes provided by the soil biota, classified according to their body size

3.2.1 Essential ecosystem services for agriculture

3.2.1.1 Nutrient cycling

The cycling of nutrients is a critical ecosystem function that is essential to life, and microsymbionts have a positive impact on crop yield by making more nutrients available to plants (Barrios, 2007). N in particular is an essential nutrient for plants, and microsymbionts such as Rhizobia provide an important source of biological nitrogen fixation (BNF) in the soil ecosystem (Checcucci et al., 2017). The amount of N fixed from Rhizobia-legume symbiosis varies greatly depending on many factors, including plant species and cultivar, and environmental conditions (Stewart, 1977). While estimates of symbiotic BNF can be as high as 400 kg N ha-1year-1, average associative BNF (by soil organisms in casual association with plant roots) is about 10-fold lower and free-living BNF by heterotrophs (neither symbiotic nor associative) about 100-fold lower (Barrios, 2007). For example, the estimated total amount of N fixed is 65 kg ha-1year-1 for peas (Pisum sativum), 103 kg ha-1year-1 for soybean (Glycine max) and 224 kg ha-1year-1 for beans (Cajanus cajan) (Stewart, 1977).

Apart from this well-documented N-fixing symbiosis, many soil microorganisms are capable of fixing N without the formulation of nodules but rather live in the rhizosphere (associative N-fixing) or in plant tissues (endophytic N-fixing) (Moreau et al., 2019). Recent studies have shown large yield increases in cereals such as maize, rice and wheat as a result of the use of N-fixing, plant growth promoting rhizobia bacteria (Souza et al., 2014). Brazilian bean cultivars (Phaseolus vulgaris) in N-poor soils inoculated with the most effective rhizobia strain delivered an increase in yield of 178 kg ha–1. The examples show that exploring the genetic capacity of microorganisms to fix N can help increase yields at low cost (Hungria et al., 2003), while reducing inputs of fertiliser (Souza et al., 2014).

Soil microorganisms also make N available to plants through their role in the decomposition of soil organic matter. This activity is central to their nutrition, that plant transfer large amounts of organic molecules to their root-associated microorganisms to stimulate them to degrade soil organic matter so that N will be released, a phenomenon known as “priming” (Kuzyakov et al., 2000; Moreau et al., 2019).

Nitrification and denitrification are the microbial processes primarily responsible for losses of mineral N from terrestrial ecosystems. Recent studies indicate that relationships exist between plant growth, the activity of N-cycling microbes, and N retention and loss, indicating competition between plants and microorganisms for N in which the plant employs several strategies to conserve N. These include limiting microbial processes that lead to N losses, such as nitrification and denitrification, directly through the release of inhibitors from their roots. Plants can also adversely affect N-cycling microbes indirectly through competition for N, with higher plant N uptake decreasing soil N availability with consequences for the abundance and/or activity of microbes (Moreau et al., 2019). For example, nitrification inhibitors can lead to a decline of up to 90% in ammonia oxidation rates in Brachiara pasture and a lower abundance of both archaeal and bacterial ammonia-oxidising micro-organisms (Subbarao et al., 2009). The same result can be achieved by the application in the field of nitrification inhibitors, however problems with persistence due to hydrolysis, sorption to soil colloids or volatilisation reduce their effectiveness and few are commercially available (McNeill & Unkovich, 2007). Similarly, another study demonstrated that some plants can inhibit denitrification by up to 80% through the release of procyanidins in root exudates (Bardon et al., 2014, 2016). However, in contrast to nitrification inhibitors, the impact of such denitrification inhibitors has not yet been quantified in the field, and more research is required to determine the various interactions taking place between plants and associated microbes in order to find solutions for retaining N in soils and avoiding negative effects.

Arbuscular mycorrhizal fungi (AMF), microsymbionts that help plants acquire phosphorous (see above), are especially important in phosphorous-deficient crop systems (Barrios, 2007).

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3.2.1.2 Decomposers and elemental transformers

The decomposition of organic matter into simpler molecules and nutrients (including N, P and sulphur as well as mineralised C) is one of the most important ecosystem services performed by soil organisms. Decomposition involves physical fragmentation, biochemical mineralisation, and leaching of organic substrates and nutrients (Barrios, 2007). The process of decomposition is to 90% carried out by microorganisms such as bacteria and fungi greatly facilitated by soil meso- and macrofauna (especially earthworms) that fragment residues and disperse microbial propagules , and thus have impacts on soil organic matter (SOM) dynamics and nutrient cycling (Lavelle et al., 1997). The adaptive management of soil biodiversity can have strong impacts on crop productivity (Barrios, 2007). Studies have found that an average earthworm presence in agroecosystems with low N content leads to a 25% increase in crop yield and a 23% increase in above-ground biomass as compared to agroecosystems without earthworms through the release of N, highlighting a potential alternative to the use of N fertiliser (Van Groenigen et al., 2014).

3.2.1.3 Soil structure modification

Soil structure can be defined as the arrangement of sand, silt and clay particles as well as SOM into aggregates of different size by organic and inorganic agents (Barrios, 2007). The size, quantity and stability of soil aggregates reflect a balance between aggregate-forming factors (organic matter amendments, soil microorganisms and soil fauna) and those that disrupt them (bioturbation, cultivation). The ‘aggregate dynamic model’ proposes that several biological processes in the soil lead to the formation of “biological macroaggregates” and their stabilisation as part of soil structure through the activity of fungi and bacteria, plant roots and macrofauna (such as earthworms) (Six et al., 2002). For example, mycorrhizal fungi produce the glycoprotein glomalin, which is crucial for soil stability and water retention and builds an important reservoir of C (Pal & Pandey, 2014). In addition, roots, through their exudates, increase SOC 2.3 times more than the composting process of dead above-ground biomass (Kätterer et al., 2011). In some particular agricultural soils (dryland or bare soils), algae and cyanobacteria have a key role in soil surface aggregation and stabilisation of soil particles, thus helping to prevent soil erosion (Crouzet et al., 2019; Renuka et al., 2018). As described above, soil macrofauna also play an important role in soil structure modification and related porosity, and thus deeply influence soil water and nutrient dynamics (Brussaard, 1997). For example, indirect management of termites through the application of organic mulch can lead to the recuperation of surface sealed soils (Mando, 1997).

3.2.1.4 Pest and disease control

Soil-borne pests and diseases cause enormous global annual crop losses (Barrios, 2007). A healthy soil community has a diverse food web that keeps pests and diseases under control through competition, predation, and parasitism (Susilo et al., 2009). Healthy soil biota leads to higher fertility and plant health as compared to crops grown in soil with low biodiversity, resulting in poor nutrition and more susceptibility to pest and disease attacks (Altieri & Nicholls, 2003; Barrios, 2007). For example, maize infestation with the parasitic weed Striga spp. in N-deficient African soils was significantly reduced following the use of N-fixing tree legumes as planted fallows that increased soil N availability through BNF and decomposition (Barrios et al., 1998). For comparison, in northern Cameroon, when maize and sorghum were inoculated with AMF and grown in Striga hermonthica infested soils, S. hermonthica emergence was reduced by 30-50% and biomass increased by 40%-63%, largely due to improved nutrition and thus, improved plant health (Lendzemo et al., 2005). The diversity of soil microbial communities creates a barrier that controls the establishment of microbial pathogens in soils (Van Elsas et al., 2012; Vivant et al., 2013). There is general consensus that a diverse soil community will not only help prevent losses due to soil-borne pests and diseases but also promote other key biological functions of the soil (Wall & Virginia, 2000).

3.3 Species diversity and abundance and soil ecosystem function

There is a general consensus that a decline in biodiversity leads to a decrease in ecosystem functioning and services and vice versa (Balvanera et al., 2006; Gamfeldt et al., 2013; Hooper et al., 2005; Isbell et al., 2011). Accordingly, the productivity of agricultural ecosystems depends on the stability of the ecosystem services provided by the soil . Examples of ecosystem services that affect agricultural productivity include pollination, biological pest and disease control, maintenance of soil structure and fertility, nutrient cycling and hydrological services (Power, 2010). Poor production and management choices lower agricultural productivity as a result of degraded land, scarcity and reduced quality of water, increased pest and disease risks, and loss of natural pollinators (Regmi et al., 2016). The net present value of taking action against nutrient depletion through soil erosion on arable lands used for cereals production over the 15 years from 2016 to 2030 has been estimated at US$ 2.48 trillion, or US$ 62.4 billion per year (ELD Initiative, 2015).

Species richness and species abundance largely determine ecosystem function and are thus often used as biodiversity indicators to assess the condition of an ecosystem (Regmi et al., 2016). It is widely accepted that plant biodiversity affects ecosystem processes (Tilman et al., 1997), and influences ecosystem responses to disturbances (Reich et al., 2001). For example, research has shown that plant biodiversity increases ecosystem services (Hautier et al., 2015), as plant biodiversity positively affects soil nutrient content and therefore soil quality (Reem Hajjar et al., 2008; Mulumba et al., 2012; Ponisio et al., 2015). Selecting the right mix of crops rather than using one or a few dominant crops can, for example, dramatically increase crop water-use efficiency (Brauman et al., 2013; West et al., 2014). Increasing crop diversity has also been shown to enhance pollinator health (Garibaldi et al., 2014; Isaacs & Kirk, 2010), whereas a lack of crop diversity has been found to cause a decline in pollinators, representing a threat to food security (Aizen et al., 2019).

Biodiversity - ecosystem multifunctionality studies have found that more species are needed to provide multiple functions because different species promote different functions (Eisenhauer et al., 2018; Zavaleta et al., 2010). Moreover, a study by Isbell et al. (2011) found that more species are needed to provide ecosystem functioning at larger spatio-temporal scales because different species promote productivity at different times or places. Therefore, although some species may appear functionally redundant when one function is considered under one set of environmental conditions (Cardinale et al., 2011), many species are needed to maintain multiple functions at multiple times and places (Isbell et al., 2011). This means that higher species diversity leads to more redundancy and therefore greater resilience of soil.

Similarly, microbial diversity has been shown to enhance ecosystem functioning (Downing & Leibold 2002; Horner-Devine et al., 2003; Bell et al., 2005; Peter et al., 2011, Wagg et al., 2019) and vice versa. Unless there is substantial functional redundancy in microbial communities (Allison & Martiny, 2009), a loss in microbial diversity would likely alter the capacity of microbes to support ecosystem functions (Delgado-Baquerizo et al., 2016). For example, recent research has shown that a strong decrease in microbial diversity affects the decomposition of C sources, confirming that microbial diversity may be of high significance for organic matter decomposition (Maron et al., 2018). On the contrary, previous works have shown that moderate disturbance of soil microbial diversity did not alter soil N cycling (Wertz et al., 2007). It is therefore important to understand and predict the functional consequences of changes in microbial diversity on soil ecosystem services in order to develop indicators of ecosystem function.

Functional traits of soil macrofauna and trophic networks in soils are also influenced by land-use type and intensity (Birkhofer et al., 2017). Some microbial populations can facilitate the degradation of pesticides in soil and act as buffers to soil ecosystems (Aislabie & Lloyd-Jones, 1995).

3.4 Trends in soil communities based on farming practices

Different agricultural practices affect agricultural habitats in different ways and the impact on soil communities and the ecosystem services they provide may be positive or negative depending on which soil biota are affected (Table 2). Comparing broad categories of farming practice is a way to assess the effects of agricultural management intensity on biodiversity (Rundlöf et al., 2016). While there is insufficient consensus on the terminology used to describe different farming practices (see Chapter 5), it is possible to examine the impacts of farming practices on soil communities by distinguishing between conventional (or mainstream), organic and conservation agriculture. Conventional farming systems vary from country to country and farm to farm. They can range from intensive to extensive, feature no-till or minimum tillage, use mono-cropping (monoculture) or mixed cropping (polyculture), and have low or high inputs of pesticides and fertilisers (CBD, 2010; Gold, 2016). Conventional agriculture generally provides high yields due to the use of pesticides and fertilisers (Seufert et al., 2012), but usually at the cost of lower biodiversity and impaired ecosystem services (Erisman et al., 2016).

Increased N fertiliser additions have been shown to change bacterial and fungal communities and alter microbial biomass by altering the C:N ratio in soils (Martínez-García et al., 2018) and affecting nutrient cycles . Nematode community composition is similarly impacted (Kardol et al., 2005). Due to their sensitivity, nematodes and earthworms are commonly used as indicators of soil quality (Neher, 2001). Meanwhile, certain pesticides can reduce the efficiency of symbiotic rhizobia, resulting in fewer root nodules, lower rates of N-fixing, and a reduction in plant yield (Fox et al., 2007). Pesticides have been widely shown to have a range of negative effects on soil microbiota, including on their growth, diversity, composition, biochemical processes and functions (Aktar et al., 2009; Chagnon et al., 2015) as well as on soil macrobiota, including the growth and survival of many amphibian species (Baker et al., 2013).

Organic farming and conservation agriculture are alternatives to conventional agriculture that are often promoted as more environmentally friendly (Mäder et al., 2002; Tuck et al., 2014). Organic agriculture minimises the use of agrochemicals and relies on natural techniques such as crop rotation, reduced tillage or no-till, biological pest control, and manure, green manure or compost application (Reganold & Wachter, 2016). Conservation agriculture represents a set of three crop management principles: (A) direct planting of crops with minimum soil disturbance (that is, reduced or no-tillage), (B) permanent soil cover by crop residues or cover crops, and (C) crop rotation (Pittelkow et al., 2015). Studies indicate that organic and conservation agriculture have a mostly positive effect on soil quality and a range of soil biota (Briones & Schmidt, 2017; Köhl et al., 2014).

Tillage affects the soil biota through changes in soil structure, loss of organic matter and moisture, altered temperature dynamics, and mechanical damage, whereby different tillage systems have different impacts (Busari et al., 2015). The abundance of microarthropods (mites and collembolans) generally decreases with increased tillage, with collembolans being more sensitive than mites (Cortet et al., 2002). It has been shown that earthworm abundance, biomass and species diversity decrease significantly with higher tillage intensity (Plaas et al., 2019). For example, the number of individuals can vary from 30 per m2 in ploughed fields to 400 under no-till (Plaas et al., 2019).

How tillage impacts soil fungi is less clear. Frac et al., (2018) showed that tillage negatively affects AMF by breaking down soil aggregates that are connected through fungal hyphae, leading to a deterioration of soil structure and nutrient uptake and of suppressive effects against pathogenic microorganisms. However, a recent meta-analysis found that AMF, fungal diversity and functional diversity were not negatively affected by tillage (de Graaff et al., 2019). It is suggested that a range of impacts are possible according to the fungal species involved (Brito et al., 2012; Douds et al., 1995), soil properties, and tillage intensity (Roger-Estrade et al., 2010; Snapp et al., 2010). Tillage can widely differ in its impact on fungi with both positive (Peyret-Guzzon et al., 2016) and negative effects (Schnoor et al., 2011) depending on the tillage practices used, which may range from conventional inversion tillage to non-inversion tillage that leaves the majority of the soil and residue undisturbed (Morris et al., 2010). For example, a recent global meta-analysis on the effect of conservation tillage (involving zero or reduced tillage with >30 % residue covers) on soil fungal and bacterial biomass, showed that conservation tillage greatly increased overall soil microbial biomass (37%), including both fungal (31%) and bacterial biomass (11%), especially in the top 20 cm of soil or in no-till systems (Oldfield et al., 2019). Another meta-analysis (Briones & Schmidt, 2017) showed that no-till and conservation agriculture significantly increased earthworm abundance (mean increase of 137% and 127%, respectively) and biomass (196% and 101%, respectively) compared to when the soil is inverted by conventional ploughing.

Different soil biota are differently impacted by soil disturbance. Tillage systems tend to harbour more bacteria than fungi as the former are more resilient to ploughing, as well as more protists, while the number of nematodes can increase or decrease according to tillage practices (Sun et al., 2018). No-till systems tend to have higher numbers of fungi relative to bacteria, as well as earthworms, and collembolans. No-till systems are characterised by a high concentration of soil organic matter in the upper layers of the soil due to plant litter decomposition and Fungi, as well as the collembolans that graze on them, are more numerous in these systems. Populations of these species can therefore be manipulated by modifying the tillage regime (Menta, 2012).

Table 2 Agricultural habitats (chemically treated soil, tillage and no-till systems) according to farming practices (organic, conservation and conventional farming) and their effects on soil biota and resulting ecosystem services

Agricultural habitat	Primary production system	Effect on soil biota
Chemically treated soils	Application of pesticides, organic and mineral fertilisers	Strong impacts on soil biodiversity, alter bacterial and fungal communities, may inhibit/kill certain fungi, can affect growth and survival of amphibians and affect nematode community compositions →nutrient and cycling processes (C, N)
Tilled soils	Organic farming, conservation farming, conventional farming - crop rotations, biological pest control, manure/compost applications	Tillage can have positive and negative effects on biomass of soil (micro)organisms, especially earthworms, nematodes and fungi, including AMF. If nematodes and earthworm biomass decreased, less microarthropods →decrease soil structure and stability, nutrient uptake (P), biological control of pathogens
No-tilled/reduced tilled soils	Organic farming, conservation farming, conventional farming - crop rotations, biological pest control, manure/compost applications	Increase in soil microbial biomass, both fungi and bacteria (fungi usually higher), as well as earthworms, collembolans →increase in soil structure and stability, nutrient uptake (P), higher SOM, biological control of pathogens

3.5 Availability of information on current soil biodiversity condition

As this report shows, soil is an ecological system rich in biodiversity that provides ecosystem services that are essential for agricultural production. Better understanding of soil biodiversity and how it supports ecosystem services is important to inform decision-making about how to achieve sustainable development in agriculture and related areas while also conserving biodiversity.

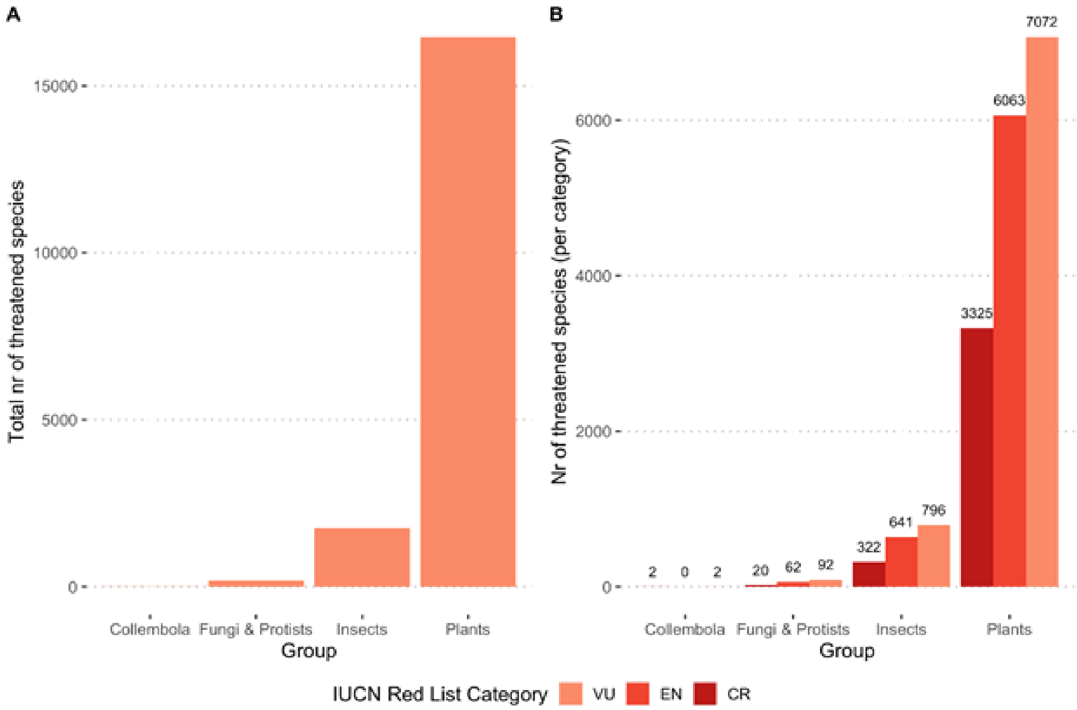
Research on soil biodiversity has largely focused on the roles of specific groups of organisms, including soil microbes, mycorrhizal fungi, and soil fauna (Wagg et al., 2014). Detailed information on soil biodiversity has been assembled in, for example, the Global Soil Biodiversity Atlas (Orgiazzi et al., 2016). However, knowledge of what biodiversity is actually present in soils in particular locations, and how soil species influence ecosystem functioning, is still scarce.

Global assessments of the main threats to and the status of soil biodiversity are important to close existing knowledge gaps. Alongside new developments with respect to assessing biodiversity (for example, new molecular approaches and tools), it is essential to link biodiversity measures with specific soil functions under particular environmental contexts (Ramirez et al., 2015). For instance, while some soil functions (such as decomposition) are driven by a diverse array of organisms, other functions involve a more specific set, which makes those functions more vulnerable to biodiversity loss (Jurburg & Salles, 2015). Furthermore, better understanding of the key roles of soil organisms in mediating soil ecosystem services, as affected by ecosystem management approaches and practices adapted to socio-ecological contexts, is central to guiding biodiversity-friendly agricultural intensification.

3.5.1 Red List data for soil biodiversity

The huge gaps in the documentation of soil biodiversity, especially of microorganisms, makes it impossible to assess the conservation status of many soil biota. Current data for soil biodiversity largely relate to plants and insects. The Global Assessment Report on Biodiversity and Ecosystem Services (IPBES, 2019) states that around half a million terrestrial species are “committed to extinction” unless their habitats improve. However, this estimate may be conservative, as the undocumented diversity of arthropods, parasites and soil microfauna could mean there are 2-25 times more animal species than widely assumed, and fungi are not included (Scheffers et al., 2012).

Overall, there are shortages of detailed knowledge of conservation status and population trends in insect, fungal and microbial species with tropical populations being extremely under-represented in trend data (IPBES, 2019). Figure 11 clearly illustrates that funghi, protists and collembolas are basically not covered in the red list because of lack of data. Another issue is that the IUCN Red List is not designed to assess the extinction risk of microorgamisms. The IUCN Red List relies on a set of quantitative criteria (such as population size, geographic range size, generation length as well as the nature of the threat facing the species) that are not appropriate criteria to assess the extinction risk of microorganisms. For this reason, a different methodology would need to be developed.



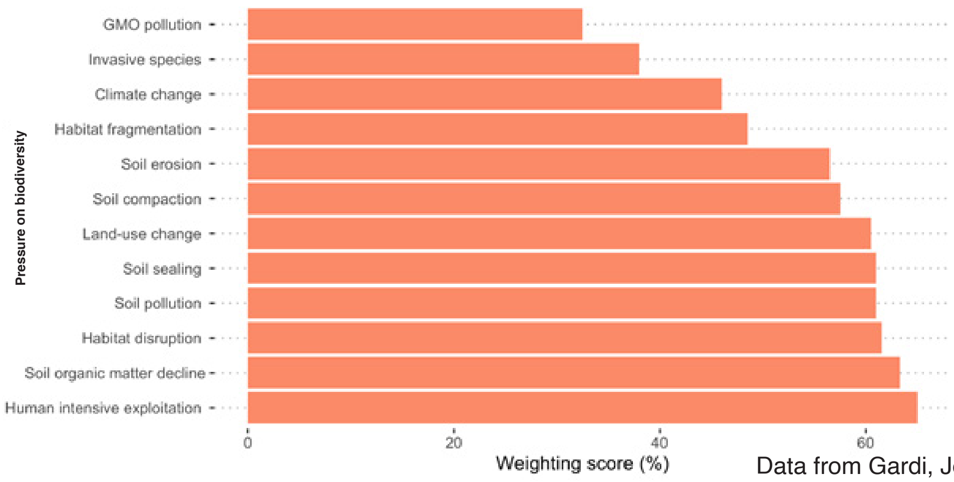
IUCN Red List Categories: CR - Critically Endangered, EN - Endangered, VU - Vulnerable[18]

Figure 12 Red list data for soil biodiversity covering plants, fungi and protists, insects and collembolan (as of 2020)

3.6 Threats to soil ecosystems

Land degradation has multiple anthropogenic drivers, including climate change and agricultural practices that degrade soils through, for example, tillage, pollution, compaction, erosion and removal of organic matter (Gomiero, 2016). Land degradation can have direct or indirect impacts on numerous important ecosystem functions of the soil biota by reducing their abundance and diversity (Wagg et al., 2014). Figure 13 illustrates the most important pressures that land degradation exerts on soil biodiversity.

[18] From the IUCN stats website: https://www.iucnredlist.org/resources/summary-statistics



Data from Gardi, Jeffery and Saltelli (2013)

Figure 13 Summed threat weightings (expressed as a percentage of the maximum possible score) of pressures on soil biodiversity as provided by the Soil Biodiversity Working Group of the European Commission

Soil compaction degrades soil structure by increasing its bulk density or decreasing porosity, leading to stagnating crop yields increased water and nutrient run-off and erosion, and reduced biodiversity (Keller et al., 2019; P. Smith et al., 2016). For example, a study looking at the effects of soil bulk density and soil penetration resistance on the decomposition rates of litter, found that soil compaction affects major soil processes such as decomposition (Carlesso et al., 2019).

Physical soil erosion typically occurs when soil is left exposed to rain or wind energy. Soil erosion leads to reduced productivity or, in extreme cases, to the abandonment of the land (Gomiero, 2016). Studies clearly show that soil erosion negatively affects soil biodiversity. However, the relationship between soil erosion and soil biodiversity is complex (Orgiazzi & Panagos, 2018). The burrowing activity of earthworms or the dense networks of mycorrhizal fungi can reduce the amount of soil eroded by rain or windstorms by keeping soil aggregates more compacted (Burri et al., 2013; Shuster et al., 2002). However, cast production by some earthworm species can also accelerate erosion processes, since cast material could be easily moved away by water (Shipitalo & Protz, 1987).

Land use intensification is another main driver of land degradation. One study found that intensification reduced soil biodiversity and simplified soil community composition, impairing ecosystem functions including decomposition, nutrient retention, and nutrient cycling. Some groups of soil organisms such as nematodes and mycorrhizal fungi were entirely eliminated, whereas fungal and bacterial communities showed reduced species abundance and richness (Wagg et al., 2014). Another study showed that agricultural intensification through the extensive use of pesticides reduced the species diversity of soil biota, especially of larger organisms including earthworms, collembolans, and mites (Tsiafouli et al., 2015). As a result, soil food webs became less diverse and were composed of smaller-bodied organisms (Tsiafouli et al., 2015). Such changes negatively impact multiple ecosystem services provided by soil macrofauna, such as regulation of soil erosion, C sequestration, and water flow and storage (Wagg et al., 2014). The same changes affect the resistance and resilience of soils to extreme climate events, such as drought, leading to elevated C and N loss to drainage and ground water during subsequent rainfall events (De Vries et al., 2011).

3.7 Conclusion to Chapter 3

The greatest variety and abundance of species in agriculture is in the soil, but soil biodiversity remains little understood and monitored. While knowledge of the importance of pollinators and the role of genetic diversity in crop and livestock breeds is reasonably developed, understanding of soil biota and its contribution to ecosystem function is weak: perhaps 90-95% of soil biota remains unidentified and less than 1% of some groups has been described.

Soil is an ecological system in which a vast array of species form complex trophic webs and provide numerous services, including nutrient cycling, decomposition, modification of soil structure, and pest and disease control. There appears to be a close correlation between species diversity and abundance and soil ecosystem function, but this relationship, as well as the interdependencies and competition between soil species, is poorly understood. As a result, management of soil functions can appear as an art rather than a science; an art that to - date relies largely on the expert knowledge and experience of farmers. Improving scientific understanding of the roles of different soil species, and how they can be manipulated to enhance ecosystem services, could make a major contribution to promoting sustainable agriculture.

Farming systems are modified ecosystems that closely depend on biodiversity to function effectively.

As Chapter 5 will show, many progressive farming practices base their success on conserving soil biodiversity in order to improve the flow of ecosystem services, including soil formation and fertility, soil moisture retention, and pest control. These farming approaches additionally provide ecosystem services to off-farm beneficiaries, for example by protecting watersheds to reduce flooding risks, or contributing to climate change mitigation. Governments and beneficiaries alike frequently take these positive externalities for granted, and as a result conserving soil biodiversity is not incentivised or effectively safeguarded.

Currently, hazards such as nutrient pollution and biodiversity loss dominate the discourse on farming and the environment and the value of biodiversity for agriculture is overlooked. A deeper understanding of biodiversity in agriculture, and its contribution to both food production and other societal benefits, will help in identifying incentives and other measures to restore agroecosystems.

Chapter 4

Modelling the outcomes from global improvement in land health

Sustainable management of farm soils and farming landscapes can restore and protect biodiversity while enhancing the overall functioning of agricultural ecosystems, as explained in Chapter 3. Sustainable farming practices provide a range of benefits that accrue directly to the farmer – for example, increased productivity, reduced input costs and reduced risks – as well as benefits that are enjoyed by off-farm and downstream beneficiaries. These 'positive externalities' are a vital aspect of sustainable agriculture and they likely hold the key to incentivising large-scale adoption of sustainable practices. This chapter shows how these benefits can be monetised to help strengthen the case for sustainable agriculture.

'Four per thousand,' an international initiative launched by the French government in 2015,[19] is a drive to restore agricultural ecosystems in order to improve food security as well as combat climate change. Known as '4‰' for short, the initiative aims to increase SOC in the top 30-40 cm of soil by 0.4% annually through the implementation of economically viable and environmentally sound agronomic practices. SOC is one of the most commonly accepted indicators of sustainability in agricultural land. A relative change in SOC concentration may be assumed to correlate with changes in soil biodiversity and the generation of supporting ecosystem services (Brady et al., 2015). The following section estimates the value of meeting the 4‰ targets in three domains: climate change, food production and green water stocks.

BOX 1 SUMMARY OF THE GLOBAL BENEFITS OF INCREASING SOC CONCENTRATION IN AGRICULTURAL LAND BY 0.4% PER YEAR

Achieving the goals of 4% could:

- Capture approximately 1 Gt C per year over the next 30 years, equivalent to 10% of global anthropogenic emissions;
- Avoid social costs of US$ 600 billion per year through climate change mitigation over the 2020 - 2050 time horizon;
- Boost production of maize, wheat and rice between 2020 and 2050 by 23.4%, 22.9% and 41.9% respectively (increases worth a combined US$ 135.2 billion per year);
- Help meet the goal of eliminating hunger by 2030, with regions including Africa enjoying the greatest productivity improvements;
- Store an additional 37 billion m^3 of water in soils, reducing global irrigation demand by 4% and saving an estimated US$ 44 billion per year, and;
- Increase the resilience of farming communities in the face of climate change, reduce reliance on inorganic fertiliser and the resultant pollution, and offset the demand for further land conversion.

[19] www.4per1000.org

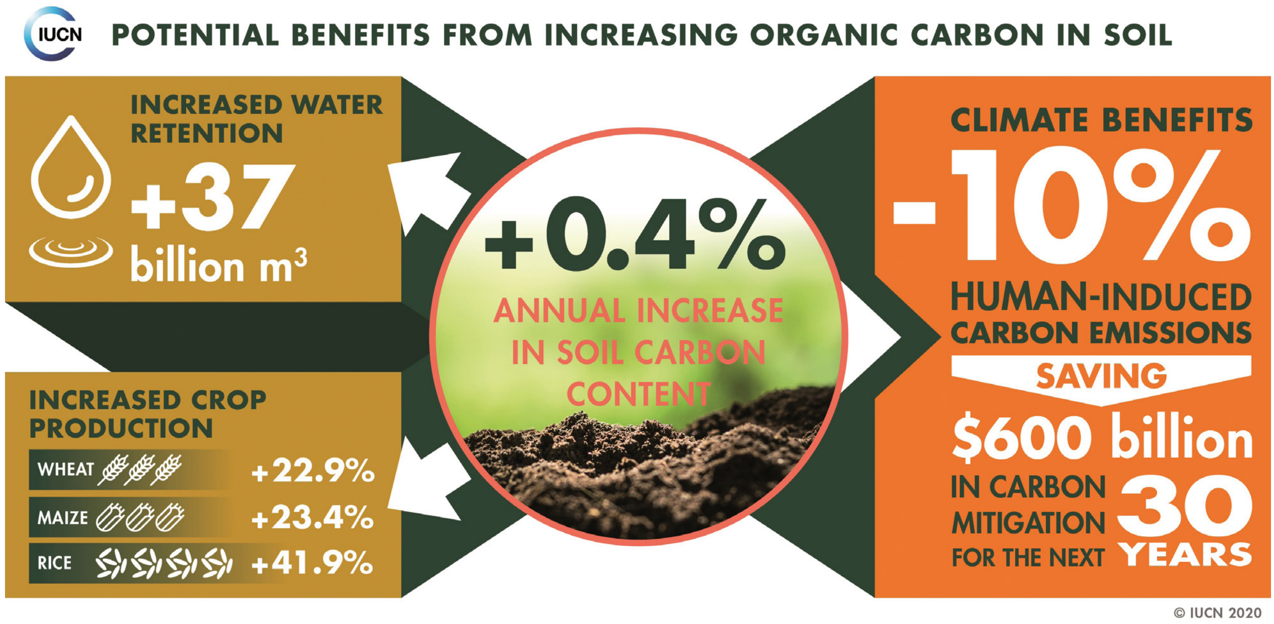


Figure 14 Towards the four per 1000: diverse benefits from increased soil carbon in soils

4.1 The benefits of achieving the 4‰ goals

If implemented globally (including in non-agricultural areas such as peatlands and forests), achieving the 4‰ target could remove 6 Gt C per year from the atmosphere, offsetting two-thirds of annual anthropogenic CO^2 emissions (Chabbi et al., 2017). Increasing SOC stocks in order to counter climate change has a number of benefits such as enhancing soil biodiversity and productivity, increasing yields, reducing erosion, increasing water retention, lowering fertiliser requirements, and enhancing crop resilience to climate variability (Laban et al., 2018).All of the aforementioned biophysical benefits have tangible impacts on human well-being. Furthermore, these benefits can be monetised in terms of, for example, avoided damage from CO^2 emissions or improved crop yields.

This section summarises the work of Westerberg and Costa commissioned for this report (unpublished)[20] to estimate the benefits from improved C sequestration and agricultural productivity within a time-horizon of 2020 to 2050 – of a 4‰ strategy in cultivated croplands and grasslands (see Box 1).[21] The results are based on a simplified model that provides a basis to assess some benefits of C sequestration in soils. The model does not account for biodiversity impacts, for two reasons: firstly, because increasing SOC does not always mean higher biodiversity and there is a need to better assess potential trade-offs; secondly, because the model does not account explicitly for the re-diversification of agricultural landscapes and increased use of crop rotations that is central to restoring SOC.

[20]The analysis is based on publicly available data. Spatial data sets included 1) estimates of SOC, 2) soil bulk density, 3) the location of cultivated land and grasslands, and 4) yields for the major agricultural commodities. Data on agronomic processes include meta-analysis of yield response for maize (Oldfield et al., 2019) and time-dependent rate of soil C uptake in soils (Minasny et al., 2017). Economic data includes the prices of major agricultural commodities in the year 2018 and estimates of the social costs of C under different discount rates.
[21]The value of increases in agricultural productivity is estimated with respect to croplands only, whilst the benefits from enhanced C sequestration applies to both grasslands and croplands.

4.1.1 Carbon and climate: potential for sequestration and climate mitigation

CO2 is a key greenhouse gas and its increased emission contributes considerably to global warming and climate change. The global C cycle includes a significant C stock in terrestrial soils including agricultural soils. Global land and soil degradation is strongly linked to the depletion of this stock.

Modelling the implementation of the 4‰ strategy from 2020 to 2050 shows agricultural soils globally sequestering up to 1 Gt C per year in the first metre of soil. C uptake is initially at a higher rate as many soils are currently depleted, and the rate of uptake declines over time. The potential for C storage in soil may be influenced by increasing temperature and extreme events, which have not been taken into account here. SOC is mainly accumulated in the topsoil where it is also more easily influenced through management practices. For these uppermost 30-40 cm of soil, the model calculates a sequestration potential of about 0.7 Gt C per year, approximately 1.6% of global C emissions in 2018 (37 Gt).[22] The C sequestration potential in cropland is about two times higher than in managed pastureland, even though the global surface is less than half (Figure 15).

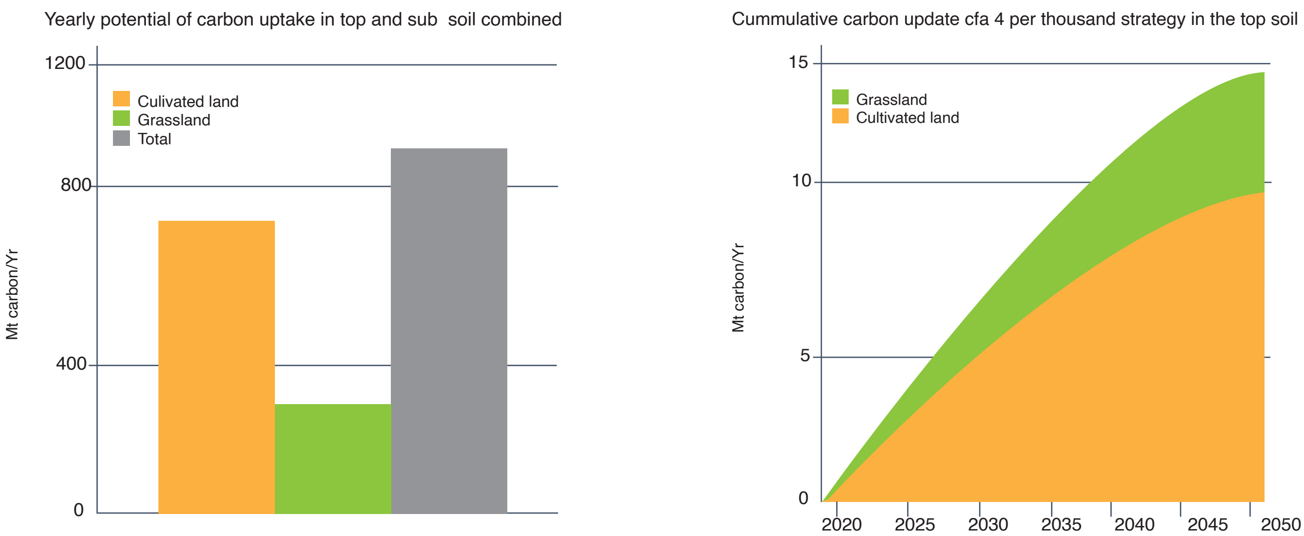


Figure 15 Potential annual and cumulative carbon uptake in global cultivated land and grasslands under the 4‰ initiative

The value of the avoided social damage costs of implementing a 4‰ strategy is an estimated US$ 600 billion per year. For comparison, natural disasters in 2017 have been estimated to have caused overall economic losses of US$ 340 billion.[23]

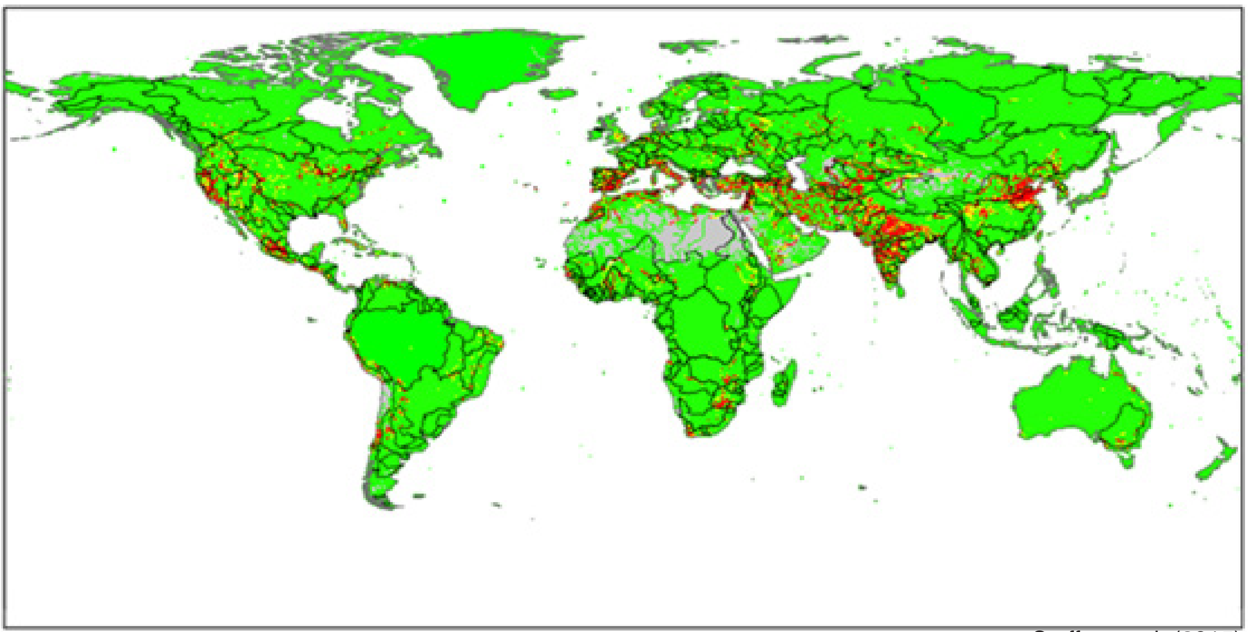
This result still needs to be refined, especially because stocking more C in soil requires other elements, especially N. More detailed modelling would consider the need for increased use of N-containing fertilisers, and the implications for increased N^2O emissions.

In addition, the model should examine the reversibility of SOC storage following events such as drought, or following changes in land use.

4.1.2 Water: Enhanced soil water storage and reduced irrigation demand

Global freshwater withdrawal is approaching the planetary boundary, as noted in Chapter 2, and shows major regional disparities, with some countries already experiencing water stress (Figure 16).[24] Most water withdrawals are for irrigation. Efficient water use is especially important in dry areas.

[22] https://www.scientificamerican.com/article/co2-emissions-reached-an-all-time-high-in-2018/ & https://www.theguardian.com/environment/2018/dec/05/brutal-news-global-carbon-emissions-jump-to-all-time-high-in-2018
[23] https://www.munichre.com/topics-online/en/climate-change-and-natural-disasters/natural-disasters/topics-geo-2017.html
[24] www.stockholmresilience.org/research/planetary-boundaries/planetary-boundaries-data.html



Steffen et al. (2015)

Figure 16 Freshwater use and planetary boundaries: green shows use within the planetary boundary (safe); yellow indicates countries in the 'zone of uncertainty' (increasing risk); and red shows where water use exceeds the boundary (high risk)

The modelling of the 4‰ strategy shows that the calculated C uptake of up to 1 Gt per year could enhance the water storage capacity of soils by up to 1.25 billion m^3 per year (Figure 15). This would allow for a gradual decrease of global irrigation withdrawals from 907 billion m^3 in 2020 to 870 billion m^3 by 2050, assuming all other parameters like irrigated surface, irrigation efficiency or climate change effects are held constant. This corresponds to an annual reduction of 4‰. In this way, improved water storage in soils richer in SOC can alleviate the growing pressure on water resources for irrigation. This is particularly relevant for regions that are already facing water scarcity, or where water scarcity is projected to increase due to climate change and other drivers.

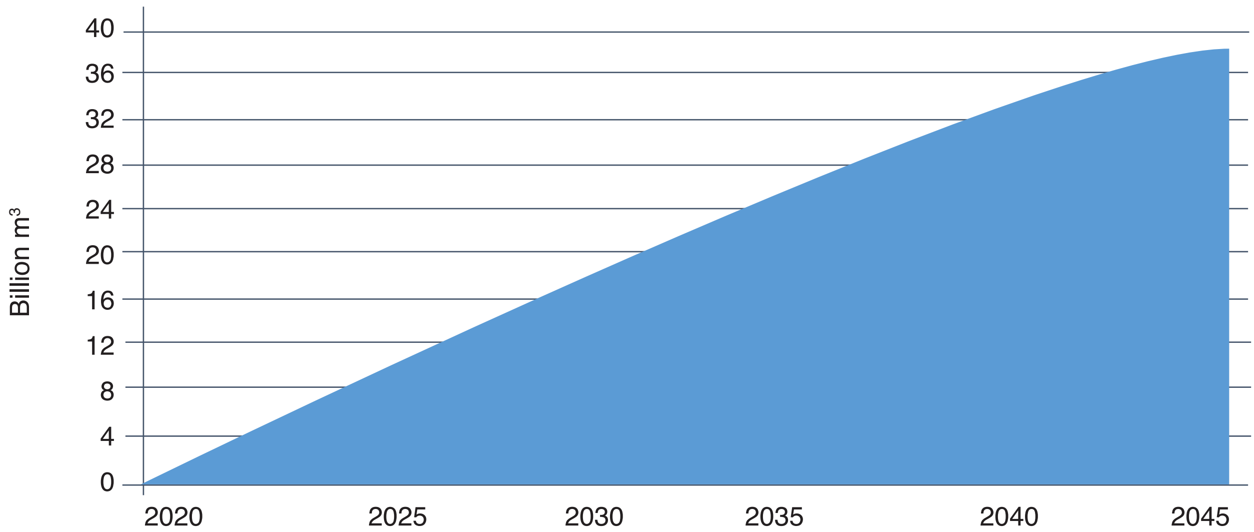


Figure 17 Cumulative savings in irrigation withdrawals as a resulting of adopting the 4‰ strategy (all other factors remaining constant)

The water saving shown in Figure 17 is likely to constitute the upper range of the potential savings, given that there are other factors such as moisture loss from evapotranspiration that are not accounted for. Furthermore, some crops take water from below the topsoil where most SOC, and so most water, is stored. On the other hand, irrigation is also associated with water losses, between the moment water is withdrawn and the moment it reaches the roots of plants. It is thus fair to assess increased water retention with potentially reduced need of irrigation water for equivalent magnitude. Nevertheless, in such a scenario, irrigation could be reduced but is likely to rise in Africa in the coming decades.

4.1.3 Food: global yield benefits for staple crops

Global yields of rice, maize and wheat benefit from a 4‰ strategy that sequesters up to 1 Gt C per year (Figure 16). Average yields of rice may increase by more than 40% from about 4.3 t/ha in 2020 to 6.1 t/ha in 2050 (omitting the effects of changing production techniques or climate). At the same time, average maize yields are estimated to rise by 23% from 4.7 t/ha to 5.8 t/ha. For wheat, the yield increase is also estimated at 23%, increasing from 3.5 t/ha to 4.3 t/ha.

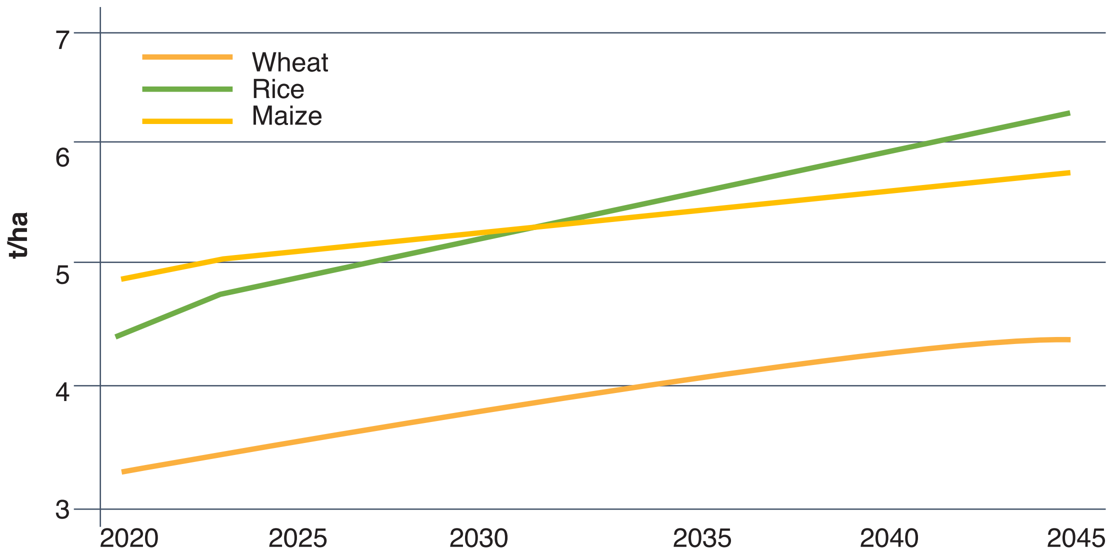


Figure 18 Global yield gains from higher SOC through the 4‰ strategy

In terms of the spatial distribution of yield benefits, Figure 17 shows the gains for maize between the years 2020 and 2050. For most developed countries, the expected increase is in the range of 5% to 25%. For African countries, additional C uptake following a 4 per 1000 strategy has a substantial impact on projected yields of maize, often above 25%. Nevertheless, it is important to keep in mind that current yields in these countries are lower than in developed countries.

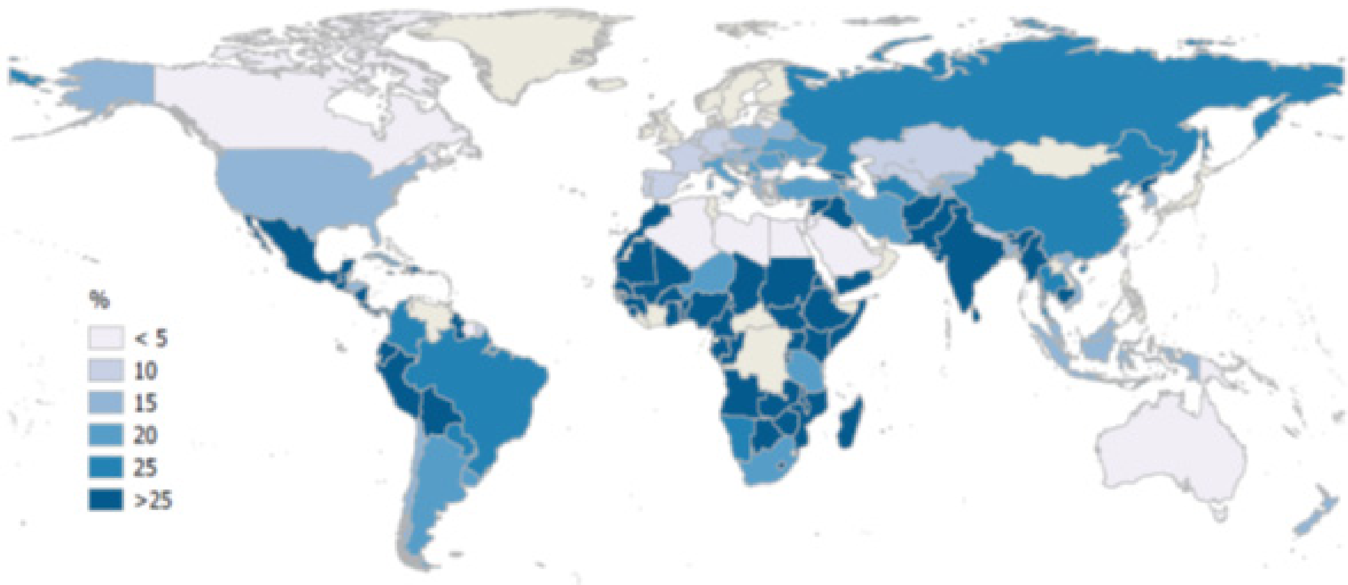


Figure 19 Estimated percentage gains in maize yield between 2020 and 2050 from the 4‰ strategy

Based on the modelling of increased SOC through a 4‰ strategy, the associated increase of food production can be considerable. For example, for Bangladesh, rice yields are estimated to increase by about 43%. This equates to 1.3 million tons of rice each year between 2020 and 2050, or 2.5% of its total rice production in 2017. Another example is the US, where maize yields could rise by 14% and wheat yields by 20%.

4.2 Conclusion to Chapter 4

The results presented in this section are preliminary estimates intended to illustrate the potential changes associated with the 4‰ initiative. The model does not take into account the effects of climate change on C sequestration potential, nor the impact that climate change can have on crop yields. Stocking more C in soil requires other elements, especially N. More detailed modelling would consider the need for increased use of N-containing fertilisers, and the implications for increased N^2O emissions. In addition, the model should examine the reversibility of SOC storage following events such as drought, or following changes in land use.

A more complete analysis would also model potential implications for biodiversity, assessing possible trade-off between SOC sequestration and biodiversity protection. This would include estimating the impact on pollinators of increased use of herbicides in no-tillage systems. Further complexities arise in modelling the impact of re-diversifying crops and re-complexifying landscapes.

The chapter provides a first estimate of the global values that restoring land health could potentially generate through increased SOC concentration, analysing the benefit of meeting the 4‰ targets in three domains: climate change, food production and green water stocks. These results require further analysis, especially to better integrate climate impacts and examine the implications for biodiversity. However, these results already highlight the multiplicity of values and the scale of benefits associated with soil health. They advocate for urgent adoption of more SLM practices on a global scale.

Chapter 5

Sustainable agriculture for managing land health

The estimated benefits of increasing SOC on agricultural land by 4‰ per year make a compelling case for widespread adoption of suitable farming practices. A wide variety of farming systems and practices have been documented that can contribute to increasing SOC, some of which are already widely used. These practices may go by various names and it is as important to agree on the fundamental principles of sustainability as it is to promote specific solutions or concepts. Agreeing on specific metrics and standards for agricultural sustainability – such as SOC content – can be an important step on the way to establishing incentives that encourage farmers and other actors to adopt the most appropriate practices according to their circumstances.

The term 'sustainable agriculture' is presented in the following section as an overarching goal. Sustainable agriculture can be seen as a subset of SLM, which has been defined as: "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" (UNCCD, 2016). SLM is a broad inter-sectoral approach that can contribute to (but is not limited to) sustainable agriculture. Hundreds of SLM practices have been documented, for example through the World Overview of Conservation Approaches and Technologies,[25] many of them traditional farming practices that have endured for centuries, although in some cases they have needed reviving and adapting to changing socio-economic, climatic and institutional environments (Liniger & Critchley, 2007). Well-known SLM practices include agroforestry, Low-External-Input and Sustainable Agriculture (LEISA), summer fallows, mobile pastoralism, pasture leys, and a wide range of methods to locally boost SOC and moisture (Schwilch et al., 2012).

Different actors use the terminologies in the following sections inconsistently. To minimise confusion, the chapter examines some of the most commonly used concepts, approaches, farming systems and practices that may contribute to sustainable agriculture.

5.1 Sustainable agriculture: an aspirational goal

Sustainable development is commonly defined in terms first published in the report *Our Common Future* (also known as the Brundtland Report) as: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (World Commission on Environment and Development, 1987) .

Consistent with this definition of sustainable development, FAO defines sustainable agriculture development as "the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such development ... conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable" (Food and Agriculture Organisation, 1988).

FAO has proposed five principles of sustainable food and agriculture that balance the social, economic and environmental dimensions of sustainability (Food and Agriculture Organisation, 2014a):

1. Improving efficiency in the use of resources;
2. Conserving, protecting and enhancing natural ecosystems;
3. Protecting and improving rural livelihoods and social well-being;
4. Enhancing the resilience of people, communities and ecosystems, and;
5. Promoting good governance of both natural and human systems.

In practice, there are numerous definitions and interpretations of sustainable agriculture and the concept remains somewhat ambiguous. The Royal Society argues that agricultural sustainability must be determined based on four principles (The Royal Society, 2009):

[25] https://www.wocat.net/en/

1. Persistence: the capacity to continue to deliver desired outputs over long periods of time (human generations), thus conferring predictability;
2. Resilience: the capacity to absorb, utilise or even benefit from perturbations (shocks and stresses), and so persist without qualitative changes in structure;
3. Autarchy: the capacity to deliver desired outputs from inputs and resources (factors of production) acquired from within key system boundaries, and;
4. Benevolence: the capacity to produce desired outputs (food, fibre, fuel, oil) while sustaining the functioning of ecosystem services and not causing depletion of clean water.

According to these principles, any system will be unsustainable if it depends on non-renewable inputs, cannot consistently and predictably deliver desired outputs, can only do this by requiring the cultivation of more land, and/or causes adverse and irreversible environmental impacts (The Royal Society, 2009).

Sustainability of agriculture is sometimes considered to lie along a continuum of increasing complexity, from improved system efficiency and reduced inputs (level I), to systems that are redesigned according to ecological principles (level III), and ultimately to the highest level in which the system is fully embedded in the social and economic pillars of sustainability (level V) (S. R. Gliessman & Engles, 2014). Concerns have been frequently raised that sustainable agriculture focuses too much on the lower levels of this continuum while neglecting higher levels (Cook et al., 2015)
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Embedding agriculture in the social and economic pillars of sustainability raises particular questions surrounding the aims of agriculture and the aims of economic development, including how to reconcile growth and consolidation of farming enterprises with rural poverty reduction and job creation. The social dimensions of sustainability in agriculture require greater attention to identify suitable targets and indicators as well as to identify a wider range of potential solutions. For example, closing the gender gap in agriculture could deliver productivity gains and it has been estimated that, with equal access to productive resources, women could increase yields on their farms by 20-30%. This could raise total agricultural output in developing countries by 2.5-4% and reduce the number of hungry people in the world by an estimated 12-17% (Food and Agriculture Organisation, 2011).

If agreement can be reached on the goals of sustainable agriculture, it then becomes possible to agree on targets and indicators of progress. Once these are agreed it becomes feasible for farmers and other actors to evaluate different approaches, activities and practices for their contribution to achieving the designated targets (for a more thorough review of sustainable farming approaches, see Oberc & Arroyo Schnell, 2020).

5.2 Sustainable agriculture: a variety of perspectives

There are many different ways to farm more sustainably that are already in use around the world, and many different terminologies are used to describe them, creating a source of confusion and unhelpful disagreement. Some of the widespread terms are outlined briefly below to illustrate the diversity of perspectives. As already mentioned, definitions of sustainability differ and therefore the relative sustainability of different approaches, according to different criteria, may be contested.

5.2.1 Sustainable intensification

Sustainable intensification refers to intensifying agriculture without adverse environmental impacts. Sustaining the future viability of agriculture requires a paradigm shift to reposition agriculture as a key contributor to the global transition to a sustainable world. Sustainable intensification of agriculture should “integrate the dual and interdependent goals of using sustainable practices to meet rising human needs while contributing to resilience and sustainability of landscapes, the biosphere and the earth system” (Johan Rockström, et al., 2017).

The goal of sustainable intensification is to raise productivity, rather than to raise production, while reducing environmental impacts. Productivity is commonly defined as a ratio between the output volume and the volume of inputs. In other words, it measures how efficiently production inputs, such as labour and capital, are being used in an economy to produce a given level of output (Organisation for Economic Cooperation and Development, 2001). Sustainable intensification can be interpreted as increasing yields per unit of inputs (including nutrients, water, energy, capital and land) as well as per unit of 'undesirable' outputs (such as GHG emissions or water pollution) (Garnett & Godfray, 2012).

The concept of sustainable intensification has received criticism due to the divergent ways in which the term is used and the different goals that it supports (Tittonell, 2014). For example, the focus on increased productivity has been used to support the ongoing drive in the agriculture sector for higher yielding varieties, including genetically modified organisms, many of which require higher levels of external inputs to achieve their potential (Cook et al., 2015). Part of the challenge with the term is the different interpretations of 'intensification,' and different opinions on whether this implies increasing production. Another part of the challenge lies in defining 'sustainability,' the expected balance between the three pillars of sustainability, and the scale at which sustainability is measured.

5.2.2 Ecological intensification of agriculture

The term ecological intensification has been popularised to emphasise practices that make "intensive and smart use of the natural functionalities of the ecosystem (support, regulation) to produce food, fibre, energy and ecological services in a sustainable way" (Tittonell, 2014). Concern has been voiced over the lack of detailed understanding on the ecological interactions within agricultural systems and landscapes and the economic value of ecosystem services associated with agriculture (Robertson & Swinton, 2005). Ecological intensification emphasises processes that operate beyond the farm boundary – such as water supply and climate regulation – necessitating a greater scale of analysis. Ecological intensification addresses the complexity of the wider agroecosystem, or agricultural landscape, and therefore is consistent with current approaches to landscape and ecosystem management (Tittonell, 2014).

Ecological intensification entails "the environmentally friendly replacement of anthropogenic inputs and/or enhancement of crop productivity, by including regulating and supporting ecosystem services management in agricultural practices" (Bommarco et al., 2013). It aims to match or increase yields while minimising negative impacts on the environment and on agricultural productivity, by integrating the management of ecosystem services delivered by biodiversity into production systems. "Effective ecological intensification requires an understanding of the relations between land use at different scales and the community composition of ecosystem service-providing organisms above and below ground, and the flow, stability, contribution to yield, and management costs of the multiple services delivered by these organisms" (Bommarco et al., 2013).

5.2.3 Agroecology

Agroecology is one of the oldest documented sustainable agriculture approaches, first defined as long ago as 1928. Other approaches to, or concepts for sustainable agriculture have evolved from, or are based on agroecology. Agroecology is a broad term that has been applied to a scientific discipline, a set of practices, and a social movement (Silici, 2014; Wezel et al., 2009). The science of agroecology studies how components of the agroecosystem interact, while the practice of agroecology aims for sustainable farming systems that optimise and stabilise yields. The agroecology social movement promotes the multifunctional roles of agriculture while promoting social justice, nurturing identity and culture, and strengthening the economic viability of rural areas. In many interpretations of agroecology, it is family farmers who are the knowledge holders and key actors for producing food in an agroecological way (Wezel et al., 2009).

Agroecology aims to increase the quantity of agricultural output and enhance its quality, manage pest populations more efficiently and effectively, and reduce reliance on inputs, by 1) increasing biological diversity in agroecosystems and 2) optimising biological interactions in those agroecosystems. Agroecology is commonly defined at plot, farm and landscape levels (Malézieux, 2012).

FAO describes agroecology as “based on applying ecological concepts and principles to optimise interactions between plants, animals, humans and the environment. By building synergies, agroecology can support food production and food security and nutrition while restoring the ecosystem services and biodiversity that are essential for sustainable agriculture.

Agroecology can play an important role in building resilience and adapting to climate change.”[26] FAO identifies the following elements of agroecology, which are interdependent:

- Diversity; synergies; efficiency; resilience; recycling; co-creation and sharing of knowledge (describing common characteristics of agroeco logical systems, foundational practices and innovative approaches)
- Human and social values; culture and food traditions (context features)
- Responsible governance; circular and solidarity economy (enabling environment)

5.2.4 Organic farming

Organic farming and biodynamic farming are related approaches that have different definitions in different countries despite having common origins (Vogt, 2007). In loose terms, they include farming that eschews the use of synthetic fertiliser and pesticides. Organic farming is defined by the International Federation of Organic Agriculture Movements as: “a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic Agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved.”[27] The federation identifies the following four principles of organic farming:

1. Health: healthy soil, plants, animals, humans
2. Ecology: emulating and sustaining natural systems
3. Fairness: equity, respect and justice for all living things
4. Care: care for generations to come

Some studies have shown that, compared to conventional farming, organic farming tends to stimulate above- and below-ground biodiversity. They also highlight three broad management practices that are largely intrinsic, although not exclusive, to organic farming, and that are particularly beneficial for farmland wildlife: prohibition or reduced use of chemical pesticides and inorganic fertilisers; sympathetic management of non-cropped habitats; and preservation of mixed farming (Hole et al., 2005). However a recent meta-analysis showed that organic agriculture had a significantly lower (-15%) temporal yield stability (the variability and reliability of production across years) as compared to conventional agriculture (Knapp & van der Heijden, 2018). The study also indicates that the use of green manure and enhanced fertilisation can reduce this yield stability gap.

5.2.5 Regenerative agriculture

Launched in the early 1980s by Robert Rodale (Gold & Gates, 2007), and originating in the United States, regenerative agriculture seeks to enhance and sustain the health of soil by restoring its organic matter, boosting its fertility and productivity, and reducing but not necessarily eliminating synthetic pesticides and fertilisers. Its primary focus is on soil health, with the aim to increase agricultural yields and adaptation to climate change.

[26] www.fao.org/agroecology/home/en (accessed July 2019)
[27] www.ifoam.bio/en/organic-landmarks/definition-organic-agriculture (accessed July 2019)

A recent published review of multiple sources defines regenerative agriculture as “a system of principles and practices that generates agricultural products, sequesters carbon, and enhances biodiversity at the farm scale” (Burgess, 2019).

The report identifies five major practices widely associated with regenerative farming:

- Abandoning tillage
- Eliminating bare soil
- Fostering plant diversity
- Encouraging water percolation into the soil
- Integrating livestock and cropping operations

The most frequently associated practices are no-till or reduced tillage, permanent cover and diversity in crops rotations, use of compost and animal manure, biological diversification (for instance through inter-cropping, agroforestry, silvopastoralism) and sustainable grazing (such as rotational grazing and pasture cropping).

Regenerative agriculture therefore focuses on soil health, but its scope is broader than conservation agriculture (described below), as it also considers livestock farming, and involves the mixing of crops and livestock, to further boost soil quality and on-farm fertility. While most examples of implementation of regenerative agriculture are found in the United States, the approach is gaining recognition and interest in Europe with support from the private sector and international groups such as the Food and Land Use Coalition (FOLU).

5.2.6 Mixed farming

Farming in many countries has traditionally involved a combination of crops and livestock, which are interdependent. Livestock can provide an important income stream, or a valuable source of protein, while yielding manure that maintains soil fertility along with numerous other ecological and economic services. Crop residues, by-products, and fodder crops are in turn used to sustain livestock (Thiessen Martens & Entz, 2011). Production of livestock and crops on the same farm is referred to as mixed farming and is still the most common farming system in developing countries, and was formerly also the norm in developed countries before the emergence of specialised farms.

Today, mixed farming systems are once again gaining popularity for their capacity to recouple crops and livestock production and to contribute to the closing of C, N and P cycles. They are seen as an option for reducing losses in the environment and limiting detrimental impacts, while increasing resilience through diversification of sources of income. In order to build more resilient and sustainable farming systems, researchers and policy makers see mixed farming as a possible alternative to specialisation. They use the principles of the circular economy, recycling nutrients more efficiently than specialised systems, using crops and grasslands for animal feeding and in return organic manure for fertilisation or biogas. In many countries, these systems also make the best use of animal power (for ploughing or transport, for instance) when mechanisation is not affordable, thereby reducing the use of fossil fuels.

Fertilisation using compost or fresh manure in cultivated systems can help maintain some production between main growing seasons while limiting the quantity of external inputs required. Manure quality is therefore an important consideration for sustainable agriculture because it has a direct bearing on the biological properties of soil, including its structure and organic matter content, as well as enhancing N fixation and weed control, which impacts on the land productivity (Erisman et al., 2017; Thiessen Martens & Entz, 2011).

5.2.7 Pasture management and sustainable grazing

Grazing land constitutes an estimated 3.6 billion hectares of land globally and supports a range of essential ecosystems functions including production of food, forage and water (Xu et al., 2018). Land productivity can be enhanced through good grazing practices which impact positively on aspects of land health, including water retention and infiltration, forage production, nutrient cycling, C accumulation, root processes and ecosystem sustainability (Thornton & Herrero, 2010; Xu et al., 2018).

The aim of pasture management and sustainable grazing is to enhance land productivity by managing herbivores as tools in a pre-determined grazing management system. This can involve continuous or rotational grazing and can be most easily established on privately owned land with few decision makers (Briske et al., 2008; Nordborg & Roos, 2016). However, in open access resource systems, which include the global rangelands of sub-Saharan African and Central and South America, land resource management remains a complex challenge. SLM in this context lies in recognising the importance of ecological, social and economic interactions and their impacts on land health (Gray et al., 2016).

Good grazing management therefore relies on knowledge of the ecological complexity of grazing land and the ecological processes and responses emanating from management decisions. This is usually context specific but relies overall on the principles of timing, intensity and frequency of grazing (Davies et al., 2015). Herbivore stocking rates then become the variable tool in the system to achieve the intended land management objectives in the short- and long term. In many countries, the predominant system of pasture management and sustainable grazing is pastoralism (including agropastoralism, silvopastoralism and other derived or related systems).

Pastoralism – defined as extensive livestock production on rangelands (Davies et al., 2010) – relies primarily on natural pastures and shrublands as a source of livestock fodder and is seen by many as an environmentally sustainable food production system that contributes to conserving biodiversity. It is practised on between one-quarter and one-third of the global land area (McGahey et al., 2014). Pastoralism often depends on organised herd movements to make seasonal use of different natural resources, and herd mobility is often essential for maintaining land health. It is sometimes classified in three general systems: settled, nomadic and transhumant (Weber & Horst, 2011).

Pastoralism is a traditional land use system that has been modernised to different degrees around the world. In some countries, rangelands still provide the majority of fodder, while in other countries this is supplemented with cultivated feeds. The use of external inputs varies according to the degree of commercialisation of products from pastoralism. The positive and negative environmental impacts of pastoralism vary greatly according to the management system, the effective movement of herds, and the overall pressure on natural resources (Davies et al., 2010; McGahey et al., 2014; Scoones, 1995).

5.2.8 Conservation agriculture

Conservation agriculture generally refers to a farming approach built on three main principles:[28]

1. Minimum mechanical soil disturbance (no tillage) through direct seed and/or fertiliser placement;
2. Permanent organic soil cover (of at least 30%) with crop residues and/or cover crops, and;
3. Species diversification through varied crop sequences and associations involving at least three different crops.

Conservation agriculture has been found to enhance biodiversity and natural biological processes above and below ground, contributing to improved water and nutrient use efficiency and improved crop production (Shah & Wu, 2019). The European Conservation Agriculture Federation describes conservation agriculture as: “a sustainable agriculture production system comprising a set of farming practices adapted to the requirements of crops and local conditions of each region, whose farming and soil management techniques protect the soil from erosion and degradation, improve its quality and biodiversity, and contribute to the preservation of the natural resources, water and air, while optimising yields.”[29]

It is important to note that, while conservation agriculture generates a number of benefits, it most often makes use

[28] http://www.fao.org/conservation-agriculture/en/
[29] http://www.ecaf.org/ca-in-europe/what-is-ca

of herbicides to manage weeds, which has detrimental effects on soil biodiversity, water quality and farmers health (Lammoglia et al., 2017). Furthermore, the contribution to mitigating climate change, through accumulation of organic C in soil, has sometimes been overstated. A meta-analysis of work on low-tillage agriculture found the increase in SOC to be relatively small. Larger concentrations may be found near the surface, which accounts for some of the benefits to farming, but this C can be lost in cases where the soil is periodically cultivated. However, by protecting soil, conservation agriculture contributes to making agricultural systems more resilient to climate and weather variability, contributing to climate change adaptation (Powlson et al., 2014).

5.2.9 Agroforestry

World Agroforestry (ICRAF) describes agroforestry as "agriculture with trees,"and more broadly as "the interaction of agriculture and trees[30], including the agricultural use of trees." Interactions between trees and other components of agriculture may be important at a range of scales: in fields (where trees and crops are grown together), on farms (where trees may provide fodder for livestock, fuel, food, shelter or income from products including timber) and landscapes (where agricultural and forest land uses combine in determining the provision of ecosystem services).

The integration of trees into agricultural landscapes has the potential to generate a number of improvements for soil organisms and for crop growth (Barrios et al., 2013). In agroforestry systems there are both ecological and economic interactions between the different components. Agroforestry is described by FAO as "a dynamic, ecologically based, natural resource management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels.[31]" Agroforestry systems are multifunctional systems that can provide a wide range of economic, sociocultural, and environmental benefits. Three main types of agroforestry systems have been described:

1. Agrisilvicultural systems with a combination of crops and trees, for example as alley cropping, live hedges and windbreaks or in home gardens;
2. Silvopastoral systems combining forestry and grazing of domesticated animals on pastures or rangelands;
3. Agrosilvopastoral systems in which the three elements – trees, animals and crops – are integrated, for example within home gardens or as scattered trees on cropland which provide fodder (or browsing after crops are harvested).

Agroforestry has the potential to raise incomes, improve food security, and conserve biodiversity and ecosystem services, so contributing to improved adaptation to climate change, as well as to climate change mitigation through increased C sequestration (Hillbrand et al., 2017). Agroforestry has been used to improve soil quality, reduce soil erosion or salinity and to improve water quality. Agroforestry systems increase ground cover and soil organic matter, thereby reducing water runoff and soil evaporation and increasing water infiltration rates and water retention capacity, making more water available for plant production in all soil layers. Farmer Managed Natural Regeneration (FMNR) is an agroforestry movement that has been very successful in restoring forests and grasslands and improve livelihoods in the Sudano-Sahelian ecozones of Africa (Binam et al., 2015).

Agroforestry can, to some extent, be considered an effective measure to counterbalance deforestation and the consequent loss of above-ground biodiversity that also negatively impacts below-ground biodiversity (Barrios et al., 2013), although agroforestry is not a replacement for primary forests. The integration of trees promotes soil biota in many ways, including increased organic matter input and nutrients to soils (Barrios et al., 2013). Pruning and mulching creates an organic top layer of the soil that helps to minimise erosion and promote soil moisture, supporting the activity of soil organisms, while providing C and nutrients which sustain crop yields (Barrios et al., 2013; Castro et al., 2009). Trees in agroforestry systems also provide shade which can lower soil temperature, resulting in reduced water losses and maintenance of suitable soil moisture for crop growth (Barrios et al., 2013; Lin, 2010).

[30] http://www.worldagroforestry.org/about/agroforestry

[31] http://www.fao.org/forestry/agroforestry/80338/en/

5.2.10 Other sustainable farming systems and practices

The farming systems and practices presented above do not cover all the options available but are intended to give an indication of how sustainable farming achieves its objectives by protecting soil biodiversity and ecosystem function. Many other approaches could be included, such as the protection of natural rangelands and permanent pastures, using cover crops to promote soil and nutrient retention between crop cycles, or incorporating crop residues to maintain soil organic matter, which assists in water retention and nutrient provision to crops (Power, 2010).

Diversification of crop land is another practice that enhances the complexity of crop species (Gan et al., 2015). Polycultures diversify agriculture and enhance overall productivity and ecosystem services through either intermixing different crops (row intercropping system, relay cropping), combining crops with beneficial neighbouring plants for pest control or pollination, and rotating cover crop polycultures and cash crops (Finney & Kaye, 2017). The above farming practices often share a similar understanding of the problems and a largely overlapping set of solutions. Developed mostly at species or farm level, they contribute to land health on farms and in agricultural landscapes.

5.3 Managing land health on farms and in agricultural landscapes

Agrobiodiversity can be examined at three distinct levels: landscapes, farms, and species (the genetic level). Starting at the macro scale, this section looks at the role of sustainable management of agricultural landscapes in maintaining critical ecosystem functions, including both those that support agriculture and those that are enjoyed outside the farming landscape. At farm level we examine how farming practices influence biodiversity that direct impacts on productivity, including soil ecosystem functions. At the genetic level, biodiversity includes the crop and livestock species that are bred and conserved by farmers, but also soil biodiversity and other species that contribute to farm productivity and resilience. However, as Chapter 3 has already shown, there are major knowledge gaps in this domain.

5.3.1 Conserving biodiversity in agricultural landscapes

Agricultural landscapes are highly diverse, from structurally simple landscapes dominated by one or two crops to complex mosaics of diverse crops embedded in natural and semi-natural habitat. Agricultural landscapes may include areas of woodland, pasture or wetland that are often integral to farming economies and also represent important reservoirs of biodiversity. In temperate, intensive agriculture, landscapes include field boundaries and margins that may have been developed originally for agricultural functions, but are often now protected as critical habitat for biodiversity. Biodiversity in agricultural landscapes can include pest species but also pest predators and other beneficial species, such as crop pollinators. Agricultural practices can eliminate much of this biodiversity – both the beneficial and the harmful – and have consequences for species at higher trophic levels, notably farmland birds (Marshall, 2004).

Drawing on the definition of land degradation, sustainable agricultural landscapes should maintain or strengthen the biological and economic productivity and complexity of the landscape, which can be measured through ecosystem services and functions. At the landscape scale, it is necessary also to consider trade-offs between land uses in order to maintain the desired balance of ecosystem functionality.

Agricultural intensification leads to the loss of ecological heterogeneity and to a simplification of landscape structure (Benton et al., 2003). Various studies have reported how intensification has increased the proportion of arable land, decreased permanent pasture or semi-natural habitats, increased field size, increased the use of inorganic fertilisers and pesticides and had numerous other effects that lead to the simplification of landscapes and the loss of biodiversity (Persson et al., 2010). Concern has been voiced over the lack of detailed understanding on the ecological interactions within agricultural systems and landscapes and the economic value of ecosystem services associated with agriculture (Robertson & Swinton, 2005). A recent meta-analysis using a global database from 89 studies in 1,475 locations, analysed the relative importance of species richness, abundance, and dominance for pollination, biological pest control and final yields. Up to 50% of the negative effects of landscape simplification on ecosystem services was due to richness losses of service-providing organisms, with negative consequences for crop yields (Dainese et al., 2019).

There is a tendency to think of biodiversity in agricultural landscapes in black and white terms, and to focus on restoring distinct patches of habitat within the landscape (Billeter et al., 2007). However, this overlooks the considerable divergence in agricultural systems, and the degree to which different management systems conserve biodiversity on productive lands. For example, the integration of trees in production systems (see the description of agroforestry above), management of pasturelands, or protection of field boundaries all contribute to the maintenance of biodiversity within the landscape (Schweiger et al., 2005). A richer understanding of agricultural landscapes and the relative biodiversity retained in different production systems is needed to ensure the optimum use of agricultural land (Norris, 2008).

Biodiversity can be increased in agricultural landscapes by converting productive lands to more natural habitat, either through cessation of production or through reduction in production intensity, or through complexifying landscape patterns. Diverse aspects of land heterogeneity appear to be crucial for biodiversity. A study conducted in eight contrasting regions of Europe and North America across 435 landscapes measured the effect of different interventions on landscape level multitrophic diversity. Increasing crop heterogeneity, decreasing mean field size and increasing semi-natural cover had a strong positive effect (Sirami et al., 2019).

According to a meta-analysis conducted in Europe, the density of hedges also appeared to be critical as a refuge for arthropods with direct impacts on pest control, pollination and yields (Volf et al., 2019). However, there is uncertainty over the implications for agricultural production at scale, and therefore the potential costs and trade-offs to farmers and society (Fahrig et al., 2011). At the same time, there is insufficient research to demonstrate the cost of biodiversity loss in agricultural landscapes. Reduced biodiversity in the landscape reduces agricultural productivity as well as supply of other ecosystem services supporting, for example, water supplies, habitat and health (Perrings et al., 2006).

Society needs to make better-informed choices over the mix of genes, species, and ecosystems retained in agricultural landscapes to maintain the flow of ecosystem services and to balance the trade-offs between food production, biodiversity conservation, ecosystem services, and human well-being. Failure to recognise the full role of biodiversity in agricultural landscapes leads to inattention to the risks associated with the loss of ecosystem services. Maintaining biodiversity in agricultural landscapes enhances the ability of the Earth's biota to respond to climate and other environmental risks (Perrings et al., 2006).

Sustainable management of agricultural landscapes is consistent with IUCN's approach to forest landscape restoration, which is defined as "the ongoing process of regaining ecological functionality and enhancing human well-being across deforested or degraded forest landscapes."[32] Agricultural landscapes are transformed ecosystems that contain variable levels of biodiversity according to factors including their management. Transformed ecosystems can be degraded with respect to their management objectives, and similarly they can be "rehabilitated towards a less degraded state, with respect to the expectation for a deliberately modified landscape" (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 2018).

Rehabilitation towards a less degraded state is consistent with the target of LDN (a target under SDG 15) if biodiversity and ecosystem functions and services are stable or increasing in each of a set of focal ecosystems over a given timeframe (Cowie et al., 2018).

[32] https://www.iucn.org/theme/forests/our-work/forest-landscape-restoration

5.3.2 Farming practices that help conserve biodiversity at the farm level

The vast diversity of soil organisms below ground is intimately linked to above-ground biodiversity and primary producers that perform photosynthesis (De Deyn & Van Der Putten, 2005). In return, above-ground biodiversity depends on the activity of below-ground key functional groups, each of them playing a particular role in contributing to essential ecosystem services and thus maintaining agricultural productivity (Barrios, 2007; Xavier et al., 2010). In this regard, farming practices affect both primary biomass production, key functional groups and soil physical-chemical characteristics (such as soil structure, organic matter, moisture, temperature and chemical content).

Biodiversity can be conserved at the farm level through practices that explicitly promote biodiversity or minimise the negative impacts of agriculture. For example, a range of practices promote soil organic matter including: maximising organic residues as continued feed provision for soil microorganisms (for example using green and animal manure, mulch and harvest residues); optimising the conditions for decomposition of organic matter and release of nutrients (for example, humidity and the ratio of C to N); reducing or optimising disturbance (for instance through no or reduced tillage and minimal compaction); or influencing the chemical state of soils (through the use of fertilisers or lime) (Bot & Benites, 2005). The architecture of the root system of crops is another factor that can be mobilised for enhancing SOM/SOC storage (Kell, 2011). Increasing plant diversity would also enhance C storage in soils.

Reduced tillage or zero tillage, which is a key component of conservation agriculture outlined earlier, is used in several countries as an alternative to ploughing. Reduced tillage helps create a suitable soil environment for growing a crop and for conserving soil, water and energy resources, through both the reduction in the intensity of tillage and the retention of plant residues. Benefits of reduced tillage can include the following (Palm et al., 2014):

- Increased topsoil organic matter
- Reduced erosion and runoff
- Higher water quality
- Higher soil moisture retention, resulting in higher and more stable yields during dry seasons
- Increased soil biodiversity

There is less agreement on the benefits of reduced tillage for carbon sequestration and GHG emissions (Palm et al., 2014). Consequently, no-till may be better viewed as a method for reducing soil erosion, adapting to climate change, and ensuring food security, while the mitigation co-benefit for society is more uncertain (Ogle et al., 2019).

The development of reduced tillage or no tillage has been enabled by broad spectrum herbicides to control weeds, although increasing resistance to herbicides is reported (Triplett & Dick, 2008). While reducing tillage can be beneficial to soil biodiversity, the application of herbicides can be detrimental. Although some studies find the harmful effects of herbicide on soil function to be minor and temporary, others have observed changes to soil function and biodiversity, including changes to earthworm ecology, inhibition of soil N-cycling and site-specific increases in disease (Rose et al., 2016).

Fertilisers have a very distinct influence on soils. While organic fertilisers include a lot of organic material along with the nutrients feeding soil organisms and increasing soil organic matter, synthetic fertilisers focus on just feeding the plants. Nutrients, namely N, are not automatically available to plants when they are in the soil due to different chemical states influenced by many soil conditions and functions (Institute of Medicine and National Research Council, 2015). Bulky organic fertilisers have a low concentration of nutrients and depending on the C:N ratio, can even reduce soil bioactivity. Concentrated fertilisers can have direct negative effects, such as burning plants and reducing their resistance against diseases. Synthetic fertiliser can decrease soil fertility by increasing salinity and acidity. Over-application of fertiliser may lead to important atmospheric pollution, GHG emissions (for instance of CO_2 and N_2O), water eutrophication, and human health risks (Galloway et al., 2008).

A balanced management of C, N and phosphate is fundamental, as those elements are tightly connected. Increase of SOC needs sufficient N and phosphate. Its reduction leads to reduced capacity of cycling N and phosphate and other nutrients (Food and Agriculture Organisation & Intergovernmental Technical Panel on Soils, 2015). An imbalance of nutrients in the soil can also alter plants and reduce their resistance to diseases and their nutritional quality.

Pesticides can do harm to crops, biodiversity and humans, with different impacts on non-target organisms like earthworms, natural predators and pollinators, and soil micro-flora. Pesticides can accumulate in the soil and harm soil biodiversity, affecting the overall functioning of the soil ecosystem and its ecosystem services. This is additional to the potential direct health hazards that pesticides may present to human, for example through contamination of food (Yadav & Devi, 2017).

Irrigation and drainage are another area where conventional farming practices can be unsustainable and where alternative approaches can be found (adapted crops, improved soil organic matter, agroforestry…) e.g Irrigation and drainage can benefit plant growth, but will also alter water flows in quantity and quality. This may have negative effects on general water availability and on the occurrence of extreme droughts and floods, particularly affecting ecosystems and human use downstream (Food and Agriculture Organisation & Intergovernmental Technical Panel on Soils, 2015). Inefficient irrigation and drainage can harm soil structure stability and lead to erosion and water pollution. Water losses may occur between the water withdrawal and the absorption by the plants, for example in inefficient water distribution to the field and on the field or evaporation losses from the soil. Irrigation and drainage can result in important CO^2 emissions, resulting from the mineralisation of SOC, especially in peatlands.

Finally, diversification of crop land is a practice that enhances the complexity of crop species (Gan et al., 2015). Polycultures diversify agriculture and enhance the overall productivity and ecosystem services through either intermixing of different crops (row intercropping system, relay cropping), or the combination of crops with beneficial neighbouring plants for pest control or pollination, crop rotation with cover crop polycultures and cash crops (Finney & Kaye, 2017).

The practices described above indicate just some of the options available to make farms more sustainable by protecting soil biodiversity and ecosystem function. Many other practices could be included, such as using cover crops to promote soil and nutrient retention between crop cycles, or incorporating crop residues to maintain soil organic matter, which assists in water retention and nutrient provision to crops (Power, 2010).

5.3.3 Conserving agricultural genetic diversity

FAO defines agrobiodiversity as “the variety and variability of animals, plants and micro-organisms that are used directly or indirectly for food and agriculture, including crops, livestock, forestry and fisheries. It comprises the diversity of genetic resources (varieties, breeds) and species used for food, fodder, fibre, fuel and pharmaceuticals. It also includes the diversity of non-harvested species that support production (soil micro-organisms, predators, pollinators), and those in the wider environment that support agro-ecosystems (agricultural, pastoral, forest and aquatic) as well as the diversity of the agro-ecosystems” (Food and Agriculture Organisation, 2004). This broad definition encompasses all aspects of biodiversity that are relevant to this report, and particularly the soil biodiversity that supports production and maintains agroecosystem functionality.

While more than 6,000 plant species have been cultivated for food, fewer than 200 make substantial contributions to global food output, and nine accounted for two-thirds of total crop production in 2014. Meanwhile, livestock production is based on about 40 animal species, and genetic diversity within livestock species is narrower than for crops (Food and Agriculture Organisation, 2019d). Although these species represent a small proportion of biodiversity in agriculture in terms of species richness and abundance, as Chapter 3 shows, they have been a significant focus of research. If agriculture is to shift towards greater sustainability, breeding objectives are likely to change, and less widespread species and breeds may harbour the desirable traits.

Although this appears to be a promising field of research, only a limited number of studies have analysed the linkages between species diversity in cropping systems, the nutritional value of consumed species, and food security and nutritional status in the human population. Available data tend to demonstrate that reducing the diversity of species can have important impacts on nutritional diversity and human nutrition, especially when considered at the level of the village or the community (Remans et al., 2011).

Soil and above ground biodiversity are increasingly recognised as providing benefits to human health because they can suppress disease-causing soil organisms and provide clean air, water and food if managed sustainably. Promoting the ecological complexity and robustness of agroecosystems biodiversity through improved management practices represents an under-utilised resource with the ability to improve human health (Wall et al., 2015).

However, it is difficult to draw general conclusions, as little scientific research has been published on farming systems' impacts on biodiversity, and there is still significant heterogeneity of practices under what is called sustainable farming.' Few scientific publications are available on biodiversity's impact on yields, quality of production and human well-being.

5.4 Conclusion to Chapter 5

This chapter highlights the diversity of sustainable agricultural approaches and practices and shows, despite the competing approaches, that knowledge already exists that supports adoption of more sustainable locally-adapted land management practices on a global scale. It also shows the importance of ecological interactions between farming systems, soils and landscape health, and particularly the positive and negative linkages between biodiversity, landscape productivity and the provision of ecosystem services. These interactions have direct consequences for all farmers, and particularly vulnerable farmers who need to develop practices that can sustain their soil capital and their livelihoods, and help increase their resilience to the adverse impacts of climate change. They have implications for policy makers, who need to deliver the most appropriate incentives and regulations, and for downstream actors who will have to adjust their own strategies and secure their activity in order to preserve food security and satisfy consumers and emerging societal expectations.

Chapter 6

Scaling up land health through food system transformation

The accumulated knowledge on sustainable agriculture has found limited traction among the key players of the food system: farmers, businesses, governments and consumers. Previous chapters have shown that managing agricultural landscapes for the optimal benefit to society means managing land for more than just food and embracing environmental stewardship. In fact, there are many precedents for environmental stewardship in the agriculture sector, such as practices to mitigate flood risks in catchments or to protect habitat in field boundaries.

While the solutions for sustainable agriculture are available, further information is often required at local levels to help farmers find the right options for their context. Realising the benefits of managing land sustainably at both the agroecosystem and the farm level entails restoring and protecting soil biodiversity in the field, maintaining biodiversity on the farm as a whole, and protecting biodiversity in the wider farming landscape. This in turn requires a combination of appropriate farming practices, such as those classified as agroecological approaches, and landscape management practices, such as protecting woodlands, pastures and wetlands.

Restoring and protecting biodiversity at these different levels has implications for different actors, and requires new institutional arrangements to govern those roles. While farmers reap some of the benefits of sustainable farming, other benefits are enjoyed by downstream consumers, creating opportunities for shared responsibility and incentives. Furthermore, action at the landscape level may depend on collective action, as well as the public sector assuming some responsibilities, which raises further challenges for implementation.

Although changes may be happening only sporadically around the world, they nevertheless indicate that momentum is building. Demand for organic foods, for example, has more than quadrupled the area of cropland under organic farming between 1999 and 2015. However, even at that rate of growth, organic farming only represented 1.4% of global agricultural land in 2017 (Willer & Lernoud, 2018). This chapter examines some of the factors that may be holding up adoption of sustainable practices by different actors in the agriculture sector. The chapter draws on some examples of innovation in scaling up, from which lessons can be drawn to inform wider practice.

6.1 Hurdles to adoption and implementation

Attitudes and knowledge, policies and perverse incentives, and entrenched paradigms and business models still limit the adoption of sustainable practices. The HLPE 2019 has classified these hurdles into five main areas:

1. Governance factors including short-term and compartmentalised political systems, trade policies, legal frameworks, and incentives which reinforce unsustainable agriculture;
2. Economic factors including lock-in path dependencies, increased corporate consolidation, declining rural employment, rising inequalities, limited market options for sustainable food products, high costs, and uncertainty or perceived risks associated with innovation for sustainable transitions;
3. Resource factors such as low soil fertility, technological gaps, productivity gaps, lack of available labour, inadequate access to land, water, seeds, genetic resources, credit and information;
4. Social and cultural factors including dietary changes, producer and consumer expectations, dominant discourses, social capital, sociocultural norms and practices and food preferences; and
5. Knowledge factors such research metrics that do not address environmental or social externalities, skewed public investments in research and development, lack of knowledge or capacity in innovations that support land health, and lack of information on existing or new technologies.

Knowledge factors are critical, as there is still a significant knowledge gap related to soil biodiversity and land health. This foundation of sustainable agriculture is ignored by many actors simply because they are unaware of it. Often biodiversity is mentioned in terms of endangered species, such as birds or pollinators, or in terms of crop and livestock breeds that farmers have consciously abandoned for different reasons. The prevailing attitude towards agricultural land is to treat soil as an inert substrate in which external inputs are required to nourish crops. A deeper and wider understanding of soil as an ecological system is urgently needed, and more broadly of how the linkages between biodiversity and landscape productivity and resilience can provide a stream of co-benefits to society.

Large-scale transformation of agriculture must include ways of incentivising small-scale farmers as well as larger producers. Contrary to widespread belief, smallholders do not produce the majority of the world's food, but they do represent the majority of the world's farmers. Globally, about 84% of farms are smaller than 2 hectares and they use about 12% of the world's agricultural land (Lowder et al., 2016). The contribution of these farms to global food calorie production has been estimated at between 18% and 34%, although estimates are highly sensitive to definitions of scale and data gaps (Herrero et al., 2017; Ricciardi et al., 2018)

While there is a tendency to see a distinction between smallholder agriculture ('the victims') and industrial agriculture ('the villains'), this overlooks the dominant role in in agriculture of the family farm, which can belongs to both category. A family farm is owned and operated by a family and relies predominantly on family labour. These farms can be of any size, and they dominate the land area under agriculture. Extrapolating from data presented above, if family farmers (which include smallholders) account for more than 90% of the world's farms and operate on about 75% of the world's agricultural land, it follows that 6% of the world's farms are family farms that manage 63% of the world's agricultural land.

This group represents a major target group for programmes to scale up sustainable agriculture. The remaining 10% of farming operations manage the remaining 25% of the world's agricultural land: this is presumably a combination of state farms and private companies. It is vital to develop better data on the profile and extent of these different farming groups in order to understand the opportunities for scaling up sustainable farming.

One of the key challenges in expanding the uptake of sustainable farming is translating agroecological principles into practical and sustainable strategies for the management of soil, water and biodiversity to enhance land productivity and improve resilience (Nicholls & Altieri, 2018). The successful scaling up of different technologies, approaches and practices in sustainable agriculture will depend on careful consideration of how they can be locally adapted to the existing social, economic and ecological context where they are to be applied (Coe et al., 2014). This includes the promotion of co-learning and harnessing local knowledge and innovation to guide the application of these technologies, approaches and practices (Pretty et al., 2011).

While farmer knowledge is vital for adoption of sustainable farming practices, agribusinesses also exert a powerful influence. Globalisation and international trade have rapidly expanded and linked many farmers to export and import markets, mostly as a result of investments by transnational food corporations. This globalisation of the food system has meant that a small number of highly influential corporations are playing a vital role in the vertical integration of food and agriculture markets and control major supply chains (Gliessman & Tittonell, 2015). The transformation of agriculture and food systems through agroecological approaches should therefore give due consideration to these transnational entities based on their ability to shape practices around food and agriculture.

The social, political and economic conditions that surround farmers inevitably influence their decisions about farming practices. Effective strategies for scaling up innovation in agriculture include reviving traditional agricultural systems, as in the case of agroforestry in the Sahel, and creating sentinel sites, or pilots, from which experiences diffuse into surrounding areas. To be fully effective, these approaches should be complemented by supportive policies and by arrangements that improve market engagement and enhance economic viability (Nicholls & Altieri, 2018).

The following sections of this chapter focus on opportunities for addressing the above barriers to scaling up sustainable agriculture and on three areas where progress can be made:

1. Improved understanding and enabling of the values of agricultural land and landscapes;
2. Incentives for transformative action, both positive and negative, economic and regulatory; and
3. Reducing risks associated with the transition towards agriculture and food production that conserves land health.

6.2 Improved understanding and enabling of the values of agricultural landscapes

Chapters 3 and 4 demonstrated how ecological processes relating to biodiversity and land health contribute to the provision of a range of ecosystem services used as agricultural inputs. Investors and policy makers have traditionally considered inputs into agriculture as land, labour, financial capital and management (‘factors of production’), and considered the value of agricultural output as a function of the cost of these inputs. Typically, the ecosystem services used as inputs into production have not been considered in economic terms, or they have been treated as public goods, which come at no cost to the producer. As such, these services have no consistent, agreed market price to regulate their consumption, or indicate their economic value. A well-known consequence of this lack of market prices is that the consumption of ecosystem services outpaces their supply, as the ecosystems they are derived from decline in quality and extent from overuse and lack of reinvestment..

Some food systems actors do recognise the essential contribution of ecosystems services to agricultural production. However, as noted above, these non-market services do not have market prices and cannot readily be valued in monetary terms and incorporated into farm budgeting and resource allocation decisions in the same way that other factors of production can. For example, soil organic matter is known to enhance soil moisture and nutrient storage, which secure increased and resilient yields, but the benefit is not easily quantifiable (Oldfield et al., 2019) and is usually not taken into account in the pricing of agriculture land. Thus, the economic value of essential ecosystem service inputs is not considered in decision-making.

A change of paradigm is required, where the value of ecosystem services to land health (especially those relating to soil processes) is recognised, and the ecosystems from which the services are derived are regarded as assets. This paradigm means that ecosystem assets, just like financial and other assets, need regular reinvestment to maintain stocks and the flow of stocks as services to users. In the case of ecosystem assets, ‘reinvestment’ may involve ecosystem conservation and protection, land restoration and rehabilitation and continuous ecological management.

Such a paradigm shift has occurred in the US, where agricultural yields continue to increase with strong policy support for soil health. This shift has its roots in the Soil Conservation Act passed in 1935 in response to the Dust Bowl period of droughts and severe soil erosion in the 1930s. By 1938, a massive conservation effort had reduced soil erosion by 65%, and since then, land health has remained a value for US farmers, landowners and investors (see Box 2). With climate change now driving changes in agricultural and business practices, investments, policies and consumer habits, a similar culture shift regarding land health is again required, and this time on a global scale.

BOX 2 EMBEDDING THE VALUE OF SOIL HEALTH IN US POLICIES

Non-operating landowners control 41% of farmland in the US, including 62% of in the Midwest. Land leases can provide incentives and barriers to improving land health. Land lease agreements vary by state within the US and many can include provisions related to land health.[33] For example, many leases in the Midwest have provisions for maintaining fertility levels within leased land and agreements between the landlord and tenant for application and removal of nutrients. This concept can be extended to other elements of land health such as broader soil health, biodiversity, water quality, water quantity. Several states are evaluating legal lease structures that address soil health and other land health services. These lease structures are dependent on evolving science on quantification of soil health, habitat potential, water quantity improvements, and other factors.[34] Numerous public and private initiatives have focused on evaluating the economic benefits of practices that enhance soil health for farmers, agricultural supply chains and society as a whole. Very few programs have compiled data at a fine enough scale to understand the full benefits of land health in improving agricultural production.

The Precision Conservation Management program[35] is a farmer-led effort to develop field-level continuous improvement plans through use of sustainability metrics, economic models, agronomic management data and individual consulting. The metrics enable farmers to better internalise land health practices into operational expense budgets and financial planning models.

The United States Department of Agriculture's (USDA) Sustainable Agriculture Research & Education (SARE) programme has been exploring the economics of cover cropping and land health. A recent SARE technical bulletin[36] summarises cover crop acreage increases in the US between 2012 and 2017 (a rise of 50%) and economic factors relating to the impact of cover crops on agricultural land health.

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[33] https://www.extension.iastate.edu/agdm/wholefarm/html/c2-01.html
[34] https://farmdoc.illinois.edu/management#handbook-farmland-leasing
[35] https://www.precisionconservation.org/
[36] https://www.sare.org/Learning-Center/Topic-Rooms/Cover-Crops/Cover-Crops-Economics

6.2.1 Barriers to valuing and conserving land health

Gaps in knowledge on the benefits, opportunities and practices of sustainable farming often hampers its adoption. Sustainable farming is a knowledge-intensive process and investing in soil health will require a significant increase in investment in science.

As noted above, farm-management decision-making is generally based on the relationship between land, labour, capital, management costs and the market price of output. This approach is likely to be a powerful perverse incentive against the adoption of sustainable farming practices. Agricultural Gross National Product and agricultural commodity prices are commonly reported indicators in national agricultural statistics used by UN agencies and development banks. In comparison, there is a lack of statistics on changes in the extent and conditions of the ecosystems underpinning the services used as farm inputs. However recent developments in environmental-economic accounting and ecosystem accounting by the UN and several national statistical agencies are beginning to redress this situation as environmental and ecosystem accounting methods become available for agricultural policy makers and planners. Also, there has been a tendency for governments to devolve responsibility for extension services and farmers' capacity building to farm input retailers (for seeds, fertilisers and agro-chemicals), who would be likely to have a vested interested in protecting their markets,[37] and not promoting the sustainable activities described in this report.

The complexity of food-agriculture systems adds further challenges to promoting the values of land health (High Level Panel of Experts on Food Security and Nutrition, 2017). Furthermore, the challenges vary considerably country by country. As discussed in Chapter 2, some countries are struggling with an increasing obesity crisis while others still face high levels of under-nutrition and micro-nutrient deficiencies. Countries that make food production a development priority may be wary of perceived risks associated with sustainable farming and sceptical of its potential as a credible alternative to tried-and-tested conventional practices. Although existing science makes a compelling case for sustainable farming, this science has not yet fully influenced mainstream agriculture policy in many countries.

Portraying sustainable farming practices as science-based and progressive future options, rather than archaic practices, may help overcome some of the resistance to change. In developed countries, agroecological systems can replace management approaches that are highly dependent on fossil fuels and chemical treatment with knowledge-intensive management. Knowledge-intensive agriculture can reduce the environmental footprint of agriculture while providing employment in rural areas. This should be a compelling argument also for developing countries with an abundant rural labour force and a relative scarcity of fossil fuels and chemical inputs. However, promoting agroecological approaches depends on providing a major impetus for education, combined with establishing institutions that empower farmers to become active agents (Carlisle et al., 2019).

6.2.2 Solutions for effectively promoting sustainable agriculture at scale

Widespread adoption of sustainable agriculture depends on innovation throughout the food-agriculture system. However, innovation refers to more than technology, and agricultural innovation combines technological, social, economic and institutional change. Agricultural innovation requires the development and exchange of knowledge, as well as addressing policy, legislation, infrastructure, funding, and market development. Agricultural innovation often depends on interactions between networks of stakeholders, which enable actors to develop a shared vision, create business links and information flows, enhance cooperation, develop markets, establish legislative and policy environments, and develop human capital (Klerkx et al., 2012). Networks of agriculture actors, including informal social networks, play an

[37] https://ag4impact.org/sid/socio-economic-intensification/building-human-capital/agricultural-extension/

important role in mediating social relations and building trust and knowledge. Networks have proven influential in promoting social change and farmer understanding and enabling uptake of sustainable agricultural practices (Carolan, 2006).

Adoption of conservation agriculture provides insights into how farmers' knowledge and attitudes influence innovation. Conservation agriculture has expanded from 45 million hectares in 2004 to over 125 million hectares in 2012 and now occupies approximately 10% of the global arable land surface (Kassam et al., 2019). Most expansion has taken place in North and South America, Oceania and Africa. The total area under conservation agriculture in Europe is estimated at 22.7 million hectares, or about 25.8% of the region's arable land (Kertész & Madarász, 2014). Adoption of conservation agriculture in Europe has been driven largely by the opportunity to improve net returns, through lower costs of operation, labour and inputs. Soil and water conservation concerns did not appear to be among the main drivers in European farmers' decisions to shift or not to conservation agriculture (Lahmar, 2010).

The adoption of conservation agriculture in Europe, for example in Norway and Germany, is being achieved step by step with large-scale farmers as early adopters. This trend is projected to continue, given the increasing pressure to improve the competitiveness of farms and the steady increase in fuel costs (Lahmar, 2010). While evidence of the environmental values of conservation farming may appear persuasive to scientists, evidence of the savings through

BOX 3 DEVELOPING CAPACITY AND PILOTING SOIL HEALTH VALUE[38]

Farmers face numerous risks if they want to change their production system, including potential yield reduction, trial and error in the implementation of new practices, and investments in equipment. These risks and barriers strongly deter farmers from adopting sustainable agricultural practices. At the same time, businesses are unable to define and measure performance in conservation agriculture as there are no agreed indicators that can be included in responsible sourcing policies.

Earthworm Foundation's Living Soils initiative aims to overcome these barriers by:

1. Creating pilot solutions that reduce risk and further incentivise the transition towards conservation agriculture, for example by remunerating farmers for conserving the ecosystem assets from which services are derived, including soil C sequestration and storage.
2. 2Creating the Living Soils Criteria to provide businesses with a mechanism for evaluating production in their supply chains based on a 'Living Soils Score'.

The foundation works with farmers, business, investors, research institutions and governments in co-creating and implementing these solutions. They provide scientific support and field training and strengthen farmer networks to share information and knowledge. A pilot landscape is being tested in Northern France (Picardy), where arable crops are grown, supplying Nestlé, Cerelia, Lidl and other companies who have joined the initiative.

[38] https://www.earthworm.org/our-work/projects/living-soils-in-rosi%C3%A8res-en-santerre-france

Adoption of conservation agriculture in Africa has been influenced by other factors, including the provision of training, membership of farmer organisations, ownership of the required equipment to practise zero tillage, and use of herbicides (Nyanga, 2012). Adoption was also influenced by farm size, mirroring the experience in Europe that larger farmers are more likely to be early adopters. This may be correlated with their ownership of, or access to, the required equipment and other resources, including human resources. Adoption was also influenced by the rapport and trust between farmers and extension agents, reciprocity and altruism, mirroring the research above on innovation networks. The extension strategy was influential, including monitoring and evaluation and the quality and extent of technical knowledge. Furthermore, traditional leadership was found to enhance adoption of conservation agriculture in most cases. Notably, the levers for adoption differed between men and women, reflecting gender differentiation in the roles and aspirations of farmers.

BOX 4 RE-GREENING THE SAHEL: MULTIPLE INCENTIVES FOR LARGE SCALE TRANSFORMATION IN NIGER

Seven million hectares of land in the Sahel has come under increased vegetation cover over the last 25 years after extensive droughts that ravaged the region in the 1970s and 1980s. The drivers of this revegetation are still being debated among scientists, but changes in tree tenure are thought to have played an important role. Progress may also have been boosted by the grass-roots level movement that adopted innovative sustainable on-farm management, known as farmer-managed natural regeneration (FMNR), an example of agroforestry practice. FMNR is defined as a process by which farmers protect and manage trees that naturally regenerate on their land, rather than cut them down. FMNR has resulted in multiple landscape benefits including increased crop yields, rehabilitation of degraded lands, expansion of dry season irrigated gardens, diversification of household incomes, reduced food insecurity and increased resilience (Gray et al., 2016).

Farmers themselves played a central role in the adoption and spread of FMNR. The early adopters served as a demonstration of how reviving these traditional approaches to farming led to direct benefits, including improved productivity on their farmlands. The accelerated adoption of the practices was dependent on the simplicity of the innovation and the availability of information provided through the intensive efforts of NGOs and extension workers.

The strengthening of institutions enhanced local ownership and community participation in decision-making, helping communities to manage trade-offs at both household and community level. The community derived direct benefits from the use of the trees for fuelwood, fodder and food. The methods used were easily demonstrable and replicable and shared through on-farm demonstrations. Although the objectives of regeneration at the landscape scale were not clearly formulated or agreed on, there was a common understanding of the collective action needed to address cross-cutting concerns about deforestation, land degradation, declining soil fertility, water scarcity, and vulnerability to climate change.

A challenge for the uptake for this innovation were policies governing ownership and use of trees. In Niger, trees are national assets and their use is subject to government control. A ban on the use of some tree species had provided a strong disincentive to on-farm protection or management. But subsequent decentralisation allowed community-level institutions to decide the use of tree and shrub resources, creating an incentive for farmers to invest in the protection and regeneration of trees. Farmers in Niger were assured of their rights to manage trees on their farms and freed from concern that the government would fine them for unauthorised cutting of protected species or tax them for the transport or trading of forest products.

The impressive long-term results in Niger were based on several factors:

- using a bottom-up approach
- demonstrating an innovation that is low-cost and tenable for the larger proportion of the community
- providing benefits at different scales
- empowering local communities and institutions to own and make decisions over natural resources
- using extension workers and civil society organisations as catalysts for driving adoption
- using an integrated landscape management approach

All details in Box 4 from Gray et al. (2016).

Nurturing long-term value is an approach that originated in the energy sector, where some investors started considering investments in non-renewable energy as 'stranded assets' that could jeopardise the long-term sustainability of these companies. In this context, a stranded asset has been defined as "those investments which have already been made but which, at some time prior to the end of their economic life … are no longer able to earn an economic return" (Caldecott, 2017).

The same concept has recently been applied to agriculture sustainability (see for example (The Economics of Biodiversity, 2018). Indeed, delaying the transition to sustainable agriculture bears a similar risk for prospective investors in agriculture and poses the question of whether to consider the value of production only or that of land health more broadly. This kind of thinking is gaining traction among companies and their boards, including in the food and agriculture sector, who are progressively redefining value[39]and recognising that "shareholder value is no longer everything" as in the declaration recently signed by 181 CEOs in the US. [40] Including the true value of food,[41] for example by accounting for soil health, as a key element of companies' financial and environmental sustainability is a promising approach to nurturing the long-term value of land health.

6.3 Incentives for transformative action

Addressing incentives for transformative action requires distinguishing between negative and positive stimuli: between incentives and disincentives. Subsidies, norms and standards in particular can block as well as encourage the desired transformation. Industry concentration or business strategies can be incompatible with the necessary re-diversification of crop rotations and agricultural landscapes. Supply chain arrangements often lead to the concentration of value capture and decision-making power in the downstream part of the supply chain, preventing farmers from transitioning to more sustainable practices.

A variety of incentives can be conceived to promote sustainable agriculture, including public compensation mechanisms and private investments to land managers. Public mechanisms include subsidies, but can also take the shape of benefit-sharing mechanisms (Preciado, 2014) including, among others, payments for ecosystem services, compensating farmers for services rendered to society (see Box 5 for other examples).

BOX 5 PUBLIC PROGRAMS FOR ENVIRONMENTAL IMPROVEMENTS IN US FARMING

Municipalities, state governments and the federal government have initiated programs for water quality trading, land health practice incentivising, and C cap and trade systems. The state of Wisconsin has initiated a public water quality trading program [42] in which parties can offset their pollutant loads by working with farmers or other parties in the state. The cities of Milwaukee and Grafton have utilised the programme in pilot projects with farmers to reduce P and N loading in city water sources. Similarly, the city of Cedar Rapids and several academic, conservation, industry, grower and public organisations have formed the Middle Cedar Partnership Project to work with farmers to implement measures for land health, water quality, water quantity (including flood reduction) and soil health.

[39] https://www.wbcsd.org/Programs/Redefining-Value
[40] https://opportunity.businessroundtable.org/ourcommitment/
[41] https://www.wbcsd.org/mtxtv
[42] https://dnr.wi.gov/topic/SurfaceWater/WaterQualityTrading.html

Sustainable agriculture can be incentivised through a number of economic measures, including certification, technical regulations, phasing out of harmful subsidies, and promoting investment in green technology. Technical regulations can include regulations for commercial quality and labelling, food safety regulations (for example for pesticide residues), and sanitary and phytosanitary measures. Certification covers regulations governing products from specific production systems. Sustainable agriculture can be promoted through investment in markets for outputs from sustainable production systems as well as markets for importing, or producing, products (for example inputs) that are adapted to sustainable production (UNEP, 2013).

Voluntary certification schemes are a governance mechanism that can address environmental challenges associated with agriculture (Box 6). Voluntary certification has been established for a number of commodities, including beef, coffee, palm oil, and soy, mostly in tropical countries. The appropriate governance mechanisms for different commodity chains is influenced by several factors, including environmental, market, and social geographies. For example, in Brazil the suitability of different mechanisms was determined by, among other things, sustainability priorities, market orientation, supply chain traceability, and social networks (R. Hajjar et al., 2019).

BOX 6 BIODIVERSITY-POINTS LABELLING FOR CONSUMERS[43]

Another possible market-based incentive is product labelling. This can influence consumption decisions by improving access to information. An example is the Swiss project “Scoring High with Diversity” aimed at developing management options for ‘wildlife-friendly’ agriculture. The project, which ran from 2008 to 2016, used a credit point system to assess on-farm biodiversity. Farmers also received guidance on how to conserve and promote biodiversity on their land. A simple label system was developed to communicate the improved biodiversity performance to consumers. The project was supported by two Swiss farmer organisations interested in promoting biodiversity on their approximately 26,000 farms. A major Swiss retailer marketed products from participating farms with the sustainability label “IP-Suisse” (where IP stands for “integrated production”).

Investments in green innovation can improve sustainability and resilience in agricultural production systems. Some governments have put in place national policy frameworks to articulate a variety of incentives to support the shift to more sustainable farming practices (Box 7). While many solutions for sustainable farming are known, the specific practices need to be locally selected and adapted. Innovation does not have to mean radical re-thinking of agricultural practices but can relate to new ways of reconciling sustainable practices with local knowledge and local social and ecological contexts. A number of international development agencies have found that “sustainable production intensification requires a major shift from the supply-driven innovation model to knowledge-specific and often location-specific farming systems which conserve and enhance natural resources” (The High-Level Task Force on Global Food Security and Nutrition, 2012).

[43] https://www.fibl.org/en/projectdatabase/projectitem/project/285.html

BOX 7 THE ‘4‰’ INITIATIVE AND THE FRENCH AGROECOLOGICAL PROJECT: A STRONG VOLUNTARY BOTTOM-UP SCHEME [44]

The French government is implementing an ‘agroecological project’ which integrates measures and strategies dedicated to upscaling agroecological approaches, while fulfilling its commitment to the 4‰ initiative (see Chapter 4). In 2014, France firmly committed to a transition towards more sustainable agriculture. The goal is to ensure that agricultural and livestock production becomes environmentally, economically and socially efficient, while remaining safe. To help reach this objective, agroecology has been recognised in law.[45]

Actions related to the agroecological project include among others the “Action Plan on Agroforestry,” the “Plant Proteins Plan” to encourage the development of grain and forage legume varieties, the “Methane Energy and Nitrogen Autonomy Plan” that encourages the return of organic material to the soil, and the “Ambition Bio” organic farming plan.

The project also includes a local and social dimension with the development of more than 500 farmers groups, 38% of them having soil health restoration as their main objective. The experience gained is widely disseminated through videos. The project also has an important education component, which has changed education curricula to include agroecology and emphasises soil health management.

The French National Institute for Agricultural and environmental Research has recently published a study on soil C sequestration potential in France, which aims to assess the potential and the cost of its implementation by sub region in reference to the 4‰ objective.[46]

Governments can take measures to promote sustainable agriculture by reforming subsidies that currently support unsustainable practices. As reported in Chapter 2, net annual support to agriculture between 2017 and 2019 exceeded USD$ 619 billion globally, and represented about 17% of gross farm receipts in OECD countries (OECD, 2020). While some countries have reformed policies to decouple income transfers to farmers, overall, price support remains the largest form of support in many OECD and emerging economies. Price support is provided through tariffs and other border measures and government interventions in the domestic market. An enabling environment for greening agriculture includes the reform of agricultural subsidies, which can be a major disincentive to innovation when they introduce market distortions, such as lowering input costs (UNEP, 2013).

Innovative subsidies were recently proposed by the Global Alliance for Improved Nutrition, (GAIN), which called on governments to provide incentives for businesses to repair the global food system (Haddad, 2018). Although GAIN’s call was focused on healthy and nutritious food, the same principles apply to food production that positively impacts land health. However, mechanisms may be needed to ensure that incentives for business actually ‘trickle down’ to the farmers who are at the forefront of restoring and conserving soil health. Some agribusiness companies are increasing their investments in developing countries to secure their supply chains, improving the livelihood of farmers and incentivising more sustainable practices (Box 8).

[44] For more information: https://www.moag.gov.il/yhidotmisrad/research_economy_strategy/publication/2018/Documents/3_Schwartz_20170620_projet_agro_%C3%A9cologique_Isra%C3%ABlv3.pdf

[45] https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000029573022&categorieLien=id

[46] http://institut.inra.fr/en/Objectives/Informing-public-policy/Advanced-Studies/All-the-news/Storing-4-per-1000-carbon-in-soils-the-potential-in-France

BOX 8 IMPROVING LIVELIHOODS AND SUSTAINABLE BUSINESS[47]

Agricultural production and sourcing are core operations for Olam, a Singapore-based company handling 45 agricultural commodities. Olam aims to invest in soil quality to simultaneously improve water use efficiency, crop productivity, trade volumes and product quality. An example is Olam's Sustainable Sugarcane Programme in Madhya Pradesh & Maharashtra, India, running since 2013 with support from IFC, Hindustan Unilever Foundation, Solidaridad and New Holland. In its first phase (2013-16), the programme reached 21,500 smallholders cultivating 20,500 hectares of sugarcane. The second phase (2017-20) is reaching 26,500 growers managing 27,000 ha. Farmers are trained on practices to improve soil health including the use of organic inputs and fertilisers. Whereas soil health is considered the foundation for productivity improvement, farmers are also exposed to adapted crop varieties, novel row spacing, companion cropping technologies, and improved irrigation and water conservation technologies (such as crop mulching). Through the program, use of organic inputs more than doubled and crop yields increased by more than one-third. Total crush volume of the sugarcane went up by 25% during the first three years.

Olam increasingly adopts digital tools to track and tailor farmer practices and progress across numerous crops. Data generated reveals that the bottom 50% of the farmer community supplies less than 15-20% of the trade volume, mainly due to farm size.

Unfortunately, many farmers in this bottom group have very limited resources or time to invest in soil health. Their small plots and low yields make cash credits risky. Olam's farm support tools focus on stepwise improvements within farmer limitations, but (public) partnerships are often required to support this bottom segment to generate additional income outside the farm, by supporting the development of off-farm economic activities.

reduced input costs may be most influential for farmers. Bilateral 'payments for results' schemes are grant finance agreements between countries, in which a donor country pays another country for a specified environmental outcome, such as reducing deforestation against a historic baseline (Wong et al., 2016). For example, in 2008 Norway agreed to pay up to US$ 1 billion over a five-year period to Brazil in return for reducing GHG emissions from deforestation below an agreed level (Birdsall et al., 2014). Such schemes could also be used to generate revenue in support of improvements in other aspects of land management, including efforts to improve soil health.

6.3.1 Assessing the performance of sustainable land use systems

6.3.1.1 Metrics

Science-based targets and associated performance metrics can also act as incentives, especially for those food system players who can achieve impact at scale, such as businesses, investors and governments. Various initiatives could contribute to developing such metrics, including the LDN programme established by the UNCCD (UNCCD, 2015). The programme has developed three sub indicators used to assess land degradation and restoration: 1) trends in land cover; 2) trends in land productivity or functioning of the land; and 3) trends in C stock above and below ground. Another basis for

[47] https://www.olamgroup.com/sustainability/olam-livelihood-charter.html

developing indicators could be the ‘3Cs’ framework (Locke et al., 2019). The framework proposes baselines for a range of biodiversity and sustainability variables including above- and below-ground carbon stocks across three land use ‘conditions’ (cities and farms, shared lands, large wild areas) to guide the definition of conservation responses and production practices. Other approaches that could underpin the development of relevant metrics include the ‘Half-Earth’ strategy embraced by the EAT Lancet Report (Willett et al., 2019), whereby 50% of all the world’s ecoregions should be managed in a way that supports biodiversity conservation by 2050. Metrics could also draw on established tools like the IUCN Red List of Ecosystems (Alaniz et al., 2019; Bland et al., 2019).

6.3.1.2 Recommendations and voluntary guidelines

A number of international recommendations and voluntary guidelines related to SLM have been issued in recent years. These provide references and standards that ensure the respect of socioeconomic rights (such as the CFS voluntary guidelines on the right to food, on responsible governance of land tenure and on responsible investments) and strengthen the value of soil health (for example, the Status of the World’s Soil Resources report, the Voluntary Guidelines for Sustainable Soil Management, the International Code of Conduct for the Sustainable Use and Management of Fertilizers, and guidelines for the re-carbonisation of global soils) (FAO, 2017, 2019b, 2019a).

6.3.1.3 Projections and pathways

The FABLE Consortium, a knowledge network comprising research teams from 18 countries that operates as part of FOLU, has proposed “integrated national pathways towards sustainable land use and food systems that are consistent with global objectives” for 18 countries and seven additional regions (FABLE, 2019). The report is aligned with other established targets, such as the Half-Earth Strategy and the Rapid Decarbonization Pathway resulting from the 2015 Paris Agreement (Johan Rockström, Gaffney, et al., 2017) and the Aichi biodiversity targets. It proposes several targets to meet by 2050 that could support a shift towards restored land health. These include making GHG emissions from crops and livestock, together with removals from land use, land use change, and forestry, compatible with the goal of holding the rise in average global temperatures to well below 1.5°C. The proposals also include ensuring that a minimum share of Earth’s terrestrial land supports biodiversity and is included in protected areas.

The FABLE initiative is an example of the long-term pathways approach that will be needed for transition policies at national scale. These approaches unfortunately often fail to include evaluations of biodiversity and agricultural practices that are key to address the challenge of soil health and biodiversity preservation in agriculture landscapes.

6.4 Reducing the risk of transitioning

Farmers face a wide range of risks and make day-to-day decisions when they may have little certainty of the outcome. Changing from established practices in conventional farming to alternative sustainable farming practices can increase uncertainty and exposure to new risks. Farmers interested in making the transition may be reluctant to expose themselves to such risks. Improving understanding of the risks involved, distinguishing actual and perceived risks, and putting in place mechanisms to absorb or offset them, can be useful ways to catalyse adoption of sustainable practices.

A traditional way of de-risking is as old as agriculture itself, is reflected in the idiom ‘don’t put all your eggs in one basket,’ and consists of diversifying a farm’s production, including crops, animals and non-food products. Agricultural biodiversity is widely considered as the backbone of sustainable agricultural intensification, a rich resource for year-round healthy, diverse diets by providing nutrient-rich species and varieties, making households which tend a diverse set of crops and animals less likely to be poor than households that specialise in their crop production (Bioversity International, 2017).

Agriculture policies are also increasingly providing de-risking tools to support farmers adopting environmentally friendly practices. For example, agri-environment measures are a key element integrating environmental concerns into the EU's common agricultural policy (CAP). They are designed to encourage farmers to protect and enhance the environment on their farmland by paying them for the provision of environmental services. Farmers commit themselves, for a minimum period of at least five years, to adopt environmentally-friendly farming techniques that go beyond their legal obligations. In return, farmers receive payments that provide compensation for additional costs and income foregone resulting from applying those farming practices in line with the stipulations of agri-environment contracts.

Insurance is another powerful means to de-risk any transition. Farmers' insurance has the potential to reinforce the resilience of smallholders. It not only provides a payout in bad years to help farmers survive and protect their assets, it also helps to unlock opportunities that increase productivity in the non-payout years, which might allow them to avoid, or escape from, poverty traps (Greatrex et al., 2015).

Insurance mechanisms, whether privately or publically operated (such as the safety nets that exist in Ethiopia), are an established and increasingly popular way to de-risk farmers' activities and transition to more resilient and sustainable practices. Most of the time they are combined with technology innovation, such as alerting farmers on weather events and market trends via mobile phones. This has been widely documented by the CGIAR Challenge Program on Climate Change, Agriculture and Food Security[48] and has not been limited to crops. Index-based livestock insurance mechanisms have also been developed, especially in Africa. [49]

Weather-based insurance is widely used in some industrialised countries, although it less widespread in developing countries, often due to the cost. Index-based insurance has been tested in which the insurer pays out when external factors pass certain thresholds, such as unusually low rainfall or high temperatures. Index based insurance can provide lower cost insurance option to smallholder farmers.

BOX 9 FEDERAL CROP INSURANCE IN THE UNITED STATES OF AMERICA

Federal crop insurance programmes in the United States are public-private partnerships between the federal government and private re-insurance companies and are managed by USDA's Risk Management Agency. Many crop insurance programmes are based on production history and revenue protections for farmers. Recently crop insurance programmes have removed barriers to planting cover crops, including in 'prevented planting' situations (where farmers are unable to plant an insured crop by a stipulated date).[50] Further efforts are underway to include and incentivise additional land health improving practices such as no-till, precision manure application, cover crops, advanced crop genetics and others in insurance programmes. The AGree Economic and Environmental Risk Coalition advocates for federal risk management programs that encourage farmers to implement practices that reduce their long-term risk while improving soil health and water quality. [51] At state level, the Iowa Department of Agriculture & Land Stewardship initiated a three-year "Cover crop crop-insurance demonstration project" [52]in 2019. The project offers an insurance premium discount for farmers that plant a winter cover crop with a spring-planted cash crop.

[48] https://ccafs.cgiar.org/publications/10-best-bet-innovations-adaptation-agriculture-supplement-unfccc-nap-technical

[49] https://ibli.ilri.org/

[50] https://www.hpj.com/crops/using-cover-crops-for-prevented-planting/article_20eac51b-e961-58b9-812f-8bac0fa4a5d1.html

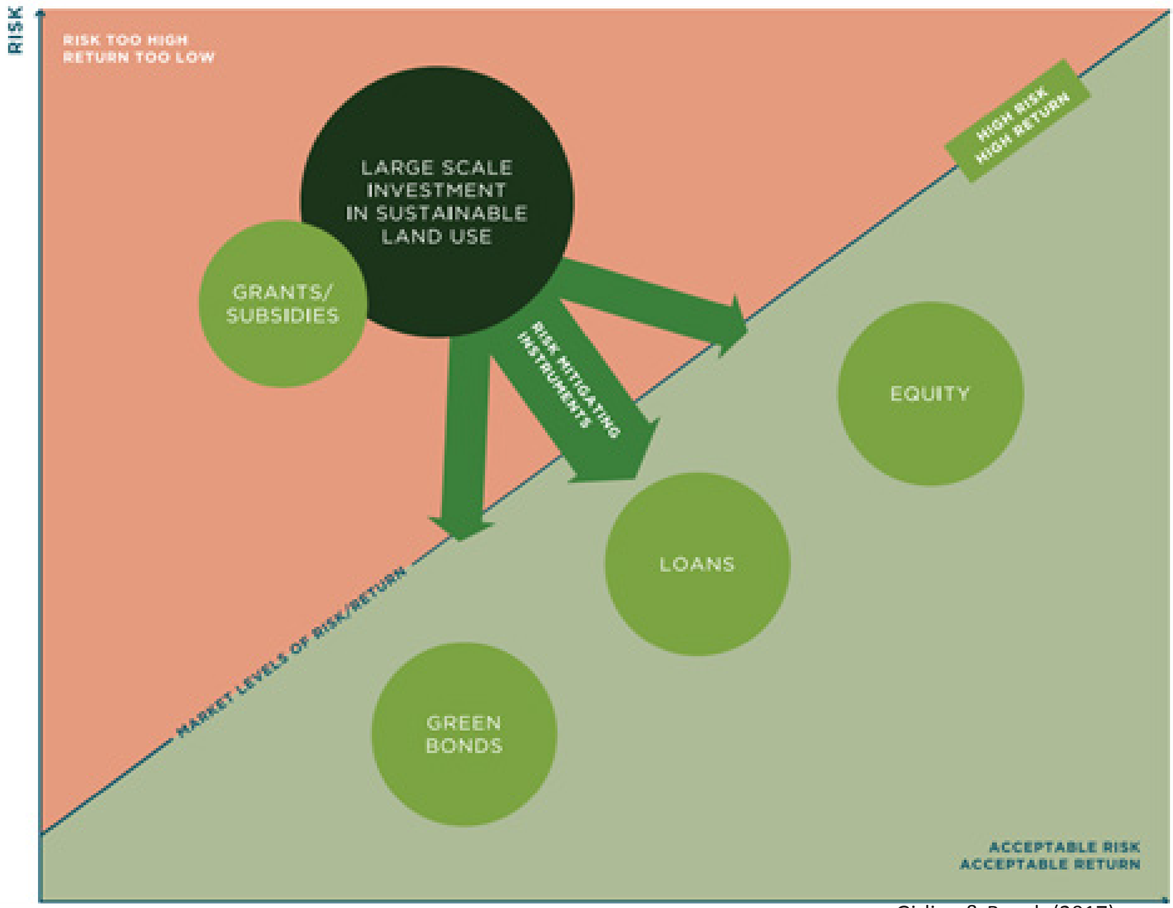
[51] https://foodandagpolicy.org/

[52] https://static1.squarespace.com/static/586bfd13be65947270902ac5/t/5b97d07f4d7a9ca99dcdca50/1536675980924/Cover+Crop+Demo+Brochure+2018.pdf

A great variety of other financial instruments have been developed to offset risk and some of these are now being adapted for use in the agriculture sector, specifically to promote sustainable agriculture. A number of financial instruments may be combined to achieve the return/risk profile needed to attract private investors. Examples include the following (Girling & Bauch, 2017):

- Adjusting loan conditions to create incentives for farmers to switch to more sustainable methods;
- Instruments that encourage investments in new areas by changing the risk profile, such as first loss and credit guarantee instruments;
- Off-take agreements or other mechanisms that can enable commodity traders to guarantee more sustainable production;
- Use of grant finance to establish conditions for future investment;
- Equity investment to help sustainable farming schemes get off the ground;
- 'Green bonds' to make large sums of money available for sustainable land use.

Many of these instruments are already used in conventional agriculture, although their application for sustainable agriculture is less widespread. There are real and perceived costs and risks associated with sustainable farming that can make it less attractive than conventional approaches. Furthermore, capital markets are underdeveloped in many of the countries with great potential for adopting sustainable agriculture. Public money, including development assistance, and risk-mitigating instruments can therefore be crucial in catalysing investment by defraying some of the costs or risks (Figure 20).



Girling & Bauch (2017)

Figure 20 Use of risk mitigating instruments to unlock more capital investment

Risk mitigating instruments can include credit guarantees or insurance as discussed above, or off-take agreements that give farmers more security for accessing credit. Other instruments can include adapted loan arrangements, or simply extending access to credit to remote populations: only 4.7% of adults in rural areas of developing countries have a loan from a formal financial institution. Lending can be subsidised and partial credit guarantees can reduce risk for investors. Some impact investors, who aim to generate social or environmental benefits alongside a financial return, as well as development banks and governments, may accept returns lower than the market rate in order to support environmental or social outcomes. These investors can take on 'first-loss' risk, changing the risk-return profile for other investors (Girling & Bauch, 2017). Investors can also shoulder risk through projects with multiple economic, social and environmental goals (see Box 10)

BOX 10 LIVELIHOODS FUNDS IN KENYA[53]

Livelihoods Funds are impact investment funds supported by major private companies including Danone and Mars that want to transform their supply chains and offset their carbon emissions by supporting sustainable farming practices and restoring ecosystems. In the Mt Elgon region of Kenya, one of the funds has invested in a 10-year project with 30,000 smallholder farms. The Livelihoods fund, which is operated by a Paris-based social enterprise, has partnered with Vi Agroforestry, an NGO with a track record of implementing agroforestry practices in East Africa, and Brookside, a leading Kenyan dairy company.

The main objective of the project is to help farmers increase their income and productivity through soil restoration, enhanced biodiversity, water resource management, and a mix of food and cash crops. A key aim is to increase production of milk in the area by 30 times, in partnership with 15 local cooperatives. There is also a focus on gender empowerment.

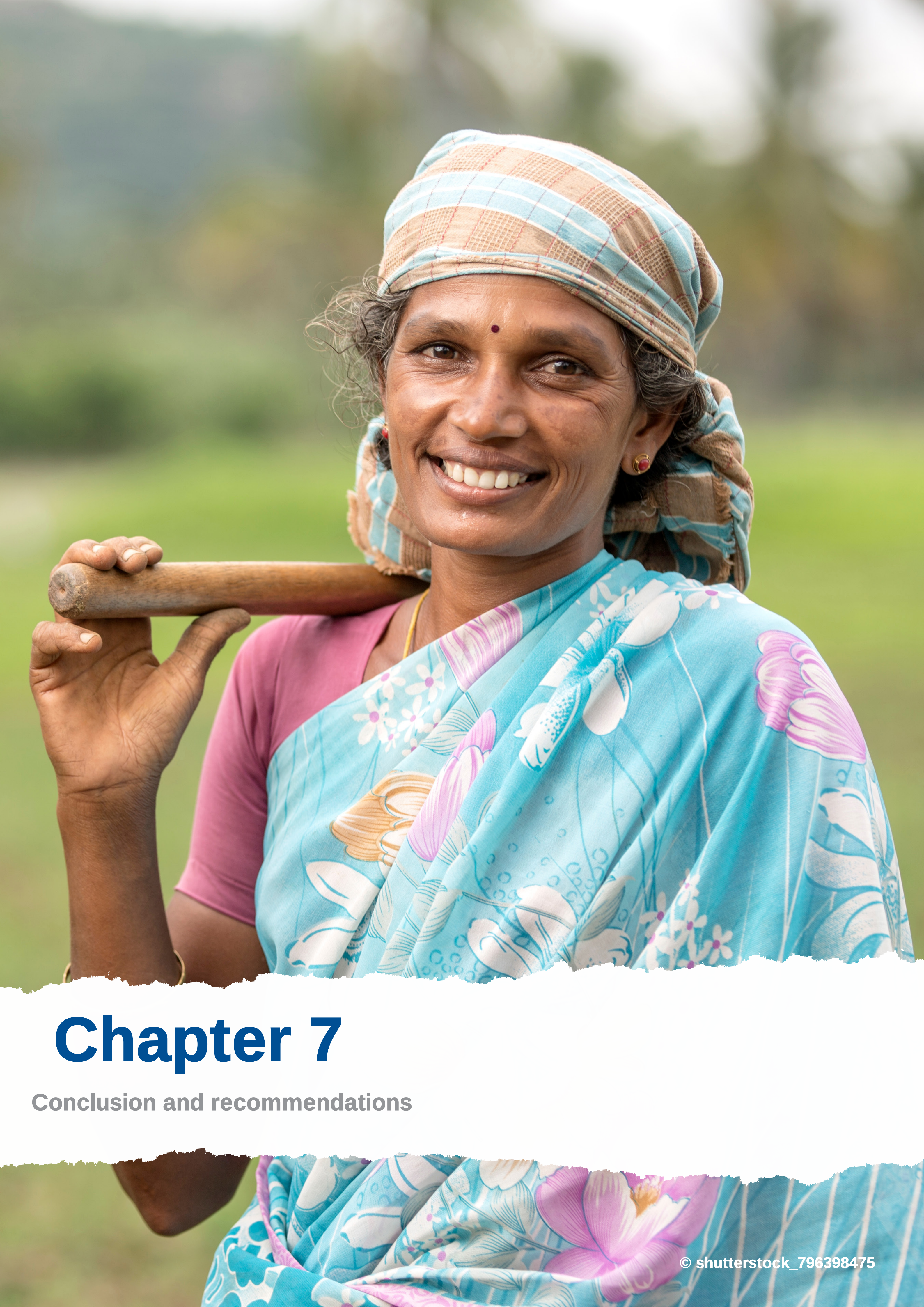
The fund bears risk by providing up-front grants to the NGO that manages the implementation. The fund generates carbon credits from C sequestered in soil and trees, and avoided methane emissions from cows as a result of improved farming practice. Brookside benefits from the increased milk volumes, reduced seasonality of supply (thanks to better water management) and lower collection costs. The company has committed to purchase milk from participating farmers and supports the cooperatives. It contributes financially through result-based payments to the fund. Agroforestry has implemented a monitoring system to track the results of the project.

[53] http://www.livelihoods.eu/projects/mount-elgon-kenya/

6.5 Conclusion to Chapter 6

A successful transition to sustainable, productive and resilient agriculture is one of the major challenges of our time. The concept of Nature-based Solutions (NbS) opens the door to a new approach to balancing environmental and agricultural development goals. By harnessing NbS it can help us reach multiple global goals, including those related to food security, climate change and biodiversity, and deserves to be considered as one of the top political priorities on the international agenda.

In the last decade, many initiatives have been launched and successfully implemented, using a variety of public and private incentives and de-risking tools. These initiatives show that sustainable farming practices and landscapes management approaches can be adopted at scale if there is political will and adequate funding. They also show the huge potential to redirect international subsidies and private investments from conventional to more sustainable agriculture. The increasing societal and consumer demand for healthy and sustainable food systems and the development of local and regional markets will increasingly accelerate the shift.



Chapter 7

Conclusion and recommendations

This report shows that restoring and protecting soil and landscape biodiversity is a common interest between the conservation and agriculture sectors. It demonstrates why the pursuit of a more sustainable food-agriculture system should give higher priority to land health. Major decision makers and economic actors largely ignore the ecological and living nature of soils, squandering many of the associated values and benefits to society. Farmers in particular need to restore and protect this vital capital for long-term profitability as well as for the wider benefit of society.The agriculture sector should aim for a net-positive impact on key indicators of biodiversity by 2030, including stabilisation of the total land area under agriculture, increase of biodiversity in agricultural landscapes, and reduced pollution and GHG emissions. To achieve this objective, it is necessary to avoid land degradation and promote land health, which can in turn be an effective catalyst for wider progress towards sustainability.

According to the target and indicators of LDN, a first step towards rebuilding and restoring soil capital is to halt land degradation. An abundance of options are available to land managers in pursuit of this goal, but the appropriate solutions in each context are not always known and many hurdles still impede progress. Land health needs to be recognised as a precondition for resilient agricultural production and incentivised to trigger the desired shift and impact at scale.

Achieving sustainability in the global food-agricultural system is a daunting task, but one that receives rapidly growing popular support. The agriculture sector's record of accomplishment in achieving its goals is impressive and the sector has the resources to make the ambitious changes required. What is urgently required is a change – or expansion – of the fundamental goals of the sector. As long as agriculture depends on land, it must treat land as a finite, non-renewable resource, by eliminating over-exploitation and protecting the ecological processes that underpin production.

The challenge for the food-agriculture sector is to achieve sustainability in the face of rapidly growing demand and increasing risks associated with climate change. These challenges should not be used as an excuse for maintaining the status quo but should be understood as further justification for protecting, restoring and enhancing agriculture's natural capital. When farmers improve land health they contribute to deliver services to society while simultaneously strengthening the overall resilience of food production and rural economies. This must then be sustained and encouraged with adequate policy frameworks, governance schemes and economic incentives.

Restoring land health is one element of wider changes needed in the food system. Efforts to improve equitable access to natural resources (especially land and water) and access to food, to reduce unhealthy diets, and mitigate food loss and wastes are also essential. This will require unprecedented coordination between many different actors in food supply chains and beyond, guided by bold political leadership.

Increasing agricultural production still takes precedence, particularly in countries that are not food-sufficient, or whose economies depend heavily on the agriculture sector. However, there is also an increasing global demand for more sustainable production systems and healthy diets. As this vision gains traction it creates new avenues for progress towards a future agriculture system built on sustainable management of land and other resources.

The scale of the challenge is huge, but the cost of sustainably managing agricultural landscapes can be met. UNCCD estimates that reversing land degradation globally requires an investment of at least US$ 2 billion annually. This is trivial compared to more than US$ 619 billion of public subsidies and trillions of dollars of private investments flowing into agriculture annually and there is great scope for reorienting financial flows towards desired sustainability outcomes.

This reorientation assumes that countries can anticipate and monitor the variety of socioeconomic and environmental impacts of such a shift. Income and employment, food and water security, and issues of equity, access and control require particular attention. Countries must also reconcile competing land uses in agriculture, including the production of biofuels and biomaterials, as well as competition from other sectors, including human settlements, infrastructure and industry.

The evidence presented in this report supports the following overarching recommendations. These priorities for urgent action are already attracting support from governments as well as private actors in the agriculture sector, not least farmers. Many critical factors are already in place to support change on the necessary scale to meet the goals of 2030. The coming decade offers a unique window of opportunity to orientate agriculture towards a more ambitious set of goals that balance society's needs for food and nature.

7.1 Agriculture as a Nature-based Solution

Prioritise soil and landscape biodiversity for food and nature

Enhancing, protecting and restoring biodiversity is central to land health and must therefore be a key goal for the agriculture sector as it seeks to contribute to ending hunger, achieving food security and improved nutrition, and promoting sustainability (in line with SDG 2) without expanding the overall area of agriculture land. To achieve this, governments should promote land health as an explicit focus of agricultural policy and monitor soil and landscape biodiversity as indicators of land health. Public policy should guide public and private investments towards NbS for food security, climate change and biodiversity challenges. This will require putting in place monitoring and reporting systems to assess biodiversity and ecosystem provision in agricultural landscapes, and of new or adapted public institutions to ensure compliance and to incentivise action.

Stronger knowledge of soil and landscape agrobiodiversity, its values, and its restoration and conservation will support the policy goal of promoting land health. A major frontier for research concerns the role of biodiversity, at the ecosystem, species and genetic levels, in the provision of ecosystem services. This science will guide the development of metrics for key ecosystem services and good practices for farm and landscape management. Greater efforts are needed to combine economic and environmental performance, while safeguarding human and animal health and well-being. These farm and landscape management practices should help restore land health in highly productive systems and sustainably increase productivity in low productive systems in a way that promotes increased resilience to climatic, economic and sanitary shocks.

7.2 Sustainable agriculture

Mainstream agroecological approaches for sustainable management of agricultural landscapes

Agroecological approaches should be mainstreamed in all relevant policies, instruments and institutions to develop knowledge, build capacities, develop services, and mobilise farmer communities and organisations. Emphasis should be placed on creating conditions that enable farmers to achieve sustainability at both the farm and the landscape level, including measures that reduce the risks of transition.

Deeper knowledge is needed on behavioural, organisational, social, political, financial and economic barriers to adoption. Efforts need to build on both scientific and indigenous knowledge to help identify innovations that facilitate adoption. Long-term scenarios of adoption of agroecological approaches and provision of ecosystems services will help evaluate the benefits and potential trade-offs for society, and provide desirable pathways for policy makers. Agriculture and conservation actors should seek consensus over indicators of sustainability and farmers should be supported to improve their performance against those indicators developing scientifically established agroecological approaches.

7.3 Assessing and monitoring sustainability

Establish targets and indicators at national and global levels for sustainable agriculture

Adoption of sustainable agriculture practices, investments and policies can be encouraged by establishing and agreeing on clear targets for specific sustainability metrics. Improved target setting will enable monitoring of progress in addressing land degradation, climate change, and biodiversity loss, while safeguarding incomes, employment, poverty reduction, and livelihood resilience, especially for those most in need, such as youth and women.

The agriculture sector should aim for a net-positive impact on key indicators of biodiversity by 2030, in particular related to stabilized land area, increase of biodiversity in agricultural landscapes, and reduced pollution and greenhouse gas emission. This net-positive impact will contribute to rehabilitated land, improved climate change mitigation and adaptation, and restored biodiversity. Governments should promote land health as a way to reach this objective and to achieve sustainability in the wider food system.

7.4 Agroecosystem services

Reward ecosystem services to incentivise sustainable farming

The global shift to sustainable agriculture requires a shift from thinking of agriculture in terms of 'food, fibre and fuel' (and other products), to thinking in terms of 'production, water, climate and nature' (and other services). The co-benefits of sustainable agriculture have considerable value and policies should be aligned in rewarding this value to rebalance agricultural production with the supply of other services. Policy makers should mobilize the full range of regulations, incentives and de-risking tools that can facilitate widespread and sustained adoption of agroecological approaches at farm and landscape levels.

Urgent efforts are needed to develop awareness and capacities of ecosystem services and natural capital among farmers and economic actors, and to increase knowledge of measurement and rewarding systems, starting with more in-depth evaluation of current successes and failures. Innovative incentives and de-risking measures need to be designed and tested, which requires coherent and innovative policy frameworks. Increasing downstream private sector involvement can contribute to enhance innovation and develop opportunities, including through public-private partnerships and blended finance.

7.5 Sustainable food systems

Promote change throughout the global food system to enhance sustainability

Achieving sustainable food systems requires an effort from all actors to align goals for biodiversity, food, land degradation and climate change. Soil and land health, while not answering every challenge related to biodiversity and agriculture, nevertheless play a critical role in the transition and should be a leading priority for farmers and other actors in the food system. Countries can put in place multi-actor governance at all scales and ensure public and private investments comply with existing international voluntary guidelines. They can also extend environmental and social safeguards. Subsidies and private financial flows should be redirected from conventional to more sustainable agriculture, with greater attention on encouraging landscape and supply-chain actors to protect healthy soils and reward sustainable farming practices, while unlocking factors that block the transition (such as input subsidies, specialisation of systems, standardised supply chains, and power asymmetries). Greater attention should be given to policy convergence and promoting international and national policies that link land health with sustainable and healthy diets, including at the level of international fora dealing with biodiversity, land degradation, climate change and food security.

Global financial flows must be redirected towards sustainable value-chains and healthy landscapes. Science can help to develop indicators and standards that can guide those investments towards more sustainable practices, products and processes along the food supply chain. Public and private incentives can enable adoption of sustainable farming and landscape management practices on a large scale and help farmers to overcome barriers to change. Public and private sectors must adapt extension systems, advice and services, including financial services, to provide farmers with the necessary technical support and knowledge. Private companies can adapt the development of new products and markets for food and biomass to foster sustainable agriculture practices. In developing countries, where governments and the private sector sometimes fail to provide the required support, attention should be given to secure tenure and access to natural resources, creation of functional markets and microfinance for smallholders.

7.6 Common ground

Build consensus on environmental stewardship in the agriculture sector

The agriculture sector should aim to contribute to a net-positive impact on key indicators of biodiversity by 2030, including a stabilisation of the land area under agriculture, increase of biodiversity in agricultural landscapes, and reduced pollution and GHG emissions. Governments should promote land health as a way to reach this objective and also to achieve sustainability in the wider food system. Conservation actors should promote sustainable farm and landscape management as contributions to OECM and thus to a major increase in global protected area coverage. The role of cultural and production landscapes in NDCs, NBSAPs, and LDN targets, should be recognised.

These policy objectives will benefit from improved demonstration of the micro- and macro-economic impacts of the adoption of agroecological approaches on rural development, including on incomes and job creation. Economic actors need to develop a better understanding of the ecological and living nature of soils. Soils should be understood as critical natural capital, requiring protection by economic actors who need to invest in the long term profitability of their own activity, and who should integrate this knowledge into their business strategies. Dialogue and coordination needs therefore to be strengthened at all scales between agriculture and conservation actors and new or adapted institutions need to be developed for improved inter-sectoral coordination and collective action.

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