Food and Agriculture Organization of the United Nations

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STUDY GUIDE

COMMITTEE OEWG 2

Sustainable Soil Management for Food Security

CORE MESSAGES

Challenges for land and water resources

➔ Land, soil and water form the foundations of agricultural production. Agricultural production and productivity were able to keep up with the increasing needs of a rapidly growing population in the past, but this was achieved at a substantial environmental and social cost.

➔ Human-induced land degradation affects cropland, pastures and forested land on which people depend for their livelihoods. Intensive agricultural practices and unsustainable use of chemicals increasingly lead to pollution and the depletion of land, soil and water resources.

Status and trends in the management of land and water resources

➔ During the 60-year period between 1964 and 2023, most of the increase in agricultural production was achieved through intensification, while the expansion of agricultural land was limited to just 8 percent.

➔ More than 1 660 Mha of land, corresponding to more than 10 percent of the world's land area, have been degraded by unsustainable land-use and management practices, with more than 60 percent of this degradation occurring on agricultural lands (including cropland and pastureland).

➔ Future agricultural development pathways need to be based on the transformation of agrifood systems for better production, better nutrition, a better environment and a better life, leaving no one behind. The additional production required to satisfy the future increase in demand must be realized through more efficient, inclusive, resilient and sustainable production systems that address the socioeconomic and environmental dimensions of sustainable development.

Producing more and better: the potential

➔ The potential exists to feed the 9.7 billion people predicted to make up the world's population by 2050, and the approximately 10.3 billion people when the global population is projected to peak around 2085. The conditions under which this food production takes place will determine the associated environmental, social and economic costs. However, the potential for agricultural expansion is limited, as further land conversion to cropland would have impacts on other ecosystems and their services, including forests, grasslands and wetlands.

➔ There is scope for significant increases in land productivity in most developing regions and for most types of crops. The bulk of increased food production should come from reductions in yield gap, the selection of crops suitable for agroecological conditions, and the adoption of sustainable management practices adapted to each crop.

➔ Climate change affects land suitability for many crops, with suitable areas for given crops usually moving to higher latitudes and altitudes. For some crops, agricultural water demand will increase in future climate scenarios, while the available water resources become more variable and less reliable.

➔ In areas where land and water resources are scarce, satisfying competing societal objectives (agriculture, industry, urbanization, energy, biodiversity conservation) often implies trade-offs and difficult choices in resource allocation. Integrated land and water resource planning provides tools to manage the competition for resources and optimize resource use.

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Interesting Facts 1

Between 1964 and 2023, the report says the area of agricultural land expanded by only 8 percent, even though agricultural production grew much faster. Much of the increase came from intensification: producing more on land already farmed, through improved crop varieties, farming methods and other inputs. This challenges the assumption that feeding more people always requires clearing new land. However, producing more from the same fields can damage soil or exhaust water supplies if farmers repeatedly harvest crops without replacing nutrients or use irrigation and fertilizers poorly.

Interesting Facts 2

The report estimates that over 1.66 billion hectares have been degraded by unsustainable land use. One hectare equals 10,000 square metres (an area measuring 100 metres by 100 metres), so this represents an enormous area. More than 60 percent of this degradation occurs on agricultural land: cropland, where crops such as rice, maize and vegetables are grown, and pastureland, where cattle, sheep and other animals graze. Soil can deteriorate differently in these settings—for example, repeated harvesting without replacing nutrients can weaken cropland, while grazing that leaves too little vegetation can expose pasture soil to erosion. Protecting both is essential to food security because damaged land becomes less reliable for growing food or feeding livestock.

Interesting Facts 3

Climate change can shift where crops grow best. 'Higher latitudes' means places farther north or south of the equator; 'higher altitudes' means places higher above sea level. As temperatures rise, some crops may become harder to grow in familiar farming areas but more suitable in cooler places. However, a suitable temperature does not guarantee suitable soil. New farming areas may have shallow soil, poor drainage or slopes vulnerable to erosion. Clearing vegetation to cultivate them could damage soil before reliable harvests are established. Countries therefore need to assess soil conditions as well as climate when considering where crops can be grown sustainably.

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Lately, such land-use challenges have been aggravated by an increase in social instability and conflicts in many countries and regions of the world, affecting an estimated 1.9 billion ha or nearly 40 percent of agricultural land in 2023 (Raleigh, Kishi and Linke, 2023).

This chapter reviews some of the challenges that most directly affect the productive and sustainable management of land, soil and water resources for food and agriculture. ■

HUMAN-INDUCED LAND DEGRADATION AND DEFORESTATION

The United Nations Convention to Combat Desertification (UNCCD) estimates that 52 percent of global agricultural land is degraded (UNCCD, 2022a). According to FAO, unsustainable land-use management and practices affect 1 660 million ha (Mha) of land globally (FAO, 2022a). Conservative estimates of the impact of soil erosion and salinization indicate that 82 Mha of rainfed cropland and 24 Mha of irrigated cropland are degraded from salinization processes alone (FAO, 2024a). Importantly, land degradation leads to a loss of habitat and a decline in species diversity, negatively impacting ecosystems and their ability to provide essential services and making them more vulnerable to drought (Rackelmann *et al.*, 2024).

Land degradation increases flood and drought hazards. These events are not just caused by the excess or deficit of precipitation. They also depend on how the land surface receives, stores, transmits and releases water. When soils are healthy, porous, well graded, and rich in organic matter and biodiversity, they can readily absorb excess precipitation, attenuate peak flows and recharge the root-zone storage. Conversely, soils damaged by erosion, compaction, crusting or the exposure of dense clay layers can see their infiltration capacities reduced by 90 percent or more. Under such conditions, even moderate storms can cause flash floods, while dry spells can translate into agricultural droughts since the degraded root-zone storage cannot hold the required moisture to sustain crops until the next precipitation event. Seo *et al.* (2025) noted that regions experiencing the most severe soil structure loss from intensive cultivation, deforestation or overgrazing exhibit the steepest decline in root-zone moisture and the highest flood peaks for comparable rainfall events. This dual impact of flood amplification and drought intensification is largely attributed to degraded land.

Some 480 Mha of human-induced land degradation occur in croplands where nutrient depletion, loss of soil organic carbon and biodiversity, soil erosion and high concentrations of salts constitute the main symptoms of land degradation (Ziadat *et al.*, 2025). Around 560 Mha of human-induced degraded land are estimated to be in pastures and land used for animal husbandry, where the degradation is driven by unsustainable grazing practices and the invasion of alien species. In other words, more than 60 percent of human-induced land degradation is occurring in agricultural land (croplands and pasturelands), creating unprecedented pressure on the world's agricultural systems.

Agricultural expansion drives nearly 90 percent of global deforestation (FAO, 2022b) and is a primary cause of the degradation of carbon-rich ecosystems such as peatlands (UNEP, 2022). The practice of burning vegetation for land clearance to sow crops is also one of the main triggers of degradation, as it contributes to loss of soil biodiversity and soil organic carbon and can affect the physical properties of soil such as aggregate stability, water repellency and retention capacity, increasing erodibility (Agbeshie *et al.*, 2022).

Human-induced land degradation also affects the 460 Mha of global surface area that are covered with trees, including forests (see Figure 2). Forest fires, although a natural process, are becoming more frequent, aggressive and widespread across the globe due to human activities, and land-use and management practices, as well as climate change. Every year, an estimated 340 to 370 Mha of the Earth's land surface are affected by fire (Giglio *et al.*, 2010), including approximately 67 Mha of forested areas (van Lierop *et al.*, 2015). There has been an increasing trend in global burnt area since 2021, with a peak recorded in

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Definition **1**

Land degradation occurs when land loses some of its ability to support crops, grazing animals or other useful functions. On farms, this can happen when rain washes away exposed topsoil, repeated harvests remove nutrients that are not replaced, or poorly drained irrigation leaves salts in the ground. These are different problems: adding fertilizer will not stop erosion, and planting trees will not by itself remove salt. Governments first need to identify the local cause before recommending a remedy.

Definition **2**

Soil erosion happens when wind or moving water carries soil away, often removing topsoil—the upper layer containing much of the organic matter and nutrients needed by crops. On a hillside, heavy rain can wash bare soil downhill. Farmers may keep soil covered with plants or mulch (a protective layer of plant material), plough across rather than down a slope, or build terraces (level steps cut into a hillside). These measures slow runoff, but they require maintenance; poorly designed terraces can concentrate water and worsen erosion.

Definition **3**

Soil organic carbon is the carbon contained in decomposing plant and animal material and other organic substances in soil. Organic matter helps small soil particles stick together in clusters (called aggregates), creating spaces that let water and air move through the soil while helping it retain moisture and nutrients. Farmers can leave crop residues (stalks, leaves and other plant material remaining after harvest) on their fields or add compost (a soil-improving material made by allowing plant waste and other suitable organic material to decompose). Burning or removing all residues can deprive the soil of this material. However, farmers who grow crops and raise livestock may also need residues as animal feed. They must balance protecting the soil with feeding their animals.

Interesting Facts **1**

More than 60 percent of the land degradation attributed to human activity occurs on agricultural land, including fields used for crops and areas used for grazing. This is striking because the land on which food production depends is itself being damaged. Protecting existing fields and grazing areas can reduce pressure to convert forests and other ecosystems into farmland. However, soil damage may take different forms in different places, so support must be based on local evidence rather than one nationwide prescription.

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Lately, such land-use challenges have been aggravated by an increase in social instability and conflicts in many countries and regions of the world, affecting an estimated 1.9 billion ha or nearly 40 percent of agricultural land in 2023 (Raleigh, Kishi and Linke, 2023).

This chapter reviews some of the challenges that most directly affect the productive and sustainable management of land, soil and water resources for food and agriculture. ■

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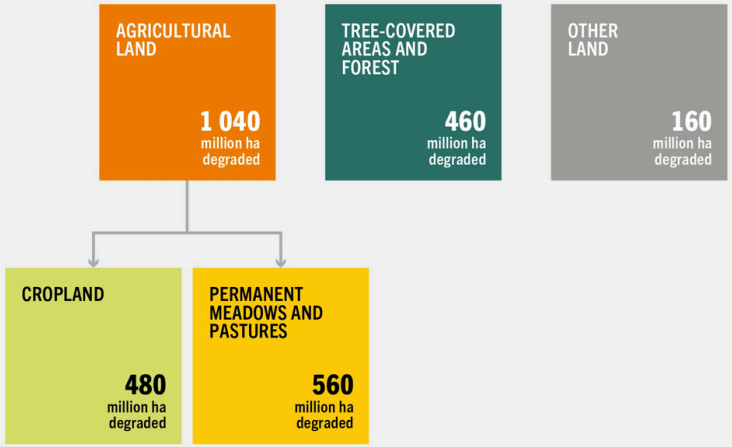
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Definition **1**

Soil biodiversity refers to the many living organisms in soil, from bacteria and fungi to earthworms and insects. Some break down dead plants and release nutrients; earthworms and roots can create tiny channels that let air and water enter. Soil can therefore be biologically active even when we cannot see most of its inhabitants. Frequent ploughing can disrupt the spaces where these organisms live and expose them to drying and heat, while excessive use of certain pesticides and other harmful chemicals can damage or kill them. Soil organisms also depend on organic material, such as dead roots, fallen leaves and plant remains after harvest, for food. When farmers remove or burn these materials rather than allowing some to decompose in the soil, organisms have less food available. A field may still produce a good harvest today while gradually losing the biological activity that helps it remain productive in future years.

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FIGURE 2 HUMAN-INDUCED LAND DEGRADATION, 2020



SOURCES: Authors' own elaboration based on FAO. 2022. *The State of the World's Land and Water Resources for Food and Agriculture – Systems at breaking point*. Rome. https://doi.org/10.4060/cb9910en; Ziadat, F., Conchedda, G., Haddad, F., Njeru, J., Brès, A., Dawelbait, M. & Li, L. 2025. Desertification and Agrifood Systems: Restoration of Degraded Agricultural Lands in the Arab Region. *Agriculture*, 15: 1249. https://doi.org/10.3390/agriculture15121249

2023 (JRC, 2018). Forest fires and wildfires not only cause a loss of above ground biodiversity, but also alter soil biodiversity and functioning (Barreiro and Díaz-Raviña, 2021), contribute to the rapid evaporation of water, and increase the risk of erosion in affected areas (Doerr, Santín and Mataix-Solera, 2023). When wildfires affect carbon-rich soils and peatlands, massive greenhouse gas (GHG) emissions occur. It is estimated that the draining and burning of peatlands to make way for agricultural activities is responsible for nearly 1 gigatonne of carbon dioxide equivalent (CO_2eq) every year or about 6 percent of the carbon emissions from global agrifood systems (FAO, 2023a).

Nutrient imbalances, including negative balances and overloads, contribute to cropland degradation (FAO, 2024b; Figure 3). A positive balance indicates excess application of nitrogen compared with the part that is extracted from the soil by crops (overload). Excessive use of nitrogen fertilizers in most regions leads to soil and water pollution. Conversely, a negative balance indicates a situation where crops extract more nutrients from the ground than those contributed by fertilizers. Soil nutrient depletion is aggravated by removals of crop residues or their burning, a practice widely adopted across the world (Lin and Begho, 2022). In 2022, the overall agricultural use of chemical fertilizers was 35 percent higher than in 2001, but declining rates have been observed since 2020 (FAO, 2025a). Rising prices, market constraints and geopolitical conflicts contribute to limiting the availability of fertilizers to farmers, leading to additional nutrient mining in already depleted soils (Smith *et al.*, 2024).

The inappropriate use of pesticides poses a serious threat to food safety and contributes to the decline in biodiversity by harming soil microbiota, causing the loss of pollinators and making agrifood systems less resilient to pests, pathogens and climate change (FAO, 2019, 2022c).

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Interesting Facts 1

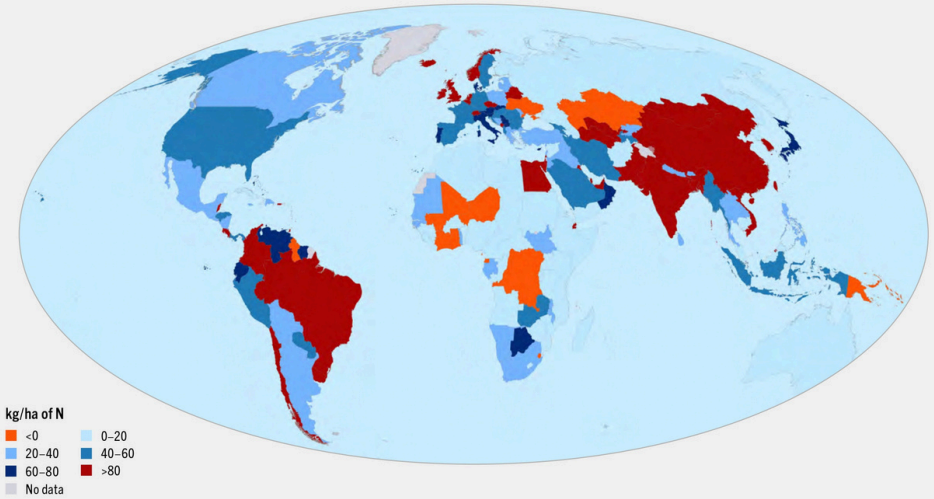
Peatlands are wetlands where partly decomposed plants accumulate in thick layers over thousands of years because waterlogged conditions slow their decay. Although peatlands occupy only a small share of the world's land, they store enormous amounts of carbon. Draining them for farming exposes buried peat to air, accelerating decomposition and releasing carbon dioxide, which contributes to climate change; dry peat can also burn. Rewetting drained peatlands can reduce these losses, but crops grown on dry fields may not survive when water levels rise, threatening farm income. Some restoration programmes therefore compensate land users or support wetland-compatible production, sometimes called paludiculture—for example, growing reeds on wet soils. This is a real policy trade-off: restoring carbon-rich land may require helping farmers change how they earn a living.

Something to Think About 1

Each harvest removes nutrients that plants have absorbed from the soil, including nitrogen, phosphorus and potassium. If these are not replaced, future crops may grow poorly. Yet adding too much fertilizer creates another problem: rain can carry unused nutrients into rivers and lakes, where they may fuel excessive algae growth. As the algae die and decompose, oxygen in the water can fall, harming fish and other aquatic life. A soil test measures nutrients already present; agricultural advisers can use the results alongside crop needs to recommend what to add, how much and when. Governments could make testing and advice affordable, especially for farmers who cannot easily reach a laboratory.

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FIGURE 3 NITROGEN NUTRIENT BALANCES PER UNIT AREA OF CROPLAND, 2022



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NOTE: Nitrogen (N) nutrient balances are calculated as the difference between inputs (synthetic fertilizers, manure, biological fixation, atmospheric deposition and seeds) and outputs (removal through harvest). Values below zero indicate soil nutrient impoverishment whereas positive balances above 80 kg/ha of N per ha suggest excessive applications.

SOURCE: Authors' own elaboration based on FAO. 2025. FAOSTAT: Cropland nutrient balance. [Accessed on 13 February 2025]. https://www.fao.org/faostat/en/#data/ESB. Licence: CC-BY-4.0.

https://doi.org/10.4060/cd7488en-fig03

Since 2001, agricultural use of pesticides has increased by 60 percent, reaching a global average of 2.4 kg per hectare of cropland, with several countries using up to six times the world average (FAO, 2024c), constituting hotspots of environmental concern (Maggi, Tang and Tubiello, 2023). It is estimated that 64 percent of agricultural land is at risk of pesticide pollution (Tang *et al.*, 2021). Of particular concern are pesticides whose ingredients include perfluoroalkyl and polyfluoroalkyl substances (PFAS), known as "forever chemicals". The presence of these high-risk contaminants can lead to significant economic losses in the event of contaminated food recalls and health hazards (Donley *et al.*, 2024). ■

COMPETITION FOR LAND

Various economic activities compete with agriculture for land. Often, the best agricultural land is flat (including alluvial plains) and situated close to human residential areas and markets. This land is also preferred for other uses such as housing and industry. In most places, urban expansion translates into loss of prime agricultural land (IPCC, 2019). Unplanned and unregulated urban expansion and peri-urban development are important drivers of land-use change in many countries. Globally, urban areas more than doubled in size in just two decades, growing from 33 Mha in 1992 to 71 Mha in 2015. This expansion consumed 24 Mha of some of the

Definition **1**

Pesticides help farmers protect crops from insects, weeds and diseases, but improper use can harm human health, soil organisms and the environment. Governments regulate pesticides through registration systems that require manufacturers to submit evidence about a product's effectiveness and potential risks before it can be approved for sale. Authorities may prohibit particularly hazardous pesticides or restrict how approved products can be used. Farmer training can explain how to apply the correct amounts, use protective clothing and equipment suited to the product to reduce exposure, and safely dispose of leftover pesticides and empty containers. These precautions help protect farmworkers and people living near agricultural areas. Governments can monitor pesticide residues in soil, groundwater, nearby rivers and lakes, and sometimes food crops to identify contamination that could harm people, wildlife or future agricultural production. The challenge is to protect crops while reducing risks to human health, soil biodiversity and surrounding ecosystems.

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irrigation water is high and resources are scarce. The challenge for these regions is to raise agricultural water productivity – that is, the benefits from agricultural systems relative to the amount of water used. The aim is to produce more food, income, livelihoods and ecological benefits per unit of water while reducing the social and environmental cost of water withdrawal. Essentially, it means growing more food or gaining more benefits with less water. ■

GROUNDWATER DEPLETION

In many countries and regions, pumping water for domestic, industrial and agricultural supply is exhausting recoverable groundwater storage. Globally, groundwater is an important source of water for irrigated agriculture and its share compared with surface water is increasing. This is especially the case in arid and semi-arid regions. Intensive exploitation of many principal continental aquifers and saline intrusion along highly productive coastal plains are evident. This leads to lower groundwater levels, increased pumping costs, and greater pollution and saline water intrusion, threatening aquifer sustainability and potable water supplies and limiting agricultural production. ■

POLLUTION AND SALINIZATION

Pollution and salinity pose a global challenge that has become more acute in both high- and low-income countries, undermining economic growth as well as socioenvironmental sustainability and people's health (FAO and UNEP, 2021; FAO, 2024c). When not managed correctly, agricultural practices can increase pollutant loads (nutrients, salts, sediments, agrochemicals and pathogens) in soil, groundwater, rivers and lakes. In many countries, agriculture is the main non-point source of water pollution. Agriculture can also be heavily impacted by poor water quality, leading to increased costs, lower profitability and potential health issues. ■

SAND AND DUST STORMS

Agricultural land, especially in drylands, is commonly affected by sand and dust storms that occur when strong, turbulent winds erode small particles from soil surfaces with little or no vegetation cover. Sand and dust storms adversely affect the yields and productivity of crops, trees, pastures and livestock. In addition to air pollution, soil material lifted into the atmosphere holds many microorganisms such as bacteria, fungi and viruses. Sand and dust storms directly affect the prospects for achieving 11 of the 17 Sustainable Development Goals (SDGs), thereby undermining efforts to achieve the 2030 Agenda for Sustainable Development (FAO, 2023c; UNCCD, 2022b). ■

BIODIVERSITY LOSS

Biodiversity supports essential ecological processes that underpin agriculture. Loss of pollinators, natural pest control agents and soil organisms can lead to reduced crop yields and increased vulnerability to pests and diseases. For instance, a decline in pollinators can directly impact the production of many crops. Healthy soils, maintained by soil biodiversity, are crucial for water regulation and food production potential; loss of soil biodiversity can lead to soil degradation and reduced water retention. Unsustainable agricultural practices themselves contribute to biodiversity loss and can degrade land, further impacting productivity. Loss of biodiversity exacerbates the current trend for a growing dependence of global food production on a limited number of crop species. While more than 6 000 plant species have been cultivated for food, fewer than 200 make substantial contributions to global food output, with just 9 accounting for 66 percent of total crop production in 2014 (FAO, 2019). ■

CLIMATE CHANGE – AN EXISTENTIAL THREAT TO AGRIFOOD SYSTEMS

Agrifood systems – the production, distribution and consumption of food – are a major contributor to global warming and are responsible for

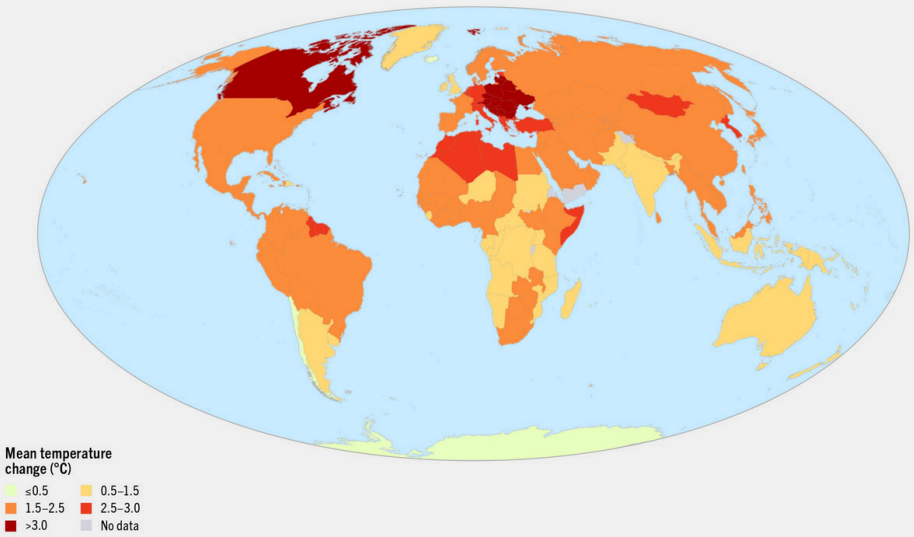
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Definition **1**

Most water used for irrigation contains naturally dissolved salts, including minerals picked up as water flows over or through rocks and soil. The amount varies greatly: water from rainfall or melting snow generally contains very little salt, while groundwater in dry regions may contain much more. When irrigation water evaporates or is absorbed by crops, much of the salt remains in the soil. Repeated irrigation can cause these salts to accumulate, particularly in hot, dry regions where evaporation is high and rainfall is insufficient to wash them away.

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FIGURE 5 AVERAGE ANNUAL TEMPERATURE CHANGE BY COUNTRY, 2024



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NOTE: Temperature changes are measured on land, excluding ocean data, with reference to a climatology baseline 1951–1980.

SOURCES: Authors' own elaboration based on FAO. 2025. FAOSTAT: Temperature changes on land. [Accessed on 24 April 2025]. https://www.fao.org/faostat/en/#data/ET. Licence: CC-BY-4.0.

https://doi.org/10.4060/cd7488en-fig05

one-third of total GHG emissions (FAO, 2023a). Direct emissions from manure and nitrogen applications to agricultural soils constitute the largest single source of nitrous oxide – a potent greenhouse gas and nowadays the first stratospheric ozone-depleting substance (UNEP and FAO, 2024).

At the same time, climate change affects all dimensions of food security, namely availability, access, utilization and stability, by disrupting food production, quality, storage, transport and retail activities. These effects exacerbate competition for land, soil and water resources (Bezner Kerr *et al.*, 2023).

Climate change contributes to land degradation through increases in rainfall intensity, flooding, drought frequency and severity (IPCC, 2019). It also affects soil carbon levels through warmer temperatures (Ren *et al.*, 2024) and altered precipitation patterns. In subtropical and tropical zones, climate-induced hazards such as floods and droughts negatively impact agricultural production. Vulnerable groups, including Indigenous Peoples, are disproportionally affected. They often rely on rainfed agriculture in marginal areas with high exposure and high vulnerability to water-related stress and low adaptive capacity (Caretta *et al.*, 2022).

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Interesting Facts **1**

Nitrous oxide is a powerful greenhouse gas produced partly by microorganisms in soil as they process nitrogen from fertilizer, manure and other sources. When more nitrogen is added than crops can absorb, some can be lost to the air as nitrous oxide; wet or poorly aerated soils can increase certain processes that produce it. The surprising connection is that nutrients used to increase food production can also contribute to climate change. Farmers can reduce unnecessary losses by testing soil where feasible, applying fertilizer at the times crops need it, and avoiding excessive doses. This does not mean that fertilizer is always harmful: crops need nutrients, and the appropriate amount varies with soil, weather and crop type.

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CHAPTER 3
PRODUCING MORE AND BETTER: THE POTENTIAL

KEY MESSAGES

➔ The potential exists to feed the 9.7 billion people predicted to make up the world's population by 2050, and the approximately 10.3 billion people when the global population is projected to peak around 2085. The conditions under which this food production takes place will determine the associated environmental, social and economic costs.

➔ With a total of more than 4 billion ha globally, a substantial amount of land is suitable for cultivation. However, the potential for agricultural expansion is limited, as further land conversion to cropland would impact other ecosystems, including forests, grasslands and wetlands.

➔ It should be emphasized that the assessment of land suitability for cultivation is based only on the characteristics of the land and does not consider existing land use and whether any conversion to cropland is acceptable. For instance, expansion of agriculture into existing forests is in most cases not a strategic option, even when that land offers high levels of suitability for cultivation. This report offers some proposals of alternative suitable areas for cropping to enhance food production and, at the same time, protect forestlands and protected areas.

➔ Land suitable for crop cultivation is not distributed evenly across the world, with regions such as Africa and South America showing opportunities for further expansion, while other regions such as the Near East have mostly reached their limit, and in some cases are experiencing a reduction in area under agriculture.

➔ Most agricultural production is practised on prime or good agricultural land. However, there are areas where population pressure and limited resources force farmers to practise agriculture on marginal land.

➔ Intensification is key: efforts to meet future demand for food must above all involve a more efficient, sustainable and productive use of existing agricultural land. It is critical to ensure that intensification is pursued in a far more sustainable manner than in the past.

➔ There is scope for significant increases in land productivity in most developing regions and for most types of crops. The bulk of increased food production should come from reductions in yield gap, the selection of crops suitable for agroecological conditions, and the adoption of sustainable management practices adapted to each crop.

➔ It is possible to enhance the productivity of marginal land by adopting practices that address factors limiting their potential. Such practices must be adapted to local conditions and need to be supported by appropriate financial and policy instruments.

➔ Among the solutions that can enhance the potential of land to increase crop production, irrigation and other water harvesting techniques can alleviate constraints related to soil moisture by ensuring an adequate water supply to crops. There is substantial scope for further increases in water productivity for agriculture, but much less for increases in water use, particularly in arid regions. Potential increases in water use need to be assessed not only at farm level, but also at river basin and aquifer levels to ensure sustainability.

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Interesting Facts **1**

There are two broad ways to increase agricultural production. Expansion can add additional land into agriculture, sometimes by clearing forests or grasslands. Intensification produces more food on land already cultivated—for example, by reducing crop losses, improving soil fertility or growing more crops each year. Both approaches can increase production, but expansion can destroy natural habitats, while poorly managed intensification can damage the resources on which farming depends. For example, growing crops more frequently without replacing the nutrients they remove can reduce soil fertility, while increased irrigation can deplete groundwater supplies. The challenge for countries is to increase food production without undermining the soil, water and ecosystems needed for future harvests.

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- The availability and quality of soil nutrients is a major constraint limiting production in many areas. This issue can be addressed by introducing better agricultural practices: nutrient-use efficiency; balanced fertilization with integration of organic inputs to avoid the underuse, misuse and overuse of fertilizers; sustainable use of fertilizers; mechanization; adoption of adapted crop varieties; and promotion of agrobiodiversity including the cultivation of opportunity crops adapted to specific conditions and cultures.

- Climate change affects land suitability for many crops, with suitable areas for given crops usually moving to higher latitudes and altitudes. For some crops, agricultural water demand will increase in future climate scenarios, while the available water resources will become more variable and less reliable.

- In areas where land and water resources are scarce, satisfying competing societal objectives (agriculture, industry, urban development, energy, biodiversity conservation) often implies trade-offs and difficult choices in resource allocation. Integrated land and water resource planning provides tools to manage the competition for resources and optimize resource use.

- In degraded agricultural lands, there is scope for restoring the production potential to increase production and productivity using sustainable management practices and techniques, while also addressing and eliminating the root causes and drivers of land degradation.

- Land use is determined by a combination of biophysical and socioeconomic factors, including demography, market, land tenure and policies, and does not necessarily respond to technocratic land-use planning logics. At global level, trade will continue to compensate for the increasing discrepancy between production capacity and demand for agricultural products.

This chapter discusses the potential for increasing production and productivity of agricultural land to respond to the increasing demand for food and other agricultural products and the environmental and socioeconomic challenges described previously. It focuses primarily on crop production, the primary source of food, for which advanced modelling capacities exist. **Chapter 4** and **Chapter 5** discuss the technical, policy and institutional measures needed to realize this potential.

An increase in agricultural production can be achieved either through an expansion of agricultural activity (increasing the land area used for farming, if possible and without compromising other ecosystems) or through intensification (increasing production on existing agricultural land). In turn, intensification can be achieved through an increase in the yield of a given crop or in the number of times the land is used during the year (cropping intensity), or through a combination of both. Given the scale of degradation of agricultural land (cropland and pastureland) discussed in **Chapter 2**, the restoration of degraded agricultural lands and soils could significantly contribute to intensification (increasing production on existing agricultural land).

In many regions, crop yields fall short of those that could be obtained with appropriate management. The difference between actual yield and attainable yield is known as the "yield gap". For example, in sub-Saharan Africa, the yield of rainfed crops is only 24 percent of that possible if appropriate management practices were adopted (FAO, 2022). Knowing the extent and geographical distribution of yield gaps is essential in order to develop strategies for enhanced production: comparing actual and attainable crop yields makes it possible to identify areas where an increase in food production is achievable through improved management practices.

Yield gaps and the potential of land to increase production were analysed for cropland under rainfed and irrigated conditions following the Global Agro-Ecological Zoning methodology developed by the International Institute for Applied Systems Analysis (IIASA) and FAO (Fischer *et al.*, 2021) and using the latest available GAEZ assessment (FAO and IIASA, 2025a). GAEZ data and methods are described in the next section and presented in more detail in the **Annex**.

Using IPCC climate scenarios, GAEZ was also used to assess the impact of climate change on land suitability, crop water demand and crop production potential for selected crop groups. ■

Definition **1**

A yield gap is the difference between what farmers actually harvest and what researchers estimate they could produce under specified growing conditions. Agricultural researchers, government agencies and international organizations study these gaps to identify opportunities to increase food production on existing farmland. They estimate attainable yields by examining local weather, soils and crop management, using information from field experiments, high-performing farms or computer models. For example, if farmers harvest two tonnes of maize per hectare but researchers estimate that four tonnes could be produced, the yield gap is two tonnes. The estimated potential and the farmers' practical ability to achieve it are different questions. An assessment may assume that farmers have access to resources such as reliable irrigation, improved seeds or fertilizer without separately examining whether they can obtain or afford them. Governments can use yield-gap assessments to identify where support might increase production, but must also consider costs, water availability and possible environmental damage before deciding which improvements are practical.

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BOX 2 SOIL AND TERRAIN FACTORS CONSIDERED IN GLOBAL AGRO-ECOLOGICAL ZONING

- Nutrient availability
- Soil nutrient retention capacity
- Soil depth
- Oxygen availability
- Salinity and sodicity levels
- Calcium carbonate and gypsum levels
- Soil workability
- Slope

SUITABILITY ANALYSIS

Crop production is the result of a combination of climatic, edaphic, biotic, physiographic and socioeconomic factors. For a given location, the suitability of land varies based on crop type and management practices. Globally available data on climate, soil and terrain make it possible to assess the suitability of land for many crops (Fischer *et al.*, 2021).

The GAEZ methodology matches available global georeferenced datasets on agroclimatic, soil and terrain conditions with specific crop requirements to determine suitable agricultural land-use options and model the agronomically attainable yield for the production of 52 crops.[f] These factors are used to evaluate the suitability of land and the production potential of individual crops under various input and management conditions; estimate yield gaps by comparing actual yield with attainable yield; and identify hotspots where more productive land use is possible.

Suitability analysis is at the core of the GAEZ methodology, providing information on the potential and limitations of land for each type of crop. GAEZ considers seven suitability classes, ranging from highly suitable to unsuitable. When land is highly suitable for a given crop, and considering optimal management conditions, it is expected that the land can produce more than 80 percent of the attainable yield. This capacity decreases progressively until it reaches zero for unsuitable land.

Land suitability refers to the potential of land to support productive agriculture and is influenced by two main variables: agroclimatic and agroedaphic factors. Agroclimatic factors include temperature, precipitation, solar radiation and the length of the growing period, all of which influence crop growth and development. Agroedaphic factors relate to soil and terrain characteristics, which can affect root development, water availability, nutrient supply and overall soil productivity (see Box 2). Understanding how crop requirements align with both agroclimatic and agroedaphic factors, combined with the application of appropriate management practices, is essential for enhancing agricultural production and land productivity.

Land suitability analysis provides the biophysical assessment of the potential to enhance productivity. To consider competing land uses and ecological/sustainability constraints, integrated land-use planning (ILUP) is needed at different levels of decision-making to address challenges and competing demands (FAO, forthcoming). ■

f Attainable yield in the context of GAEZ refers to the maximum yield that can be achieved under specific agroecological conditions, combining agroclimatic potential yields with soil and terrain evaluations. It takes account of biophysical limitations such as temperature, moisture availability, soil type and slope, as well as specified levels of agronomic inputs and management practices. Attainable yield is distinct from potential yield as it integrates realistic constraints of soil and terrain, providing a more practical estimate of productivity for a given crop under defined conditions. For further details, see: GAEZ 4 FAQ

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Definition **1**

'Agroclimatic' refers to the climate conditions that affect farming, such as temperature, rainfall and the length of the growing season. 'Terrain' refers to the shape and slope of the land. A crop may tolerate the local temperature but still fail if the soil is too shallow to hold moisture or if rain runs quickly off a steep hillside. Useful crop advice therefore combines climate information, soil conditions and farmers' knowledge of what happens in their fields.

Definition **1**

Land suitability means how well a particular location can support a particular crop. A crop may need deep, fertile soil, reliable rainfall and a gentle slope; another may tolerate drier or rockier conditions. FAO's assessment considers climate, soil and terrain, but a map showing where crops could grow does not show whether cultivation would keep the soil productive over time. For example, a steep hillside might support a crop initially but lose fertile topsoil when cleared and ploughed. Governments need to consider erosion risks and the soil-protection measures farmers could realistically use before encouraging expansion.

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TABLE 8 SUITABILITY CLASSES CONSIDERED IN THE GLOBAL AGRO-ECOLOGICAL ZONING ANALYSIS

Category of land suitability	GAEZ suitability class	Attainable percentage of maximum yield	Farm economics
Prime land	VS – very suitable	80–100	Prime land offering best conditions for economic crop production
Good land	S – suitable	60–80	Good land for economic crop production
	MS – moderately suitable	40–60	Moderate land with substantial climate and/or soil/terrain constraints requiring high product prices for profitability
Marginal land	mS – marginally suitable	20–40	Commercial production not viable; land could be used for production when no other land is available
	vmS – very marginally suitable	<20	Economic production not feasible
Unsuitable land	NS – not suitable	0	Production not possible

SOURCE: Fischer, G., Nachtergaele, F.O., van Velthuizen, H.T., Chiozza, F., Franceschini, G., Henry, M., Muchoney, D. & Tramberend, S. 2021. *Global Agro-Ecological Zones (GAEZ v4) – Model Documentation*. Rome, FAO. https://doi.org/10.4060/cb4744en

LAND POTENTIAL FOR CULTIVATION: UNEVEN GEOGRAPHICAL DISTRIBUTION

Leveraging GAEZ v5 data (FAO and IIASA, 2025a), the suitability and spatial distribution of land for cultivation was evaluated. The analysis focused on rainfed potential, through the evaluation of agroclimatically suitable areas for the 52 crops. The methodology aggregated data across all crops to identify the maximum cultivable extent for each geographic unit, land cover/land use type and management intensity level – specifically low-input and high-input systems (see Box 3). The high-input system represents theoretical scenarios useful to explore and contrast outcomes under different management conditions. GAEZ v5 contains information for the historical scenario 2001–2020 as well as for future climatic scenarios as defined by the IPCC. The analysis further classifies GAEZ crop-specific categories of land suitability into prime land, good land, marginal land and unsuitable land (see Table 8). The land cover classification of GAEZ v5 (FAO and IIASA, 2025b) integrates a cropland agreement map obtained from multiple high-resolution products (Tubiello *et al.*, 2023a) with FAOSTAT statistics. Finally, all the areas listed in the World Database on Protected Areas, totalling approximately 1.8 billion ha (UNEP-WCMC and IUCN, 2022), of which about half are protected forest, were excluded from the analysis.

It should be emphasized that the assessment of land suitability for cultivation is based only on the characteristics of the land and does not consider existing land use and whether any conversion to cropland is acceptable. For instance, the expansion of agriculture into existing forests is in most cases not a strategic option.

The extent of prime land – land with the highest suitability for cropping – varies significantly depending on the management level. Globally, GAEZ estimates that approximately 800 Mha of land can be considered prime land under a low-input scenario (see Figure 15). This area doubles to over 1 600 Mha under an advanced management scenario, an area larger than the current extent of cropland (FAO, 2025a). Approximately one-fifth of current cropland is classified as prime land under a low-input scenario, and one-third under a high-input scenario. In terms of land cover/land use, prime land is distributed roughly equally between croplands, grasslands and shrublands, and tree-covered areas.

The spatial extent of good land remains stable at about 3 300 Mha across both input scenarios,

Definition **1**

A 'low-input' scenario assumes limited use of resources such as fertilizer, irrigation and machinery; a 'high-input' scenario assumes more intensive use of them. These are modelling assumptions, not descriptions of what every farmer can actually afford. For example, a map may suggest that maize could yield much more if a field had reliable irrigation and fertilizer. Yet farmers may lack pumps, water rights, money or access to supplies; extra irrigation can also put pressure on already scarce water supplies. Before using projected yields to set production targets, governments should ask which inputs the estimate assumes, whether farmers can obtain them and what environmental costs would follow.

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BOX 4 UNLOCKING THE POTENTIAL OF MARGINAL LANDS

Since its initial conceptualization (Ricardo, 1817), the definition of marginal land has remained a subject of debate. Existing definitions vary significantly depending on application purposes and contextual frameworks. Against a backdrop of escalating global food demand driven by population growth and dietary transitions towards resource-intensive diets, the potential of marginal lands to enhance food security has garnered significant global attention.

A growing body of research has investigated marginality through agricultural or arable land-use perspectives. While marginality emerges from multifactorial interactions, studies consistently identify two interlinked underlying determinants: biophysical and socioeconomic factors (Csikós and Tóth, 2023). Marginal land therefore refers to land with low productivity due to biophysical conditions such as rugged terrain, poor soil quality and extreme weather conditions (including scattered and low precipitation), as well as to productive land constrained by socioeconomic factors such as human-induced land degradation, market price instability, land tenure conditions and limited access to markets and infrastructure, which render it incapable of cost-effective production under given conditions.

The literature offers a variety of figures on the extent and prevalence of marginal lands, as different studies employ different methods, assumptions and criteria to estimate the extent of global marginal lands. The Global Agro-Ecological Zoning (GAEZ) methodology used in this report combines climate characteristics and soil and terrain qualities with crop requirements, and estimates the suitability in terms of attainable yield given the different levels of technology and management. It therefore focuses more specifically on biophysical factors.

It is important to note that the boundary between marginal and productive land is not static. Inappropriate land-use activities and a changing climate may lead to the degradation of productive land into marginal land, while – with appropriate technology and land management practices – marginal land can be transformed into productive agricultural land (Csikós and Tóth, 2023).

Given the varying characteristics of marginal lands in different regions and the diversity of factors affecting land marginality, the management of marginal lands should be adapted to local conditions. Financial and policy instruments, including flexible policies and practices, need to be developed to achieve the sustainable management of marginal lands. The land suitability and yield gap analyses presented in this report provide information about opportunities to enhance the productivity of marginal lands. Examples of coping strategies for marginal lands are presented in the table.

Climatic zones	Coping strategies	Financial input
Arid and semi-arid zones	Soil improvement, development and modernization of irrigation and drainage systems, water harvesting, use of drought-resistant crops and improved varieties	High initial investments
Humid tropics	Planting of acid-tolerant crops, crop rotation, conservation tillage, intercropping	Relatively low costs
Temperate and semi-humid regions	Reduction of soil disturbance, use of crop rotation, soil and water conservation, ecological restoration	Relatively low costs
Highlands	Terracing, soil and water conservation, ecological restoration	Substantial initial investments and policy support
Mediterranean zones	Conservation tillage, planting of drought-resistant varieties, improvement of irrigation and drainage facilities	Moderate costs
Boreal and cold zones	Planting of cold-resistant varieties, rangeland management	Moderate costs

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Something to Think About 1

'Marginal land' is land where farming is difficult because of conditions such as steep slopes, shallow soil or unreliable rainfall. Ploughing a steep hillside may produce a crop for a few seasons but expose soil to heavy erosion. Before encouraging cultivation there, governments can compare the expected harvest with the cost of terraces, water access and soil protection. Improving existing farmland or choosing crops adapted to local conditions may sometimes produce more reliable food supplies.

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substantially less than the 4 billion ha of prime and good land currently available. However, this global figure has limited meaning. It does not consider the large variations between regions and between countries; it takes into account neither competition with other uses (including urbanization), nor the degradation of currently used land. Furthermore, whatever increase in cropland occurs, it will be at the expense of other land uses and will further increase the already large environmental footprint of agriculture. Ignoring the competition with other environmental services and the need to address the trade-offs would result in further degradation of the resources, in particular biodiversity and the regulating functions of ecosystems (Fischer *et al*, 2011).

Preserving forest and grassland ecosystems is crucial to address the challenges of climate change and biological diversity. These ecosystems are essential to maintaining global carbon balance (IPCC, 2022) and providing critical products and services (e.g. non-timber forest products, biodiversity, pollination, water quality) that support adaptation and resilience (FAO, 2020). Although prime and good land amount globally to more than 4 billion ha, the opportunities for expansion are limited, as large shares of this land are used by forest or for pastures (see Figure 17). Globally, 160 Mha of primarily good land under grasslands are estimated to be potentially available for cultivation or for mixed livestock–cropping systems. About half of this land is in Africa, with 40 Mha in the Americas and 30 Mha in Europe. Grasslands and shrublands already sustain the livelihoods of millions of people who rely on these ecosystems for food, fuel and fibre, as well as cultural services (Bardgett *et al*., 2021). For instance, the Sahel Great Green Wall initiative aims to restore 100 Mha of degraded land under agrosilvopastoral systems by 2030. More than 50 Mha – or 10 percent of the total area of interest of this regional effort – are under grazed land (Sacande *et al*., 2022). ■

YIELD GAP AND OPPORTUNITIES TO INCREASE PRODUCTION ON EXISTING RAINFED LAND

Yield gap across main crop groups and selected crops

Yield gaps arise from a series of limitations faced by producers, including technical constraints such as limited access to seeds, plant nutrients and pest control capacities, as well as technologies such as mechanization, storage facilities or irrigation. Furthermore, poor access to knowledge and finance, as well as market inefficiencies and policy gaps, play an important role in determining the yield of specific crops.

For each of the 52 crops analysed, GAEZ provides estimates of the attainable yield for given local conditions. GAEZ v5 was used to assess attainable yields and compare them with country-level yield data obtained from FAOSTAT (FAO, 2025b). This analysis was conducted for three crop groups (cereals, roots and tubers, and oil crops) and selected crops, comparing GAEZ v5 data for the historical scenario 2001–2020 with FAOSTAT data averaged over the same period. For a description of the detailed methodology, see the **Annex**.

At global level, cereal yields averaged slightly above 50 percent of the estimated attainable yields, corresponding to a yield gap of approximately 2 200 kg/ha in absolute terms. In contrast, oil crops performed better, with actual yields corresponding to over 65 percent of their attainable levels and yield gaps of 1 800 kg/ha. Roots and tubers showed actual yields averaging approximately half of the attainable yields, with a substantial yield gap of more than 12 000 kg/ha.

Important variations in cereal production performance exist between countries and between regions (see Figure 18). Africa exhibits the largest gap between attainable and actual yields for cereals, pointing to significant opportunities for improvement: on average, cereal yields in Africa are only one-third of their attainable level,

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Something to Think About **1**

Land that appears suitable for growing crops may already help protect the soil or support food production in other ways. A forest on a steep slope can hold soil in place with its roots, while grassland can provide pasture for livestock. Converting either area into cropland may increase harvests initially but create new problems. For example, ploughing a steep, cleared hillside can expose fertile topsoil to heavy rainfall and erosion. Converting pasture into crop fields may also leave herders with less grazing land and force them to buy feed or reduce their herds. Natural grasslands store carbon in soil as roots grow and decompose; ploughing can accelerate the breakdown of some of this material, releasing carbon dioxide. Before promoting agricultural expansion, governments should consider whether the new cultivation would degrade soil and whether production could instead be increased sustainably on farmland already in use. A suitability map alone cannot answer these questions.

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To reverse the trends associated with the unsustainable management of land and water resources and ensure global food security, land and water users around the world need to adopt technologies, practices and approaches that enhance ecosystem health, resilience and productivity, while ensuring inclusiveness and improving the livelihoods of the most vulnerable populations.

Appropriate governance, legal and regulatory frameworks, finance, research, extension services and market development are all elements of the enabling environment needed to support the adoption of these practices. Institutional support and an enabling environment are further discussed in **Chapter 5**.

Recognizing that there is no one-size-fits-all solution and given the wide array of often context-specific technical solutions, practices and innovations across different sectors, this chapter is not exhaustive and presents a few examples of technical options and innovations for sustainable plant production and protection; land and water management in irrigated and rainfed systems; urban and peri-urban agriculture (UPA); rangeland, pastureland and forest and agricultural land restoration; and integration of inland fisheries and aquaculture within land-based agricultural systems. In addition, the chapter shows the interconnectedness between sectoral approaches and the need to adopt integrated solutions. Many of the approaches discussed here are aligned with and contribute to the UNCCD Land Degradation Neutrality objectives (Hartmann *et al.* 2024).

Technological solutions depend on socioecological context and production systems, of which there are a wide variety around the world. Practices need to be matched with land suitability to ensure that they are both sustainable and profitable and that they contribute to inclusive rural transformation.

Crop-based food production systems (rainfed and irrigated) are the most widespread, but these are not the only options. Agricultural lands, including pasture systems that support livestock production, also have global relevance. Forests account for up to 25 percent of rural household income in tropical and subtropical countries (FAO, 2022a). Non-wood forest products (NWFPs) play an important role in providing food, income and nutritional variety for millions of people worldwide. Inland fisheries produce about 12 percent of global fish supply, with 90 percent of production coming from small-scale fisheries (FAO, 2024a). The rapid growth of inland aquaculture, which now accounts for 63 percent of total aquaculture production, demonstrates its potential to support food systems, with freshwater fish supplying organic protein and nutrients. ■

TECHNICAL OPTIONS FOR RAINFED AGRICULTURE

Rainfed agriculture accounts for 52 percent of global crop production and is practised in areas where precipitation is usually sufficient to secure good harvests. This type of agriculture is common in a wide range of farming situations, from large- to small-scale systems. It supports millions of smallholder farmers in developing countries, with diverse cropping patterns that ensure income and food security and maintain biodiversity. Key staple crops grown under rainfed conditions include cereals and pulses.

When practised correctly, rainfed agriculture contributes to enhanced production, nutrition and environmental sustainability. Diversified cropping patterns support nutritious diets while increasing the resilience of farming practices. Practices such as crop rotation and cover cropping improve soil health and biodiversity. Technical innovations such as integrated plant nutrient management, integrated pest management, the adoption of drought-resistant crops, and water harvesting and soil management techniques are essential to boost the productivity of rainfed agriculture in a sustainable way.

The following are examples of technologies that contribute to addressing current challenges in rainfed agriculture.

Conservation agriculture

Conservation agriculture (CA) combines practices that help to preserve soil moisture,

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Definition 1

Crop rotation means planting different crops on the same field in a planned sequence instead of growing one crop repeatedly. For example, a farmer might grow maize one season and beans the next. Some legumes, including beans, work with bacteria around their roots to take nitrogen from the air and convert it into forms plants can use. Rotating crops may also interrupt pests that depend on a particular crop. Farmers must still consider seed costs, rainfall and whether the additional crop can be eaten, fed to animals or sold.

Something to Think About 1

Conservation agriculture combines three practices: disturbing the soil as little as practical, keeping it covered with plants or crop residues, and varying the crops grown over time. Reducing ploughing helps preserve channels through which air and water move; plant cover shields the ground from heavy rain and slows water loss; crop rotation can interrupt some pests and diseases. However, putting these practices into use can present practical challenges for farmers. Farmers who also keep livestock may need crop residues for feed, while farmers who stop ploughing must find other ways to control weeds. Some may need different planting equipment or training to implement these conservation methods. Rather than recommending a one-size-fits-all approach, governments and agricultural advisers can help farmers test which combination works best on their land.

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BOX 5 FAO'S AGRICULTURAL STRESS INDEX SYSTEM

FAO has developed the Agricultural Stress Index System (ASIS) for the early identification of agricultural areas prone to being affected by dry spells or, in extreme cases, drought. The system has been in operation since July 2014 and is updated three times per month, as soon as new satellite data become available. The ASIS annual and multi-annual data archive (dating back to 1984) also contributes to various climate and socioeconomic studies.

The system focuses on detecting areas where crops are under stress due to water scarcity, providing timely information to decision-makers and farmers so that they can mitigate the impacts of drought. In addition, with the integration of artificial intelligence-driven climate models and satellite data, decision-makers can now better predict drought events and make informed decisions about water management and planting schedules (Cancela *et al.*, 2019).

prevent runoff and erosion, and maintain soil structure; they include minimum tillage, cover cropping and crop rotation. Since 2008–2009, the CA cropland area has been expanding globally at a rate of more than 10 Mha per year. In 2015–2016, global CA cropland area was 180.4 Mha, corresponding to 12.5 percent of the total cropland area. In 2018–2019, global cropland area was 205.4 Mha, corresponding to 14.7 percent of total cropland area (Kassam, Friedrich and Derpsch, 2022). Conservation agriculture increases water infiltration and soil moisture conservation, and it reduces soil erosion by 50 percent (Pittelkow *et al.*, 2015). In Southern Africa, where these practices have been widely adopted, crop yields increased by 15 to 25 percent and soil degradation was significantly reduced (Pittelkow *et al.*, 2015).

Drought-tolerant varieties and drought-resilient practices

The development of drought-tolerant crop varieties is vital for maintaining productivity in rainfed systems facing increasingly erratic rainfall patterns due to climate change. FAO's Global Partnership Initiative for Plant Breeding Capacity Building has contributed to improve food security in arid regions worldwide by promoting drought-resistant crop varieties (FAO, 2025a). In Africa, for example, the introduction of drought-tolerant maize has led to significantly higher yields and reduced crop failure rates (Abate *et al.*, 2017).

Rainwater harvesting and soil moisture conservation help to mitigate the impacts of drought and ensure more stable food production in rainfed agriculture. To cite just one case, Ethiopia has experienced notable success in using rainwater harvesting systems to boost crop yields and enhance resilience during dry seasons (Mekonnen *et al.*, 2022).

In addition to these on-the-ground practices, early warning systems and climate forecasting tools play a crucial role in supporting both rainfed and irrigated farming. The FAO Agricultural Stress Index System (ASIS) is an example of an early warning tool designed to monitor agricultural droughts and assess crop conditions using satellite-based data (see Box 5).

Crop diversification, composting and raised beds

Crop diversification and organic matter management are two important components of sustainable farming strategies. Crop diversification can contribute to better use of water and nutrients, improved plant health and enhanced overall farm productivity through a combination of practices such as well-planned crop rotations and biological pest control. Soil organic matter management, through green manuring, mulching and composting, helps to enhance the accumulation of organic matter in the soil and nutrient cycling (Altieri and Nicholls, 2018). Box 6 presents an example of the application of such practices in Cuba.

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Something to Think About 1

'Tillage' means loosening or turning soil before planting, commonly by ploughing. Repeated deep ploughing can break up soil structure and leave the surface exposed to wind and rain, increasing erosion. Minimum tillage disturbs less soil, helping preserve channels made by roots and soil organisms and keeping more protective material on the surface. However, farmers may need special planting equipment that can place seeds in the soil without first removing the crop residues (stalks and leaves left after harvest) covering the ground. Another challenge is weed control. Farmers who stop ploughing must find other ways to control weeds that would previously have been buried or uprooted by ploughing.

Some farms use herbicides, while others rely on crop rotation, cover crops or mechanical weed control. The best combination depends on local soils, costs and available tools.

Something to Think About 1

A cover crop is grown mainly to protect or improve the soil between or alongside crops harvested for food or sale. After harvesting maize, for example, a farmer might plant a legume that covers exposed ground and reduces erosion. Some legumes also add nitrogen through bacteria associated with their roots. But cover crops require seed, labour and water; where rainfall is scarce, they can compete with the next crop for moisture. The choice of species and planting date must fit local conditions.

Something to Think About 1

Rainfed farming relies mainly on rainfall rather than irrigation. When rain falls on bare, compacted soil, some water runs off before crops can use it; strong sun and wind can also dry the surface. Farmers can conserve moisture by keeping soil covered with crop residues or mulch (a layer of plant material), reducing unnecessary ploughing and improving soil structure so more water can soak in. These measures can help during dry spells, but they cannot create water when rainfall fails. In very dry areas, a cover crop may itself use moisture needed by the following food crop, so farmers must choose practices suited to local rainfall and growing seasons.

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Definition **1**

Compost is made when microorganisms break down plant remains, food scraps, manure and other suitable organic materials. When properly prepared, compost can improve soil structure, help soil retain moisture and provide nutrients for crops. However, making compost requires care. Fresh animal manure may contain disease-causing bacteria that can contaminate crops and pose risks to human health. Compost that has not fully matured may contain high concentrations of ammonia or organic acids produced during decomposition, which can damage young roots or prevent seeds from germinating. As compost matures, microorganisms break down or transform many of these substances, generally reducing their concentrations to levels that are less likely to harm plants. Proper composting requires adequate moisture and air, as well as temperatures high enough for sufficient time to reduce harmful microorganisms. Farmers and compost producers must also prevent unsuitable materials, such as plastic packaging, from entering the compost, since plastic fragments can remain in the finished product and contaminate agricultural soil.

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BOX 6 CROP DIVERSIFICATION, COMPOSTING AND RAISED BEDS IN CUBA

In Cuba, crop diversity, water efficiency, organic matter recycling and crop–animal synergies in raised beds over a 30-year period have enabled the supply of more than 50 percent of the fresh foods consumed in the country, while simultaneously creating 300 000 jobs and contributing over 1 million tonnes of food annually (RUAF, 2017).

Raised beds provide a medium for intensive crop production in soil elevated above the surrounding ground level, reducing exposure to contaminated soil from previous land uses (Altieri and Nicholls, 2018). By easing the management of crops, due to their elevation from the soil, raised beds also contribute to improving yields per unit of labour input (FAO, 2020a). The farmer-to-farmer movement launched by the Cuban National Association of Small Farmers in an effort to co-create and share knowledge has been a driving force for the adoption of improved practices that embrace agroecology (RUAF, 2017).

Composting is particularly relevant in urban and peri-urban settings where organic waste is abundant. The Madrid Agrocomposta municipal initiative has converted 23 tonnes of residents' food waste into compost and fixed 2 400 kg of CO_2eq in the soil since 2016 (Agrocomposta, 2021). Agroecology also presents a significant opportunity for recycling urban food waste. Ecuador's AGRUPAR programme has successfully supported local food production in underutilized spaces in Quito, benefiting 1 300 productive units and enhancing social inclusion via farmers' markets through responsible governance. Similar human and social values have guided interventions in Taiwan Province of China, where Indigenous Peoples' research has made it easier to reclaim land rights. In Gorakhpur, India, low-external input practices such as management of effective microorganisms have significantly increased farmers' incomes and resilience, illustrating the economic benefits of agroecological approaches (RUAF, 2017). Meanwhile, the ØsterGRO Community-Supported Agriculture initiative in Copenhagen embodies circular and solidarity economy as well as cultural and food tradition elements, fostering direct producer–consumer relationships and local foods while minimizing food and packaging waste by avoiding supermarket intermediaries (Shaw, 2017). ■

TECHNICAL OPTIONS FOR IRRIGATED AGRICULTURE

Latest estimates based on FAOSTAT data indicate that around 22.5 percent of the world's cultivated land is currently irrigated, accounting for approximately 48 percent of global crop production (see **Chapter 2**). As irrigation plays an increasing role in agricultural production, better use of water in agriculture becomes increasingly important.

Improving irrigation water productivity

There is considerable scope for improving water productivity in agricultural systems around the world. Many farmers in developing countries could increase water productivity by adopting proven agronomic and water management practices; this is because raising land productivity generally leads to increases in water productivity. Promising pathways for raising water productivity are available along the continuum from fully rainfed to fully irrigated farming systems. These include supplemental irrigation (irrigation supplements rainfall); soil fertility maintenance; deficit irrigation (the crop is irrigated with water below the full requirement for optimal plant growth, to increase crop water productivity); small-scale practices for water storage, delivery and application; pressurized irrigation technologies (e.g. sprinkler and drip irrigation);

Did You Know That... 1

The example from Cuba combines crop diversification (growing different crops), composting (turning organic waste into material that improves soil) and raised beds (planting areas built above the surrounding ground). These practices address different soil-management challenges. Compost adds organic matter that can improve soil structure and help it retain moisture; growing different crops can reduce dependence on one crop and may help manage some pests; and raised beds can improve drainage where soil becomes waterlogged. The value of the example is how farmers can combine practices to maintain productive growing conditions, rather than relying on a single technique.

Did You Know That... 1

In the Cuban example, farmers learned directly from other farmers rather than relying only on written instructions. Seeing a neighbour use compost or raised beds allows a farmer to ask practical questions: How much work did it take? Where did the materials come from? Did the crop improve? This can make unfamiliar methods less risky to try. Farmer-to-farmer learning works best when techniques are tested under similar conditions and participants can adapt them rather than copy them blindly.

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BOX 10 SOIL AND WATER MANAGEMENT IN PASTURELANDS OF CHINA

On the Qinghai-Tibet Plateau of China, soil-water storage in degraded grasslands improved by 41.9 percent from 2012 to 2018 through increased biomass input, litter and vegetation cover (Guo *et al.*, 2021).

In the arid conditions of grazed dairy pastures in northwest China, studies have shown that the application of irrigation and nitrogen – and their interaction – significantly influence alfalfa forage yield, water-use efficiency and nitrogen-use efficiency. It has been demonstrated that 450 mm of irrigation combined with 150 kg of nitrogen per hectare yield the most favourable outcomes: optimal forage output, improved forage nutritional qualities, and increased resource-use efficiency of alfalfa (Kamran *et al.*, 2022).

Pasture improvement and rehabilitation

Improving soil and water management in pasturelands

Increasing soil organic matter – and therefore the amount of carbon in the soil – significantly reduces soil erosion and enhances water infiltration by improving soil structural stability and water retention (Lai and Kumar, 2020). Soil organic matter enhances pasture resilience by supporting microbial decomposition, which supplies nitrogen to plants, and by improving water retention. Effective strategies such as incorporating cover crops during non-grazing periods enhance soil organic matter, wet aggregate stability and overall soil health (Shepherd, Nichols and Selbie, 2021; Stoner *et al.*, 2021). In arid regions, optimizing irrigation and nitrogen application is crucial for sustainable pasture systems (see Box 10). Specific combinations of irrigation and nitrogen levels can maximize forage yield, improve water-use efficiency and enhance forage quality (Kamran *et al.*, 2022).

Improving grazing practices

The impact of grazing intensity on soil's physical properties is significant. Heavy and moderate grazing increases soil compaction, bulk density and penetration resistance, which reduces water infiltration and depletes soil organic carbon and total nitrogen. Conversely, light grazing limits compaction while increasing organic carbon and nitrogen levels. Grassland root morphology plays a vital role in mitigating soil compaction and improving infiltration, especially in arid environments, highlighting the importance of soil management strategies to enhance water supply for sustainable forage production (Liu *et al.*, 2020).

Selection of drought-tolerant and water-efficient grass species

Perennial forage grass species offer specific advantages for high-quality livestock forage production. In comparison with most drought-sensitive annual species, perennial grass species can provide better water-use efficiency with fast regrowth at the start of autumn rains, more efficient use of residual soil moisture at the end of spring, and a reduction in the risk of soil erosion (Lelièvre and Volaire, 2009). Only a limited number of cultivars for perennial forage species adapted to arid climates are currently used in production systems. It is therefore recommended to use intraspecific and interspecific plant diversity to increase the drought resistance of permanent and sown productive grasslands (Lüscher *et al.*, 2022).

The selection of suitable grass species with high yield levels, drought tolerance and recovery capacity is essential to reduce drought stress, which can compromise forage productivity and ensure the survival of grass species, especially in arid and semi-arid regions. Optimal species and desirable genotypes for forage utilization, including *Festuca arundinacea*, *Lolium perenne* and *Lolium×hybridum*, were identified across various water conditions and geographical zones for prospective projects (Taleb *et al.*, 2023).

Integrating alternative forage and legumes

The integration of legumes contributes to the restoration of dryland pastures that can withstand harsh agroecological conditions and support high animal growth rates. The method consists of using drought-tolerant native forage

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Interesting Facts 1

After rain, water does not all stay in the soil. Some runs across the surface, especially where ground is bare or compacted (pressed tightly together), and some evaporates. Plant roots, vegetation cover and decomposing organic material can help water soak in and remain available to plants. This is why soil management can make farms more resilient during short dry spells even without irrigation. The amount of benefit depends on soil type, rainfall and how the land is managed.

Interesting Facts 1

A study on China's Qinghai–Tibet Plateau found that reducing the number of sheep grazing on severely degraded grassland helped the land recover. The area had previously supported approximately 12–18 sheep per hectare, but grazing was reduced to about 7.5 sheep per hectare. Between 2012 and 2018, more grass grew, less soil was left exposed, and more dead plant material accumulated on the ground. This plant cover helped protect the soil from drying out. Researchers found that the amount of water stored in the soil increased by 41.9 percent during this period. The finding illustrates how reducing grazing pressure can help restore both vegetation and the soil's ability to retain water. However, the number of animals that land can sustainably support depends on local conditions.

Something to Think About 1

Pastureland is land where animals such as cattle, sheep and goats graze. When too many animals feed on the same area for too long, plants may not have time to regrow. Hooves can also compact damp soil, pressing the grains of soil together so rainwater enters less easily and more runs off. Farmers and herders may rotate animals between grazing areas, reduce stocking numbers when grass is scarce, or protect damaged patches while vegetation recovers. These measures can improve plant cover and reduce erosion, but they require access to enough grazing land and sometimes reliable water points. Seasonal grazing routes and local land rights must also be considered.

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legumes to rehabilitate degraded soils by covering the soil, fixing nitrogen, increasing water infiltration and preventing soil erosion (Smith and Elgersma, 2021). Water-use efficiency of native grassland is potentially enhanced by interseeding legumes. For instance, in the United States of America, alfalfa–grass mixtures produced 35 percent more forage mass and 96 percent greater nitrogen yield than grass alone, and reduced water-use competition with weeds (Dhakal *et al.*, 2020). On grazed pastures and nutrient-poor land on the Loess Plateau of China, a grass–legume mixture and nitrogen application significantly improved forage yield (by up to 44 percent) and water-use efficiency (by up to 52.5 percent) compared with monoculture and non-fertilized grasslands (Xu *et al.*, 2023).

The use of *Opuntia* spp. (cactus) as alternative feed has been suggested as added value to conventional feed due to its water conservation properties and nutritional quality (high content of minerals, proteins, dietary fibre and phytochemicals) (Pastorelli *et al.*, 2022). However, *Opuntia* should be carefully managed, as it can be an invasive species in some contexts.

Improved pasture management

Pasture management optimizes livestock production by providing animals with nutritious forage while maintaining soil health. This approach encompasses techniques to enhance grass growth, increase forage yield, support ecosystem balance and reduce production costs. Success in pasture management relies on understanding the interconnections between various components. For example, cattle grazing affects grass growth, which in turn influences weed presence, while water management plays a critical role in both environmental health and livestock well-being.

Improved grazing management

Livestock grazing management affects stream water quality, which is improved through integrated best management practices (BMPs) that consider hydraulic and geomorphic characteristics. In the southern humid region of the United States of America, BMPs include alternative water sources, exclusion fencing with riparian buffers, controlled grazing, improvement of forage availability with fertilizers and herbicides, and supplement feeding (Agouridis *et al.*, 2005).

Regenerative rotational grazing with extended resting periods facilitates uniform pasture utilization by cattle and mitigates the negative effects of both overgrazing and undergrazing. In the Basque Country of northern Spain, regenerative rotational grazing yielded a 30 percent increase in spring grass production and a 3.6 percent higher level of topsoil carbon storage compared with conventional rotational grazing, while improving water flow regulation (Díaz De Otálora *et al.*, 2021).

Rotational grazing can mitigate trade-offs between livestock production and water quality in semi-arid rangelands. Research conducted in northeastern Utah in the United States of America indicates that reducing grazing duration and shifting its timing are effective synergistic approaches: conflicts between livestock grazing and water quality are alleviated without the need to fence riparian zones or exclude cattle from pastures adjacent to streams. It should be noted, for example, that periods of high concentration of the bacterium *E. coli* in streams were determined by grazing periods (Hulvey, Mellon and Kleinhesselink, 2021).

On Canadian grassland soils, adaptive multi-paddock grazing – characterized by a very short grazing period at high stocking densities followed by an extended resting period – is considered beneficial to plant regeneration and has positive effects on hydrological processes through increased water infiltration (Döbert *et al.*, 2021).

An optimal grazing solution, which involves meticulous planning of animal units by area based on expected grass yields, must be combined with multifunctional agriculture and flexible land use (Centeri, 2022). The use of many paddocks per herd, together with adaptive stocking management, demonstrates reduced sensitivity to overstocking compared with fixed stocking (Teague and Kreuter, 2020).

Definition **1**

Some plants, especially legumes such as beans, clover and alfalfa, form partnerships with bacteria living inside small, rounded growths that form on the plant's roots, called nodules.. The bacteria convert nitrogen gas from the air into forms the plant can use to grow. This is called 'biological nitrogen fixation'. When legume roots and other plant remains break down, some nitrogen may become available to later crops, which can reduce the need for purchased fertilizer. But the benefit depends on the legume species, soil conditions and how much plant material is removed at harvest; planting a legume does not automatically provide enough nitrogen for the next crop.

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BOX 12 APPLYING THE PARTICIPATORY INFORMED LANDSCAPE APPROACH IN NIGERIA

FAO's Participatory Informed Landscape Approach (PILA), developed under the Food Systems, Land Use and Restoration Impact Program of the Global Environment Facility (GEF-7), demonstrates how cross-sectoral coordination can drive tangible and resilient outcomes on the ground while minimizing trade-offs between forest conservation, ecosystem restoration and agricultural productivity. The approach is guided, structured and tailored, and leverages FAO's state-of-the-art tools and methodologies to support integrated landscape management (ILM) for transformative food systems.

With PILA, countries receive integrated technical support and expertise from diverse domains, including forestry, crop and livestock production, land and water resources, geomatics, transformative governance, tenure, finance and multistakeholder processes. All these components work in synergy, to address landscape management challenges in a single holistic approach.

The Participatory Informed Landscape Approach is currently being applied in Nigeria's Delta Region, where the cultivation of high-value crops such as cocoa and oil palm has resulted in severe environmental degradation, including deforestation and a decline in ecosystem services. To address these challenges, the technical and institutional capacities of national counterparts in Nigeria have been strengthened through, for example:

- **Tool for Agroecology Performance Evaluation (TAPE)** – a household and farm-level survey for measuring/monitoring the agroecology performance of farming systems across the multiple dimensions of sustainability.
- **Transformative governance** including tenure and integrated land-use planning – tools to enhance institutional frameworks and multistakeholder landscape governance.
- **The Economics of Ecosystem Restoration (TEER) Initiative** – an initiative supporting cost-effective restoration practices and monitoring the costs and effectiveness of restoration activities as agroforestry.
- **Geospatial approach** – tools supporting integrated geospatial analysis, incorporating reliable field and remotely sensed data, as well as mapping restoration potential and assessing land-use change dynamics.

Additionally, multistakeholder processes have been facilitated, engaging landscape participants – including governments, project partners and producer organizations – and bringing them together around a unified planning table. The anticipated outcome is the development of more inclusive, better informed and fit-for-purpose ILM plans that empower stakeholders to manage their landscapes in a holistic, sustainable and consensus-based manner.

the cork oak forest landscape in Maâmora and of the Atlas cedar forest landscapes in the Middle Atlas, both in Morocco (see Box 13).

Promoting agroforestry

Agroforestry, a collective term for land management practices where woody perennials are deliberately integrated and managed with agricultural crops and/or animals, is a good example of the synergies between trees and agriculture, whether implemented as tree management on farms or as farming in forest landscapes (Udawatta, Rankoth and Jose, 2019). It is estimated that 40 percent of global agricultural land has more than 10 percent tree cover, including a diversity of agroforestry systems that fulfil a variety of livelihood objectives while contributing to ecosystem functions (Zomer *et al.*, 2009).

As an integrated food system, agroforestry has the potential to advance global food security by increasing crop yield and resilience, improving livelihoods, providing ecosystem services and addressing land degradation. Of the more than 2 billion ha of degraded land identified as potentially available for restoration worldwide, 1.5 billion ha are considered best suited to mosaic restoration, where forests and trees are combined with other land uses, such as agriculture (Minnemeyere, Laestadius

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Did You Know That... 1

In Nigeria's Delta Region, the report describes an approach that brings government agencies, farmers, local communities and other groups together to plan how land should be used. This matters for soil management because an agency promoting agricultural expansion may recommend cultivation in places where clearing vegetation or farming steep or fragile land could increase erosion. An agency responsible for environmental protection may have information about these risks, while farmers and local residents can explain where soil washes away, where grazing occurs and which land is already productive. If each agency plans separately, decisions intended to increase food production can unintentionally damage the soil needed for future harvests. Jointly reviewing maps and local knowledge can help identify where farming can expand without serious soil degradation and where protection or restoration is needed. The report describes planning and technical assistance underway, not proven restoration results.

Something to Think About 1

Agroforestry involves growing trees or shrubs on farmland used for crops or livestock grazing. For example, farmers may plant trees among crops to provide shade or grow trees in pastures where livestock graze. Tree roots can help hold soil on slopes, fallen leaves can add organic matter, and shade can reduce heat stress for some plants or livestock. In windy areas, rows of trees can slow winds that would otherwise blow away exposed topsoil. But trees also use water and nutrients, and dense shade may reduce the yield of sun-loving crops. Farmers therefore need to choose species, spacing and pruning methods suited to local rainfall and crops. The goal is to design a system in which the benefits of trees outweigh competition with food production.

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➔ Integrated water resources management (IWRM) is recommended to optimize the spatial and temporal allocation and use of water resources. This is crucial given that agriculture accounts for more than 70 percent of global freshwater withdrawals. Different needs must be met, taking into consideration quantity, quality and adequate timing. Furthermore, IWRM should go hand in hand with integrated land-use planning. The necessary trade-offs will be addressed by relevant institutions and stakeholders at relevant scales, such as at catchment or river basin, national, regional or international levels.

➔ The Water–Energy–Food–Ecosystems (WEFE) nexus approach acknowledges the interconnectedness between water, energy and food systems and their impact on ecosystems. The WEFE nexus enhances resilience, maximizes synergies and promotes the participation of stakeholders and the sustainability of agrifood systems.

➔ Institutional capacities and integrated systems of data, information, science and technologies must be set in place and strengthened to enable sustainable and integrated land, soil and water resources management and inform supportive and coherent policies.

➔ Rural development policies need to consider efficient and sustainable natural resources management, building resilience and diversifying production systems. A resilient rural economy is vital, and policies must aim to reconcile different land uses, demands and objectives.

➔ Tenure arrangements for land and water management often ignore smallholders and vulnerable groups and their legitimate claim to access these resources. Securing access for smallholders and vulnerable groups offers the potential to enhance productivity, protect resources and contribute to inclusive rural development.

➔ Data and information are key to ensuring the sustainable and productive management of land and water. The rapid development of information and communication technologies, including remote sensing, offers new opportunities for supporting land and water management. Efforts should be made to ensure that the right type of information reaches the different decision-makers at all levels, and on time.

➔ Regulatory frameworks are essential to create a more conducive environment for clarifying land and water rights, and supporting the sustainable management of natural resources and, in turn, public and private sector investment. Too often, unclear environmental regulations, compounded by weak enforcement, exacerbate existing challenges. Stronger policies to promote sustainable land, soil and water management should include clear land and water rights, incentives for sustainable practices and disincentives for unsustainable ones.

➔ Most traditional agricultural investment fails to capture the environmental and social costs and benefits associated with agricultural production. Public and private investment instruments that increase agricultural productivity, contribute to inclusive development and preserve natural resources need to be developed and put in practice; at the same time, harmful incentives and subsidies should be reduced and repurposed. Sustainable investments require coordinated collaboration between the public sector and the financial and private sectors.

➔ Farmers, especially in developing regions, often lack access to the necessary technologies, information and skills required to implement sustainable practices. This knowledge gap hinders the adoption of innovative and sustainable land and water management approaches and techniques. Farmer-centred training and extension programmes should be institutionalized and use modern communication technologies to promote the adoption of sustainable practices that strengthen resilience, while ensuring the overall improvement of farmers' socioeconomic status.

➔ Farmers need to be recognized as agents of change. Their participation must be strengthened, ensuring that they are involved in the design of local solutions, and supporting their meaningful contribution in policy dialogue at all levels.

➔ Partnerships should be forged at different levels, from local to national, regional and international, to avoid duplication and enhance synergies and complementarities.

The previous chapters provide information about the potential to increase production and call for an enabling environment that should be enhanced to realize these options in practice. Thus far, the report has shown how, over the past decades, agriculture has responded to

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Something to Think About **1**

Integrated land-use planning means considering how different uses of land affect one another rather than making decisions about farming, grazing and forest protection separately. This is important for sustainable soil management because expanding agriculture into unsuitable areas can damage soil and reduce its ability to produce food in the future. For example, clearing forests on steep slopes to grow crops may increase food production in the short term, but removing tree roots and vegetation exposes the soil to erosion during heavy rainfall. Planning can combine maps of soil quality, slopes and rainfall with information from farmers and local communities about how land is currently used. Governments can then identify where agricultural production could be increased without causing serious soil degradation and where protecting or restoring soil should take priority.

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BOX 18 MAIN FEATURES OF INTEGRATED LAND-USE PLANNING (ILUP)

- Aims to enhance the sustainability of land use and management with the full participation of stakeholders.
- Assesses the prevailing biophysical, socioeconomic and legal conditions, drawing on multidisciplinary, multisectoral and local expertise to optimize land use across different parts of the landscape.
- Offers an approach to planning, taking into account that each situation is unique and demands its own solutions.
- Results in a negotiated outcome that needs to be implemented, evaluated and monitored.

SOURCE: Ziadat, F., Berkat, O., Ouchna, R., Touami, M., Fetsi, T. Harari, N., Mekdaschi Studer, R. & Schlingloff, S. 2022. Participatory land resources planning to promote sustainable landscape management in rainfed areas – Morocco. *Frontiers in Sustainable Food Systems*, 6. https://doi.org/10.3389/fsufs.2022.848043

BOX 19 MOROCCO: DEVELOPING A TERRITORIAL PLANNING PACT IN THE SOUSS-MASSA REGION

In Morocco, analyses were carried out to assess the types, degree and severity of land degradation "hotspots", as well as "bright spots", using FAO's Land Degradation Assessment in Drylands (LADA) and World Overview of Conservation Approaches and Technologies (WOCAT) tools. The analyses helped to identify appropriate technological solutions for sustainable land management (SLM). Results from local assessments were used to implement a process of participatory land-use planning in selected communities of the Souss-Massa region. The process led to the development of a Territorial Planning Pact for land-use planning and a three-year action plan to help implement and mainstream SLM in selected communities. The pact forms a base for the planning development programme in the region, with the involvement of key stakeholders. This example highlights the importance of integrating biophysical and socioeconomic information as part of a participatory process to identify the actions and responsibilities of various stakeholders and ensure both the sustainable management of scarce natural resources and improved livelihoods.

SOURCE: Ziadat, F., Berkat, O., Ouchna, R., Touami, M., Fetsi, T. Harari, N., Mekdaschi Studer, R. & Schlingloff, S. 2022. Participatory land resources planning to promote sustainable landscape management in rainfed areas - Morocco. *Frontiers in Sustainable Food Systems*, 6. https://doi.org/10.3389/fsufs.2022.848043

jurisdictions along an urban–rural continuum (UNCCD, 2023). The term "integrated" refers to recent trends in land-use planning: optimization of land and water use across different planning scales, participation by and consultation with stakeholders, multidisciplinary technical support, coordination with multiple sectors at different decision-making levels and the use of multiple tools. Modern approaches to ILUP are based on the principles of decentralization and participation, whereby the primary land users such as farmers, herders, fisherfolk or forest dwellers have a legitimate stake in the planning process, along with the actors who use the land for different purposes (e.g. settlements, sources of energy, industry, mineral resources, recreation and tourism). Increasing recognition is given to inclusiveness, taking account of the

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Something to Think About **1**

Soil maps and land-use plans may overlook how farmers and herders actually manage the land. For example, a map may label an area 'unused' even though herders graze animals there seasonally, allowing other pasture to recover. If officials convert that area to permanent cropland without consulting herders, grazing animals may be concentrated on the remaining pasture, leaving less vegetation to protect the soil from erosion. Meaningful participation means asking affected farmers, herders and residents about these practices early enough to change a plan. Their knowledge can help officials avoid land-use decisions that unintentionally increase soil degradation and weaken future food production.

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TABLE 11 NINE STEPS IN THE FAO GUIDELINES FOR INTEGRATED LAND-USE PLANNING

Step	Description
Step 1: Initiate the integrated land-use planning process	Identify the area and decide on the goals and approach of the planning exercise. Determine characteristics, problems and the people involved.
Step 2: Perform stakeholder mapping	Ensure that all stakeholders at the relevant levels are identified. Analyse their characteristics, concerns and the anticipated benefits or losses they will experience from land-use changes. Pay special attention to land tenure and inequality issues, as well as to people who have legitimate tenure rights, whether they own land or depend on common property resources and ecosystem services.
Step 3: Establish a multidisciplinary taskforce	Ensure that adequate technical expertise and all stakeholder groups, particularly local actors, are represented on the taskforce. Prepare terms of reference, ensure access to necessary information and communicate their powers and authority.
Step 4: Characterize the land, its uses and users	Describe the distinctive environmental and socioeconomic features of the planning area, including land-use and user categories. Compile data using methods that are appropriate to each planning level.
Step 5: Undertake integrated analysis of land-use options	Assess the environmental, economic and social impacts of different land-use options for land users and their communities, with particular reference to women, young people, Indigenous Peoples and vulnerable groups. List the consequences, both positive (opportunity) and negative (impact), of different courses of action, considering issues of sustainability and equity.
Step 6: Consult and decide on suitable and acceptable land-use options	Hold public and executive discussions on the options and their consequences, based on the appraisal undertaken in Step 5. Decide which land-use changes to undertake using inclusive and participatory approaches.
Step 7: Prepare the integrated land-use plan	Allocate the selected land uses to target areas. Make plans for appropriate land management and determine how the land-use plan is to be put into practice. Prepare a budget and identify available financial resources. Communicate the decision to all stakeholders.
Step 8: Implement the integrated land-use plan	Employ a specific development project. Ensure that the implementation team works in close consultation with the target stakeholders.
Step 9: Monitor and evaluate the integrated land-use plan	Monitor the progress of the plan towards meeting its goals. Revise the plan as necessary, with the adequate engagement of all stakeholders.

SOURCE: FAO. (forthcoming). *Guidelines for integrated land-use planning – an update.* Rome.

specific needs of men and women, and vulnerable and marginalized persons from different socioeconomic and ethnic groups (see Box 18).

Integrated land-use planning uses participatory approaches that empower stakeholders to analyse an existing situation and enable them to propose the necessary changes and develop an agreed plan. This calls for land users to be given a central role, since their intimate knowledge and experience of their own territory places them in the best position to articulate their needs and desires for change (see Box 19) (Ziadat *et al.*, 2022).

Integrated land-use planning considers the following issues: climate change, land degradation neutrality (LDN) and restoration, conservation and sustainable use of biodiversity, urbanization, peri-urban and urban agriculture, governance, land and water tenure, and the rights of women and Indigenous Peoples. FAO is in the process of updating the guidelines on ILUP based on nine steps (see Table 11 and Figure 27).

Lever 2: Integrated landscape management

Integrated landscape management is the basis of natural resource management; it ensures that, by managing the natural resource base and ecosystem services through a coordinated process across sectors and stakeholders, the full range of societal needs can be met in the short and long term (FAO, 2017a).

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Something to Think About **1**

People who farm or graze land often know details that national maps miss: where water collects after heavy rain, which fields are left fallow (rested between crops), and where animals travel seasonally. Their knowledge does not replace soil surveys, but it can help officials interpret them correctly. Publishing draft land-use plans and inviting corrections can prevent mistakes, such as treating temporarily rested farmland as abandoned land.

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The management of land and water resources has implications for multiple societal objectives. Agricultural productivity-led models rarely address environmental concerns and the need to promote resilient and inclusive rural transformation (Davis *et al*., 2024). In many cases, focusing exclusively on productivity tends to favour large-scale commercial operations and neglect environmental and social considerations. Policy coherence means adopting or adjusting policy measures to achieve multiple goals, while preventing the unintended consequences of sector-focused approaches. The Organisation for Economic Co-operation and Development – a central voice on policy coherence – has extended the definition of the Policy Coherence for Sustainable Development concept beyond the fostering of synergies and trade-offs across sectors in a jurisdiction; it also reconciles domestic policy with internationally agreed objectives and considers the transboundary and long-term effects of policies in order to address trade-offs and enhance synergies.

Evidence demonstrates that restoring degraded resources, promoting sustainable intensification and increasing resilience can be achieved through joint cross-sectoral planning and implementation, greater policy coherence and multistakeholder initiatives. This can be done through territorial approaches such as watershed or river basin management, integrated landscape management and restoration, and integrated land-use planning, or through approaches such as the Water–Energy–Food–Ecosystems nexus. These approaches need to be supported by long-term strategies, investments, financing and partnerships.

Finding appropriate pathways to make these approaches work in practice is challenging (FAO, 2023b): policy coherence is not just a techno-managerial issue, but also a political one. Indeed, greater policy coherence and joint cross-sectoral planning involve taking into account the perspectives of different actors with often contradictory interests and objectives. This is further complicated by the significant rise in interconnected economic, environmental, social and geopolitical crises, all of which have had serious implications for countries' prospects for developing sustainability in line with their international commitments.

Specific barriers to policy coherence need to be recognized and identified upfront. While often of a similar nature, they differ in function of the context. Coherence challenges can arise from insufficient communication and coordination; from lack of data, funding, knowledge, shared goals or institutional spaces to meet and coordinate; and as a result of stakeholder resistance. In most cases, such challenges are driven by patterns rooted in formal and informal institutions, tenure regimes, routines or standard operating procedures in government administrations. There may be inherently contradictory interests and mandates such as conflicts between resources, conservation concerns and infrastructure development interests. Therefore, policy coherence is not only about optimization, but also about the design and facilitation of never-perfect processes of decision-making through which two or more objectives and means can be redefined, so that new (temporary) compromises can be determined.

The role of governance and political economy to support policy coherence

Governance plays a specific and crucial role in navigating interactions and collective action, especially through decision-making processes that consider potential consequences across domains and impacts on different stakeholders and actors, in particular, small-scale producers and other actors who are economically or politically vulnerable. The question of how to recognize rights and give agency and voice to those actors in decision-making processes is perhaps the most challenging and the one that deserves the most urgent attention (Nilsson, Griggs and Visbeck, 2016).

Coherence and joint cross-sectoral planning generate important benefits, but they also come with some potential downsides, from the perspective of a specific sector or agency. Such concerns include blurred lines of accountability, more time-consuming processes, uprooting of existing routines and practices, difficulties in measuring impact or effectiveness, loss of control, influence or autonomy, and dilution of priorities.

Facilitating policy coherence and joint cross-sectoral planning across food, land and water systems in a territory thus requires a good

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Something to Think About **1**

Policy coherence means ensuring that different government policies support rather than undermine one another. In the United States, agricultural support programmes once encouraged farmers to continue growing crops on land highly vulnerable to soil erosion, while other government programmes paid farmers to reduce that erosion. To address this contradiction, the 1985 Food Security Act required farmers cultivating highly erodible land to follow approved soil conservation plans to remain eligible for certain government benefits. These plans could include practices such as keeping soil covered or reducing ploughing to prevent rain and wind from carrying away topsoil. Research by the U.S. Department of Agriculture found that, between 1982 and 1997, water erosion declined by 39 percent on highly erodible cropland covered by these requirements, compared with 24 percent on similar land not covered by them. Other factors also contributed to the improvements, but the evidence suggests that linking agricultural support to soil protection made a difference. This example shows how governments can align policies that support food production with policies that protect the soil needed for future harvests.

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BOX 21 REPURPOSING AGRICULTURAL SUBSIDIES

Agricultural subsidies do not always achieve the intended objectives; sometimes, the benefits do not last once the subsidies end. Therefore, it is increasingly advocated to redirect support to more sustainable and long-term investments.

Indeed, agricultural support does not provide desirable results for sustainability and human health. Repurposing it can be a game changer, offering governments an opportunity to optimize the use of scarce public resources to transform food systems, increasing efficiency and supporting the Sustainable Development Goals. Support to agricultural producers, which accounts for almost USD 540 billion a year – or 15 percent of total agricultural production value – is heavily biased towards measures that are distorting, unequally distributed and harmful to the environment and human health (FAO, 2021).

It is vital to design a repurposing strategy that considers, prior to implementation, the future impact and how to best achieve it. The strategy also requires close and gradual monitoring of the outputs and outcomes. At the same time, a review of success stories of agricultural subsidies can provide lessons to guide such repurposing. Success factors typically include capacity development and the empowerment of targeted beneficiaries in decision-making and in the financing model adopted to roll out the subsidy. It is imperative to integrate appropriate innovative financing mechanisms for the repurposing of subsidies to limit the risk of failure and guarantee a return on the investment.

Repurposing agricultural subsidies is a policy that has an impact on the scaling up of strategic finance and investments.

understanding of the local context in terms of governance and political economy. Such an understanding can be helpful in developing innovative institutional arrangements and processes to manage and coordinate policies, budgeting and regulatory development across sectors. It is also important for strengthening capacities to build on synergies, address trade-offs, and manage processes that may involve (re)allocating limited resources, addressing inequalities and changing the way of empowering actors at different levels of decision-making. Required actions include strengthening of capacity for public institutions, implementation of coordination and consultation mechanisms across ministries, adoption of appropriate planning and monitoring tools, and realization of upgraded and integrated data and information systems.

For example, improving the design of irrigation investments to include gender, health and nutrition outcomes can make irrigation an integral part of strategies to reduce poverty, hunger and malnutrition. Targeted subsidies can spur the adoption of more appropriate irrigation technology, and the provision of environmental services and measures for maintaining and restoring healthy freshwater and soil systems. Paying for environmental services – that is, payments to farmers or landowners who agree to manage their land or watersheds for environmental protection – can also help to ensure the proper valuation of well-functioning ecosystems (see Box 21).

Initiatives aimed at advancing policy coherence have emerged globally and regionally to address the challenges related to water and food security. A promising approach to coordinating water and agriculture sector policies has been adopted in the Arab region. The League of Arab States, with support from FAO and the Economic and Social Commission for Western Asia, has institutionalized coordination between the water and agriculture sectors through the establishment of a High-Level Joint Technical Committee. The joint ministerial resolution led to the 2019 Cairo Declaration,[1] which stresses the importance of enhancing policy coherence by reviewing sectoral policies on cross-cutting issues such as water allocation, non-conventional

1 The Cairo Declaration was adopted during the First Joint Meeting of Arab Ministers of Agriculture and Water held by the League of Arab States in Cairo on 4 April 2019.

Interesting Facts 1

Agricultural subsidies support farmers and food production, but some encourage practices that damage soil and make healthy diets less affordable. In 2021, FAO, UNDP and UNEP estimated that 87 percent of the $540 billion in annual agricultural producer support distorted prices or could contribute to environmental damage that impacts food security. How can support intended to strengthen food security have these unintended consequences?

First, subsidies that reduce the cost of synthetic fertilizers can encourage excessive use, which may increase soil acidity, disrupt nutrient balances, harm beneficial soil organisms and pollute waterways. Subsidies are also distributed unequally. According to the Environmental Working Group, the top 10 percent of U.S. farm subsidy recipients received 78 percent of payments between 1995 and 2021, while the bottom 80 percent received only 9 percent. Payments based on acreage or production favor larger farms and can encourage cultivation of erosion-prone land without requiring soil protection.

Second, subsidies often support commodities such as corn and soybeans, used to produce ingredients for ultra-processed foods. Lower commodity costs make these ingredients attractive to manufacturers, while fruits, vegetables and beans may be relatively more expensive. Food companies also stimulate demand through advertising and promotions, including marketing to children. Many ultra-processed foods are high in sugar, salt or unhealthy fats and provide "**empty calories**"—energy with few essential nutrients. People can therefore consume excess calories while lacking nutrients needed for good health, increasing their risk of obesity and diet-related diseases.

Governments can redirect subsidies toward soil-friendly practices such as composting, cover crops, crop rotation and efficient fertilizer use, while supporting the production and distribution of nutritious foods. The challenge is to reform subsidies without undermining farmers' livelihoods or food security.

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water resources, trade and social protection, with the goal of achieving water and food security in the Arab region.

At the International Soil and Water Forum in Bangkok, held in December 2024, representatives from 27 countries endorsed the Ministerial Declaration on managing water scarcity and reversing soil degradation for sustainable and resilient agrifood systems. The declaration recognizes the importance of "strengthening cross-sectoral coordination, cooperation mechanisms and the consistency of policies, planning, investment and implementation across land, soil, water, agriculture, climate change, biodiversity, environment, and energy" as the first urgent action to accelerate agrifood systems transformation (FAO, 2024a).

Enabler 2: Governance of natural resources

Land tenure

Land tenure security is a key enabling factor to address climate change, biodiversity loss and land degradation (IPCC, 2019, 2022; IPBES, 2018; Verburg *et al.*, 2019). UNCCD Decision 26/COP14, Decision 27/COP15 and Decision 28/COP16 repeatedly acknowledged the relevance of land tenure to achieve land degradation neutrality (UNCCD, 2019, 2022). Safeguarding legitimate tenure rights of Indigenous Peoples has also been integrated under the the Kunming-Montreal Global Biodiversity Framework (GBF) of the Convention on Biological Diversity (CBD, 2022, Target 22).

Governance of tenure and land tenure are interrelated but distinct concepts. A responsible governance of tenure relates to mechanisms and processes that articulate the interests of different actors, mediate their differences and ensure that their rights and duties with respect to land, water or other natural resources are exercised with transparency and equity. Land tenure can be defined as "the relationship, whether legally or customarily defined, among people, as individuals or groups, with respect to land", or in simpler terms: "tenure systems determine who can use what resources for how long, and under what conditions" (FAO, 2022a). Another relevant concept when discussing the importance of land tenure to achieve food security and global environmental goals is tenure security, which can be defined as "the guarantee of continued occupancy or use rights whether by virtue of formal rights, customary rules or other forms of assurance" (AGROVOC, 2022 in FAO and UNCCD, 2022). In short, it could be said that land tenure security is a result of the responsible governance of tenure of lands.

The adoption of the VGGT by the Committee on World Food Security in 2012 – and their revision in 2022 – enabled the definition of the concept of "legitimate tenure rights" (FAO, 2022a). This concept invites states to review the customary tenure rights in use and socially accepted, and to promote their recognition through the revision of their legal frameworks, offering a pathway to address the dichotomy between formal and informal tenure arrangements.

In 2022, FAO and the UNCCD Secretariat produced a technical guide supporting the integration of tenure into implementation of the UNCCD and Land Degradation Neutrality framework (FAO and UNCCD, 2022) and launched a joint initiative on tenure security for land restoration to support the integration of tenure in the achievement of LDN targets and programmes at national level.[m,n] More than 30 countries have applied to join the initiative. National consultations in a first group of countries (Kazakhstan, Kenya, Mexico, Senegal, Sri Lanka) demonstrated the relevance of gathering stakeholders from both the tenure and the land management communities (FAO and UNCCD, 2024) to advance concrete recommendations to tackle land tenure insecurity.

At national level, improving tenure security and its governance can be addressed by reviewing the policy and legal framework to sustain the recognition of legitimate tenure rights and plan for tenure security enhancements. Land or water governance raises questions of resource-related rights, risks, responsibilities, benefits and incomes, as well as of voice, power and authority.

m For more details see: https://www.prindex.net

n For more information about the FAO–UNCCD joint initiative, see: https://www.fao.org/land-water/land/tenure-ldn/fao-unccd-joint-initiative/en/#:~:text=UNCCD20and20FAO20have20launched,be20held20in20late202024

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Interesting Facts 1

The report notes that representatives of 27 countries endorsed a ministerial declaration at the International Soil and Water Forum in Bangkok in December 2024. A ministerial declaration records political intentions; it is not, by itself, a legally binding treaty or proof that national programmes have been implemented. Its value for negotiations is that countries have already expressed support for coordinating soil, water and agricultural policies. Delegates can consider what practical follow-up—such as soil monitoring or farmer training—would make such commitments meaningful.

Definition 1

Land tenure means the rules that determine who may use, control or transfer land. These rights may come from ownership, renting land or long-established community arrangements known as customary rights. A farmer who expects to lose access next year may hesitate to build terraces or plant trees that take years to pay off. Secure and fairly recognized rights can encourage such investments. But issuing individual ownership titles is not the only solution; some communities legitimately manage grazing land or forests together.

Something to Think About 1

Building terraces to prevent erosion or planting trees to protect soil requires farmers to spend money on materials and labour, while the benefits may take years to appear. Tenant farmers who rent land may hesitate to make these investments if their landlords can end their leases before they benefit from the improvements.

Governments can encourage long-term soil protection by providing greater security for farmers who own or rent land, as well as those whose families have cultivated land for generations under traditional community arrangements without formal ownership documents. This can include protecting farmers' rights to continue using the land, establishing fair rental agreements and providing ways to resolve land disputes. Farmers may also need affordable loans or financial assistance to cover the initial costs of soil conservation. The Revised World Soil Charter recognizes that insecure land rights and difficulty obtaining financing can prevent farmers from adopting sustainable soil management practices.

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In 2022, the FAO Committee on Agriculture reviewed FAO's work on water tenure (FAO, 2022b). It encouraged countries to participate in a Global Dialogue on Water Tenure,[p] with a view to discussing principles for responsible governance of water tenure. The aim was to strengthen the secure and equitable access to water resources of all legitimate water users, including women and marginalized groups, in support of the wider goals of health, food security, social inclusion and climate resilience (FAO, 2022c). Within this framework, a regional consultation on water tenure was held at the International Soil and Water Forum in Bangkok in December 2024.[q]

Enabler 3: Data, information and technology

The availability, quality and accessibility of data at all levels are prerequisites for the effective and sustainable management of land and water resources. Good progress has been made recently, in particular through remote sensing and communication technologies, allowing the collection of much better knowledge on water and land resources and their use, including real-time or near real-time data. Challenges remain, however, regarding the collection of specific types of data and ensuring that the right data are accessible to the right people at the right time. Integration across the data domain is still in its infancy. Different types of data are needed at different levels of management:

- **At local level**, farmers need access to real-time information on soil moisture, soil nutrient content, weather forecasts, water availability and reliability of supply, as well as early warning data on pests and pest control, to ensure good harvests. Real-time evolution of market prices is critical to ensure the best return from investments. Seasonal weather forecasts provide insights into production potential. Mapping trends associated with climate change is critical to ensure the resilience of long-term investments.
- **At national and river basin level**, developing effective and coordinated strategies requires good knowledge of the accessible resources and the trends in their use and availability, as well as monitoring of economic, social and environmental performance. More efforts must be made to invest in systematic soil, water and land-use surveys. Here, integration across sectors plays a critical role in supporting cross-sectoral coordination. Data need to be made available across ministries at minimal or no cost to their users.
- **At global level**, more and better understanding of status and trends is needed to guide global discussions and support evidence-based guidance in relation to major conventions and global initiatives. Substantial efforts are required for better monitoring of land degradation, biodiversity, progress towards sustainable agricultural practices and the impact of climate adaptation approaches.

The agroinformatics platform (previously called Hand-in-Hand Geospatial Platform)[r] gathers over 2 million data layers in support of evidence-based interventions in the field of agriculture and food security. This digital public good provides open access geographic information, key food and agriculture indicators, and agricultural statistics sourced from FAO and other organizations.

The use of digital platforms or decision support systems, based on satellite imagery, maps, drones and internet of things sensors, is gaining traction in many countries. These technologies enable farmers to optimize the use of natural resources and agricultural inputs. Mobile apps and platforms, such as FAO's AquaCrop and Water Productivity Open-access Portal (WaPOR),[s] provide real-time data on soil moisture conditions. WaPOR monitors and reports on water productivity of terrestrial vegetation in near real time, with global coverage and a 10-day time interval. Analyses of WaPOR information can also help to identify areas with potential to increase water productivity. Box 22 presents an example of a web-based decision support system for irrigation management.

p See: https://www.fao.org/in-action/scalewat/global-dialogue-on-water-tenure/en

q See: https://www.fao.org/in-action/scalewat/news/news-detail/new-water-tenure-publication-presented-during-first-regional-consultation-for-asia-pacific-in-bangkok/en

r See: https://data.apps.fao.org/?lang=en

s See: https://data.apps.fao.org/wapor/?lang=en and https://www.fao.org/in-action/remote-sensing-for-water-productivity/en

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Something to Think About 1

Soil maps and tests can identify problems such as erosion, high salt levels, nutrient deficiencies or excessive acidity, but farmers also need to know how to address them. For example, highly acidic soil can prevent crops from absorbing certain nutrients. An agricultural adviser may recommend applying lime to reduce acidity, but the correct amount depends on the soil test and crop being grown. Salty soil, by contrast, may require improved drainage to remove excess salts rather than additional fertilizer.

Governments and FAO can help train advisers to interpret soil tests and recommend appropriate treatments. However, farmers may still be unable to act if they cannot afford the necessary materials or equipment. Soil information is most useful when farmers can understand the results and obtain the assistance needed to address the problems identified.

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BOX 22 DECISION SUPPORT SYSTEMS FOR IRRIGATION MANAGEMENT

On-farm irrigation water management is crucial because it directly impacts the performance of irrigation schemes. Surface irrigation techniques that are widely used throughout the world often have low performance due in large part to poor water management, resulting in low water application efficiency, inequitable distribution of water across schemes, energy waste and poor soil moisture management. Improving on-farm water management, especially in water-scarce regions, is important to ensure productive and sustainable water use.

Traditional surface water management often relies on limited factual data. Methods of computation and manually collected on-farm irrigation and soil moisture data do not offer the real-time calibre of information required to support effective on-farm water management. Thanks to advances in cloud computing and the increasing availability of remotely sensed data on land surface processes and weather forecasting, it is now possible to provide on-farm water management with integrated real-time models, allowing the optimization of on-farm irrigation.

The web-based semi-automated irrigation decision support system IrrigaSys was developed to optimize water use in on-farm irrigation using open-source data and technology (Simionesei *et al.*, 2020). The system automatically accesses real-time meteorological data, weather forecasts, soil moisture dynamics and satellite-based remote sensing data. It computes weekly optimum irrigation schedules, offering a solution for efficient water use in agriculture. IrrigaSys requires minimal input from farmers (plot location, crop type, soil texture and irrigation method) and provides weekly irrigation recommendations through multiple communication platforms. The system has demonstrated significant benefits, particularly in water-scarce regions, where efficient water management is critical to increase agricultural productivity. Close collaboration with local stakeholders and continuous farmer feedback are key strengths to ensure the system's relevance and practicality. Such systems have the potential to function in a fully automated way when integrated with a Supervisory Control and Data Acquisition (SCADA) system and sensor-based irrigation monitoring.

Integration of datasets across sectors and with sustainability objectives remains a challenge. For instance, despite increasing documentation on agroecology's contributions to sustainable agriculture, there is still a critical need for harmonized evidence. The Tool for Agroecology Performance Evaluation, which is rooted in the 10 elements of agroecology (FAO, 2019), produces multidimensional evidence of the performance of agroecology across the social, ecological and economic dimensions of sustainability. It facilitates harmonized, evidence-driven decisions that can guide transformational change towards more sustainable agricultural practices (Mottet *et al.*, 2020). The use of visual narratives representing the 10 elements of agroecology can enhance food systems policy analysis by identifying intervention points, discovering co-benefit opportunities and developing integrated policy packages (FAO, 2023c).

Resilience assessment, although widely recognized as a critical development and emergency objective, remains difficult to put into practice. The Self-evaluation and Holistic Assessment of Climate Resilience of Farmers and Pastoralists (SHARP+) offers a comprehensive and integrated approach to analysing and measuring resilience. It is grounded in the 13 agroecosystem resilience indicators developed by Cabell and Oelofse (2012) and adopts a holistic approach to analysing and measuring an agroecosystem's resilience at the household level. The tool is designed to support evidence-based decision-making at household, project and national levels by identifying specific areas of vulnerability. It can also be used to monitor and evaluate changes in resilience over time, providing insights into the long-term impact of interventions. By targeting these weak points, SHARP+ helps to inform strategies aimed at strengthening resilience and enhancing the capacity of smallholder farmers to produce

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Something to Think About 1

Governments and researchers need reliable evidence to determine whether sustainable farming practices are improving soil health and food production. However, comparing results from projects within a country or across countries becomes difficult when they measure different outcomes or use different methods. For example, one project may measure improvements in crop yields while another measures reductions in soil erosion. Both provide useful information, but they cannot be directly compared.

"Harmonized evidence" means collecting information using agreed definitions and methods so results can be compared across projects and countries. FAO's Tool for Agroecology Performance Evaluation (TAPE), mentioned in the report, provides a common approach for assessing the environmental, social and economic results of farming practices. For soil management, projects could measure changes in erosion, soil organic carbon and crop yields while also recording soil type, rainfall and farming conditions. This would help researchers understand why a practice works well in one location but produces different results elsewhere, allowing countries to share approaches that could be adapted to local conditions.

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and the private sector. The pathway to a sustainable future lies in fostering an enabling environment that supports integrated, inclusive and forward-looking investments in land, soil and water resources.

In many cases, the financial instruments are inadequate. There is limited availability of financial products tailored to the needs of smallholders and community-based water management initiatives, and a lack of investments in land conservation and management. Conventional financial institutions tend to favour large-scale, capital-intensive projects, leaving small-scale sustainable practices underfunded. Innovative financial instruments that adequately consider the needs of farmers in land and water development investments must be developed. Blended finance models, green bonds and impact investing are examples of instruments that can attract private investment while promoting sustainability.

Climate financing, including the new mechanism for carbon credits (the Paris Agreement Crediting Mechanism), holds potential for smallholder farmers, offering a pathway to earn revenue through carbon credits by implementing sustainable agricultural practices. These practices can generate carbon credits and bring about additional benefits such as improved soil health, increased productivity and resilience to climate change. However, challenges remain in ensuring accessibility and fairness for smallholders, including high certification costs and market volatility. Aggregation models, digital platforms and financial support can help farmers to access carbon markets and maximize their economic and environmental gains.[t]

Investments often prioritize short-term financial returns over long-term sustainability. This short-sighted approach leads to investments that may boost productivity temporarily but ultimately contribute to the degradation of land and water resources. Encouraging investors to adopt a long-term perspective is essential for the sustainability of land, soil and water resources. This can be achieved through formalizing land tenure regimes, tax incentives, subsidies and other financial mechanisms that reward sustainable practices and long-term investment strategies.

Boosting investment for biodiversity, conservation and ecosystem-based adaptation to climate change is becoming a priority. Investing in sustainable land management includes financing of businesses that contribute to biodiversity and adaptation, including sustainable forestry and agriculture, green infrastructure investments, climate mitigation projects and payment for ecosystem services (EIB, n.d.). Not only do such activities generate income for local communities, protect natural assets such as forests and water, and restore degraded lands, but the corresponding investments can also generate financial returns. Forward-looking banks, companies and other investors have in recent years made commitments to make capital available, taking into account not only financial returns, but also socially equitable and environmental returns (IDH, 2021).

It is becoming increasingly important to improve the environment for private sector investments. A promising approach to increase farmers' active participation in investing in irrigation is being promoted by the World Bank under the concept of Farmer-Led Irrigation Development (FLID),[u] which aims to improve the environment for private sector investments by empowering smallholder farmers to design and manage their irrigation systems. It fosters collaborative partnerships between farmers, government agencies and private investors, creating a more secure investment climate. By reducing risks and increasing returns through sustainable practices, FLID catalyses further investment in rural infrastructure. This innovative model builds trust, encourages technological adoption and establishes a replicable framework for scaling private sector-led rural development initiatives, driving sustainable economic growth.

Finally, investing in soft capital, including capacity building, extension services and

t The International Fund for Agricultural Development, with financial support from Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (German Agency for International Cooperation) (GIZ), promotes one such scheme in Ethiopia through Compens Action, available at: https://compensaction.com/ethiopia

u See: https://www.worldbank.org/en/topic/water/brief/farmer-led-irrigation-development-flid

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Something to Think About 1

Farmers may need money to buy cover-crop seeds, build terraces or purchase equipment before these investments improve soil conditions and crop yields. Governments and financial institutions can help through different forms of financial support, sometimes called "financial instruments".

A grant provides money that does not have to be repaid. A loan must be repaid, usually with interest. A loan guarantee means that a government or another organization agrees to cover part of a lender's losses if a farmer cannot repay, making the lender more willing to provide financing. Farmers can also reduce costs by sharing expensive machinery.

However, financial support must match farmers' circumstances. A tenant farmer may not qualify for a loan without land to offer as security, while a smallholder may struggle with repayments until improved harvests generate additional income. Programmes need to consider these barriers rather than encouraging farmers to take on debts they cannot repay.

Something to Think About 1

A smallholder is a farmer who operates a relatively small area of land, although the size considered "small" differs among countries. Smallholders may have limited savings, equipment or access to affordable loans, making it difficult to invest in terraces that prevent erosion, crops planted to protect exposed soil, or other soil-conservation measures even when those practices would improve future harvests.

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digital platforms, can provide farmers with the knowledge they need to adopt sustainable practices. Public–private partnerships can play a significant role in disseminating technology and information to rural communities. Investing in rural infrastructure, including internet connectivity and affordable energy solutions, is critical to address communication barriers. Public–private partnerships can support these processes, and governments can provide incentives for technology providers to extend services to underserved areas. In addition, crowdfunding models, where farmers pool resources to share technology, can also be effective. It is also urgent to invest in early warning systems and climate information services, which provide farmers with timely and accurate data, enabling them to make informed, real-time decisions and better adapt to increasingly unpredictable and changing environmental conditions, ultimately safeguarding their livelihoods and enhancing food security.

Enabler 6: Innovation

The right environment is needed to foster innovation in sustainable land and water management. Making more productive use of irrigation water, for instance, can be achieved through increasing crop yields and reducing evapotranspiration. Significant differences in water productivity (output per unit of water consumed) across countries can be explained by farmers' access to modern agricultural inputs, efficient irrigation systems and better soil and water management.

One common mistake in seeking to increase water productivity is to focus exclusively on reducing losses at farm level, without considering implications at the level of the water system. Typically, in conventional irrigation, a substantial part of the water that is applied to crops percolates in the soil and is not used by the plant. Efforts and incentives to reduce this "loss" do not consider that the water that is not used can recharge aquifers or flow in drains and be reused further downstream. Reduction of losses at farm level therefore does not necessarily translate into more efficient use of water at the level of the basin and may lead to unintended change in water allocation across the basin.

Enhanced reliability of deliveries and greater flexibility in the timing and amount of irrigation water are important factors in farmers' investment decisions. When the supply of water is unpredictable, farmers tend to cultivate crops that are resilient to water stress and variable irrigation timing. Typically, these crops have low yields and low monetary value.

Modernization of irrigation systems can contribute to greater irrigation efficiency amid rising water scarcity, as well as to more reliable and cost-effective services that match farmers' needs and ensure increased productivity to meet growing demand. In more demand-driven, service-oriented irrigation systems, innovative tools can help farmers by indicating the optimum time and volume for irrigation. Such tools can use real-time information on evapotranspiration and soil moisture to optimize on-farm irrigation practices. Innovation, therefore, lies as much in changes in managerial capacities as in technological upgrades – sometimes even more.

There are several key innovations that enhance sustainable land management, particularly in the areas of technology, land-use practices, governance, and finance. Technological advances such as precision agriculture make use of Global Positioning System (GPS), sensors and data analytics to optimize inputs and boost productivity, while remote sensing supports land condition monitoring. Sustainable farming methods – like agroforestry, conservation agriculture, and integrated soil fertility management – help maintain soil health and productivity. On sloped land, terracing and contour farming are effective in reducing erosion. Governance innovations include secure land tenure, which encourages long-term investment, and community-based land-use planning, which promotes local stewardship. Financial tools such as climate-smart subsidies support land restoration and sustainable practices. At a broader level, integrated land-use planning and landscape management align efforts across sectors, while the Land Degradation Neutrality framework aims to offset degradation through restoration, ensuring no net loss of productive land.

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Something to Think About 1

Mobile-phone services can send farmers weather warnings, planting advice or information about soil tests without requiring a visit to an office. But they may exclude farmers who lack network coverage, electricity to charge phones, affordable data, or the ability to read messages in the language used. Some farmers may share a phone rather than own one. Programmes can combine digital advice with radio broadcasts, local-language voice messages and visits from agricultural advisers. To evaluate whether digital advisory services are effective, governments need to determine whether farmers actually receive and understand the information and can use it to improve their farming practices, particularly when some farmers lack reliable internet access or digital skills.

Interesting Facts 1

Land Degradation Neutrality aims to maintain the area of land that remains productive and at the same time prevent the health and quality of that land from declining. For example, a country might retain the same amount of farmland but lose soil fertility because erosion removes nutrient-rich topsoil. Although the area has not changed, the land has become less productive.

Countries pursue this goal by preventing new degradation, reducing existing damage and restoring degraded land. Farmers can prevent erosion on steep slopes by building terraces or keeping soil covered with vegetation. Herders can reduce damage to overgrazed pasture by allowing grass to regrow, while restoration projects can help vegetation recover on land where much of the soil has been exposed.

Progress cannot be measured by counting restored hectares alone. Governments also need to assess whether soil and land conditions have improved. Preventing degradation should take priority over assuming that damage can always be repaired elsewhere. For example, restoring one hectare of damaged pasture cannot necessarily compensate for destroying one hectare of fertile farmland or an ancient forest, because these areas differ in soil quality, biodiversity and the benefits they provide.

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BOX 24 THE FARMER FIELD SCHOOL APPROACH

The Farmer Field School (FFS) concept was first launched in the late 1980s by FAO in Indonesia and now operates in more than 90 countries, equipping hundreds of thousands of farmers, pastoralists and fisherfolk with the knowledge not just to boost productivity, but also to sustain the ecosystems that support their livelihoods. Recognizing the long-term threats posed by unsustainable farming practices, the FFS approach now emphasizes holistic agroecosystem management, offering farmers training on all aspects from improving soil health and managing water to regenerating degraded landscapes and tackling climate change.

Enabler 7: Institutionalized capacity development

Modern extension approaches aim to equip farmers, communities and technicians with the tools and skills needed to enhance income and food security while promoting environmental sustainability. The integration of participatory approaches, digital tools and innovative agricultural techniques, while recognizing the critical value of local knowledge, forms the backbone of modern efforts to address the complex challenges of sustainable resource management.

Understanding and approaching capacity development in its comprehensive dimension requires the use of integrated and multilevel approaches and the development of technical as well as functional skills. One valuable approach is knowledge sharing, where farmers team up and learn from each other through hands-on experiences, discussions and practical demonstrations. Another important integrated approach involves participatory training initiatives such as watershed management and integrated land-use planning, which engage communities in sustainable natural resource management.

FAO has developed two key peer-to-peer training programmes of relevance to land and water management: Farmer Field Schools (FFS, see Box 24) and the Global Soil Doctors Programme. The Farmer Field School approach not only builds the technical capacity of farmers, it makes a significant contribution to community development, including social dynamics, gender equality and social inclusion. A key to the success of FFS in tackling these challenges is a participatory learning model. Rather than delivering top-down solutions, the FFS approach empowers farmers to experiment, observe and learn by doing, helping them to understand vital processes such as soil–plant–water interactions, biodiversity and nutrient cycling. The strength of the FFS model lies in its collaborative nature. For example, in the Kagera River Basin, which is shared by Burundi, Rwanda, Uganda and the United Republic of Tanzania, FFS groups have restored degraded lands, improved biodiversity and conserved water across entire watersheds (FAO, 2017b). In Andhra Pradesh, India, the FFS approach has supported the Community Managed Natural Farming initiative,[v] showcasing its potential to regenerate ecosystems and improve livelihoods simultaneously.

To effectively address land, soil and water challenges, the FFS approach has adapted its methods to an integrated, landscape-wide perspective, encouraging farmers to view their farms as part of a broader ecosystem, learning to build organic matter, enhance soil structure and improve water retention. These practices help farmers to boost carbon sequestration and mitigate droughts, all crucial for building climate resilience. By empowering farmers to manage their natural resources wisely, FFS build resilient farming systems capable of withstanding environmental pressures, while safeguarding the planet's long-term health.

Since 2020, FAO has also implemented the Global Soil Doctors Programme to solve issues such as improper use of organic and mineral fertilizers and pesticides, and limited knowledge of soil conditions, and to promote sustainable soil management.[w] Among the programme's strengths are its high adaptability to local conditions and

v For more information, see: https://apcnf.in

w For more information, see: https://www.fao.org/global-soil-partnership/soil-doctors-programme/about-the-programme/en

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Did You Know That... **1**

A Farmer Field School brings farmers together regularly during a growing season to learn by observing crops, testing farming methods and comparing results. Rather than simply being told which practices to adopt, farmers examine how different methods work under local conditions.

For example, a group might compare two plots after rainfall: one covered with crop residues after harvest and another left bare. Farmers could observe whether more soil was washed away from the uncovered plot and whether the covered plot retained more moisture. They could also compare the labour required and the yields of the following crop. This helps farmers judge whether the benefits justify the additional work or costs. FAO can help train instructors and support demonstration plots, while farmers decide which practices are suitable for their own fields.

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BOX 25 PRIORITIZING INSTITUTIONAL CAPACITY DEVELOPMENT

Investments in capacity development should focus on institutions rather than individuals. Institutions catering for the needs of farmers and extension officers can provide a supporting framework that optimizes the benefits. Ideally, locations should be within the proximity of the target groups; this is the case of Farmer Field Schools and extension centres, where the school or extension centre is the place of reference for training.

Institutional custodianship can also be fostered through the training of trainers model or through arrangements where the focus is on both the individual trainee and the home, resulting in sustainable learning outcomes. In the long term, institutional capacity development will produce a critical mass of trainees who gradually become experts with the latest knowledge and technologies and who adopt best practices to do business.

capacity to collaborate with national stakeholders including academia, governments, the private sector and farming communities. The programme provides efficient solutions to soil management challenges and creates a self-sustaining system at national level. To date, over 15 000 farmers in 28 countries have been trained with educational materials translated into more than 20 local languages. The programme has several success stories of local champion farmers, known as soil doctors, who train other farmers in methods for overcoming soil threats. A case in point is in Xochimilco, Mexico, where farmers are learning to manage soil salinity using compost and water filters and to monitor it through soil pH measurement. In Togo, farmers are being shown how to monitor the negative effects of burning forests on soils, through visual soil assessment of soil organic matter, root development and water retention.

FAO peer-to-peer training programmes use communication strategies and tools to promote social change, development and the adoption of sustainable practices within communities. Communication for Development (ComDev) is instrumental in combining participatory processes with the use of adequate media and digital solutions that can be adopted by family farmers, rural communities and institutions. ComDev uses a variety of communication channels such as radio, mobile phones, social media, community meetings and participatory video to reach a wider audience, including those in remote or underserved areas. This multichannel strategy ensures that farmers with various levels of access to technology can benefit from the information provided. It also ensures that solutions are locally relevant and that farmers feel ownership of the changes being promoted.

In addition, the ComDev approach enables the co-creation of knowledge by encouraging farmers to share their own experiences, as well as traditional or Indigenous Peoples' knowledge, which can be integrated into the training modules. In Zambia, global research partnership CGIAR has been supporting reality TV shows created by national broadcasters to teach climate-smart agriculture and provide climate information services to millions of farmers on a weekly basis (CGIAR, n.d.). Strengthening extension services through participatory capacity development, increasing the number of trained extension agents and integrating local languages into training materials are all essential. Given the success achieved by peer-to-peer learning models, these should be further promoted by broadening the approaches and thematic areas covered, reinforcing principles of inclusivity and gender responsiveness, and respecting local traditions, while promoting the knowledge and use of digital technologies. Adapting such approaches to targeted interventions can significantly accelerate the adoption of sustainable land, soil and water management practices, which will ultimately support long-term agricultural sustainability and resilience (see Box 25). ■

LOOKING AHEAD: OPPORTUNITIES FOR CREATING AN EFFECTIVE ENABLING ENVIRONMENT

The urgency of scaling up solutions to the interconnected climate, land and water crises is recognized in many international processes, such as the United Nations Convention to Combat

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World Federation of United Nations Associations

Did You Know That... **1**

Teaching farmers a new soil-management technique in a single workshop may not be enough to help them use it successfully. A farmer may later discover that a cover crop is failing, equipment is malfunctioning or a soil test shows an unexpected problem. Without someone to consult, the farmer may abandon the practice.

'Institutional capacity' means that organizations such as agricultural advisory services, soil laboratories and agricultural colleges have the trained staff, equipment and funding needed to provide reliable assistance over time. Governments and FAO can strengthen these services by training advisers, maintaining laboratories and helping specialists communicate practical recommendations to farmers. Success should be measured not only by how many people attend training but also by whether farmers continue receiving useful support when problems arise.

Did You Know That... **1**

FAO's soil-doctor approach trains farmers to help other farmers recognize soil problems and test possible solutions. A trained farmer might show neighbours how to identify signs of erosion, compare soil samples or leave stalks and leaves from harvested crops on the ground to protect the soil from being washed away by rain or blown away by wind. As these materials decompose, they also add organic matter that helps the soil retain moisture and nutrients.

Because the advice comes from someone farming in similar conditions, neighbours can ask practical questions about costs, labour and results. But a farmer "soil doctor" cannot diagnose every problem by sight. Suspected chemical contamination or complex nutrient problems may require laboratory tests and specialist advice. The programme works best when trained farmers have simple tools and a way to refer difficult cases to experts.

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