MODULE 7:

CLIMATE-SMART CROP PRODUCTION SYSTEM

Overview

Climate-smart crop production contributes to food security, by addressing different aspects of current and projected climate change impacts through adaptation and mitigation actions. While agriculture contributes significantly to climate change, it also provides opportunities for adapting to, and mitigating, climate change effects. The first part of this module outlines the impacts of climate change on crop production. The second part describes the sustainable crop production intensification (SCPI) paradigm and illustrates how sustainable agriculture is inherently "climate-smart." In describing the underlying principles of SCPI, the module draws heavily on the FAO publication *Save and Grow*. *Save and Grow* — a rich source of information, case studies and technical references — was produced following an Expert Consultation held in 2010: it is a guide and toolkit of sustainable technologies and practices, but also explores the policies and institutional arrangements for the large-scale implementation of SCPI. The module also describes options for land managers and farmers to adapt, and contribute to the mitigation of climate change. Text boxes provide examples of sustainable crop production practices, techniques and approaches for climate change adaption and mitigation.

Key messages

- Unpredictable and erratic climatic patterns resulting from climate change will affect crop production. This will have an impact on farmer livelihoods and food availability. Climate-smart crop production provides management options to farmers to both adapt to, and mitigate, climate change.
- Climate-smart agriculture (CSA) is sustainable agricultural production "seen from the lens" of climate change. Sustainable crop production looks at reducing reliance on non-renewable external inputs, and capitalizing on/enhancing natural biological processes to improve production in a more environmentally-friendly way and avoiding degradation of production relevant natural resources.
- To cope with the challenges of climate change, crop production must adapt (e.g. crop varietal selection, plant breeding, cropping patterns and ecosystem management approaches) and become resilient to changes (frequency and intensity).
- Crop production can contribute to mitigating climate change by reducing greenhouse gas (GHG) emissions - for example by reducing the use of/judiciously using inorganic fertilizers, avoiding soil compaction or flooding to reduce methane emissions (e.g. in paddy rice systems) and sequestering carbon (e.g. planting perennial crops and grass species).
- Farmers are the primary custodians of knowledge about their environment, agro-ecosystems, crops and cropping patterns, and local climatic patterns. Adapting cropping practices and approaches will be related to local farmers' knowledge, requirements and priorities. Sustainable crop production provides farmers with options for farming sustainably, taking into account the local ecosystem.
- Integrated approaches — such as crop-livestock systems, rice-fish systems and agroforestry — diversify food sources and consequently strengthen the resilience of farmers' livelihoods. They also provide opportunities for mitigating climate change.
- CSA needs to be strongly supported by sub-national and local policies. Agricultural ecosystems are site specific, with their own environmental, social and economic specificities.

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7.1 Introduction

Crop production, which is vital to global food security, is being affected by climate change all over the world. However, the impact is being felt more severely in the more impoverished communities. It has been predicted that over the next decades, billions of people, especially those living in developing countries, will face shortages of water and food and greater risks to health and life because of climate change. With fewer social, technological and financial resources for adapting to changing conditions, developing countries are the most vulnerable to the impacts of climate change (UNFCCC, 2007).

Although some crops in some regions of the world may benefit, the overall impacts of climate change on agriculture are expected to be negative (IFPRI, 2009). For example, climate variability and the frequency of extreme climatic events, such as droughts and flooding, will affect precipitation. Higher temperatures may affect yields in a negative way and favour the growth of weeds and the proliferation of crop pests. In many areas, rising sea levels also will hamper crop production. Furthermore, crop failures and long-term declines in productions will occur. The impact of climate change will hit developing countries the hardest, and it is in these countries where food security will be most threatened.

7.2 Climate change impacts

The successes and failures of crops have always been subject to prevailing environmental factors, and the mechanisms for managing the stresses created by these factors continue to be the subject of extensive studies in a variety of disciplines. Crop production is increasingly vulnerable to risks associated with new and evolving climatic changes. These are variations in environmental conditions that pose significant challenges to farmers, over and beyond those that are experienced 'normally.' The planet is facing more extreme weather events, such as heavy precipitation, higher coastal waters, geographic shifts in storm and drought patterns, and warmer temperatures (IPCC, 2012).

Climate change is expected to cause substantial crop reductions in southern Africa (up to 30 percent by 2030 for maize production) and South Asia (up to 10 percent for staples, such as rice, and more than 10 percent for millet and maize) (Lobell *et al.*, 2008). In mid- to high-latitudes, depending on the crop, productivity may increase slightly with increases in local mean temperatures of up to 1–3 degrees Celsius. At lower latitudes, crop productivity will decrease even with a relatively minor change in temperature (IPCC, 2007). Localized extreme events and sudden pest and disease outbreaks are already causing greater unpredictability in production from season to season and year to year, and require rapid and adaptable management responses (FAO-PAR, 2011).

By 2050, it is predicted that the global population will be over 9 billion people, increasing the demand for food and other agricultural products. At the same time, the world faces challenges such as land and water scarcity, increased urbanization, and climate change and volatility. Agricultural production remains the main source of income for most rural communities (about 86 percent of rural people - 2.5 billion), who depend on agriculture for their livelihood (World Bank, 2008). Improving adaptation of the agricultural sector to the adverse effects of climate change will be imperative for protecting and improving the livelihoods of the poor and ensuring food security (FAO, 2012a). In practical terms, climate change adaptation requires more than simply maintaining the current levels of performance of the agricultural sector; it requires developing a set of robust and yet flexible responses that will improve the sector's performance even under the changing conditions brought about by climate change engenders.

Measures must be devised for reducing the negative impacts of agriculture on the ecosystem. Agriculture accounts for 13.5 percent of GHG emissions, or about 1.8 gigatonnes of carbon equivalent per year (Gt C eqv./year) (6.6 Gt carbon dioxide [CO_2] eqv./year), mainly in the form of methane (CH_4) and, more pertinent to crop production, nitrous oxide (N_2O) from fertilized soils, enteric fermentation, biomass burning, flooded rice production (paddy) and manure and fertilizer production (IPCC, 2007).

In addition, overall land use and land use change accounts for about 31 percent of the total human-induced GHG emissions into the atmosphere (Scherr and Sthapit, 2009).

The overall efficiency of the agricultural sector– its resilience, adaptive capacity and its potential for contributing to the mitigation of the effects of climate change and variations– can be enhanced by improving these constituent components. Indeed, by improving the efficiency of agricultural production, emissions can be reduced and sequestration capacity enhanced. Conversely, climate change will have a significant impact on crop production (Table 7.1), but alternative adaptation approaches and practices can address this by helping to reduce the net GHG emissions while maintaining or improving yields (FAO, 2011; Pretty *et al.*, 2011).

Table 7.1
Examples of projected climate change impacts on crop production

Event	Potential impact
Cold periods becoming warmer and shorter; over most land areas, days and nights becoming hotter (*virtually certain*)	Increased yields in colder environments; decreased yields in warmer environments; increased outbreaks of new insect pests and pathogens; potential impacts on crop production
Heavy precipitation events increasing in frequency over most areas (*very likely*)	Damage to crops; soil erosion; inability to cultivate land owing to waterlogging of soils
Drought-affected area increases (*likely*)	Land degradation and soil erosion; lower yields from crop damage and failure; loss of arable land
Intense tropical cyclone activity increases (*likely*)	Damage to crops
Extremely high sea levels increase in incidence (excludes tsunamis) (*likely*)	Salinization of irrigation water, estuaries and freshwater systems; loss of arable land

Source: adapted from IPCC, 2007, in FAO, 2008a

7.3 Sustainable crop production intensification

Crop production has been evolving since the domestication of crop species 10 000 years ago. Varietal selection, the use of wild plants and wild relatives of plants, irrigation techniques, planting methods, cropping patterns and fertilization are some of the practices that have been, and are being, used to improve crop production. In relatively recent times, crop production has increased significantly, providing more food for a growing global population. The best known and documented example of this is the Green Revolution, which swept through much of the developing world during the 1960s. The Green Revolution was characterized by the planting of high-yielding crop varieties, with the associated chemical package and irrigation. As a result, farmers increased cereal food production from 800 million tonnes to over 2.2 billion tonnes between 1961 and 2000. While an estimated one billion people were saved from famine, this has come with a high price tag in the long term. In many countries, decades of intensive cropping have degraded fertile land, depleted groundwater, triggered an upsurge in pests, eroded biodiversity and polluted the air, water and soil. Intensive crop production is no longer sustainable, and a new paradigm should emerge – and this is what *Save and Grow* – i.e. sustainable crop production intensification – is about (FAO, 2011). It means a productive agriculture that conserves and enhances natural resources through an ecosystem approach that capitalizes on natural biological inputs and processes. It reduces the negative impacts on the environment and enhances natural capital and the flow of ecosystem services. SCPI also contributes to increasing systems' resilience – a critical factor, especially in light of climate change.

SCPI can be achieved through good farming practices that are based on improving efficiencies and managing biological processes. It is based on agricultural production systems and management practices that include:

- maintaining healthy soil to enhance soil-related ecosystem services and crop nutrition;
- cultivating a wider range of species and varieties in associations, rotations and sequences;
- using quality seeds and planting materials of well adapted, high-yielding varieties;
- adopting the integrated management of pests, diseases and weeds; and
- managing water efficiently.

SCPI, and the crop production practices and approaches that it entails, is inherently climate smart. The sustainability of crop production systems presupposes that the risks and vulnerabilities arising from climate change are also addressed.

CSA aims at achieving the same food security objectives as sustainable agriculture, but through the lens of climate change.

It is important to understand that crop production, from land preparation through planting to the delivery of produce to the farm gate, constitutes an integral part of a farming system, which in turn is a part of the broader agro-ecosystem and landscape. The actual crop is but one element of an agro-ecosystem. Other elements include soil, biodiversity and ecosystem services— but crops can also be integrated within other production systems, such as agroforestry, integrated crop-livestock and rice-fish systems.

Box 7.1
Integrated crop-livestock systems

In conventional farming systems, there is a clear distinction between arable crops and pastureland. Under SCPI, this distinction is no longer applicable, since annual crops may be rotated with pasture without the destructive intervention of soil tillage (FAO, 2011). Practical innovations have harnessed synergies between crop, livestock and agroforestry production to improve the economic and ecological sustainability of agricultural systems and at the same time provide a flow of valued ecosystem services. Through increased biological diversity, efficient nutrient recycling, improved soil health and forest conservation, integrated systems increase environmental resilience and contribute to climate change adaptation and mitigation. They also enhance livelihood diversification and efficiency by optimizing production inputs, including labour. In this way, integrated systems also increase producers' resilience to economic stresses (FAO, 2011).

Integrated crop-livestock systems imply a diverse range of integrated ecological, biophysical and socio-economic conditions (FAO, 2010a). They aim to increase profits and sustain production levels while minimizing the negative effects of intensification and preserving natural resources (IFAD, 2009). They also have environmental, social and economic benefits. These systems, which enhance the natural biological processes above and below the ground, represent a synergistic combination that: (a) reduces erosion; (b) increases crop yields, soil biological activity and nutrient recycling; (c) intensifies land use, improving profits; and (d) can therefore help reduce poverty and malnutrition and strengthen environmental sustainability (IFAD, 2009).

There are numerous examples of how crop-livestock systems are being implemented. In the Southern Caucasus region, grain and livestock production have been integrated into a system of mixed farming in which cereals and pulses are grown in flatter, better-watered lowland soils and sheep and goats graze and browse on rougher upland terrain (whether locally or by means of seasonal transhumance). This has proven to be effective, both ecologically and nutritionally, in sustaining the growing number of sedentary villages (FAO, 2010b). Also, in Azerbaijan, near Xudat, farmers have adapted to the great diversity of land forms, climate and soils by developing a mosaic of crops and livestock systems. To protect wild biodiversity, soil and water resources, they alternate annual and perennial crops, and avoid cultivating crops in fragile environments (FAO, 2010b).

A priori, crop production is aimed at providing food security, contributing to sustainable diets, supplying raw materials for industries and generally, improving and sustaining livelihoods. The linkages between crop production to wider overarching agricultural production systems and its value in socio-economic contexts are part of the *Save and Grow* paradigm. These relationships and other elements of the production system are largely covered in other modules (see for example Module 1 on general principles of climate-smart agriculture, Module 3 on water management, Module 4 on soil management, Module 5 on energy systems, Module 6 on genetic resources and Module 8 on livestock and crop-livestock systems).

As climate changes, the resilience and adaptive capacity of agricultural production systems and agricultural landscapes will become more important (see Module 2 on climate-smart landscapes and production systems). To become more resilient and better able to adapt to changing conditions, crop production systems will need to rely more on ecological processes that produce positive feedbacks on sustainability and production and ensure improved provision of all ecosystem services (FAO-PAR, 2011). Progress in this area could be made by adopting existing agricultural practices that have already been proven to have multiple benefits for food security and environmental health. However, there are barriers to adoption of these practices that need to be addressed through enabling means (e.g. investments, capacity building, financing, information, research, incentives and supportive policies).

7.4 Underlying principles: management of natural biological processes

Sustainable crop production and climate change adaptation and mitigation in agriculture are not distinct from each other. The management of agro-ecosystems for producing food, fodder and fuel and the management of agro-ecosystems to adapt to and mitigate climate change have the same underlying principles and can work together to achieve the same goal: ensuring that everyone has enough safe, nutritious food now and in the future. Both crop production and climate change adaptation and mitigation require a resilient ecosystem, which can be attained through approaches and practices that are based on the sustainable management of biodiversity and ecosystem services.

Climate-smart crop production is a sustainable crop production system, both of which address climate change. Sustainable agricultural systems provide opportunities for climate change adaptation and mitigation by contributing to the delivery and maintenance of a range of public goods, such as clean water, carbon sequestration, flood protection, groundwater recharge and landscape amenity value. By definition, sustainable agricultural systems are less vulnerable to shocks and stresses. In terms of technologies, productive and sustainable agricultural systems make the best of crop varieties and livestock breeds and their agro-ecological and agronomic management (Beddington *et al.,* 2012).

The negative effects of climate change on productivity are already being felt by the agriculture sector. For example, in India, rice production decreased by 23 percent during 2001–2002 (FAOSTAT, 2012) because of drought. In Indonesia, flooding caused about 1 344 million tonnes of losses in rice production (Redfern *et al.,* 2012). In Mississippi in the United States of America, flooding before the harvest season caused an estimated loss of up to US$ 8 billion in 2008 (USGCRP, 2009). To secure future food production, crop production will need to adapt to and mitigate climate change. To contrast the effects of climate change, there is a need for a better understanding of the biological processes (below and above ground) involved in farm management practices. In this regard, ecosystem management must incorporate measures for building resilience and mitigating risk in agriculture. These elements are becoming increasingly critical under changing climatic conditions.

Box 7.2
System of Rice Intensification in Afghanistan

The System of Rice Intensification (SRI) is a set of farming practices developed to increase the productivity of land, water and other resources (see Annex A.4.1 in Module 4 on soils). SRI is based on the principle of developing healthy, large and deep-root systems that can better resist drought, waterlogging and rainfall variability, all of which are potential impacts of climate change. It has proved particularly beneficial to some areas worldwide as it requires only intermittent water application to create wet and dry soil conditions, instead of continuous flood irrigation. The average increase in income from SRI in eight countries (Bangladesh, Cambodia, China, India, Indonesia, Nepal, Sri Lanka and Viet Nam) has been shown to be around 68 percent with yield increases of 17 to 105 percent and decreases in water requirements between 24 and 50 percent (Africare *et al.*, 2010).

Considering the better growth and performance of rice plants and subsequent increase in yields and productivity of the rice field with SRI elsewhere, in 2011 Afghanistan introduced SRI as an important practice of sustainable rice intensification to the farmers in Farmer Field Schools (FFS). With SRI, yields of up to 7 tonnes per hectare were achieved (PIPM, 2012) – double the farmers' average yields in the area – using 50 percent less water than used in conventional rice cultivation practices in Afghanistan. It has also reduced the use of chemical fertilizers, and there has been no insect or disease infestation at all in SRI fields. The use of SRI is now being extended throughout a number of provinces in Afghanistan as one way to mitigate the effects of unreliable rainfall.

Biodiversity is necessary to sustain key functions of the ecosystem (its structure and process) and provide essential ecosystem services. It is an important regulator of agro-ecosystem functions, not only in the strictly biological sense of its impact on production, but also in satisfying a variety of needs of the farmer and society at large. In particular, biodiversity increases resilience of agro-ecosystems and is, as such, a means for reducing risk and adapting to climate change. Agro-ecosystem managers, including farmers, can build upon, enhance and manage the essential ecosystem services provided by biodiversity as a part of their efforts towards sustainable agricultural production.

The conservation and enhancement of biodiversity in cropping systems both above and below ground (e.g. soil biodiversity – see Box 7.3), and the management of ecosystem services underpin sustainable farming practices. The composition and diversity of planned biodiversity (e.g. selected crops) influences the nature of the associated diversity (plant, animal, microbial) and consequently the delivery of ecosystem services. An ecosystem approach is also a means to integrate planned biodiversity that is maintained with the associated diversity (e.g. wild pollinators – see Box 7.4). For example, greater on-farm diversity of plants, greater soil coverage and more perennial cultivation may build resilience throughout the agro-ecosystem (e.g. resistance to noxious species).

Box 7.3
Biological nitrogen fixation

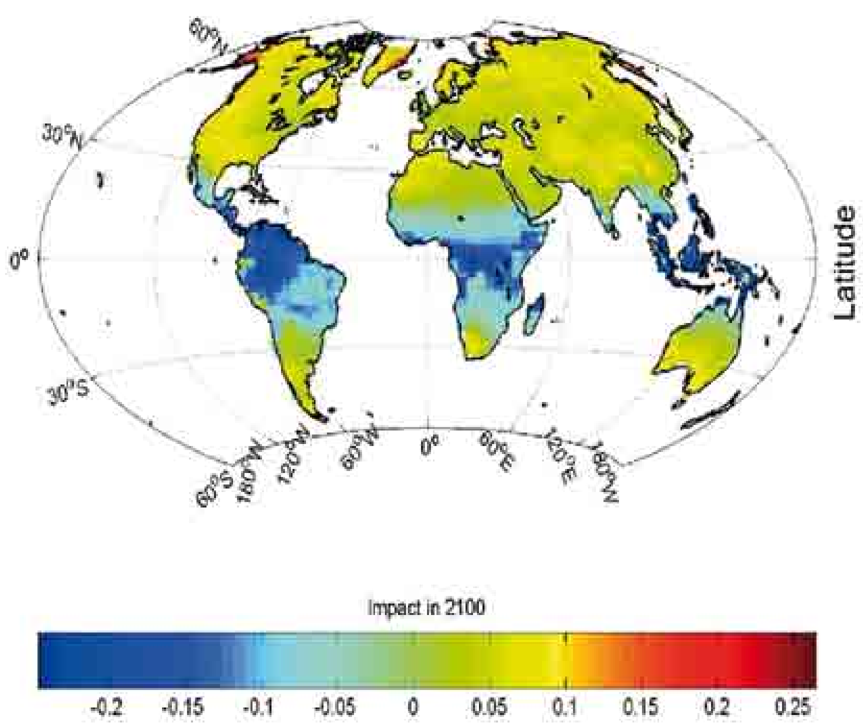
In agricultural systems, some types of microbes can carry out biological nitrogen fixation (BNF) as free-living organisms: heterotrophic and autotrophic bacteria and cyanobacteria. Other micro-organisms can only fix nitrogen through a symbiotic relationship with plants, mainly legume species. In agricultural areas, about 80 percent of BNF is achieved by the symbiotic association between legumes and the nodule bacteria, *rhizobia*. Farmers have some scope to influence BNF, through legume selection, the proportion of legume and grass seed in forage mixtures, inoculation with bacteria such as *rhizobia*, crop nutrition (especially nitrogen and phosphorous), weed, disease and pest controls, planting time, cropping sequence and intensity, and defoliation frequency of forage swards. However, some factors, including unfavourable temperatures and droughts, that affect BNF cannot be controlled. Also some legume species are better at fixing nitrogen than others. In perennial temperate forage legumes, red clover and lucerne can typically fix 200–400 kg of nitrogen per hectare (whole plant fixation, above and below ground).

Source: FAO, 2009a

Box 7.4
Managing ecosystem services: the case of pollination

Over 75 percent of the leading global food crops are dependent on pollination services provided by animals. Pollinators, especially bees, affect 35 percent of the world's crop production. The global economic value of pollination services is estimated to be US$ 214 billion per year (Gallai *et al.*, 2009). However, pollinators can be sensitive to rising temperatures, and crop growth may equally be affected by high temperatures and drought. These changes can potentially cause dysfunctions in plant-pollinator interactions (Kjøhl *et al.*, 2011).

Figure 7.1
Predicted impact of warming on thermal performance of insects in 2100



On the basis of patterns in warming tolerance, climate change is predicted to be most deleterious for insects in tropical zones

Source: Deutsch *et al.*, 2008

In the tropics, most pollinators already live close to their optimal range of temperature tolerance. Increases in temperature, therefore, could have greater negative impacts in tropics, and thus the developing world.

Although more targeted data sampling is needed to better understand the impacts of climate change on pollinators, pollination-friendly management practices contribute building resilience in ecosystems (at the landscape level).

In multiple agro-ecosystems and ecologies, pollinator-friendly management practices have been identified that serve to enhance yields, quality, diversity and resilience of crops and cropping systems. Examples include:

- preserving wild habitat;
- managing cropping systems, flower-rich field margins, buffer zones and permanent hedgerows to ensure habitat and forage;
- cultivating shade trees;
- managing for bee nest sites through such means as leaving standing dead trees and fallen branches undisturbed;
- reducing application of pesticides and associated risks; and
- establishing landscape configurations that favour pollination services.

Pollination management practices can also be undertaken to explicitly build safeguards in response to climate change. Examples of how farming communities may best adapt to climate change impacts on pollinators include giving consideration to the seasonal availability of resources needed by pollinators and ensuring connectivity of natural habitats in farming areas (allowing easier pollinator dispersal for range shifts in response to changing climates).

Source: FAO, 2009a

Agricultural intensification also requires fertile and healthy soils. Nutrient deficiencies and soil-borne pests and diseases are major limiting factors for crop production, especially on degraded soils in large areas of Africa and Southeast Asia. For example, the parasitic weed, *Striga* (Box 7.5), causes less damage when found in healthy soils. Even the damage caused by pests not found in the soil, such as maize stem borers, is reduced in healthy soils.

Box 7.5
Climate change may influence Striga distribution and invasive potential

Striga, considered to be one of the biggest obstacles to food production in Africa, includes about 40 species, of which 11 species are parasites on agricultural crops (FAO, 2003). It is a parasitic weed that enters the roots of other plants and removes their essential nutrients and reduces their growth. The weed is one of the major constraints to the production of cereals and legumes in sub-Saharan Africa. On average, Striga infests as much as 40 million hectares of farmland in sub-Saharan Africa. It can cause yield losses of up to 100 percent (IAASTD, 2009) and an average reduction in productivity of 12 to 25 percent. In Africa, it affects the livelihoods of about 300 million people (FAO, 2003).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The monoculture of cereals, in which farmers use continuous cropping and follow poor agronomic practices such as the lack of crop rotation, promotes the formation of Striga. This is particularly true in agro-ecosystems where high human population densities put strong pressures on arable land. Striga has been known to have devastating effects on many food crops, specifically maize (Zea mays), sorghum (Sorghum bicolor) and sugar cane (Saccharum officinarum) (Eplee, 1992) and represents a real threat to cereal production and food security of affected countries.

To deal with striga, people hand-weed the land, but in extreme cases where there is heavy infestation, the only option is to abandon the farm land. However, abandonment only increases the parasite pressure in contaminated fields, as the seed can remain dormant and viable in the soil for at least 5 to 10 years (Parker and Riches, 1993). Farmers use a variety of pest control methods (organic manure, crop rotation, fallow), but the results can often be unsatisfactory. A rational combination of pest control methods (cultural, biological and low risk pesticides) prevents spread of pests, provides better protection for the crops and improves yields. In particular, the introduction of legumes (e.g. mucuna) into the crop rotation as cover and catch crop tends to suppress the incidence of Striga. Projects have been implemented in Benin, Burkina-Faso, the Niger, Mali and Senegal to compare different management methods to alleviate the problem (FAO, 2008b).

Stiga thrives in temperatures of 30 to 35 degrees Celsius under semi-arid conditions. Climate change that leads to increased temperatures or affects rainfall patterns may influence the geographic distribution and invasive potential of Striga (Cotter *et al.*, 2012).

In addition, the maintenance and enhancement of soil health contributes to food security in "more direct ways." A large portion of global crop production is taken up by maize, rice, wheat and other crops, such as oil crops. For human nutrition, however, a healthy diet is based on the variety of crops. These provide a range of essential nutrients, vitamins and minerals, and fruits and vegetables of high nutritional value. In addition, crop variety not only provides food, fuel and fibre goods, but also environmental services. For example, pulses are an important part of local food crops in developing countries and are a key source of protein in the diets of the world's poorest countries. In farming systems, pulses represent an input-saving and resource-conserving technology because they fix nitrogen in the soil and thereby reduce the need for chemical fertilizer. The cultivation of pulses also reduces soil pathogens (FAO, 2012b).

Conservation agriculture is an example of an approach that manages natural biological processes for resource-saving agricultural crop production. It aims at achieving competitive agricultural yields while helping to reduce degradation of natural resources. Undisturbed soil with a sufficient supply of organic matter provides a good habitat for soil fauna. Avoiding mechanical soil tillage increases the populations of earthworms, millipedes, mites and other animals living in the soil. This microfauna takes over the task of tillage and builds soil porosity and structure. It incorporates organic matter from the soil surface; the excrements provide stable soil aggregates and the vertical macro-pores created by worms serve as drainage channels for excess water. This makes the land less susceptible to flooding and erosion, since it improves the infiltration of water into the ground. The organic matter incorporated by soil microfauna into the soil improves soil structure and water storage capacity, which in turn helps plants to survive longer during drought spells. Both are important strategies for farming adaptations to changing climate effects and contribute to mitigation efforts. By managing biological processes, conservation agriculture can contribute to climate change adaptation and mitigation by reducing GHG emissions and sequestering carbon (FAO, 2012c).

Box 7.6
Conservation agriculture with ripper-furrower system in Namibia

Farmers in the north of Namibia are using conservation agriculture practices to grow drought-tolerant crops, including millet, sorghum and maize. The farming system uses a tractor-drawn ripper-furrower to rip the hard pan to a depth of 60 centimetres and to form furrows for in-field rainfall harvesting. The harvested water is concentrated in the root zone of crops, which are planted in the rip lines together with a mixture of fertilizer and manure. Tractors are used in the first year to establish the system. From the second year onwards, farmers plant crops directly into the rip lines using an animal-drawn direct seeder.

Crop residues are consumed mainly by livestock, but the increased biomass produced by the system also provides some residues for soil cover. Farmers are encouraged to practice crop rotation with legumes. These techniques lengthen the growing season and improve soil structure, fertility and moisture retention. Average maize yields have increased from 300 kilograms per hectare to more than 1.5 tonnes.

Source: FAO, 2011

Increased levels of organic matter in soil also help mitigate climate change by storing carbon from atmospheric CO_2 in soil organic matter. The formation of stable organic matter through the process of humification is mediated by soil micro-organisms. Another element of biological tillage is the introduction of crops, including trees and shrubs, with deep penetrating tap-roots. Some 'pioneer' crops, such as lupine, jack-beans (*canavalia*) or radish, can break subsoil compactions if, for example, they are planted in the crop rotation or intercropped as green manure cover crops (FAO, 2009a).

7.5 Climate-smart approaches and practices

To achieve SCPI, all aspects of sustainability (social, economic, political and environmental) must be taken into consideration in conjunction with the overall context. Global, regional and national instruments, treaties, conventions, codes and policies are an essential component in the enhancement and sustainable use of natural resources. Policies at, or that impact, the sub-national and local levels— as well as institutional capacity— are also important for addressing local social, economic and agro-ecological conditions (see Module 12 on institutions and Module 13 on policies). Improving market linkages, reducing post-harvest losses (see Module 11 on post-harvest practices) and conserving agricultural biodiversity will also contribute to ensuring that improved farming practices deliver the anticipated benefits.

At the field level, there are a wide range of agricultural practices and approaches that are currently available that can contribute to increased production while still focusing on environmental sustainability. It needs to be emphasized that outlining these is not a blueprint of actions that can be undertaken in all agro-ecosystems. What this module does is present options of management practices and approaches that— considering the ecological, social, policy and economic dimensions of a specific location— can contribute to climate-smart crop production. These practices and approaches for crop production can provide adaptation measures and/or mitigation benefits.

Adaptation

Environmental stresses have always had an impact on crop production, and farmers have always looked for ways to manage these stresses. Climate change adaptation requires more than simply maintaining the current level of performance from the agricultural sector, it requires developing a set of responses that allow the sector to improve performance under the changing conditions brought about by climate change. Because agricultural production remains the main source of income for most rural communities, adaptation of the agricultural sector to the adverse effects of climate change will be imperative for protecting and improving the livelihoods of the poor and ensuring food security (FAO, 2012a). Some ways of local adaptation to stress is through plant breeding, pest management strategies, and seed delivery systems, to name a few.

Examples of changes in climatic conditions that influence crop systems include: rain quantity and distribution, and consequently water availability; extreme events, such as floods and droughts; higher temperatures; and shifting seasons. The rate of climate change may exceed the rate of adaptation for natural systems, including crops, and this creates high concern for food availability (Allara *et al.*, 2012). In essence, what this means is that crops that were usually planted in one area may no longer be able to grow there. In addition, the ecosystem services that ensure crop growth (e.g. pollination, soil biodiversity) may also be affected. For these reasons, it is necessary to address crop production at the farming systems level. With appropriate technical, institutional, socio-economic and policy infrastructure in place, there is a huge potential for crop management practices and approaches to adapt to, and contribute to, the mitigation of climate change.

Box 7.7
Agricultural approaches and practices that contribute to climate change adaptation

Different approaches and practices for sustainable crop production can contribute to climate change adaptation. They provide options for location-specific contexts and should be adapted with local farmers/farming communities.

Examples include:

- ecosystem-based approaches;
- conservation agriculture;
- integrated nutrient and soil management;
- mulch cropping;
- cover cropping;
- alterations in cropping patterns and rotations;
- crop diversification;
- using high quality seeds and planting materials of adapted varieties;
- integrated pest management;
- integrated weed management;
- grasslands management;
- water and irrigation management;
- landscape-level pollination management;
- organic agriculture; and
- land fragmentation (riparian areas, forest land within the agricultural landscape).

Sources: FAO-PAR, 2011; FAO, 2008a; Lin, 2011; FAO, 2009b; FAO, 2012a

While some of these measures can be implemented readily at the level of individual farms or households, others need broader infrastructural and political support and have much longer timeframes. An example is with the conservation and management of grasslands, which has an enormous potential to sequester carbon, provide food and feed (e.g. honey, grazing livestock, wild cereals, hunting, medicinal plants) and energy (e.g. solar, charcoal, hydropower, wind-power).

Mitigation

Agriculture is a significant source of GHG emissions, but at the same time, it offers tremendous potential for mitigating climate change. Agricultural production accounts for over a third of global GHG emissions mainly in the form of CH_4 and N_2O from fertilized soils, enteric fermentation, biomass burning, paddy rice production, as well as manure and fertilizer production. In addition, contributors to the release of CO_2 into the atmosphere are land-use changes and soil degradation. Through practices that capitalize on natural biological processes, crop production can provide an opportunity to mitigate climate change in two ways: by storing carbon and by reducing GHG emissions.

Box 7.8
Agricultural approaches and practices that contribute to climate change mitigation

There are many different approaches and practices for sustainable crop production that can contribute to climate change mitigation. As with climate change adaptation, these approaches and practices can provide options for location-specific contexts and should be adapted with local farmers/farming communities.

Examples include:

- conservation agriculture;
- soil compaction management;
- improved farming systems with several crop rotations;
- crop diversification;
- promotion of legumes in crop rotations;
- growing cover crops;
- mulch cropping;
- restoration of cultivated peaty soils and degraded lands;
- soil management practices that reduce fertilizer use (e.g. urea deep placement);
- integrated nutrient management;
- growing nutrient-use efficient crop varieties;
- integrated crop and livestock systems;
- dedicated energy crops to replace fossil fuel use;
- emission control and reduction (combustion engines, animal waste);
- improved rice cultivation techniques;
- water management/conservation, irrigation, water table management; and
- agroforestry.

Sources: FAO, 2004; FAO, 2008a; FAO, 2009b; FAO, 2012a; FAO, 2012c

7.6 Conclusions

Crop production contributes to climate change, but it also presents opportunities for adapting to and mitigating climate change. The principles underlying SCPI are in line with the practices and approaches available for climate change adaptation and mitigation. Climate-smart agriculture is agriculture that moves away from unstable systems and systems that depend mainly on external inputs, towards systems that can be more efficient and resilient by relying on natural auto-control mechanisms. This is mainly reflected in systems being managed through an ecosystem approach at the landscape level, as well as in integrated systems. Practices and approaches can be used by land managers/farmers, but climate change adaptation and mitigation options cannot be implemented from a "purely technical" standpoint alone— they also rely on the social support of the population involved. It is crucial that land managers/farmers be supported by being given options and opportunities, sustained by institutions and policy. Strong policies as well as tools and institutions at country level are essential to counteract the effects of climate change in agricultural production systems and the livelihood of the rural population, particularly in developing countries. There is the need for strong government commitment to develop and/or adapt agricultural policies to take into consideration climate change, its potential impact and ways to overcome or minimize its effects. In addition, local expertise offers an immense repository of knowledge— not only about biophysical aspects of agricultural production, but also of the needs of communities and farmers. Climate-smart systems are able to respond and adapt to changing climates, particularly to the increased variability, and can, in targeted instances, contribute to mitigating a further change in the climate. By the very nature of such systems, they need to be efficient, which at the same time makes them sustainable and productive. Conversely, a production system, which is productive and sustainable at the same time, can only be so if it is climate-smart. Therefore production systems as reflected in the *Save and Grow* approach, are at the same time inherently climate-smart.

Notes

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Acronyms

BNF	biological nitrogen fixation
C	carbon
CH_4	methane
CO_2	carbon dioxide
CO_2 eqv.	carbon dioxide equivalent
CSA	climate-smart agriculture
FFS	Farmer Field Schools
GHG	greenhouse gas
Gt	gigatonne
IAASTD	International Assessment of Agricultural Knowledge, Science and Technology for Development
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
IPCC	Intergovernmental Panel on Climate Change
N2O	nitrous oxide
PAR	Platform for Agrobiodiversity Research
PIPM	Promoting Integrated Pest Management Project
SCPI	Sustainable Crop Production Intensification
UNFCCC	United Nations Framework Convention on Climate Change
USGCRP	United States Global Change Research Program

References

Africare, Oxfam America & WWF-ICRISAT Project. 2010. *More rice for people, more water for the planet.* Hyderabad, India, WWF-ICRISAT Project. (available at http://www.sri-india.net/documents/More_Water_For_The_Planet.pdf)

Allara, A., Kugbei, S., Dusunceli, F. & Gbehounou, G. 2012. *Coping with changes in cropping systems: plant pests and seeds*. FAO-OECD Workshop on Building Resilience for Adaptation to Climate Change in the Agriculture Sector. Rome. (available at http://typo3.fao.org/fileadmin/templates/agphome/documents/faooecd/PestSeeds.pdf)

Beddington, J., Asaduzzaman, M., Clark, M., Fernandez, A., Guillou, M., Jahn, M., Erda, L., Mamo, T., Van Bo, N., Nobre, C.A., Scholes ,R., Sharma, R. & Wakhungu, J. 2012. *Achieving food security in the face of climate change.* Final report from the Commission on Sustainable Agriculture and Climate Change. Copenhagen, CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). (available at www.ccafs.cgiar.org/commission)

Cotter, M., Renzoandre de la Pena-Lavander, R. & Sauerborn, J. 2012. *Understanding the present distribution of the parasitic weed Striga hermonthica and predicting its potential future geographic distribution in the light of climate change.* Braunschweig, Germany, 25th German Conference on Weed Biology and Weed Control. Stuttgart, Germany, Universitat Hohenheim.

Deutsch, C.A., Tewksbury J.J., Huey R.B., Sheldon K.S., Ghalambor, C.K., Haak D.C. & Martin P.R. 2008. *Impacts of climate warming on terrestrial ecotherms across latitude.* Proc. Natl. Acad. Sci. USA, 105: 6668–6672.

Eplee, R.E. 1992. *Witchweed (Striga asiatica): an overview of management strategies in the USA.* Crop Protection, 11(1): 3–7.

European Commission. 2011. *Climate change.* (available at http://ec.europa.eu/dgs/jrc/index.cfm?id=2290)

FAO. 2003. *Weed management for developing countries, R.* Labrada, ed. Rome (available at http://www.fao.org/docrep/006/y5031e/y5031e0j.htm)

FAO. 2004. *Carbon sequestration in dryland soils.* (available at http://www.fao.org/fileadmin/templates/nr/images/resources/pdf_documents/wsrr102.pdf)

FAO. 2008a. *Climate change adaptation and mitigation in the food and agriculture sector.* High-level conference on food security – the challenges of climate change and bioenergy. (available at ftp://ftp.fao.org/docrep/fao/meeting/013/ai782e.pdf)

FAO. 2008b. *Progress on farmer training in parasitic weed management, R.* Labrada, ed. Rome.

FAO. 2009a. *Increasing crop production sustainably, the perspective of biological processes.* Rome.

FAO. 2009b. *Climate change and biodiversity for food and agriculture: taking systemic and second order effects into account, by M.* Flitner & J. Herbeck. Commission on Genetic Resources for Food and Agriculture. (available at ftp://ftp.fao.org/docrep/fao/meeting/017/ak223e.pdf)

FAO. 2010a. *An international consultation on integrated crop-livestock systems for development, the way forward for sustainable production intensification.* Integrated Crop Management. Vol. 13. Rome.

FAO. 2010b. *Gardens of biodiversity – conservation of genetic resources and their use in traditional food production systems by small farmers of the Southern Caucasus.* Rome.

FAO. 2011. *Save and grow: a policymaker's guide to the sustainable intensification of smallholder crop production.* Rome.

FAO. 2012a. *Economics of plant genetic resource management for adaptation to climate change.* A review of selected literature, by S. Asfaw & L. Lipper. (available at http://www.fao.org/docrep/015/an649e/an649e00.pdf)

FAO. 2012b. *FAO statistical yearbook, 2012: world food and agriculture.* (available at http://www.fao.org/docrep/015/i2490e/i2490e00.htm)

FAO. 2012c. *Soil organic carbon accumulation and greenhouse gas emission reductions from conservation agriculture: a literature review.* (available at http://www.fao.org/fileadmin/user_upload/agp/icm16.pdf)

FAO. 2012d. *What is conservation agriculture?* (available at http://www.fao.org/ag/ca/1a.html)

FAO-PAR (Platform for Agrobiodiversity). 2011. *Biodiversity for food and agriculture: contributing to food security and sustainability in a changing world.* Rome. (available at http://agrobiodiversityplatform.org/files/2011/04/PAR-FAO-book_lr.pdf)

FAOSTAT. 2012. *FAO statistical yearbook.* (available at http://www.fao.org/docrep/015/i2490e/i2490e00.htm)

Gallai, N., Salles, *J.M.,* Settle, J. & Vaissiere, B.E. 2009. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. Ecol. Econom., 68: 810–821.

International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). 2009. *Agriculture at a crossroads.* Subglobal report, Vol. 5. B.D. McIntyre, H.R. Herren, J. Wakhungu & R.T. Watson, eds. Washington D.C., IAASTD. (available at http://www.agassessment.org/reports/subglobal/agriculture_at_a_crossroads_volume%20v_sub-saharan%20africa_subglobal_report.pdf)

International Fund for Agricultural Development (IFAD). 2009. *Integrated crop-livestock farming systems.* Livestock thematic papers, tools for project design. (available at http://www.ifad.org/lrkm/factsheet/integratedcrop.pdf)

International Food Policy Research Institute (IFPRI). 2009. *Climate change: impact on agriculture and costs of adaptation.* (available at http://www.ifpri.org/publication/climate-change-impact-agriculture-and-costs-adaptation)

Intergovernmental Panel on Climate Change (IPCC) . 2007. *Technical Summary.* In Climate change 2007: mitigation. Contribution of Working Group III to the Fourth Assessment Report of the IPCC. Cambridge, UK, and New York, USA, Cambridge University Press.

IPCC. 2012. *Summary for policy makers.* In C.B. Field, V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G-K. Plattner, S.K. Allen, M. Tignor & P.M. Midgley, eds. Managing the risks of extreme events and disasters to advance climate change adaptation, pp. 1–19. A special report of Working Groups I and II of the IPCC. Cambridge, UK, Cambridge University Press.

Kjøhl, M., Nielsen, A. & Stenseth, N.C. 2011. *Potential effects of climate change on crop pollination.* Rome, FAO.

Lin, B.B. 2011. *Resilience in agriculture through crop diversification: adaptive management for environmental change.* BioScience, 61(3): 183—193.(available at http://www.aibs.org/bioscience-press-releases/resources/Lin.pdf)

Lobell, D.B., Burke, M.B., Tebaldi, C., Mastrandrea, M.D., Falcon, W.P. & Naylor, R.L. 2008. *Prioritizing climate change adaptation needs for food security in 2030.* Science, 319 (5863): 607–610.

Parker, C. & Riches, C.R. 1993. *Parasitic weeds of the world: biology and control*, 332 pp. Wallington, UK, CAB International.

PIPM (Promoting Integrated Pest Management) Project. 2012. *FFS for building the capacity of farmers for healthy crops, more yields and more incomes.* Bulletin No.2. Kabul, Ministry of Agriculture, Irrigation and Livestock, Government of Norway and FAO.

Pretty, J., Toulmin, C. & Williams, S. 2011. *Sustainable intensification in African agriculture*. International Journal of Agricultural Sustainability, 9(1): 5–24.

Redfern, S.K., Azzu, N. & Binamira, J.S. 2012. *Rice in Southeast Asia: facing risks and vulnerabilities to respond to climate change.* In Building resilience for adaptation to climate change in the agriculture sector. Proceedings of a Joint FAO-OECD Workshop. Rome, FAO.

Scherr, S.J. & Sthapit, S. 2009. *Farming and land use to cool the planet*. Module 3. State of the world: into a warming world. Washington D.C., The Worldwatch Institute.

The World Bank. 2008. *Agriculture and poverty.* Agriculture for Development Policy Brief. (available at siteresources.worldbank.org/SOUTHASIAEXT/Resources/223546-1171488994713/3455847-1192738003272/Brief_AgPovRedctn_web.pdf)

United Nations Framework Convention on Climate Change (UNFCCC). 2007. *Climate change: impacts, vulnerabilities and adaptation in developing countries.* (available at http://unfccc.int/resource/docs/publications/impacts.pdf)

United States Global Change Research Program (USGCRP). 2009. *Global climate change impacts in the United States* . Karl, T.R., J.M. Melillo, and T.C. Peterson, eds. United States Global Change Research Program. New York, USA, Cambridge University Press.