

Agricultural practices and technologies to enhance food security, resilience and productivity in a sustainable manner

Messages to SBSTA 44 agriculture workshops

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Abstract

This paper synthesizes knowledge within CGIAR and its partners on agricultural practices and technologies to enhance food security, resilience and productivity in a sustainable manner. A number of agricultural practices and technologies which contribute to these objectives were identified and assessed to generate four key lessons. Firstly, agricultural practices and technologies do not necessarily have universal applicability, they will have to be selected, tailored and applied as appropriate for the context, including agro-ecological zones, farming systems as well as cultural and socio-economic context. Secondly, strong mechanisms for capacity enhancement and technology transfer are prerequisites for success of interventions. Thirdly, suitable sources of funding are required to support implementation and scaling up efforts. Lastly, many agricultural practices and technologies have the potential to achieve co-benefits for environmental health and climate change mitigation. In contexts where mitigation is feasible, managing for multiple outcomes can help countries and smallholder farmers adopt low carbon development pathways.

Keywords

Agricultural practices; adaptation technologies; food security, resilience, productivity

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Acronyms

AAS	Agro-meteorological Advisory Service
ACRE	The Agriculture and Climate Risk Enterprise
ANACIM	Senegalese National Meteorological Agency
AWD	Alternate Wetting and Drying
BIRU	Biogas Rumah
CA	Conservation Agriculture
CAS	Cocoa Agroforestry Systems
CCAFS	CGIAR Research Program on Climate Change, Agriculture and Food Security
CIMMYT	International Maize and Wheat Improvement Center
CIRCLE	Climate-Informed Rice Crop Low Emission
CONAF	La Corporación Nacional Forestal
CSAFECC	Certification System for Adaptation of Forest Ecosystems to Climate Change
CSB	Contour Stone Bunds
DI	Deficit Irrigation
DTMA	Drought Tolerant Maize for Africa
DAAS	District-level Agro-meteorological Advisory Service
FAD	Fish Aggregating Device
FAO	Food and Agriculture Organization of the United Nations
FMNR	Farmer-Managed Natural Regeneration
FONGS	Federation of NGOs
GHG	Greenhouse Gas
HIVOS	Humanist Institute for Development Cooperation
IBLI	Index Based Livestock Insurance
ICRAF	World Agroforestry Centre
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IITA	The International Institute of Tropical Agriculture
IMD	India Meteorological Department
IMTA	Integrated Multi-Trophic Aquaculture

IMWI	International Water Management Institute
IPCC	Intergovernmental Panel on Climate Change
IRI	International Research Institute for Climate and Society
ISFM	Integrated Soil Fertility Management
ISRA	Senegalese Agricultural Research Institute
LDSF	Land Degradation Surveillance Framework
LLL	Laser-Assisted Precision Land Levelling
LU	Landscape Units
MFMR	Solomon Islands Ministry of Fisheries and Marine Resources
MGAP	Ministry of Agriculture of Uruguay
NARS	National Agricultural Research Systems
NCMRWF	National Center for Medium-Range Weather Forecasting
NDVI	Normalized Difference Vegetation Index
RCM	Rice Crop Manager
RCPs	Representative Concentration Pathways
SFM	Sustainable Forest Management
SI	Supplemental Irrigation
SPaRC	Solar Power As a Remunerative Crop
SPC	Secretariat of the Pacific Community
SSA	Sub-Saharan Africa
UNFCCC	United Nations Framework Convention on Climate Change
URAC	Union of Rural Radio
WUE	Water Use Efficiency

Introduction

In 2014 the United Nations Framework Convention on Climate Change (UNFCCC) Subsidiary Body for Scientific and Technological Advice (SBSTA), as part of its mandate to consider issues related to agriculture, decided to invite submissions from parties and observers, covering four topics, in 2015 and 2016. Of the two topics for consideration in 2016, one relates to *‘identification and assessment of agricultural practices and technologies to enhance productivity in a sustainable manner, food security and resilience, considering the differences in agro-ecological zones and farming systems, such as different grassland and cropland practices and systems’*. The UNFCCC (2005) has provided an operational definition for technologies for adaptation, *‘the application of technology in order to reduce the vulnerability, or enhance the resilience, of a natural or human system to the impacts of climate change’*. Using this definition, this working paper presents a number of up-to-date agricultural practices and technologies to enhance food security, resilience and productivity in a sustainable manner. This paper serves as a knowledge base for parties and observers preparing submissions to the SBSTA and participating in in-session workshops during May 2016.

Agriculture affects and is affected by climate change in a wide range of ways; agricultural practices and technologies can help respond to these changes, so as to enhance food security, resilience, and productivity in a sustainable manner. These practices and technologies are implemented at field, farm and landscape scales and their adoption and performance are conditioned by the social, economic and cultural context, making interventions at various, technological, organizational, institutional and political levels important in determining outcomes. At the farm level, interventions may target specific management practices for livestock, fisheries, crops, trees or soil and water conservation within the farming system, as well as focus on household energy consumption. Increasingly attempts are being made to manage a broader range of ecosystem services in addition to agricultural production, many of which manifest at landscape scales and require collective action (Pagella and Sinclair 2014). Beyond the farm level, adaptation interventions can include infrastructure, agricultural extension systems, meteorological services and crop and livestock insurance. In this paper, we identify and assess both on-farm and beyond-farm interventions, relating to soil management,

crop management, livestock management, tree management on farms and in farming landscapes, forestry, fisheries, water management, energy management, climate information services, and crop and livestock weather insurance. We also identify in-country examples and pilots of these practices and technologies. While we discuss the practices in isolation, in the majority of natural resource management interventions there will be synergies and trade-offs among practices and technologies. For example, an intervention to help reduce rainfall run-off and soil erosion is likely to involve soil management, water management, crop management through the use of crop residues to protect the soil surface, and planting of trees or perennial grasses. These synergies make a systems approach to implementation important applied across field, farm and landscape scales.

Agricultural practices and technologies will need to be implemented in the context of adaptation measures and policies, which incorporate (1) governance, policy frameworks and readiness; (2) national planning; (3) local planning; (4) finance, economic incentives and value chain interventions; (5) research, extension, capacity building and knowledge systems; and (6) foresight, models and scenarios. This will allow for planning and implementation within a much broader context and for achievement of adaptation objectives at different scales. Adaptation measures are discussed in CCAFS Working Paper 145, “Adaptation Measures in Agricultural Systems”.

Interventions also need to take into account the differences in agro-ecological zones and farming systems, since projected climate change impacts on these systems will vary (see Figure 1, example of projected changes in climatic suitability for crops and livestock in different parts of Africa). Global/regional projections of climate change impacts will need to be downscaled to local levels and combined with the socio-economic context to identify the most suitable practices and technologies.

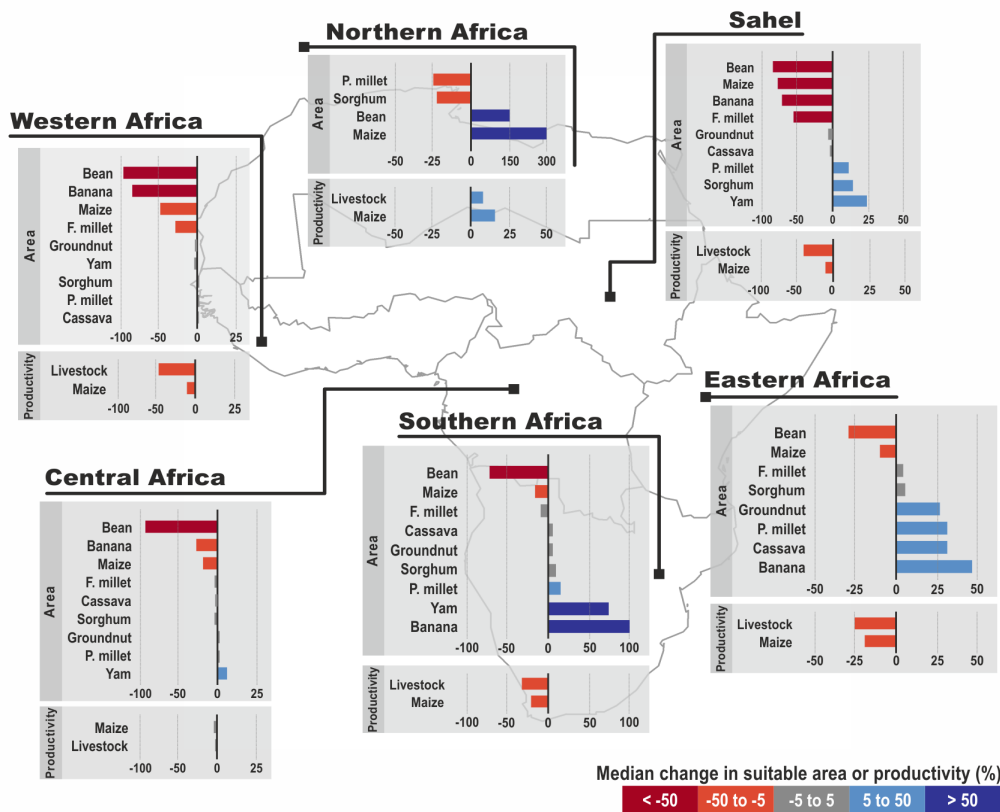


Figure 1 Projected median changes in climatically suitable area and productivity by 2050s and RCP8.5, relative to a historical period (1970-2000). Median values given are based on ensemble simulations of niche and productivity models, and therefore should be interpreted in light of associated uncertainties. Livestock productivity refers to Annual Net Primary Productivity (ANPP) of rangelands (a proxy for livestock productivity), rather than to a direct measure of meat or milk productivity (Dinesh et al. 2015a).

1. Soil management

Soil provides multiple ecosystem services: provisioning services such as food, fibre and fuel production; supporting services such as nutrient cycling and soil formation; and regulating services including filtering of toxins and pollutants, regulating the hydrologic cycle and the sequestration of carbon. In addition to potentially mitigating climate change, carbon sequestration (and overall soil organic carbon content) is an important indicator of the health of the soil, as it influences soil fertility (specifically by increasing the capacity of soil to exchange micronutrients (or cations), increases water holding capacity and as well as enhancing other soil physical properties. Therefore, maintaining or improving soil health is fundamental to sustainable and productive agriculture. Key aspects of a ‘healthy’ soil in order to enhance food security, resilience and productivity in a sustainable manner include (FAO 2013a):

- Minimal loss of soil nutrients through for example, leaching and soil erosion
- Zero or minimal rates of rainfall run-off leading to soil erosion
- Maintenance of soil carbon content, acknowledging that different soil types have different capacities to store carbon
- No accumulation of contaminants in the soil
- Agriculture which does not rely excessively on fossil energy through inorganic fertilizers
- Reduction of bare soil through increased soil cover
- Presence of soil fauna and associated processes

However, in many regions of the world, soil health is severely threatened by human and livestock population increases which have resulted in the intensification of soil cultivation in existing high potential areas, reduced fallow periods, expansion of farming into agriculturally more marginal environments with fragile soils and the overstocking and overgrazing of natural pastures. These, combined with the constraints that small-scale farmers face with regard to the availability, accessibility and cost of organic and inorganic nutrient inputs, have resulted in wide scale decline in soil health and hence productivity (Lal 2007; Vågen et al. 2016). As a result numerous global efforts have initiated soil and land restoration platforms and programs.

Assessments of soil health status

Soil properties vary across space and time. In order to understand constraints to soil carbon sequestration under varying climates and land uses, as well as quantify the impact of management practices on carbon storage, baseline assessments are needed. CGIAR researchers have developed a landscape-level approach that assesses the various drivers of Soil Organic Carbon (SOC) across different spatial scales, the Land Degradation Surveillance Framework (LDSF) (see case study 1.4) which have been applied in East Africa (Vågen and Winowiecki 2013; Winowiecki et al. 2015; 2016) and are now being implemented globally through the establishment of a network of land and soil health monitoring sites. By applying these methods, baselines of land and soil health are created allowing future impact assessments of interventions, while also understanding key drivers of land degradation and agricultural productivity in order to strategically target context-specific management practices.

Contribution to enhancing food security, resilience and productivity in a sustainable manner

Improved soil management which aims to enhance soil health contributes to enhancing food security, resilience and productivity in a sustainable manner.

- **Productivity/food security:** In all types of interventions which target improved soil fertility, improved soil water availability, increased soil organic matter, and reductions in the loss of nutrient-rich topsoil through erosion, productivity will be improved (see case studies 1.1, 1.2, 1.3, 1.4, 1.5, and 1.6). In most cases, productivity increases can be achieved in 2-5 years. This is critical, as farmers need immediate returns when they are food insecure. Often, a combination of different interventions leads to a gradual increase in soil fertility thus leading to productivity increases over time (Thierfelder et al. 2015).
- **Resilience/adaptation through short-term risk management:** In many parts of the world, intense rainfall events are already a common occurrence and result in a high risk of rainfall run-off and soil erosion, especially on sloping land and if the soil surface is not protected from the impact of rainfall. Key to adapting to these risks is the increased infiltration capacity of soils to absorb rainwater which holds the water on-site, increases its availability for plant growth and adds to groundwater recharge (Thierfelder and Wall 2009). Climate change projections suggest that the frequency and severity of such events are likely to increase. There are a wide range of soil management interventions which target the reduction of the risk of run-off and soil erosion ranging from field or farm level interventions such as no- or drastically reduced tillage, contour tillage with tied ridges, permanent cultivation of perennial crops, contour stone bunds, zai, half-moon basins (see

case study 1.1), agroforestry (Carroll et al. 2004), micro-catchments and surface mulching to landscape-level approaches such as land terracing or reforestation/restoration.

- **Mitigation co-benefits:** Soil management can help mitigate climate change by increasing soil carbon, which acts as a below-ground 'sink' for carbon sequestration (Smith et al. 2008; Powlson et al. 2014; see also case studies 1.1, 1.3 and 1.6).

Case studies

Case study 1.1: Contour Stone Bunds, zaï and half-moons in the West African Sahel

High intensity rainfall is characteristic of large areas of the Sahel causing widespread rainfall runoff and erosion (Barry et al. 2008). In response, three integrated soil, water, and nutrient management practices have emerged from indigenous knowledge in the West African Sahel. These have been further developed through action research with stakeholders in the region (Zougmore et al. 2014). These practices are:

Contour Stone Bunds (CSBs): Involves building stone bunds on natural contour lines to prevent erosion and run off. When used in combination with the planting of grass and trees on the contour lines, it can deliver better results (Bayala et al. 2012). It is estimated that across the region, 300,000 ha of land has been reclaimed through the use of CSBs.

Zaï: Involves concentrating run-off water and organic matter into small pits, which helps to rehabilitate bare, sealed and crusted soil (Zougmore et al. 2014). The pits act as micro-catchments into which crops are planted (Roose et al. 1999)

Half-moons: This practice originated in Niger and is similar to zaï, the main difference is that while zaï involves pits which are 20-40 cm in diameter and 10-15 cm deep, half-moons consist of a basin 2 m in diameter. Each half-moon supports cultivation in 6.3 m² of surrounding land.

Both the zaï and half-moon practices are often used in conjunction with CSBs, since CSBs slow down run off and allow better water retention and infiltration in the zaï and half-moon basins (Zougmore et al. 2014). A recent review by Zougmore et al (2014) has found that these practices, when combined with appropriate nutrient inputs can increase agricultural productivity, reduce erosion, increase vegetative cover and also increase carbon sequestration. These practices can also play an important role in improving the scarce organic resources in the region.

Case study 1.2: Integrated Soil Fertility Management (ISFM)

The ISFM approach is based on the principles that (Sanginga and Woomer 2009):

- Neither practices based solely on mineral fertilizers nor solely on organic matter management are sufficient for sustainable agricultural production;
- Well-adapted, disease- and pest-resistant germplasm is necessary to make efficient use of available nutrients; and
- Good agronomic practices in terms of planting dates, planting densities, and weeding are essential to ensure efficient use of scarce nutrient resources.

In addition, ISFM recognizes the need to target nutrient resources within crop rotation cycles, preferably including legumes, thus going beyond recommendations for single crops. Productivity can be substantially enhanced when ISFM is successfully adopted and often a positive synergistic effect between organic and inorganic inputs is observed (Roobroeck et al. 2015). As a result, greatly enhanced rainfall-use efficiency is achieved. However, ISFM does not necessarily lead to greater water infiltration and soil moisture content, which can restrict its adaptation potential under African conditions. ISFM advocates strategic timing and placement of inorganic nitrogenous fertilizers, often at rates that are much lower than recommendations based on the sole use of inorganic fertilizers (Bationo et al. 2012). This will contribute to mitigation through improved nitrogen use efficiency and reduced nitrous oxide emissions. However, ISFM may lead to greater soil erosion and run-off by comparison to soil management practices designed to cover soil surface or minimum tillage as soils are left unprotected and are often tilled as well. ISFM is being widely promoted across Africa. For example, in Malawi, about 30,000 farmers, as well as several hundred farmer associations and agricultural extension workers, have been trained in ISFM technologies (Nyasimi et al. 2014).

Case study 1.3: Conservation agriculture (CA)

CA was introduced in the 1930s as a soil conservation system to counter the Dust Bowl in the United States, but more recently has become widely promoted and adopted, largely in Latin America. Approximately 157 million hectares are currently cultivated worldwide under CA (11% of the arable land area) (Kassam et al. 2015).

However, adoption rates by small-scale farmers in Africa are slower and more context specific (FAO 2009). CA is based on three principles (Richards et al. 2014).

- **Minimum soil disturbance.** Zero tillage is ideal, but may involve some reduced tillage systems in which no more than 20 to 25% of the soil surface is disturbed.
- **Retention of crop residues or other soil surface cover, including green manures.** Whereas a permanent soil cover of at least 30% reduces erosion by 80%, the actual level of soil cover is often site-specific and primarily dependent on the level of crop-livestock interactions in the predominant farming system.
- **Diversification through crop rotations or intercropping systems.** Crop rotation, ideally with legumes, helps reduce build-up of weeds, pests and diseases and supports nutrient cycling. Where farmers do not have enough land to rotate crops, intercropping can be used.

Like any other cropping technology, good agriculture practices (e.g. timely planting, weeding, adequate fertilization and plant populations) are required to achieve high yields from CA and its applicability varies according to local context (Giller et al. 2009). CA generates adaptation benefits since increased concentration of soil organic carbon in the near-surface soil reduces run-off and soil erosion, and more water is stored in the soil profile (Thierfelder et al. 2015). This is particularly important in regions where future climates are projected to become drier or extreme rainfall events more frequent. CA also addresses heat stress as temperature amplitudes are smoothed in reduced tillage and residue covered fields. CA can mitigate climate change through some level of carbon sequestration in the soil as well as through diversification, but this benefit may not be as large on a global level as had been previously anticipated. (Richards et al. 2014). The benefits of CA in terms of productivity, climate buffering and carbon storage can be enhanced in many circumstances by incorporating trees in crop fields (Bayala et al. 2012). However, implementing CA involves reallocation of men's and women's resources which will affect their ability to realize their gender interests, with additional implications for labour requirements, labour allocation, and investment decisions, relating to mechanization and herbicide use, crop choice, and residue management (Farnworth et al. 2015). Beuchelt and Badstue (2013) point out that in developing countries CA may have undesired effects for smallholders relating to drudgery, nutrition and food security, and these issues need due consideration.

Case study 1.4: Socio-ecological analysis to target agricultural interventions for increased resilience in East Africa

The Land Degradation Surveillance Framework (LDSF) was conducted at four 100 km² sites in Uganda, Kenya, and Tanzania to assess baseline soil and land health status. These data were used to generate predictive maps of soil erosion and soil properties for sites where CCAFS also conducted geo-referenced socio-economic household (HH) surveys. The CCAFS HH surveys were designed to identify commonly used farming practices, household baseline characteristics, as well as diversity of management practices. CCAFS conducted interdisciplinary analysis to understand how socio-economic factors and soil health status influence the uptake of farming practices that increase food security and adaptation potential. For example, farmers with higher soil and land health status were generally able to produce most of their food on-farm (e.g. the farmers were more self-sufficient compared with farmers on highly degraded soil). Diversity indices of agronomic practices were also calculated and results showed that more diverse farming systems were correlated with higher soil health status with implications for their resilience. There were also large variations among sites in terms of on-farm self-sufficiency, food insecurity, household size, cropping diversity, farm size dedicated to food crops, as well as soil health indicators, showing the importance of local context when designing land management or farming interventions. This analysis demonstrates both the possibility and utility of combining biophysical and socio-economic datasets to assess on-farm self-sufficiency and food insecurity of smallholder farming systems in East Africa.

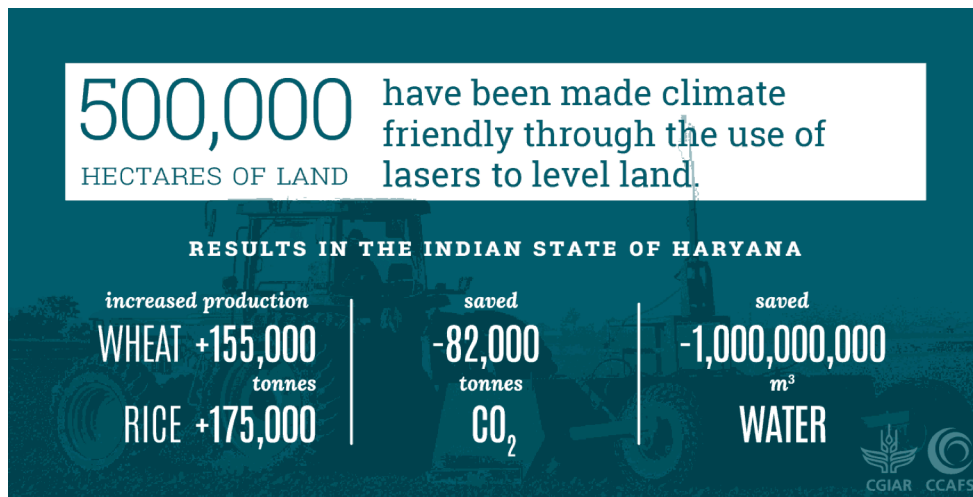
Case study 1.5: GreenSeeker technology for better nutrient management in India and Mexico

In the high northwest Indo-Gangetic Plains of India, intensive tillage and overly generalized fertilizer recommendations limit the potential of the region's high-yielding wheat production systems (Sapkota et al. 2014: 233). Specifically, such practices lower nutrient-use efficiency, reduce profits, raise production costs and cause adverse environmental impacts. (Sapkota et al. 2014: 233). Site-specific nutrient management helps match supply of soil nutrients to that of the demand, generating positive outcomes for productivity, farmer incomes, and mitigation (Richards et al. 2015). GreenSeeker® is a tool for site-specific nutrient management. It is a handheld device which includes a sensor. Farmers position GreenSeeker's sensor over a plant and pull the trigger, outputting calculations of the appropriate fertilizer dosages (CIMMYT 2012). With proper knowledge of crop health, farmers can make more informed decisions on fertilizer use, benefitting the environment and farmers' input costs. Proper timing and placement of nitrogen fertilizer can improve uptake efficiency, yield, emissions and profitability. Compared to farmers utilizing state recommended nutrient management or farmers own fertilizer practices, farmers using GreenSeeker in India saw 10% increases in yields (0.5 tonnes/ha). This yield increase and nutrient-use efficiency gains translated into an increased net income of USD 187.50/ha (Basak 2016: 9). In addition, farmers using GreenSeeker were able to reduce GHG emissions by 47% (0.9 tonnes CO₂/ha) (Basak 2016: 9).

In some areas of northern Mexico, low nitrogen-use efficiency in wheat farming causes negative environmental impacts and reduces farmer incomes. Site-specific nutrient management utilizing a combination of GreenSeeker and N-rich strips has the potential to reverse this tendency (Ortiz-Monasterio and Raun 2007). Test fields in the Yaqui Valley using the technology showcased savings of 69 kg N/ha, in comparison to conventional nitrogen management applications. In larger commercial areas with an average farm size of 10 ha, farmers were able to enhance their incomes by USD 50/ha by applying the sensor-based technology. The technology has now spread across several major farming regions in Mexico, with 6,400 ha of wheat across 271 plots in 2009 in Sonora alone; 101 of these plots saved an average 70 kg of N/ha, totalling monetary savings of USD 90/ha (CIMMYT 2009).

Case study 1.6: Laser-Assisted Precision Land Levelling (LLL) in the western Indo-Gangetic Plains

In the western Indo-Gangetic Plains, rising temperatures put pressure on water resources needed to maintain and increase yields. In response to this challenge, CCAFS researchers at the International Maize and Wheat Improvement Center (CIMMYT) found that removing undulations in the soil's surface can make better use of water resources, create a larger planting area, and increase productivity and yields. However, traditional methods of land levelling proved expensive and time consuming. As a solution, CIMMYT is promoting laser-assisted precision laser land levelling (LLL). Introduced in 2011, the LLL involves a tractor-towed, laser-controlled device which achieves an exceptionally flat and even surface. Studies indicate that LLL helps improve crop establishment, reduce weed infestation, improve uniformity of crop maturity, decrease time requirements, improve crop yields, increase cultivated area (due to elimination of bunds), and reduce water requirements for land preparation and irrigation. It is estimated that LLL has been applied on 500,000 hectares of land, which has led to savings of 82,000 tonnes of CO₂ and 1 billion m³ of water (Gill 2014).



2. Crop management

Crop production for food, fibre and animal feed is practised within a hugely diverse range of rainfed and irrigated farming systems and under widely differing socio-economic, climatic and soil environments, which varies in vulnerability and resilience to climate change in response to agro-ecological, social and economic factors that are not fully described in a holistic way. Increasing attention is now being given to the wide range of crop production practices that can be considered as ‘climate resilient’ either from a short or longer-term adaptation perspective. Many examples are evident whereby the soil and /or water management or agroforestry system in which crop production and trees takes place together on farm can provide substantial opportunities to increase climate resilience, productivity, and mitigation. These are discussed under the sections on soil management, forestry and agroforestry and water management. However, there are also many examples whereby ‘crop specific’ innovations can substantially contribute to climate resilience. Nevertheless, the adaptation/mitigation responses of agriculture to climate change calls for a holistic approach that considers all factors (both internal to the farming systems and external to them) that affects and drives the capacity of agriculture to successfully function under new and dynamic climate conditions. Among those factors are infrastructure, services, education, information, finance, land tenure, and enabling policies and their interaction with a particular agro-ecology. Improving those limiting factors in developing regions in order to move from a peasant based economy into a truly farmer based economy is an unavoidable requisite to give agriculture the capacity to adopt new varieties, crops, cropping management and technologies to confront climate change.

Crop-specific innovations need to be identified in relation to the context in which they could occur (see case study 2.7). There is a need to understand both the farming systems in a certain agro-ecological zone and the impact of climate change on the main enterprises within these farming systems. For example, interventions in coffee-based farming systems in Mount Elgon, Uganda will be based on climatic suitability within different areas of the system, which in turn can be based on climate projections (see case study 2.5). Developing climatic suitability maps for each region and for each crop may be difficult. However, there are participatory approaches that allow describing the farming systems in the region, major enterprises that provide opportunities to improve livelihoods and the impact of climate change

to identify adaptation zones. Based on this, crop-based opportunities can be identified for other crops also.

Contribution to enhancing food security, resilience and productivity in a sustainable manner:

- **Productivity/food security:** Crop productivity can be increased through the breeding of higher yielding crop varieties, though crop and crop nutrient management (see case study 2.8), and through the choice of crop species that have higher yield potentials under given environmental conditions (see case study 2.6).
- **Resilience/adaptation through short-term risk management:** Crop breeding for greater drought tolerance or the choice of earlier maturing varieties for ‘terminal drought escape’ provide substantially reduced risk of yield reduction or crop failure (Sipalla and Cairns 2015) (see case studies 2.2 and 2.3). Similarly, many outbreaks of crop pest and diseases are ‘triggered’ by single or a combination of weather events. Breeding for resistance to such pests and diseases provides an important source of climate risk reduction. Plant breeding for drought, pest and disease resistance will increase in importance since the risk of drought and heat is projected to increase in many regions and the distribution and severity of pest and disease outbreaks will also change as climates change (FAO 2008). Other strategies include making incremental changes to cropping systems which help cope with impact such as water stress (see case study 2.2).
- **Resilience/adaptation through longer-term risk management:** Longer-term adaptation by farmers will become necessary through the planting of more heat tolerant crop varieties or by changing the crop species they grow to those which can tolerate higher temperatures and the greater risk of drought. For example, dryland cereals like millets and sorghum are the hardest, resilient and climate adaptable crops for harsh, hot and dry environments (ICRISAT 2014). Farmers who currently rely on maize may well have to switch to these alternative cereals in the future (ICRISAT 2015). Farmers growing water intensive crops such as rice and wheat may shift to maize. Another adaptation strategy is the substitution of potentially vulnerable annual crops with more hardy perennials. Furthermore, in regions which are already marginal for annual crop production, farmers may well have to adapt more radically by abandoning cropping altogether for livestock production (Jones and Thornton 2008; Thierfelder et al. 2014). Another strategy, which is likely to be the most successful, is the integrative diversification and intensification of

farming systems, moving them from mono-cropping or not integrated cropping systems into a diverse, highly integrated, both in time and space, mixed crop-livestock-agroforestry system (see case study 2.1). This strategy is synergistically complementary to the use of better-adapted varieties or novel crop species (see case study 2.3).

- **Mitigation co-benefits:** The mitigation potential of crop production largely stems from the soil and / or water management or agroforestry system under which they are grown. However, perennial crops with life spans of 10 to 20 years are able to sequester greater amounts of carbon below ground in their root systems than annual crops. Inevitably, fertilizer inputs will have to increase in regions such as SSA in order to address current and future food security needs in a changing climate (Sanchez 2015). A key challenge will be to identify practices that will narrow the yield gap and also have a low GHG emissions intensity (Bellarby et al. 2014).

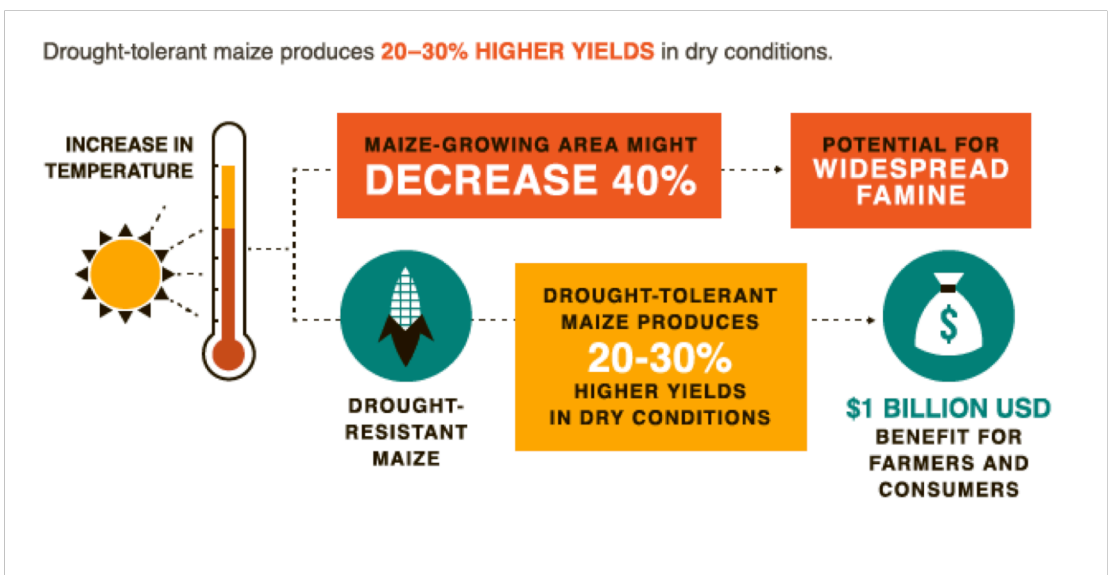
Case studies

Case study 2.1: Coffee Banana Intercropping in East Africa

Coffee is an important export crop and source of revenue across East Africa. However, temperature increases brought forth by climate change are already having substantial impacts on the sector, resulting in decreased suitability in major coffee growing regions. The consequences of declining productivity are severe for both national incomes and smallholder livelihoods, and will likely worsen as the century progresses. Coffee-Banana Intercropping (CBI) presents an opportunity to enhance the climate resilience of the East African coffee sector, while providing an additional source of food security and income. Banana trees provide shade against temperature increases, while simultaneously reducing incidence of coffee leaf rust. CBI is by no means a new approach—it is a traditional practice that has been developed by smallholders (Ekong 2015). Generally, shade trees take 5-10 years to grow, presenting a significant barrier for their adoption. However, banana trees take only 6-12 months to achieve full canopy cover, making them an effective alternative. Studies indicate that growing the two crops together can increase incomes by over 50% compared to monocropping either crop alone (Ekong 2015). Climate resilience is increased as well, by diversifying farmer incomes and allowing coffee to recover more quickly from drought periods. In addition, CBI enhances climate change mitigation, by increasing above- and below-ground carbon stocks (van Asten et al. 2015).

Case study 2.2 Drought tolerant maize for Africa (DTMA)

In sub-Saharan Africa (SSA), “maize is life,” due to its importance to food security and economic wellbeing. Around 40% of Africa’s maize-growing area faces occasional drought stress, resulting in yield losses of 10–25%. Around 25% of the maize crop suffers frequent drought, with losses of up to half the harvest. To reduce vulnerability and improve food security, the DTMA project has made releases of 160 drought tolerant maize varieties between 2007 and 2013. These have been tested in experimental and farmers’ fields, and disseminated to farmers in 13 African countries through national agricultural research systems and private seed companies. Yields of the new varieties are 25-30% superior to those of currently available commercial maize varieties under both stress and optimum growing conditions (Cooper et al. 2013). Given the extent to which current drought occurs, drought tolerant maize varieties make a major contribution to short term adaptation through climate risk management. Combinations of drought tolerant varieties with other climate-resilient technologies such as conservation agriculture offer multiple benefits (Thierfelder et al. 2015). An *ex-ante* assessment study by La Rovere et al. (2010) on the potential impacts of the DTMA project indicates that (with optimistic adoption rates and yield increase of 10-34% over non-drought tolerant varieties) the DTMA project could lead to a cumulative economic benefit of nearly USD 0.9 billion to farmers and consumers. In addition they estimate that drought tolerant maize could assist more than 4 million people in escaping poverty while improving the livelihood of many millions more.



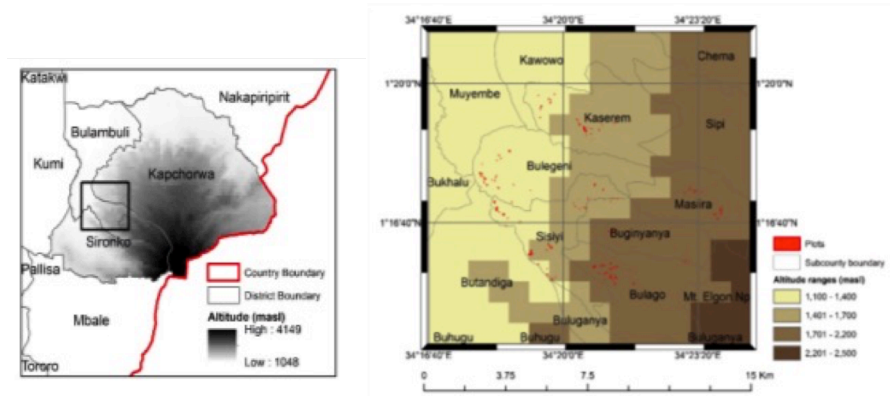
Case study 2.3: Disease resistant and early maturing chickpea boost production in Andhra Pradesh, India

South and Southeast Asia account for about 84% of the global chickpea area (ICRISAT 2012). The crop is mainly rainfed, and is grown in the post-rainy season on receding soil moisture. It often experiences terminal drought and heat stress. In two thirds of chickpea growing areas, however, the growing season is short (90–120 days) because of the risk of extreme drought or high temperatures during pod filling at the end of the season. The International Crops Research Institute for the Semi-Arid Tropics' (ICRISAT) first extra-short duration kabuli cultivar, ICCV 2, matures in only 85–90 days and demonstrates fusarium wilt resistance and heat tolerance. Subsequently, several early-maturing, high-yielding cultivars have been developed, including two new kabuli types and four desi types. Avoiding terminal drought and heat stress through growing shorter-term varieties of chickpea provides a substantial contribution to short-term adaptation through climate risk management and / or avoidance. The adoption of early-maturing chickpea cultivars has brought a chickpea revolution in Andhra Pradesh State in India. Chickpea production has increased 9-fold (95,000 to 884,000 tons) over the past 10 years (2000–2009) (ICRISAT 2012). This is a result of a 5-fold increase in area (102,000 to 602,000 ha) combined with a 2.4-fold increase in yield levels (583 to 1,407 kg ha⁻¹). Over 80% of the chickpea area in Andhra Pradesh is now cultivated with the short-duration improved cultivars which were developed through a partnership between ICRISAT and the Indian national agricultural research system. Andhra Pradesh was once considered to be a low yielding state for chickpea because of its warm, short-season environment, but it now has the highest yield levels in India.

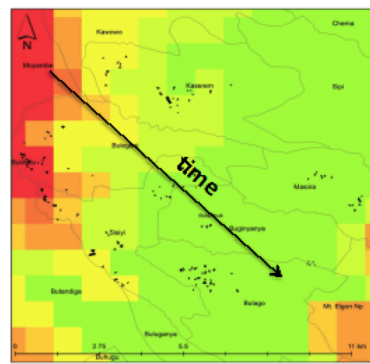
Case study 2.4: Enhanced productivity and livelihoods and reduced vulnerability in the Peruvian High Plateau

The Peruvian Highlands is one of the world's poorest areas, with high climatic variability, where the main goal of smallholders farming, based on potato cropping, is food security and the minimization of production risk. An integrated systems approach was used to enhance agricultural productivity, family income and the resilience of these farming systems. The objectives were the diversification of farming activities, improving access to markets and to strengthen livelihood capitals for reducing vulnerability. Innovations were selected based on their capacity to withstand climate variability and extreme events, available resources and the competitive advantage of production options for access to markets, income generation, food and nutritional security and asset building. The project promoted organic quinoa production, an activity with a high-income generation potential. Another innovation was milk and cheese production supported by the cultivation of alfalfa and forage oats to provide additional feed. A third innovation was trout farming. All this was complemented with vegetable production in greenhouses run by families and schools. Altogether, the innovations and farm diversification substantially improved family income and reduced vulnerability to high climatic variability in the region, which will be exacerbated by climate change.

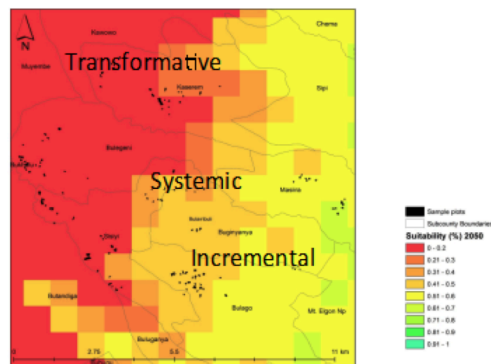
Case study 2.5: Climatic suitability maps for coffee-based farming systems in Mount Elgon, Uganda



Current suitability



Future suitability



Climatic suitability maps help decision makers choose interventions based on the level of adaptation required.

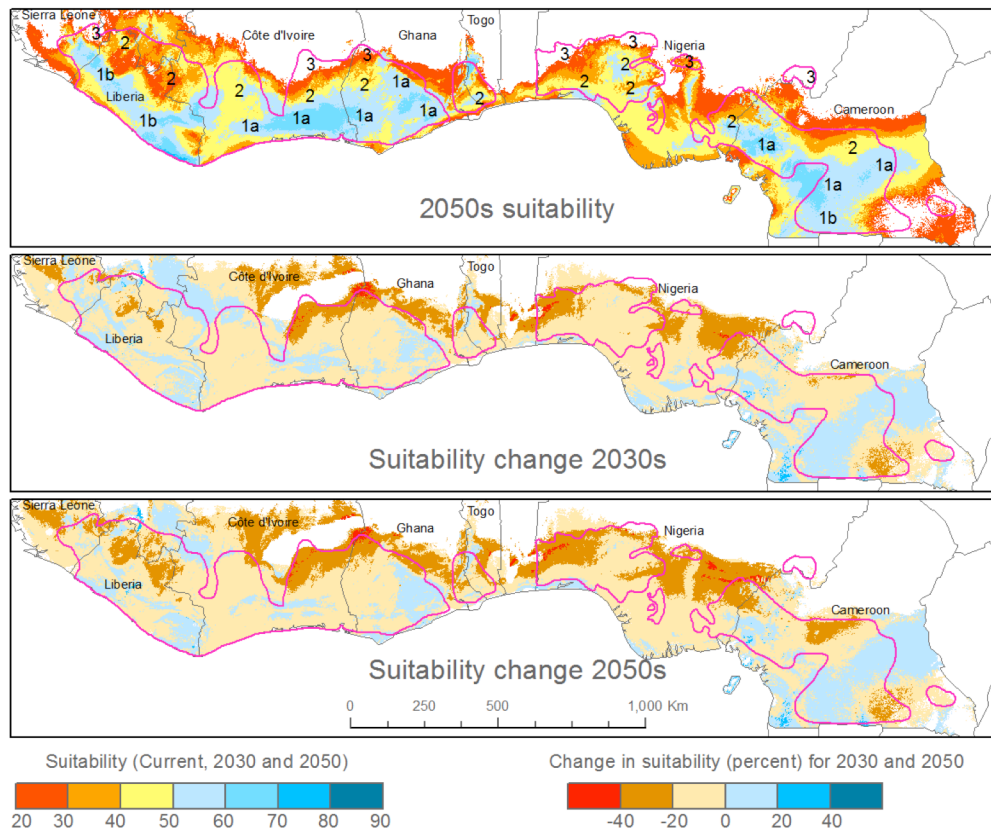
For example, in the incremental adaptation zone, crop requirements will be different from that in the transformational zone. The accompanying figures show the climatic suitability for coffee-based farming systems in Mt Elgon, Uganda. For coffee, higher yielding varieties, good agricultural practices and agroforestry systems will be options in the incremental adaptation zone. In the systemic adaptation zone, drought resistant varieties can play a key role for adaptation or resistant varieties to major pests and diseases. In the transformative adaptation zone, it may be necessary to look at other cash crops like Robusta or other Arabica varieties again.

Case study 2.6: Seeds for Needs project

Farmers need new crops and crop varieties in order to respond to climate change impacts. Such new crops and varieties may exist in genebanks and farmers' fields in the form of germplasm and seeds, but these have to be identified and matched with the right growing environments. Seeds for Needs is a global initiative led by Bioversity International which aims to address these issues. It uses Geographic Information Systems (GIS) technology to identify gene bank accessions that may be suitable for current and future climatic conditions. The accessions identified in this manner are subjected to further field testing to characterize them under present conditions; they are also subject to evaluation by women farmers to assess suitability. Through these steps, the most suitable accessions are identified. Thereafter, the focus is on a mechanism based on community genebanks to ensure availability among farmers, as well as creating awareness and capacity for implementation (van de Gevel et al. 2013).

Case study 2.7: Adaptation in the West African cocoa belt

Climate change impacts on cocoa systems are highly site-specific, requiring site-specific adaptation strategies (Läderach et al. 2013). Furthermore, different types of adaptation are needed for different time horizons: incremental adaptation in the short term; systematic adaptation in the mid term; and transformative adaptation in the long term (Vermeulen 2014). The figure below shows climate suitability for cocoa in West Africa by 2050, and changes in suitability by 2030 and 2050. Depending on future suitability, different adaptation options will be appropriate, from the farm level, to national and international level, and private sector. For example, in the short term, while the use of better planting material will be relevant across all zones indicated in the figure, increased shade use will be most relevant for zone 2 (Schroth et al. 2016). For adaptation efforts to be successful, they will need to carefully consider location, time scale, and climate change impacts to pinpoint the most effective interventions for different actors.



Case study 2.8: Vietnam's sustainable intensification of rice production

While rice is an important food staple for over 3.5 billion people worldwide, its production is environmentally taxing. Paddy rice consumes almost 40% of all irrigation water, while producing 10% of methane emissions, and pollution from excess nitrous oxide (Neate 2013). Rice farmers in Vietnam have successfully adopted measures to reduce input use while maintaining or increasing yields, totalling over 1 million farmers in the Mekong Delta by 1999. While this is certainly impressive, seed rates and fertilizer usage remained high, leaving room for further improvement. A 2002 study launched by IRRI and the Ministry of Agriculture and Rural Development tested the economic potential of reduced seeding and input use, indicating that farmers could save USD 58/ha in the winter-spring seasons, and USD 35/ha in the summer-autumn seasons. Numerous media campaigns and local pilot projects during the 00's promoted the use of less nitrogen fertilizer, less seed, and reduced water use, culminating with the launch of a nationwide dissemination in 2007, spearheaded by Vietnam's Plant Protection Department, with the support of Oxfam America and the Centre for Sustainable Rural Development. By 2011, over 1 million farmers were applying the input reduction recommendations, over 185,000 ha. Farmers benefitted by increasing yields 9-15% compared to conventional practices, while reducing seed inputs 70-75%, nitrogen fertilizers 20-25%, and conserving 33% less water. These savings have improved farmer incomes by USD 95-260/ha, per crop and per season.

Source: Cooper et al. 2013

3. Livestock management

In the face of increasing demand, the livestock sector is growing rapidly throughout the developing world (Thornton 2010). The drivers of this demand growth include population increases, income growth, and shifting consumption patterns and preferences. At the same time, climate change is likely to have considerable effects on livestock production in many places in the coming decades (Thornton et al. 2009). Impacts include substantial reductions in forage availability in some regions, negative impacts on forage quality, and heat stress in animals. Higher temperatures, changing rainfall patterns and more frequent extreme events may affect the spread and severity of existing vector-borne diseases and macro-parasites, accompanied by the emergence and circulation of new diseases (Ibid.). Adaptation interventions are thus crucial to ensure that the sector is resilient to climate change impacts. Fortunately, the sector offers a wide range of opportunities for enhancing resilience, while mitigating emissions and increasing productivity (FAO 2013a). These opportunities link to several other approaches, particularly those revolving around soil and water management, insurance, and value chain development.

Contribution to enhancing food security, resilience and productivity in a sustainable manner:

There are various ways in which improved or modified livestock management can contribute to enhancing food security, resilience and productivity in a sustainable manner.

- **Productivity/food security:** The livestock sector makes critical contributions to food and nutritional security. Their productivity can be improved in all types of interventions that target improved feed resources. For cattle, examples include improved grazing management, the use of improved pasture and agroforestry species (see case studies 3.1, 3.3, 3.4), exploring other locally available feeds such as sweet potato vines or cassava leaves, and the judicious use of highly nutritious diet supplements and concentrates (Thornton and Herrero 2014), as well as better feed conversion. Similarly, interventions aimed at improving animal health management will improve animal performance and productivity. Disease risks may be able to be managed via improved disease surveillance, appropriate vaccination programs and the use of more disease-resistant animals (Thornton 2010). In non-grazing livestock systems in particular, interventions aimed at breeding for heat tolerance or reducing heat stress in animals (e.g. via effective animal cooling

systems) will increase productivity (see case study 3.2). Appropriate manure management can increase soil organic matter and water-holding properties, leading to increased productivity of both food and fodder crops.

- **Resilience/adaptation through short-term risk management:** Projections indicate that the frequency and severity of extreme events such as hot days, floods and droughts will increase in the future. In grazing systems, livestock insurance instruments and early warning systems can help pastoralists to manage risk. In mixed crop-livestock systems, risk can sometimes be ameliorated and income diversified via the addition or substitution of crop and livestock species and varieties that are more tolerant of heat or drought (Thornton and Herrero 2014). Developing alternative feed sources to cope with seasonal variation is also an option.
- **Mitigation co-benefits:** Key mitigation opportunities in livestock systems are improved grazing management, feed management and manure management (Thornton and Herrero 2014). Improving efficiency through direct breeding for better performance under local environmental conditions is also a co-benefit opportunity.

Case studies

Case study 3.1: Supplementary feeding of leaves of the tree *Leucaena leucocephala* to cattle

The availability of feed for ruminants, particularly in the dry season, is a major constraint in many parts of the wet-dry tropics (Thornton and Herrero 2010). Smallholders make use of many different feeds to cover the gap, including crop residues from staples such as maize and rice, small areas of planted legumes (“fodder banks”), and opportunistic feeds cut-and-carried from road-side verges, for example. There is considerable evidence to show that appropriate tree species, when planted in smallholder farms, can be advantageous across a wide range of situations. One such tree is *Leucaena leucocephala*, native to meso-America but now naturalized throughout the tropics. The leaves of *Leucaena* are highly nutritious, and when fed as a supplement can increase meat and milk yield substantially, when compared with a low-quality baseline diet (Thornton and Herrero 2010). The planting of agroforestry species like *Leucaena* on a mixed farm can thus increase productivity per animal considerably as well as resilience, with substantial impacts on income. At the same time, because the leaves improve the diet of ruminant livestock, the amount of methane produced by the animal per kg of meat and milk produced is substantially reduced. In addition, having trees such as *Leucaena* on the farm increases carbon sequestration in the soil, possibly by up to 38 t C per ha in some situations (Albrecht and Kandji 2003).

Case study 3.2: Changing from local breeds to cross-bred cattle

Local breeds of cattle are often well adapted to their environments, in terms of disease resistance and tolerance to heat and low planes of nutrition. However, in addition to low levels of production, the greenhouse gas emissions intensity of milk and meat production from local breeds of cattle (i.e. the amount of emissions per kg of milk and meat) can be very high. Selecting more productive animals is one strategy to enhance productivity and reduce emissions intensity. Cross-breeding programmes can deliver simultaneous adaptation, food security and mitigation benefits. Cross-bred cattle developed for the tropical grasslands of northern Australia demonstrate greater heat tolerance, disease resistance, fitness and reproductive traits compared with the breeds normally used (FAO 2013a). Cross-breeding strategies that make use of locally adapted breeds that are tolerant not only of heat and poor nutrition but also to parasites and diseases will become increasingly relevant as the climate changes. Cross-breeding coupled with diet intensification can lead to substantial efficiency gains in livestock production and methane output. With widespread uptake, this would result in fewer but larger, more productive animals being kept, which would have positive consequences for methane production and land use. To meet projected milk and meat demand in 2030 using local breeds would need 363 and 173 million bovines, respectively; with 29% adoption of crossbreeds, this could be reduced to 308 and 145 million, respectively, with a mitigation potential of about 6 Mt CO₂ eq (Thornton and Herrero 2010). Cost, lack of experience and knowledge are factors that may constrain the widespread adoption of cross-bred animals in the future.

Case study 3.3: Sowing improved pastures in the savannas of the humid-subhumid tropics

A major constraint to ruminant livestock production in many developing countries is the quantity and quality of forage production. Native grasses tend to be of relatively low digestibility. Improving pasture quality and productivity offers a readily available means of increasing livestock production, particularly in the humid-subhumid tropics; there are very few practical opportunities for sowing improved pastures in arid/semi-arid grazing systems. The sowing of better quality forages and better pasture management can improve forage digestibility and nutrient quality, resulting in faster animal growth rates, higher milk production, earlier age at first calving, and increased incomes. Better nutrition can also increase cow fertility rates and reduce mortality rates of calves and mature animals, thus improving animal and herd performance and system resilience. In the humid-subhumid tropical grazing systems of Latin America, for example, substantial improvements in soil carbon storage and farm productivity are possible, as well as reductions in enteric emission intensities, by replacing natural vegetation with deep-rooted pastures such as *Brachiaria* (Thornton and Herrero 2010). In seasonally dry pastures, however, more diverse semi-natural pastures may outperform sown pastures because they remain productive for longer into the dry season (Ospina et al. 2012). In parts of Latin America, *Brachiaria* grasses have been widely adopted with large economic benefits: animal productivity can be increased 5-10 times compared with diets of native savanna vegetation. In Brazil, where about 99 million ha have been planted, annual benefits are about USD 4 billion (Rao et al. 2014). In the humid-subhumid livestock systems of Latin America, total mitigation potential of improved pastures such as *Brachiaria* is estimated to be 44 Mt CO₂-eq (Thornton and Herrero 2010).

Case study 3.4: Optimizing grazing systems for adaptation and co-benefits in Uruguay

The adoption of a set of good practices is taking place in the framework of the project “*Building Resilience to Climate Change and Variability in Vulnerable Smallholders*”, funded by the Adaptation Fund (USD 9.97 million), implemented by the Ministry of Agriculture of Uruguay (MGAP) and running from 2012 to 2017. The project’s objectives are: (a) Reducing vulnerability and building resilience to climate change in small cattle farms located in two highly drought-sensitive Landscape Units (LU) (2.5 million hectares); (b) Strengthening local institutional networks at the LU level and (c) Developing mechanisms for monitoring and assessing the climate effects and the capacity of the measures adopted to reduce vulnerability, build resilience and produce other co-benefits. These actions are important in Uruguay, where extensive cattle and sheep production occupy 70% of the national territory. Meat productivity per hectare is very low in small farms (50-70 kg). However, research and pilot farms show that through changes in grasslands (increase forage supply) and animal management, it is possible to increase productivity and incomes, without significant increase in costs. At the same time, other co-benefits arise: a) more resilience and less vulnerability, b) less GHG emissions intensity and carbon sequestration in soils, and c) land restoration and biodiversity conservation in grassland ecosystems.

4. Forestry and agroforestry

Forestry and agroforestry play an important role in global efforts to tackle climate change. An estimated 1.6 billion people depend in part or fully on forests and tree resources for their livelihoods (Chao 2012). More than 800 million people (30% of the global rural population) live on 9.5 million km² of agricultural lands (45% of the total area) with >10% tree cover; 180 million on the 3.5 million km² agricultural lands with >30% tree cover; and about 350 million within or near 40 million km² of dense forests (Zomer et al. 2009). The estimated value of ecosystem services stemming from forests, trees and savannas represents more than USD 76 trillion, compared to USD 9 trillion for cropland (Costanza et al. 2014). Climate change and climate variability threaten the delivery of these ecosystem services, and can consequently impact rural livelihoods. The agriculture, forestry, and other land use sector accounts for a quarter of global emissions. Forests are also an important carbon sink in the case of afforestation and reforestation efforts (Lewis et al. 2015). Deforestation is the major cause of emissions from the forestry sector, and agriculture remains the key driver of deforestation.

In smallholder farming systems, trees and forests are often key to livelihoods. Increasing the resilience of farming and forest systems to maintain and enhance the flow of ecosystem services, mitigating emissions from the sector by reducing deforestation (see case study 4.4) and increasing forest cover, and agroforestry (see case studies 4.1, 4.2, 4.3 and 4.5) are possible interventions that need to be considered in the context of the wider landscape (Locatelli et al. 2015; Jackson et al. 2013). Ongoing efforts in sustainable forest management (SFM) provide a sound foundation for climate-resilient forestry that will involve more widespread application of SFM principles (FAO 2013b) and trees are key components of many climate-resilient agricultural practices (see cases 2.1, 2.5 and 3.1) because they may increase and sustain soil health, regulate nutrient and water cycling and increase carbon storage as well as producing fodder, fuel, food and high value products for sale (Barrios et al. 2012; Carroll et al. 2004; Luedeling et al. 2016). Capacity building within local institutions and strengthening governance process is a priority within the sector (FAO 2013b). Increasing the amount of trees on farms and in the landscape not only provides important ecosystem services but also leads to a direct increase in income through diversification of products and greater resilience to climate shocks (e.g. Thorlakson and Neufeldt 2012; Mbow et al. 2014).

Contribution to enhancing food security, resilience and productivity in a sustainable manner:

Actions in the forestry and agroforestry sector can contribute to enhancing food security, resilience and productivity in a sustainable manner.

- **Productivity/food security:** The production of ecosystem services, including provisioning services, can be improved by using an integrated approach. For example, by adopting agroforestry practices on farms, farmers are able to harvest tree products (including fodder and fuel), supplement their diets, and also develop additional income streams. Integrating trees in farming systems (see case study 4.1) contributes to soil protection and water infiltration that reduces soil erosion, maintaining beneficial soil organisms and tightening water and nutrient cycles thereby improving soil fertility, leading to higher and more stable crop yields (Barrios et al. 2012)
- **Resilience/adaptation through short-term risk management:** Healthy and diverse ecosystems are more resilient to natural hazards (Elmqvist et al. 2003). Trees on farms can be used as shelterbelts and windbreaks (see case study 4.2), and play an important role in protecting against landslides, floods and avalanches (Carroll et al. 2004). Trees also stabilize riverbanks and mitigate soil erosion. Agroforestry practices may increase the absorptive capacity of soil and reduce evapotranspiration from crops and bare soil but trees also use water, so the impact of changing tree cover on the water balance depends on species, density, planting arrangement, soil conditions and rainfall patterns. The canopy cover from trees can also have direct benefits: reducing soil temperature for crops planted underneath, and reducing runoff velocity and soil erosion caused by heavy rainfall (see case studies 4.3 and 4.5). Forests and trees on farms are known to have a positive effect on regulating watershed hydrology, reducing the impacts of both droughts and floods on agriculture (FAO and CIFOR 2005; Carroll et al. 2004).
- **Mitigation co-benefits:** Actions that increase tree cover (afforestation, reforestation, agroforestry) and reduce deforestation and degradation, increase carbon sequestration through increased biomass both above and below ground (see case studies 4.1, 4.2). This can be used as a strategy to offset emissions from agriculture in a landscape approach. Mitigation actions like REDD+ schemes may, however, reduce smallholders' access to forest resources negatively impacting their livelihoods, making considerations of equity important in the design of such interventions (Chomba et al. 2016).

Case studies

Case study 4.1: Farmer-Managed Natural Regeneration (FMNR) in Niger

Niger has faced challenges of crop failures, extreme climate events and food insecurity for decades. The situation became worse as a result of rapid deforestation in 1960s and 70s, which severely degraded the farmland. Faced with frequent and severe droughts, the degraded farmland was unable to provide sufficient food to feed the country's population. In order to counter this, the Government launched an initiative to plant 60 million trees, but this was not successful due to high (over 80%) mortality amongst the saplings (Pye-Smith 2013). In this context, the FMNR approach was developed, which made use of the extensive systems of living roots underneath the degraded land. Living tree stumps and root systems grow more quickly than saplings from seeds. Under the programme, farmers identified and protected tree and shrub wildlings found on farmland, and pruned away the weak stems, allowing the wildlings to grow into full sized trees rapidly. Cereal yields on FMNR fields increased by an average of 100kg/ha (Reij et al. 2009). At the programme level, FMNR contributed approximately 500,000 tonnes of cereals, providing food for 2.5 million people (Ibid.). Tree products also provided fodder for livestock, allowing farmers to build an additional income stream. Tree products could also be sold for their medicinal qualities or as construction material, generating income for farmers. The increased tree canopy from FMNR protects crops from harsh Sahelian winds. The greater yields achieved through the less degraded, better quality soils permits the surplus in good years to balance deficits in years with poorer yields. Over 5 million hectares of land have been covered with approximately 4.5 tonnes of above ground biomass per hectare, in addition to over 200 million trees (Ibid.). The programme also helped enhance social capital and reduce conflict (Sendzimir et al. 2011). FMNR is widespread across the Sahel and can often be enhanced by enrichment planting of appropriate high value and climate resilient trees.

Case study 4.2: National agroforestry policy of India

Of the 118 million farmers in India, over 80% are rainfed smallholders, who cultivate on two hectares of land or less. The dependence on seasonal rainfall as well as the small size of landholdings makes them highly vulnerable to climate change impacts. Agroforestry (incorporating trees and shrubs into farmlands and rural landscape) is a useful strategy for such farmers to increase the productivity from their land as well as to increase the resilience to climate change impacts (Chavan et al. 2015). In this context, the World Agroforestry Centre (ICRAF) and partners have promoted the approach in India. Taking cognizance of the multiple benefits of agroforestry, the Government of India launched an ambitious National Agroforestry Policy in 2014, to mainstream tree growing on farms (Government of India 2014). The policy aims to create convergence between various programmes, schemes and agencies containing agroforestry elements, in order to enhance the productivity, income and livelihoods of smallholder farmers. The policy also helps meet the increasing demand for agroforestry products such as timber, food, fuel, etc., protecting the environment and natural forests, and minimizing the risk during extreme climatic events. Since the policy was adopted in 2014, grants have been provided to six states and will cover approximately 70,000 ha in agroforestry (Dinesh et al. 2015b).

Case study 4.3: Protocol for adaptation of forest ecosystems to climate change in Chile

In Chile, La Corporación Nacional Forestal (CONAF) is working to design a protocol to evaluate vulnerability of forest ecosystems as measure of adaptation to Climate Change. The protocol will allow CONAF to monitor future adaptation performance of initiatives, projects and policies based on benchmarks of the attributes surveyed (e.g., hydrological regulation, soil protection, carbon sequestration, biodiversity conservation, etc.). The work that has been carried out so far includes a draft Protocol, which follows the traditional structure of sustainability performance standards (i.e., Principles, Criteria and Indicators). The key concept here is how the proposed intervention impacts the vulnerability of ecosystems and communities to the effects of climate change. The approach used is of minimum safety standards: critical thresholds of the variables of interest are defined, and the implementation of a policy, intervention or project can produce trade-offs -improving some variable at the expense of other-, but the increased vulnerability of the latter must never cross the level that has been pre-defined as minimum performance. All this work is included in the framework of the National Strategy of Climate Change and Vegetation Resources (ENCCRV by its initials in Spanish) led by CONAF and that includes REDD+ and UNCCD approaches.

Case study 4.4: Improving livelihoods through communal tenure rights in the Maya Biosphere Reserve, Guatemala

The Maya Biosphere reserve was created in 1990, and covers over 50% of Petén state in Guatemala and is connected to protected areas in Belize and Mexico (FAO 2013a). At 2.1 million hectares, it is one of the largest areas of tropical forests north of the Amazon (Ibid). The reserve has three zones, a core zone which consists of state-owned national parks and reserves, and where harvest activities are restricted. A second state-owned zone, where regulated harvest of zate palms, chicle gum, allspice and timber is permitted. A less regulated buffer zone, which includes privately-owned land (Ibid). Rapid land-use change has been occurring in the buffer zone, with agriculture turning into the dominant activity and reducing forest cover (Ibid). In an effort to develop a long-term model which integrates livelihoods and conservation priorities, local communities were granted concessions, which gave them management rights over the state-owned multiple-use zone (Ibid). Currently 13 concessions covering 500,000 hectares have been granted to local communities. This allows local communities to sustainably harvest wood and non-timber forest products, which helps meet livelihood needs. However, communities need to be certified in order to carry on these activities, which act as a safeguard against over exploitation. The concessions not only serve as a source of livelihood opportunities for communities, but also act as an incentive for communities to protect and sustainably manage forest resources (Ibid).

Case study 4.5: Cocoa Agroforestry Systems (CAS) in West and Central Africa

Cocoa is an important cash crop in forested landscapes of West and Central Africa. Around 70% of global production of cocoa comes from this part of the world. Although cocoa is a shade plant, the crop grows under partial and no shade. The promotion of cocoa orchards (zero shade) has contributed to deforestation in West Africa (Cote d'Ivoire and Ghana), whereas in Central Africa, CAS are considered to have contributed to forest conservation. Depending on the type of agricultural practices promoted (partial or no shade) cocoa systems can host significant biodiversity, carbon stocks and be more or less resilient to climate change. Depending on the shade intensity, CAS increases vulnerability or resilience to climate change. Maintaining shade allows the creation of microclimate that make the CAS more resilient to climate change, while excessive shade can lead to the development of Black Pod disease and very low shade can lead to the increase of mirid attacks. Optimal shade also allows diversification of products that can help to cope with climatic shocks. A recent study showed how climate change will impact the cocoa area (Läderach et al. 2013). The main recommendation is to promote shade as an option to reduce the impacts of climate change. If grown under forest shade, CAS mimics forest structure and can contribute to maintain the forest biodiversity (Sonwa et al. 2007). The relationship between shade levels and cocoa productivity are complex and depend on many factors, including fertilization and pest and disease incidence but for many smallholder farmers who do not use high inputs, integrating trees generally increases overall productivity of the system when tree products are taken into account (Vaast and Somarriba 2014). CAS are now promoted among the REDD+ activities by SNV and IITA in Cameroon and Ghana (Acheampong et al. 2014) and farmers in Cote d'Ivoire want more trees and more tree diversity in their cocoa farms to improve their food security (Dumont et al. 2014).

5. Fisheries and aquaculture

Consumption of fish has increased rapidly over the past decades, particularly in Africa, and is likely to continue into the future (World Bank 2013). With a potential global shortfall in fish supply for direct human consumption of around 62 million metric tonnes by 2030, increasing attention is focused on the capacity of the global fish food system to meet demand (Hall and Schaffer 2015). Options for increasing the production of fish include wild capture fisheries and aquaculture production. The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment report predicts that the geographic ranges of many global marine species will change, that marine biodiversity will reduce in sensitive regions, and that this will affect fisheries productivity. Small-scale fisheries in coastal and inland waterways may similarly decline in the face of a changing climate, and land-use change (Welcomme et al. 2010). In particular, it is believed that aquaculture, in view of its resilience and adaptability and diversity of species cultured, will emerge as an alternative source of livelihoods for many.

Contribution to enhancing food security, resilience and productivity in a sustainable manner:

The global fish food system can contribute to enhancing food security, resilience and productivity in a sustainable manner.

- **Productivity/food security:** Productivity can be improved through: (a) interventions that reduce waste occurring across the fish food system; (b) policies, enforcement and management actions that support fishing of wild stocks at optimum levels, and through the adoption of co-management approaches with communities reliant on coastal and inland small-scale fisheries (see case study 5.4); (c) continuing the rapid growth of aquaculture (more than 6% annually during the 2000's (World Bank 2013)) through greater efficiencies in resource use (see case study 5.3, and expansion (particularly in areas where production gaps are predicted to be largest, e.g. throughout Africa, South Asia and parts of South East Asia) (see case study 5.1)
- **Resilience/adaptation through short-term risk management:** In the case of aquaculture, interventions can focus on sustainably intensifying production through more efficient and integrated systems that capitalize on ecological processes (e.g. water filtration), improving stocks for productivity (see case study 5.1), nutritional and resilience characteristics and outcomes through breeding and more efficient feeds (see case studies 5.2)

- **Mitigation co-benefits:** Fish production through wild catch and aquaculture already offers a relatively low greenhouse gas emissions profile compared to ruminant meats (beef and lamb) (Tilman and Clarke 2014). Further mitigation opportunities for wild capture fisheries include fuel use efficiencies within the value chain (FAO 2013a) and the conservation of mangroves, woody vegetation and wetlands in coastal and riverine areas (Alongi 2012; Greiner et al. 2013). Mitigation opportunities for aquaculture are in fertilization and feed production, and carbon sequestration through interventions such as integrated multitrophic aquaculture (IMTA).

Case studies

Case study 5.1: Rice field fish rings in Bangladesh

Microhabitats (fish rings) are man-made habitats that help maintain the biodiversity of ecosystems and make sure that fish thrive in rice fields. The microhabitat is made up of 3 small cemented rings which are usually used as outdoor toilets and are easily available (costing 900 BDT or USD 12) (WorldFish 2014). The monsoon season in Bangladesh brings extremely variable weather and tidal flows. Some fish enter rice fields from nearby rivers and canals but they can be trapped when water levels recede and eventually die. The monsoon season also coincides with the spawning period for most floodplain fish. If a fish ring is established at the onset of the monsoon season, it can ensure that fish remain and survive in rice fields, providing nutritious fish for consumption. Current climate-change scenarios in the region show that southern Bangladesh will experience extremely erratic and unpredictable rainfall patterns, which could mean more floods and droughts in years to come. However, in the dry period (November-April), many farmers struggle to grow crops. Fish found in the fish rings at the end of the monsoon (October) may provide extra income opportunities and food. Smaller fingerlings can also be caught and cultured in homestead ponds in preparation for the dry period. Fish rings therefore, provide farmers with a secondary livelihood opportunity. It also means that farmers can catch nutritious fish if flooding ruins rice crops.

Case study 5.2: Community-based fisheries management building resilience in Timor Leste

While Timor Leste has a bio- and geo-diverse coastal environment, extreme bathymetry means that inshore reef areas are narrow, providing limited space for small-scale canoe fishers. On Atauro Island, the increasingly unpredictable start to the wet season has also meant that upland farmers often turn to fishing when crops fail, increasing competition for limited fishing resources. According to coastal villagers, as farmers are less skilled and equipped for fishing, they tend to use destructive fishing methods such as poisoning and breaking coral. In participatory livelihood diagnosis in Adara village, men and women fishers noted that they did not have traditional skills or equipment to expand into offshore waters to catch ocean fish. A community plan was developed where a traditional natural resource rule-making system (tara bandu) was used to limit fishing in reef areas. Rules include the declaration of a protected area (with particular benefit to a community tourism enterprise), and the banning of a number of fishing methods. Under discussion is a ban on turtle harvesting. To offset the loss of fishing area and capacity, the community requested assistance in establishing 'rumpon' (or fish aggregating devices) – bamboo rafts or similar surface float systems anchored in 200-500 m to attract oceanic fish into their fishing areas closer to shore. Participatory trials of rumpon have shown considerable promise for improving catch rates. Reducing community dependence of vulnerable coral reef systems has a clear longer term benefits due to the vulnerability of reef systems to rising water temperatures and increased storm severity.

Case study 5.3: Catchment Water Allocation Tool in Malawi

The expansion of small-scale irrigation in the Malawi portion of the drought-prone Chinyanja Triangle offers the opportunity for integrating pond aquaculture into the farming systems there. The potential for multiple water and land use systems has already been demonstrated to increase incomes amongst poor farmers in this area. However, given the increased climatic variability, highly variable distribution of water resources, and competition from multiple sources, improved water allocation and management strategies were needed. Research focused on developing an integrated aquaculture and small-scale irrigation system based on a water budgeting approach and called the Catchment Water Allocation Tool (CAWAT). It is a decision support tool able to explore options in water allocation and management across and within sub-catchments. Using CAWAT modelling on the Chingale catchment in Southern Malawi, revealed harvesting and storing surplus water during the rainy season within selected sub-catchments can complement and feasibly augment transfer volumes to neighbouring deficit sub-catchments during the dry season. Small storages development is most feasible given the distributed nature of the surface water resources. It provides flexibility to accommodate multiple uses and support integrated farming of crops, livestock and fish for increasing food security and nutrient intake, and diversifying sources of farm income. By providing supplemental water supply to crops during the dry season fish ponds enhance total farm productivity, which contributes to overall crop and fish production and value, for nominal demand imposed on the sub-catchment.

(Source: Kam et al. 2013)

Case study 5.4: Nearshore fish-aggregating devices in the Solomon Islands

Fish Aggregating Devices (FADs) or 'rafters' concentrate pelagic fish such as tuna to a single location, making them easier to catch (Albert et al. 2015). While FADs can be both industrial and artisanal in scale, nearshore FADs are artisanal in nature and are anchored to the seafloor, thereby allowing coastal communities to access them and improve fish supply at the local level (Albert et al. 2015). Under a collaboration between the Solomon Islands Ministry of Fisheries and Marine Resources (MFMR), Secretariat of the Pacific Community (SPC), University of Queensland and WorldFish, 21 nearshore FADs were deployed at various locations in the Solomon Islands as part of a pilot programme. The pilot efforts found that nearshore FADs increase coastal communities' access to fish, and can play a key role in ensuring future food security in the Solomon Islands (Albert et al. 2015). Nearshore FADs are considered to be a key adaptation technology across the Pacific (Bell et al. 2011). It is anticipated that in the event of decline in demersal and coral reef fisheries, nearshore FADs can be an effective adaptation strategy across the Pacific at least until 2035 (Bell et al. 2011). The low cost of deployment (USD 1000-2000 per device depending on the depth) is easily outweighed by the value of fish caught using these devices (Bell et al. 2011). However, climate change impacts need to be a key consideration prior to deployment and a climate risk assessment should be conducted to ensure that the exposure of FADs to extreme weather events is limited (Beverly et al. 2012). Capacity building at the community level is also crucial for effective utilization of nearshore FADs (Albert et al. 2015).

6. Water management

Agriculture is the largest user of the world's freshwater resources, consuming 70% of the available supply (UNW-DPAC 2011). As the world's population rises and consumes more food, and industries as well as urban developments expand, water scarcity is becoming an important issue that demands improved water management systems. Water management approaches, both within rainfed and irrigated agriculture, are applicable at different scales including (i) farm level, (ii) irrigation system or catchment level, and (iii) national or river basins at the planning level. Many of the options for water management can appear generic at any of these levels. However, when applied in different combinations in specific contexts, unique improved water use efficiency (WUE) systems will emerge that are suited to specific ecological systems.

Under rainfed agriculture, improved water management can be achieved through land management practices that result in the capture and retention of rainfall and through soil fertility and crop management innovations that enhance crop growth and yield and hence water use efficiency (Landolt 2011; Roose et al. 1999; Bationo et al. 2012) or through supplemental irrigation of dry-land crops (Oweis and Hachum 2012). In irrigated systems, improved water management for greater WUE is achievable at many stages in the total process of irrigation, from the source of the water, through conveyance and application systems, scheduling and the availability of water in the root zone of the plant. Nicol et al. (2015) describe many such examples drawn from East Africa. Water management within the livestock sector and fisheries sector also offers substantial potential to increase efficiency, productivity, and resilience.

Contribution to enhancing food security, resilience and productivity in a sustainable manner:

- **Productivity/food security:** In the absence of other limitations to crop growth, all innovations which target reduced crop water stress through improved capture and retention of rainfall or improved scheduling and application of irrigation water (see case studies 1.1, 6.3 and 6.4) will boost crop productivity.
- **Resilience/adaptation through short-term risk management:** Many water management innovations (e.g. supplemental irrigation and rainfall capture) are specifically designed to

reduce / eliminate the risk of crop water stress and yield reduction (see case studies 6.1, 6.2).

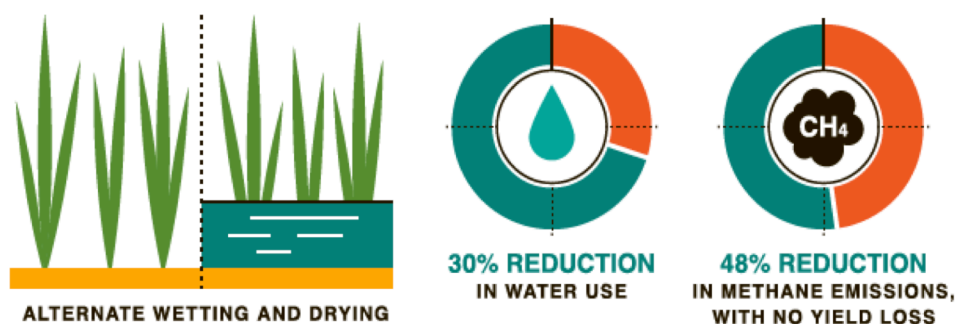
- **Resilience/adaptation through longer-term risk management:** Climate change implications for water management are context specific. However, in many regions it will likely include increased water demand and reduced water availability. Under such scenarios, especially where human populations are projected to increase substantially, all innovations which target reduced water use through greater water-use efficiency in irrigations systems are an important longer-term adaptation mechanism (see case study 6.5).
- **Mitigation co-benefits:** Flooded rice systems emit substantial amounts of methane. Alternate wetting and drying cycles in such systems not only save water, but also result in greatly reduced methane emissions (see case study 6.1). In addition, irrigation strategies that reduce the amount of water required can reduce energy consumption for pumping, thereby reducing emissions.

Case studies

Case study 6.1: Improved water management in irrigated rice through Alternate Wetting and Drying (AWD)

Flooded rice systems (irrigated, rainfed, and deepwater rice) emit significant amounts of methane (CH₄) contributing about 10–12% of emissions from the global agriculture sector (Richards and Sander 2014). AWD involves the periodic drying and re-flooding of the rice field. About two weeks after transplanting, the field is left to dry out until the water level is at 15 cm below the soil surface. Then the field is flooded again to a water depth of approximately 3–5 cm before draining again. This irrigation scheme is repeated during the crop growth cycle, except during flowering time, when the field is maintained at a flooded water depth of 3–5 cm. When used correctly, AWD does not reduce productivity compared to continuous flooding, and may in fact increase yields by promoting more effective tillering and stronger root growth of rice plants (Richards and Sander 2014). By reducing the number of irrigation events, AWD helps farmers avoid the risk of water scarcity and increases the reliability of downstream water supply, an attribute likely to become more important as populations increase and climates progressively changes. AWD has a significant mitigation potential and is assumed to reduce methane (CH₄) emissions by an average of 48% compared to continuous flooding (IPCC 2006). Combining AWD with nitrogen-use efficiency and management of rice straw can further reduce greenhouse gas emissions.

Alternate wetting and drying in rice cultivation **REDUCES WATER USE BY UP TO 30%** and **METHANE EMISSIONS BY 48%**.



Case study 6.2: Supplemental irrigation (SI) or Deficit irrigation (DI) of rainfed crops.

Supplemental (or Deficit irrigation) has been widely investigated as a valuable and sustainable production strategy for a wide range of crops in dry regions. By limiting water applications to drought-sensitive growth stages, this practice aims to maximize water productivity and to stabilize – rather than maximize – yields (Geerts and Raes 2009; FAO 2002). It involves the addition of limited amounts of irrigation water to essentially rainfed crops, in order to improve and stabilize yields during times when rainfall fails to provide sufficient moisture for normal plant growth. Unlike full irrigation, the timing and amount of SI cannot be determined in advance given the natural season-to-season and within season rainfall variability (Oweis and Hachum 2012). As well as achieving high water productivity, the productivity and stability of crop production can be greatly increased through the addition of small amounts of SI at the correct time. SI has substantial adaptation benefits through the reduction and /or the elimination of the short-term risk of yield losses, or crop failure, in rainfed crops due to water stress at critical stages, an adaptation benefit which is likely to become even more important in the future in regions where rainfed agriculture is important and where climate change projections suggest lower and more variable rainfall amounts.

Case study 6.3: Building capacity of small-scale farmers in the use of low-cost gravity-fed drip irrigation systems.

With drip irrigation, water is conveyed under pressure through a pipe system to the field where it drips slowly into the soil through ‘emitters’ which are located next to the plant, only wetting the immediate root zone (Stauffer 2012). It is thus a very water efficient irrigation system compared with others (Ibid.). Water savings result from reductions in deep percolation, in surface runoff and in direct evaporation from the soil surface. The small amount of water used also reduces weed growth and limits the leaching of plant nutrients. Large-scale commercial drip irrigation has a high ‘start-up’ cost which has led to the wide-scale promotion in Africa (Belder et al. 2007) and Asia (IWMI 2013) of simple low-cost gravity-fed drip irrigation systems more appropriate for small-scale farmers. Such systems typically use raised barrels or buckets placed between 1 and 2 meters above ground level to provide the head required to distribute the water and bamboo or PVC tubes to distribute the water (Stauffer 2012). With proper management, plant nutrients can be added to the irrigation water before conveyance, known as ‘fertigation,’ enabling very precise timing, placement and availability for plant uptake (IWMI 2013). When successfully managed, low-cost drip irrigation can provide substantial increases in crop and / or tree productivity for small-scale farmers. In addition, in regions where current or projected water scarcity is likely to impact on farmers’ welfare, resilience is enhanced through the high water-use efficiency of drip irrigation and the water saved compared with other systems.

Case study 6.4: Participatory approach for land and water development for rice-based systems in inland valleys

Inland valleys in West Africa are commonly preferred for agricultural production since soil fertility and water availability are higher compared to the surrounding uplands (Rodenburg et al. 2014). Still rice productivity is low with values reported between 1 and 2 tonnes per hectare in traditionally managed systems. Environmental risks such as droughts and floods as well as weeds pressure are reported by farmers as major constraints for intensification (Saito et al. 2013). Projects that aim an increase of productivity and income through improved land and water management are numerous, but often do not achieve long-term impact. Farmers are absent in the decision making processes and implementation and often return to old practices of before the intervention.

The Africa Rice Center has developed and validated a participatory approach – *Smart-valleys* – for land and water development in inland valleys. Small-scale farmer groups design a system of bunds, drainage canals and where possible irrigation infrastructure with guidance of trained technicians. Land clearing, construction of the system and field levelling are conducted by farmers using hand work and small tools. In Benin and Togo more than 200 sites have been developed using the *Smart-valleys* approach involving more than 3,000 farmers. Almost all sites are used for rice cultivation under rainfed growing conditions. Yields have improved to 3.5 to 4 tonnes per hectare and income has doubled. Farmers noticed less impact of drought compared to neighbouring traditionally managed sites due to increased water retention and higher investment in fertilizers and seeds.

Case study 6.5: Water harvesting

Water harvesting (WH) is based on the principle of depriving part of the land of its share of rain, which is usually small and non-productive, and adding it to the share of another part. This brings the amount of water available to the latter area closer to crop water requirements and thereby permitting economic agricultural production. WH is a low-external-input technology, particularly advantageous in arid and semi-arid areas where rainfall is low and unfavourably distributed. WH makes farming possible on part of the land, provided other production factors such as climate, soils and crops are favourable. Much of the economy of arid lands depends upon livestock, so most of the work that has been accomplished in WH has been aimed at providing water for livestock. In rainfed areas, WH systems can provide additional water to supplement rainfall to increase and stabilize production. Furthermore, it can alleviate the risk associated with the unpredictability of rainfall in these areas. Various WH systems have been piloted in different geographies, these include mechanized water harvesting systems in Syrian rangelands, small basins and semi-circular bunds in Jordan and Egypt. In Morocco, a system combining trees and shrubs with the use of contour ridges proved very successful in areas with rainfall of 100–200 mm. In the Kurdistan region of Iraq (Nangia 2015), supplemental irrigation has been shown to increase the yields.

Case study 6.6: Low-hanging vegetables in the Climate-Smart Village “Ban Phailom”, Lao PDR

Water is scarce during the dry season in Ban Phailom, one of the two CSVs in Lao PDR. Groundwater is too deep and saline. In villages such as Ban Phailom, vegetables play a key role in diets, providing nutrients that are not present in staple foods like rice. Malnutrition is a key problem in Laos, and promoting dry season irrigation of vegetable gardens is a way to alleviate this problem and improve farmers’ livelihoods. In November 2015, the National Agriculture and Forestry Research Institute (NAFRI), IWMI and local authorities set up a demonstration site for vegetable gardening around Ban Phailom’s community pond. Two electric pumps and various vegetable seeds were purchased. This vegetable garden will be maintained by 12 households nearby a pond. Each of the 12 households is expected to irrigate a vegetable plot of 10m×15m. The volume of water stored in the pond at the beginning of the dry season (about 900 m³) will be sufficient to sustain the vegetable production through the dry season. This experience exemplifies the concept of low-hanging fruit (or vegetables), and sets a prime example for other villages in the region where community ponds exist and where vegetable production remains moderate.

7. Energy management

Energy plays a crucial role during every stage of the agri-food system: from the pre-production stage of inputs (fertilizers, machinery, etc.), to the production of crops, fish, livestock and forestry products, in post-production and post-harvest operations, in food storage and processing, in food transport and distribution and in food preparation. These systems are comprised of two different types of energy, direct energy, which includes electricity, mechanical power, solid, liquid and gaseous fuels, and indirect energy, which refers to the energy required to manufacture inputs such as machinery, farm equipment, fertilizers and pesticides (FAO 2012).

Over the last decades, increased use of energy inputs has contributed significantly to feeding the world (FAO 2013a). Currently, the food sector accounts for around 30% of the world's total end-use energy consumption (ibid), and is highly dependent on fossil fuels, which are considered to be a threat to food security (ibid). In addition, it is estimated that two-fifths of the world's population still depends on unsustainably harvested wood energy for cooking and heating (Bogdanski 2012). Increased food production to meet the needs of a growing population is likely to increase energy use within the sector. This could potentially widen the gap between energy demand and access and increase the negative impact on the environment through land-use change and increasing emissions. This, together with unsustainable energy use in consumption, are likely to be significant challenges for energy management in agriculture. However, proper management of energy sources and diversification through the use of sustainable renewable energy can reduce reliance on fossil fuels, increase energy supply and access, and reduce the impact on the environment. Based on this, energy management has three main aims: increasing energy efficiency, generating a supply of renewable energy from the sector, and broadening access to modern energy services (FAO 2013a).

Contribution to enhancing food security, resilience and productivity in a sustainable manner:

Proper energy management in agriculture can enhance productivity in a sustainable manner, contribute to food security and also build resilience of smallholder farmers in the following ways.

- **Productivity/food security:** Agricultural production can be increased by: improving energy management and reducing losses; energy diversification with the use of renewable energy sources (see case study 7.1); and energy access with efficient and affordable small-scale systems (see case study 7.2). For example, improved cooking stoves can simultaneously reduce: greenhouse gas emissions, indoor air pollution, time and labour expended in collecting fuel (primarily of girls and women), and deforestation (Karlsson et al. 2015).
- **Resilience/adaptation through short-term risk management:** Reducing reliance on fossil energy and associated costs can result in increased income available to enhance resilience to climate change impacts and reduce vulnerability of farmers to shocks in energy prices (FAO 2013a). Other adaptation benefits include improved health and rural development.
- **Mitigation co-benefits:** Bioenergy, solar energy, and other renewable such as hydro and geothermal can replace fossil fuels and reduce CO₂ emissions in both the short- and long-term. Energy management can help mitigate climate change by carrying out life-cycle assessments of energy systems, identifying sustainable renewable energy resources, promoting efficient and replicable technologies, and examining policies to look for areas of improvement.

Case studies

Case study 7.1: Solar Power as a Remunerative Crop (SPaRC) in India

In India, solar energy constitutes just 1% of the energy mix, but the Government aims to increase this to around 10% by 2020 i.e. add 100,000 megawatts of solar energy generation capacity (Shah 2015). The bulk of this additional capacity will come from megawatt power plants, but if farmers were able to set up solar panels on their farmland, generate energy for on-farm needs such as irrigation, and sell the excess power back to the grid, it could rejuvenate the farm sector and augment the incomes of millions of farmers. Solar Power As a Remunerative Crop (SPaRC) project aims to address this potential, and proposes 'growing solar power' as a remunerative 'crop'. SPaRC was established by the International Water Management Institute (IWMI) as part of the CGIAR Research Program on Water, Land and Ecosystems, and is being scaled up with support from the CGIAR Research Program on Climate Change, Agriculture and Food Security. SPaRC offers farmers a guaranteed buy-back of the surplus solar power they produce, provided they are connected to the electricity grid. This guarantee allows farmers to invest in solar powered pumps, which has higher capital costs, but reduces the use of carbon intensive diesel pumps on farms. Not only that, while solar pumps are becoming very popular, these pumps add to the problem of ground water depletion since solar energy is considered to be free and farmers are not incentivized to optimize their usage. By incentivizing the sale of excess energy to the grid, SPaRC ensures that ground water resources are not excessively used. The project also provides additional income for farmers, increasing their resilience in the event of crop failures (Shah et al. 2015). SPaRC is being piloted in the state of Gujarat, India, which is abundant in sunlight, with nearly 3,000 hours of sunlight each year.

Case study 7.2: BIRU (Biogas RUmah) programme in Indonesia

In 2008, the Indonesian government proposed a study to determine the potential demand for biogas of one million small domestic biogas plants. The study, funded by the Dutch government, indicated that farmers on Java island were a suitable target to kick start the programme since most stabled their cattle, making the collection of animal waste for use as inputs relatively easy. In May 2009, the Biogas RUmah, or 'household biogas' (BIRU) programme, started. The Humanist Institute for Development Cooperation (HIVOS) was appointed by the Dutch government as programme manager, with technical assistance from the Netherlands Development Organization. EUR6 million was allocated to implement the programme, with the target of installing 10,000 bio-digesters by the end of 2013. HIVOS's latest data (mid-2013) shows that approximately 11,000 bio-digesters have been installed with further expansion of the number of participating households anticipated. The utilization of animal wastes for bioenergy lessens the dependence on fossil fuels, which can help mitigate climate change. In addition, the by-products of household biogas act as organic fertilizers, benefiting agricultural production. It also helps rural communities improve their access to energy for cooking and electricity, reduces negative health impacts, and enhances livelihoods at the same time (FAO 2014b).

8. Climate information services

Reducing vulnerability to climate risks in the present is necessary for adapting to climate change in the future, as vulnerable farmers experience climate change largely as shifts in the frequency and severity of extreme events (Cooper et al. 2008). Extreme events erode livelihoods through loss of productive assets, impaired health and destroyed infrastructure; while the resulting uncertainty is an impediment to adoption of climate resilient practices, and to the transformational change required to adapt to climate change (Hansen et al. 2014). In risk-prone environments, efforts to foster the transition toward more productive and resilient agricultural livelihoods must therefore be supported by strategies, programmes and policies that enable vulnerable populations to overcome the obstacle of climate risk (Ibid.).

With enabling institutional support and policies, value-added climate information (historical, monitored, predicted) and advisories reduce this uncertainty, and enable farmers to better manage risk, take advantage of favourable climate conditions, and adapt to change. Figure 2 shows how different forms of climate information helps farmers make decisions. Yet a substantial body of research also shows that the availability of information is not sufficient for smallholder farmers to benefit; several additional challenges must be addressed, including: *salience* (bridging the gap between the content, scale, format, lead-time that farmers need; and the information that is routinely available), *legitimacy* (giving farmers an effective voice in design and delivery of services), *access* (supporting timely access and understanding for remote rural communities), *equity* (ensuring that women, and economically and socially marginalized groups, benefit), and *integration* (connecting climate services to the broader agricultural development effort) (Hansen et al. 2011; Tall et al. 2014).







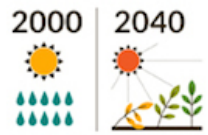


	Type of information	Vehicles for delivering information	Farmer decisions affected
WEATHER Days to weeks	 <ul style="list-style-type: none"> Observed rainfall and temperature Daily forecasts up to one week ahead of time Alerts on pests and diseases Early warning of extreme weather events 	 <ul style="list-style-type: none"> Mobile phones Radio Television 	 <ul style="list-style-type: none"> Timing of planting and harvest Timing of fertilizer, pesticide, and irrigation application Protecting lives and property from extreme events
CLIMATE VARIABILITY Months to Years	 <ul style="list-style-type: none"> Probabilities for seasonal rainfall and temperature conditions Seasonal climate variables targeted to particular agricultural risks (dry spells, rainy season start date, etc) Historical variability of climate variables 	 <ul style="list-style-type: none"> Workshops with experts Conversations with agricultural extension agents (farm educators) 	 <ul style="list-style-type: none"> Selecting crops and varieties Livestock stocking rates and feeding strategies Intensity of input use (fertilizer, pesticides) Labor or marketing contracts Intensifying and diversifying crops Diversifying sources of income
CLIMATE CHANGE Decades or longer	 <ul style="list-style-type: none"> Projections of future rainfall and temperature Historical trends in rainfall and temperature Historical changes in extreme events 	 <ul style="list-style-type: none"> Workshops with researchers, agricultural extension agents, and meteorological services. 	 <ul style="list-style-type: none"> Major capital investments (buying or expanding landholding, irrigation systems, farm equipment etc) Changing farming system or livelihood strategy Deciding whether or not to farm

Figure 2 How farmers around the world are making decisions based on weather and climate information

Contribution to enhancing food security, resilience and productivity in a sustainable manner:

The provision of weather information and associated advisories (see case study 8.4 and 8.5) contributes to enhancing food security, resilience and productivity in a sustainable manner, from several important perspectives.

- **Productivity/food security:** Since climate-related risk is often a barrier to adopting climate-resilient technologies and to making the transition toward more productive agriculture, effective climate services foster adoption of improved technology and facilitate the transition toward more climate-resilient agricultural systems (see case studies 8.2, 8.3, 8.4 and 8.5). Timely weather and climate information contributes to productivity by supporting farmers' decisions such as choice of variety and production technology, and timing of planting.
- **Resilience/adaptation through short-term risk management:** The effective use of weather information services contributes to resilience by enabling farmers to better manage the negative impacts of weather-related risks in poor seasons, while also taking greater advantage of average and better than average seasons (see case study 8.1).
- **Mitigation co-benefits:** By better matching the use of fertilizer and other production inputs with year-to-year climatic conditions, the existing evidence suggests that climate services can make a contribution to mitigation by supporting more efficient use of fertilizers (see case study 8.4).

Case studies

Case study 8.1: Scaling Up Climate Services for Agriculture in Senegal

CCAFS has worked closely with the National Meteorological Agency (ANACIM) to develop locally relevant climate information services, and enhance the capacity of partners to communicate information to farmers and help them incorporate it into their training. Work that began at a pilot scale in 2011, with farmer training and planning workshops in Kaffrine, revealed strong demand, and led to requests to scale up beyond the initial pilot. Scaling up to new regions in Senegal involved partnership with the Union of Rural Radio (URAC), a federation of NGOs (FONGS), and the Senegalese Agricultural Research Institute (ISRA). CCAFS scientists worked with ANACIM to provide seasonal and 10-day forecast information targeted for farmers. A special programme communicated this information through URAC's radio station network. Journalists from 40 radio stations were trained to understand and communicate climate information. The interactive radio programming allowed listeners to share feedback, including additional information, views, and requests of clarification. A recent evaluation estimated that 7.4 million rural people potentially have access to climate information services in Senegal as a result of this effort (CCAFS 2015a). The study showed that farmers are changing their practices in response to the information, but more work is needed to understand the extent of the changes in management, and how they impact farmers' livelihoods.

Case study 8.2: India's Integrated Agro-meteorological Advisory Service

India's Integrated Agro-meteorological Advisory Service (AAS) is one of the largest agro-meteorological information programmes in the world. India Meteorological Department (IMD) started broadcasting weather services for farmers by radio in 1945, and in 1976 began working with state governments to issue forecast-based agricultural advisories. In 1988, the National Center for Medium-Range Weather Forecasting (NCMRWF) began piloting agro-meteorological advisories based on 5-day forecasts. IMD took over leadership of the AAS in 2007, and launched a District-level Agro-meteorological Advisory Service (DAAS) in 2008 with the aim of providing relevant weather information and management advisories at a district scale across the country. The programme provides meteorological (weather forecasting), agricultural (identifying how weather forecasts affect farming), extension (two-way communication with users) services using information (media, IT and others) services. Tailoring information to farmer needs at a district scale is accomplished through multi-institutional teams, or "Agro-Meteorological Field Units" in each of 127 agro-climatic zones (Maini and Rathore 2011). The current number of farmers that benefit from the AAS is not known, but in 2011 IMD estimated the number to be 3 million and announced plans to reach at least 10 million within a year (Venkatasubramanian et al. 2014).

Case study 8.3: Farmers in Colombia combine scientific and local knowledge to manage agro-climatic risk

Since 2013 Senegal and Colombia have been exchanging knowledge and experiences on tailored climate services for smallholder farmers (Howland et al. 2014). As a result, Local Technical Agro-climatic Committees meet monthly in four regions of Colombia to produce agro-climatic forecasts and recommendations tailored to farmers' context-specific needs. By the end of 2014, CCAFS worked with the Ministry of Agriculture and Rural Development, and partners such as Corpoica (Colombian NARS), Rio Piedras Foundation and Fenalce and Fedearroz (Cereals and Rice Producers Association), to establish Committees in the Córdoba and Cauca regions in order to bring together scientific (seasonal forecasting and crop modelling outputs) and local knowledge (farmers, indigenous groups, technicians). The success of these Committees prompted establishment of two more, in Sucre and Magdalena, in 2015. This initiative now provides agro-climatic information to more than 1,500 farmers; and supports early warning systems, farm planning, scaling up crop varieties resistant to drought and flood, conservation of native varieties, use of crop calendars, water harvesting, optimization of fertilizer use and flexible planting dates. These climate-informed activities support agricultural decision-making, reduce negative impacts of climate extremes, and generate mitigation co-benefits.

Case study 8.4: Improving rice crop management through mobile phone based advisories in Vietnam

The Rice Crop Manager (RCM) is a decision-making tool developed by IRRI, which provides farmers with customised advice on crop management practices best suited to their specific rice-growing conditions and needs. The tool can be accessed through smartphones and computers with internet access. In 2014, a climate related component called Climate-Informed Rice Crop Low Emission (CIRCLE) was added to RCM and piloted with rice farmers in Vietnam. CIRCLE allows RCM to include information on climate-adjusted crop yields, climate and environmental risks and low-emission options for rice cultivation. It also presents the opportunity for farmers to access agro-meteorological advice for pest and disease prevention, historical climate data and seasonal weather forecasting (CCAFS 2015b).

Case study 8.5: Participatory Integrated Climate Services for Agriculture (PICSA) in Africa

Participatory Integrated Climate Services for Agriculture (PICSA) is an approach for equipping agricultural extension staff and other intermediaries to work with groups of farmers to understand climate information and incorporate it into their planning. It is being developed and scaled up in a partnership of CCAFS and the University of Reading. The PICSA approach involves agriculture extension staff working with groups of farmers ahead of the agricultural season to analyze historical climate information and use participatory tools to develop and choose crop, livestock and livelihood options best suited to individual farmers' circumstances. Then soon before and during the season extension staff and farmers consider the practical implications of seasonal and short-term forecasts on the plans farmers have made. PICSA was initially piloted in Zimbabwe, where more than 1200 extension officers were trained, and has since incorporated into climate service capacity development initiatives in Tanzania, Malawi, Ghana and Lesotho. Efforts are underway to expand the scope of PICSA and enhance the utility of PICSA training resources.

9. Crop and livestock weather insurance

Small-scale farmers and pastoralists in low-income countries are often trapped in poverty because they are often unable or unwilling to make investments in improved agricultural practices because of the weather-related risks associated with these investments (Barnett et al. 2008; Dercon and Christiaensen 2011). Well designed and targeted agricultural insurance can enable farmers to invest in inputs and technology that can increase their average yields and income (Carter et al. 2014), and protect them from suffering losses and slipping into debt (Janzen & Carter 2013; Bertram-Huemmer and Kraehnert 2015).

Traditional crop insurance, which relies on direct assessment of the loss or damage suffered by the farmer, is costly and time consuming particularly where there are a large number of small-scale farmers or pastoralists who can also ill afford the inevitable delay in payments. Index-based insurance largely overcomes major obstacles to insuring smallholder farmers in the developing world, including moral hazard (incentive for farmers to let their crops fail to receive a payout), adverse selection (less skilled farmers preferentially purchase insurance, increasing premiums and payouts), and the high transaction costs and logistical challenges of verifying reported losses. In index-based insurance, payouts are based on an objectively measured index that is correlated with farmers' losses, rather than actual losses. Indexes used to represent agricultural risks include rainfall, area-average yield statistics, and vegetation conditions measured by satellites. When an index exceeds a certain threshold, farmers receive a fast, efficient payout, in some cases delivered via mobile phones. Innovative use of index insurance is able to contribute to enhancing food security, resilience and productivity in a sustainable manner. There are significant challenges to implementing effective index insurance for farmers and pastoralists at scale, and scale of index insurance coverage is still quite low globally. However, several index-based agricultural insurance initiatives are finding innovative solutions to the challenges of insuring smallholder farmers, and are scaling rapidly (Greatrex et al. 2015).

Contribution to enhancing food security, resilience and productivity in a sustainable manner:

- **Productivity/food security:** There is substantial evidence that index-based agricultural insurance programmes have a positive effect on increased access to credit, and increased adoption of improved production practices and technologies that increase that increase

productivity and food security, even in a situation of adverse weather conditions (see case study 9.2 and 9.4).

- **Resilience/adaptation through short-term climate risk management:** Under conditions of high climate-related risk farmers and pastoralists inevitably experience the risk of livestock loss, crop yield reduction or crop failure. Index insurance is explicitly designed to manage such risk, and thus makes a substantive contribution to farmers' resilience (see case studies 9.1, 9.5 and 9.6). Index-based livestock insurance payouts in Kenya (see case study 9.3) and Mongolia have been shown to reduce loss of productive assets and speed recovery from major climate-related shocks.
- **Mitigation co-benefits:** This will generally depend on the degree to which insured farmers are able to invest in improved production practices that either sequester carbon or reduce GHG emissions. Index insurance programmes that allow poorer farmers to pay premiums through labour on community projects raise the possibility that insurance – with its associated benefits – could be an incentive to manage landscapes in a manner that reduce or capture greenhouse gasses (see case study 9.4).

Case studies

Case study 9.1: Index Insurance for the Agricultural Sector in Central America

As part of an engagement with CCAFS, the IRI has been building capacity and working together with the Zamorano Pan-American Agricultural School, the Honduran Ministry of Agriculture and Fisheries, and other local partners to identify and implement producer-driven, development-focused processes for generating climate risk solutions for basic grain farmers in Honduras. Many farmers have opportunities to take productive risks, such as taking a loan to buy higher quality seeds, however the risk of a failed production can prevent them from investing in new technologies. In May 2015, the IRI led experimental dry-run research activities with over 200 participants in El Paraiso, Honduras to learn about producers' preferences when faced with several climate risk management options and to test the viability of the index insurance design. For example, from this study project stakeholders were also able to identify necessary adjustments to the initial product design that will help better capture the risk of drought, as experienced during the 2015 agricultural season in Honduras. It was also found that when offered the option of insurance as an individual, farmers generally bought more insurance. The experimental activities allowed project partners not only to gauge and build demand for index insurance among basic grains producers in Honduras, but also to identify refinements in alignment with producers' preferences and experiences, so that the commercial product can reach scale responsibly and sustainably. During 2016, the feedback gathered will help project stakeholders finalize an index to be sold as a commercial pilot insurance product in the region and define scaling to other regions in Honduras and Central America, where farmers face similar needs.

Case study 9.2: The Agriculture and Climate Risk Enterprise (ACRE): Linking insurance to credit

The Agriculture and Climate Risk Enterprise (ACRE) is the largest index insurance programme in Africa in which the farmers pay a market premium. It is projected to reach 3 million farmers across 10 countries in Eastern and Southern Africa by 2018 (ACRE 2014). Indexes have been developed for maize, beans, wheat, sorghum, millet, soybeans, sunflowers, coffee, and potatoes. There are three pillars to ACRE's approach. First, ACRE offers a wide range of products based on several data sources, including 130 automatic weather stations, remote sensing technologies and government area yield statistics. Second, ACRE acts as an intermediary between insurance companies, reinsurers and distribution channels. Third, links to the mobile money market, particularly the M-PESA scheme in East Africa, allows quick enrolment and payment of claims.

ACRE supports increased productivity by bundling insurance to credit schemes that target farmers who wish to improve their crop or dairy production. As with other weather index insurance, farmers are compensated if they suffer a production loss that is represented by the index. In parts of Eastern and Southern Africa, where climate change projections suggest drier and more variable climatic conditions, this will become increasingly important. By 2013, the sum insured by ACRE reached USD 12.3 million, and the recorded insurance payout was USD 370,405. Insured farmers invested 19% more and earned 16% more than neighbouring uninsured. 97% of the farmers insured in 2013 received loans linked to the insurance (IFC 2014).

Case study 9.3: Index Based Livestock Insurance (IBLI) for nomadic pastoralists in northern Kenya and southern Ethiopia

The arid and semi-arid lands of northern Kenya and southern Ethiopia are regularly hit by regional droughts. These can have particularly severe impacts on pastoralist households who have almost non-existent communication and transport options and who depend on livestock for food, income, and as their main form of savings. These challenges led the International Livestock Research Institute to develop an innovative new insurance scheme for pastoralists, based on the relationship between livestock mortality and forage availability (Greatrex et al. 2015). Satellite-based Normalized Difference Vegetation Index (NDVI) serves as an indicator of the vegetation available in the area. In Kenya, an index based on NDVI was calibrated using data on livestock mortality, collected monthly since 2000. Due to a lack of livestock data in Borana, Ethiopia, the index triggers a payout when cumulative deviation of NDVI in a given season falls below the historic 15th percentile. The programme was launched in Marsabit in northern Kenya in January 2010, and now reaches three regions in northern Kenya (Marsabit, Isiolo and Wajir) and the Borana region of southern Ethiopia. IBLI enhances the resilience of pastoralists by reducing risk of asset loss through mortality or distress sale resulting from drought. Following a severe drought in northern Kenya in 2011, insurance payouts protected the asset base of relatively well-off households by reducing the likelihood of selling livestock; while for poorer households the payouts avoided the need to reduce food intake, thereby protecting the human capital of the next generation (Janzen and Carter 2013).

Case study 9.4: The R4 Rural Resilience Initiative

The R4 Rural Resilience Initiative (R4) is a strategic partnership established in 2011 between the UN World Food Programme and Oxfam America that aims to improve the income and food security of vulnerable rural households in the face of increasing climate risks. R4 reaches more than 32,000 farmers in Ethiopia, Senegal, Malawi, and Zambia. R4 incorporates several innovations. First, the R4 approach combines four resilience-building interventions: *Risk Reduction* through community asset building or rehabilitation projects, *Risk Transfer* through index insurance, *Risk Reserves* in the form of farmer savings, and *Prudent Risk Taking* facilitated by access to micro-credit. Second, it involves farming communities and local experts in the design of insurance contracts, including identifying risks that cannot be managed through other means, verifying historic index data against their memory of major drought events, and providing input into the timing of coverage needed and the size and frequency of payouts desired (Greatrex et al. 2015). Third, building on existing government safety net programs, the R4 initiative allows eligible farmers – the poorer farmers within the programme’s target populations – to pay fair market premiums through labour instead of cash. The labour is used for community projects such as building dikes, rehabilitating watersheds, and improved water management at the community level. In R4 work at an early stage in Zimbabwe, investing insurance-for-work in conservation farming practices have potential mitigation co-benefits, by reducing soil carbon losses and using fertilizers more efficiently. R4 in Ethiopia has been shown to improve the asset base of farmers, increase access to credit, increased investment in production inputs, and benefit women farmers at least as much as men (Madajewicz et al. 2013).

Case study 9.5: Weather-based Insurance in India

In many states in India, public and private programmes offer weather index-based insurance contracts for a variety of crops, providing cover against a wide range of adverse weather conditions such as excessive rainfall, drought and heat stresses. About 30 million farmers are subscribed under crop insurance schemes, of which nearly 38% have weather-based index insurance coverage (Aggarwal and Shirsath 2015). As part of research on how farmers can be insulated from climate risks, the CCAFS in South Asia has been working on developing improved products for weather-based agriculture insurance. CCAFS South Asia has assisted the Agriculture Insurance Company of India Limited (AIC) with technical guidance on developing and improving rainfall triggers for weather-based insurance products. By studying the correlation between historical crop yields and weather parameters, CCAFS's research team generated the 'triggers' or weather thresholds beyond which crops begin to suffer. Pay-outs are structured against these triggers to compensate farmers for their losses. Determining accurate weather triggers is therefore extremely important when designing agriculture insurance products.

In 2014, the AIC was able to incorporate the indices into their existing weather-based index insurance products. These refined insurance products were implemented in 32 unit areas in Bihar and Andhra Pradesh for paddy, maize, groundnut, cotton and redgram. According to their figures, in all, 56,623 farmers were insured against weather losses in Nawada district in Bihar and Karimnagar and Mehboobnagar in Andhra Pradesh using these refined triggers (Aggarwal 2014). Similarly, the Government of Maharashtra has used the improved insurance products developed by CCAFS in the Kharif (July-October) of 2015 to protect several thousand farmers for the vagaries of the weather (Aggarwal and Shirsath 2015). The State Government has implemented insurance products with improved rainfall trigger for soybean, rice, cotton and pearl millet farmers.

Case study 9.6: Increasing agricultural resilience and flood-proofing livelihoods in India and Bangladesh

Growing population, poor management of land and water resources, and increased exposure to extreme climatic events have left many agricultural communities vulnerable to floods and their impacts on assets and livelihoods. Index-based flood insurance (IBFI) is an innovative approach being developed in India and Bangladesh to develop practical insurance for flood-prone smallholder communities. An effort by IWMI and partners is integrating high-resolution satellite imagery and hydrological modeling with other data to quantify risk and produce indexes that could trigger speedy payouts in the event of damaging floods. The resulting technical solutions are being developed for use by public-private insurance partnerships. This initiative seeks to extend agricultural flood insurance to roughly 1 million farmers in flood-prone regions in South Asia by 2025, creating new employment opportunities within strong public-private-partnerships, and providing USD 250 million in flood protection. At the national level, the initiative seeks to incorporate the new financial risk transfer solutions into national adaptation plans, and into Disaster Management Plans in line with the Sendai Disaster Risk Reduction (DRR) framework to increase agriculture resilience and flood proofing the livelihoods.

Conclusion

There are a number of agricultural practices and technologies which enhance food security, resilience, and productivity in a sustainable manner. These include on farm practices such as those relating to management of soil, water, crops, livestock, forests and fisheries, as well as beyond farm interventions such as agricultural extension systems, meteorological services and crop and livestock insurance. In this paper, we highlight some promising practices and technologies that have been implemented, but there are many other options available and under development. The collation of these examples from across the natural resource management spectrum, allows us to tease out four general lessons important for the continued implementation of these and other climate resilient agricultural practices and technologies.

Firstly, the case studies presented are successful examples in specific agro-ecological zones and farming systems, they however do not necessarily have universal applicability. Agro-ecological zones and farming systems are extremely diverse and interventions need to be targeted to specific contexts. It is possible to match practices and technologies with agro-ecological zones, as shown in case studies 2.5 and 2.7. However, a comprehensive database matching practices and technologies with agro-ecological zones and fine scale variation in farming systems is currently lacking. New approaches to testing interventions across the fine scale variation in farming contexts by embedding planned comparisons within development initiatives have been developed and are beginning to yield data on matching options to sites and farmer circumstances (Coe et al. 2014). Different practices and technologies may be applied in tandem to realise the objectives of food security, resilience and increased productivity. Trade-offs and synergies amongst these objectives often exist and need to be taken into account, often in spatially explicit ways to inform action and policy development (Jackson et al. 2013). Therefore, agricultural practices and technologies need to be considered as part of a broader set of adaptation measures and policies for agricultural systems at a range of scales.

Secondly, the agricultural sector has rich experience in designing and implementing agricultural practices and technologies, drawing upon both scientific and indigenous knowledge (Cerdan et al. 2012). This means that designing context specific interventions is

achievable, however strong mechanisms for capacity enhancement and technology transfer are prerequisites for success. There is a pressing need to facilitate sharing of best-fit practices amongst countries and farming communities, and to enhance capacity for sound implementation that includes matching options to context and adaptation of practices to fine scale variation in local circumstances.

Thirdly, many of the case studies have been successful because of availability and access to funding. Scaling up of agricultural practices and technologies will only be feasible if suitable sources of funding are available. Funding can be in the form of international climate finance, but also national development finance and private sector investments, strategically programmed to achieve multiple objectives. Many of the practices and technologies assessed are low cost in nature, and are low hanging fruits for investment.

Finally, many of the case studies demonstrate the potential for agricultural practices and technologies to achieve co-benefits related to environment and gender. Co-benefits related to the environment include higher biodiversity, reduced soil erosion and higher water-use efficiency. Significant mitigation co-benefits can also be achieved under many conditions. In contexts where mitigation is feasible, managing for multiple outcomes makes sense, since agriculture is a major contributor to global greenhouse gas emissions. Co-benefits related to gender represent an opportunity to promote gender equality in implementation of agricultural practices and technologies. Since women and men farmers have different levels of access to assets, time, resources, and different needs and priorities, an approach which addresses women's interests, resources and demands is highly beneficial. This can be done by recognizing and supporting women as innovators, capable of developing new technologies and adapting existing ones to meet their needs (Huyer et al. 2015).

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RESEARCH PROGRAM ON
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