B5 Integrated production systems

Overview

Integrated production systems use some outputs (e.g. by-products) and services of one production component as input to another within the farm unit. These kinds of systems are the focus of this module and include: agroforestry, integrated crop-livestock, rice-fish, food-energy systems, and less widespread systems, such as aquaponics.

Chapter B5-1 presents the interrelations between integrated production and climate change. Chapter B5-2 discusses the contribution of each integrated system to sustainable production intensification, climate change adaptation and mitigation and provides guidance on adaptive management. Chapter B5-3 discusses the barriers to the adoption of climate-smart integrated production systems and the enabling environment for overcoming them.

Specialized production systems are the subject of other modules in the Sourcebook: module B1 on climate-smart crop production, module B2 on livestock production, module B3 on forestry and in module B4 on fisheries and aquaculture. In integrated systems, specific methods for diversifying production are promoted to minimize risks. Diversification may consist of mixing within crops and/or animal systems (e.g. multiple cropping over time and/or space, or managing different feed resources and animal species or breeds), or it may entail diversifying the orientation of production in ways that the different production components of the farming system co-exist independently from each other. Individual production systems, both integrated and specialized, that exchange resources and act together as a diversified system at the landscape level are addressed in module A3.

Key messages

- Successful production integration rests on a comprehensive understanding of the synergies and trade-offs between the various components of the system and the farmer’s ability to optimize synergies and reduce these trade-offs.

- Agroforestry, integrating crops with trees and/or livestock, provides diversified production that can increase farmers' resilience to market fluctuations and market failures that may result from the impacts of climate change. Farmers often respond to climate variations by progressively modifying their farming practices and integrating trees on farms. It is important to understand this autonomous adaptation process in order to replicate the most successful agroforestry systems in similar social, cultural and ecological circumstances.
- In integrated crop-livestock systems, livestock transform plant residues and by-products into edible high-quality protein and manure, which is an organic fertilizer and increases crop productivity. Worldwide, livestock integration with crops is the only large-scale example of successful long-term integrated production system at the supply-chain level.
- Integrated rice-fish systems, though highly variable in terms of their input intensity and management practices, provide additional food and income by diversifying farm activities and increasing yields of both the rice and fish crops.
- Integrated food-energy systems address both food and energy needs in a sustainable manner, while contributing to climate change adaptation and mitigation. However, there are relatively few examples of successful integrated food-energy systems. Barriers to their wider implementation revolve around the fact that integrated food-energy systems are knowledge-intensive systems and often demand more labour and investments. Often there is a lack of market opportunities for the additional products they generate compared to conventional systems. The adoption of integrated food-energy systems requires the systematic assessment of their sustainability, their replicability and potential incentives.

Integrated production systems and climate change

In integrated production systems the products, by-products or services of one component of the system serve as a resource for the other production component (horizontal integration); and scarce or degraded natural resources are efficiently allocated over space (vertical integration). In these systems, the production components of the farm are mutually supportive and mutually dependent. Since these systems are cyclical in nature (see chapter B5 - 1.1), there are a large number of interactions between their components, and resource competition is a key characteristic. An important aspect of integrated production is that the total production from the system is more important than the yield and/or efficiency of any individual production component. Box B5.1 provides an example of a highly integrated production system.

Box B5.1 Songhaï integrated farming system

Songhaï is an innovative non-governmental development organization with an integrated approach designed to tackle challenges related to agriculture, food security, demography, environment and energy.

To increase agricultural productivity, the Songhaï production model uses an integrated system that combines crop production, aquaculture and livestock production. It uses mycorrhizal associations, adapted crop varieties and animal breeds.

Little is wasted in such a system. The water that is used to clean the ponds where fish are raised is recycled and used to irrigate crops. After harvest and/or processing of food crops, vegetable, and perennial crops, the residues, which are commonly thought of as waste, are reinvested back into the production. Similarly, the by-products generated by livestock (litter and droppings) are composted for use in the place of chemical fertilizers to improve the soil on which organic food and feed crops are grown or they are used to produce bio-gas. This can be used for cooking, lighting, and heating.

Source: Songhai website

B5 - 1.1 Contribution of integrated production systems to sustainable production intensification and diversification

The growing pressures on land, water, biodiversity and ecosystems makes it increasingly important to sustainably and efficiently use natural resources to meet the growing demand for food, fiber and energy (see module A1). Following the principles of efficient resource use, as articulated in the 2011 FAO publication, *Save and Grow, A policymaker's guide to the sustainable intensification of smallholder crop production*, integrated production systems can increase the provision of goods and services from agriculture in a sustainable way and deliver synergistic benefits.

Because it is a cyclical system, integrated production systems can offer many opportunities for intensified cycling of nutrients, water and energy on farms. This can increase profitability by reducing inputs, pollution and waste. The waste products of one production component, which would otherwise be released into the environment, are used by the other production component, which in turns returns its own waste products back to the first component (Attwood *et al*., 2017). Maximum efficiency in recycling resources (e.g. waste into biogas) creates a system with minimum environment impact, and lowers operating costs (e.g. fertilizer, feed and energy). However it requires substantial knowledge and potentially upfront investments.

Because it is a mixed system, it provides more opportunities to ensure stability of production. If one enterprise or component of the integrated production system fails, another may compensate. As integrated production systems are diversified, they contribute to a varied landscape, which favours diverse habitats, trophic networks and interactions between taxa (see also module A3 on integrated landscape management). These systems also conserve more agricultural biodiversity on farms than would be the case if food demands were to be met by specialized systems. Agricultural biodiversity refers to the biological variety among the organisms used for food and agriculture as well as those that have indirect effects on agriculture, such as soil fauna, weeds, pollinators, pests and predators (see module B8). Agricultural biodiversity, in addition to providing the resources farmers need to adapt to variable conditions in marginal areas and increase productivity in more favourable settings (Fanzo *et al*., 2013), also fosters dietary diversity and the consequent health benefits (Bélanger and Johns, 2008). Agricultural biodiversity refers to the biological variety among the organisms used for food and agriculture as well as those that have indirect effects on agriculture, such as soil fauna, weeds, pollinators, pests and predators (see module B8).

B5 - 1.2 Contribution of integrated production systems to climate change adaptation

In integrated systems the adaptive capacity of farmers is influenced by the nature and extent of trade-offs between the components of the farming system, and their degree of integration (Dixon *et al*., 2014). Successful integration rests on the flexibility to reduce trade-offs and competition between the various production components of the farming system.

Integrated production, through the diversification of resources and incomes, offers farmers a greater number of risk management strategies and options to adapt to climate-induced disturbances than specialized systems. At the same time, due to the interdependencies of specific resource flows and exchanges, there will always be a resource limiting the overall performance of the household. During periods of ecological regime change (climate change is perhaps best conceived as endless regime change) relationships between system components that are highly dependent in nature are more vulnerable to disturbance. Less tightly integrated systems that allow for the substitution of component parts are less vulnerable.

Loss of assets is a possible major cause and consequence of vulnerability that can be triggered very rapidly through the whole production system. Although each farming system has different limiting resources, labour is often the only asset of resource-poor farmers (see module C7). Labour availability is one of the key determinants in farmers' decisions to allocate resources, including land, to respond to changes in climate and prices. The loss and reduction of the availability of labour hampers the adaptive management of the farm to external stressors, such as those induced by climate change. These shortages could be caused by illness or fluctuating labour demand between the various productive components of the farm (e.g. if farm operations for more than one component coincide). On the other hand, climatic stressors that cause losses in other stages of production and productive components also result in the loss of invested labour, which reduces the resilience of the farmer to adapt in a timely, efficient and sustainable manner to disturbances, including climatic stressors.

Adaptive management options appropriate for each integrated system are systematically discussed in the B5 - 2 "in practice" chapters. In considering possible options, it must be acknowledged that the overall understanding of climate change adaptation mechanisms in integrated production systems is limited. One reason for this is that most research on the impacts of climate change has been directed to specialized systems or isolated components of farming systems. The actual nature and magnitude of the impacts of climate change on integrated systems in their entirety are not well documented. In addition, most of the work on the interactions (trade-offs and/or synergies) between the various components of integrated systems has been undertaken in the context of current climatic conditions. More analysis and research at the local level will help evaluate the influence of the continuing process of climate change on the interactions between the various components of integrated production systems, especially in relation to the availability of resources at the farm level, and understand the barriers limiting the adoption of adaptation measures. The enabling environment for integrated production is addressed in chapter B5 - 3.

B5 - 1.3 Contribution of integrated production systems to climate change mitigation

Integrated systems can play a critical role in mitigating greenhouse gases from agriculture, as their emission intensities are typically lower than the sum of those from specialized systems. For example, the inclusion of timber trees in coffee production systems can change a monocrop coffee plantation from a carbon emitter to a carbon sequestrating system as shown by the assessment by Andrade *et al*. (2014) of the carbon footprint of coffee plantations in monoculture, in agroforestry systems with *Cordia alliodora*, and in agroforestry systems with plantain (*Musa* sp. var AAB) in Líbano, Colombia. In integrated crop-livestock systems, emissions from disposal of crop residues and by-products can be avoided if they are fed to animals, as can the emissions associated with the production of alternative feed or forages. Emissions from manure storage can also be reduced if the manure is properly applied to crop fields. Planting trees can also sequester carbon sequestration in biomass and the soil, which can also partially or entirely offset greenhouse gas emissions from ruminants. The rate of increase in soil carbon stocks after adoption of improved management practices follows a sigmoid curve: it attains a maximum level of sequestration rates in 5 - 20 years and continues at decreasing rates until soil organic carbon stocks reach a new equilibrium. Therefore, in the short term an exponential relationship between application and accumulation of soil organic matter can be expected, until a saturation point, which is mainly determined by soil texture and the chemical composition of soil organic matter, is reached. In the long term, the ratio of the current soil organic carbon level to the steady-state level is more important than agronomic management. This means that gains can be made in soil carbon stocks where initial soils are eroded and degraded, and there is the opportunity to increase soil carbon through planting trees (FAO, 2012a).

Table B5.1 provides an overview of the comparative climate change mitigation advantage of integrated systems with respect to the equivalent specialized production systems.

Table B5.1. Synopsis of comparative advantages of integrated systems relative to equivalent specialized systems, and their contribution with respect to climate-change mitigation.

Integrated System	Specialized system	Climate change mitigation co-benefit
Agroforestry	vs. CROP PRODUCTION SYSTEMS	- Higher carbon sequestration in biomass (and soil). - Improved soil health through higher availability of biomass for ground cover/mulching purposes. - Improved water infiltration rate and retention capacity through increased ground cover.
	vs. LIVESTOCK PRODUCTION SYSTEMS	- Longer and higher availability of fodder through integration of trees and shrubs on farm. - Improved thermal comfort, welfare, health and productivity of animals thanks to the protection from shade and wind offered by tree canopies.
Integrated crop-livestock systems	vs. CROP PRODUCTION SYSTEMS	- Use of manure for crop production and consequent avoidance of (part or all) greenhouse gas emissions from the production, transport and application of synthethic fertilizers. - Higher Soil Organic Matter through manure restitution. - Reduced land area for production of feed crops and consequent avoidance of greenhouse gas emissions related to land-use change (through more efficient use of land).
	vs. LIVESTOCK PRODUCTION SYSTEMS	- Higher-quality diets for livestock (ruminants, pigs and chicken can eat crop residues and by-products) and lower enteric methane and manure emissions. - Reduced land area for production of feed crops and consequent avoidance of greenhouse gas emissions related to land-use change (through more efficient use of land). Improved quality of grasslands through periodic renovations (through close association of grassland or rangeland systems with cropping systems). On permanent grasslands renovations can be done every 5-10 years by overseeding, clearing of possible bushes or inedible plants, and may include fertilisation and scarification.
Integrated rice-fish systems	vs. AQUACULTURE	- Lower feed requirements. - More efficient use of water.
	vs. CROP PRODUCTION SYSTEMS	- Lower requirement of synthethic fertilizers or pesticides.
Integrated food-energy systems	vs. FOOD PRODUCTION SYSTEMS	- Use of manure/slurry for crop production and consequent avoidance of (part or all) greenhouse gas emissions related to the production, transport and application of synthethic fertilizers. - Enhanced soil carbon sequestration through the use of manure/slurry. - Enhanced recycling of crop residues and by-products and avoided emissions related to their disposal and to feed production.
	vs. ENERGY PRODUCTION SYSTEMS	- Lower greenhouse gas emissions in agrifood chains through the replacement of fossil fuel with bioenergy. - Reduced risk of deforestation and forest degradation linked to unsustainable production and use of woodfuel through the production of sustainable bioenergy.

Source: Authors

Climate-smart integrated production systems

B5 - 2.1 Agroforestry

Agroforestry is the collective term for land-use systems and technologies in which woody perennials (e.g. trees, shrubs, palms or bamboos) and crops or grasses and/or animals are used deliberately on the same parcel of land in some form of spatial and temporal arrangement (Choudhury and Jansen, 1999).

Agroforestry is a dynamic, ecologically-based natural resource management system that through the integration of trees on farm and in agricultural landscapes, or through the production of agricultural products in forests, agroforestry diversifies and sustains production for increased economic, social and environmental benefits for land users at both the farm and landscape levels (Alao and Shuaibu, 2013). This makes it a valuable and cost-effective climate-smart production system.

Agroforestry systems vary considerably from landscape to landscape, country to country, and region to region, depending on human needs and capabilities and on the prevailing environmental, cultural and socio-economic conditions. Generally speaking, three main types of agroforestry systems can be identified depending on the components associated with the trees: agrosilvicultural systems, silvopastoral systems, and agrosilvopastoral systems.

Agrosilvicultural systems

Agrosilvicultural systems consist of the integration of woody periennial trees with crops to optimize the synergies between the two productive components and the overall productivity of the land. A comprehensive overview of climate-smart agrosilvicultural practices is provided in Table B5.2.

Table B5.2. Overview of climate-smart agrosilvicultural practices

Agroforestry practice	Brief description	Major groups of components *(w= woody; h=herbaceous; f=fodder for grazing; and a=animals)*
Improved fallow	Woody species planted and left to grow during the 'fallow phase'	w: fast-growing preferably leguminous h: common agricultural crops
Taungya	Combined stand of woody and agricultural species during early stages of establishment of plantations	w: usually plantation forestry spp. h: common agricultural crops
Alley cropping (hedgerow intercropping)	Woody species in hedges; agricultural species in alleys in between hedges; microzonal or strip arrangement	w: fast-growing, leguminous, that coppice vigorously h: common agricultural crops
Multilayer tree gardens	Multispecies, multilayer dense plant associations with no organized planting arrangements	w: different woody components of varying form and growth habits h: usually absent; shade tolerant ones sometimes present
Multipurpose trees on crop lands	Trees scattered haphazardly or according to some systematic patterns on bunds, terraces or plot/field boundaries	w: multipurpose trees and other fruit trees h: common agricultural crops

Agroforestry practice	Brief description	Major groups of components *(w= woody; h=herbaceous; f=fodder for grazing; and a=animals)*
Plantation crop combinations	(i) Integrated multistorey (mixed, dense) mixtures of plantation crops; (ii) Mixtures of plantation crops in alternate or other regular arrangement; (iii) Shade trees for plantation crops; shade trees scattered; (iv) Intercropping with agricultural crops	w: plantation crops like coffee, cacao, coconut, etc. and fruit trees, esp. in (i); fuelwood/fodder spp., esp in (iii) h: usually present in (iv), and to some extent in (i); shade-tolerant species
Homegardens	Intimate, multistorey combination of various trees and crops around homesteads	w: fruit trees predominate; also other woody species, vines, etc. h: shade tolerant agricultural species
Trees in soil conservation and reclamation	Trees on bunds, terraces, raisers, etc. with or without grass strips; trees for soil reclamation	w: multipurpose and/or fruit trees h: common agricultural species
Shelterbelts and windbreaks, live hedges	Trees around farmland/plots	w: combination of tall-growing spreading types h: agricultural crops of the locality
Fuelwood production	Interplanting firewood species on or around agricultural lands	w: firewood species h: agricultural crops of the locality

Source: Nair, 1991

Silvopastoral systems

Silvopastoral systems are defined as the integration of trees and shrubs in pastures with animals for economic, ecological and social sustainability. Well-managed silvopastoral systems can improve overall productivity (Bustamante, Ibrahim and Beer, 1998; Bolívar *et al*., 1999), while sequestering carbon (López *et al*., 1999; Andrade, 1999; Ibrahim *et al*., 2007), and providing potential additional economic benefit for livestock farmers (FAO, 2010a).

In tropical areas, the diversification of the production through the integration of livestock and tree species is a very common practice, especially in small farming systems. Intensive silvopastoral systems are also common. Intensive silvopastoralism is a sustainable form of agroforestry for livestock production that combines fodder shrubs planted at high densities, trees and improved pastures. For example, in the Caribbean region of Colombia trees are present on 26 to 69 percent of pastures in each farm with a density ranging from less than 3 to more than 50 trees per hectare. Bigger trees (e.g. *Tabebuia rosea* and *Albizia caribae*) provide shade for the animals and supply timber to farmers, while the medium sized trees (e.g. *Albizia saman* and *Guazuma ulmifolia*) provide fodder for the livestock (Devandra and Ibrahim, 2004). An overview of climate-smart silvopastoral practices is provided in Table B5.3.

Table B5.3. Overview of climate-smart silvopastoral practices

Agroforestry practice	Brief description	Major groups of components (w = woody; h = herbaceous; f = fodder for grazing; and a = animals)
Trees on rangeland or pastures	Trees scattered irregularly or arranged according to some systematic pattern	w: multipurpose; of fodder value f: present a: present

Agroforestry practice	Brief description	Major groups of components (w = woody; h = herbaceous; f = fodder for grazing; and a = animals)
Protein banks	Production of protein-rich tree fodder on farm/rangelands for cut-and-carry fodder production	w: leguminous fodder trees h: present f: present
Plantation crops with pastures and animals	Example: cattle under coconuts in south-east Asia and the south Pacific	w: plantation crops f: present a: present

Source: Nair, 1991.

Agrosilvopastoral systems

Agrosilvopastoral systems are those in which perennial crops are grown simultaneously with a herbaceous crop, and livestock production is integrated in combinations.

This system is particularly widespread in those parts of Africa where uncertain weather conditions put crop production a risk. Integrating livestock production with crop and trees is considered a strategy to diversify production, increase the resilience of farming systems and overcome economic risks associated with yield loss. For instance, growing food or forage crops between hedges of multipurpose trees (e.g. *Leucaena* and *Gliricidi*a) is a successful strategy to enhance soil fertility, improve crop yields, provide feed to animals, and increase the availability of fuelwood for farmers (Devandra and Ibrahim, 2004). An overview of climate-smart agrosilvopastoral practices is provided in Table B5-4.

Table B5.4. Overview of climate-smart agrosilvopastoral practices

Agroforestry practice	Brief description	Major groups of components (w = woody; h = herbaceous; f = fodder for grazing; and a = animals)
Home gardens involving animals	Intimate, multistorey combination of various trees and crops, and animals, around homesteads	w: fruit trees predominate; also other woody species a: present
Multipurpose woody hedgerows	Woody hedges for browse, mulch, green manure, soil conservation, etc.	w: fast-growing and coppicing fodder shrubs and trees h: similar to alley cropping and soil conservation
Apiculture with trees	Trees for honey production	w: honey producing (other components may be present)
Aquaforestry	Trees lining fish ponds, tree leaves being used as 'forage' for fish	w: trees and shrubs preferred by fish (other components may be present)
Multipurpose woodlots	For various purposes (wood, fodder, soil protection, soil reclamation, etc.)	w: multipurpose species; special locationspecific species (other components may be present)

Source: Nair, 1991.

Contribution to sustainable production intensification and diversification

The range of products and services that woody perennial trees integrated in farming systems can provide is quite varied. This variety makes agroforestry a valuable approach to sustainably improve production for better diets and diversified incomes.

- Trees support the growth of annual crops by recycling nutrients in the soil, which reduces the need for fertilizers and improves soil fertility and crop water productivity. In agroforestry systems, crop yields are comparable with (and more stable than) those obtained with synthetic fertilizers in specialized production systems (Hall *et al*., 2006). Greenhouse gas emissions are also lower. There are a large number of agroforestry practices that capitalize on biological nitrogen-fixation from leguminous trees to supply nitrogen and organic matter to annual and perennial crops (Sileshi *et al*., 2014). The higher stability of crop yields in agroforestry systems is due to the fact that trees protect shade from intense sunlight. In the long term, this also helps retain soil moisture and ensures a more stable microclimate. The crowns of trees can also protect crops against damage from wind and hail (Nasielski *et al*., 2015).
- The presence of trees on farms also increases the local presence of the natural predators of pests, which can reduce crop losses without increasing pesticide use.
- The microclimatic niches created by tree crowns can support the diversification of crop systems with edible and/or non-edible products, which can be used to enrich farmers' diet and increase their income if sold on the market (DeSouza *et al*., 2012).
- Trees provide benefits to grazing livestock by providing physical protection from cold wind and snow in winter and from the hot sun and drying winds in summer. This helps decrease livestock's stress and increase their health and productivity. In addition, certain species of trees can provide fodder, which can decrease feed costs for farmers.
- In crop-livestock smallholder systems, including trees on farm provides enough biomass to both meet livestock dietary needs and maintain a constant soil cover to improve crop yields in conservation agriculture systems.
- The livestock-tree-crop interactions include the benefits of animals' urine and dung on soil fertility; the benefits of the crop and trees residues on animal diets; and the benefits of the shelter and shade from trees on animal production. When livestock is allowed to utilize the vegetative ground cover under the tree canopy, it increases overall production and reduces the use of (and the costs associated with) weed control inputs, and provides additional income from meat and/or milk production.
- The presence of trees on farm makes the collection of timber and fuelwood easier for farmers; protects naturally grown trees for forest and woodland conservation; and represents an important source of additional income for producers; and contributes to the preservation of forests and wooded lands.

Contribution to climate change adaptation

Ambient carbon dioxide concentrations, temperature and precipitation affect all organisms in an agroforestry system, possibly in very different ways (Luedeling *et al*., 2014). As climate change is projected to alter all of these factors, the spatial and sequential combinations of the different components of the systems will need to be progressively adjusted.

- The presence of trees regulates soil temperature and moisture, improves water infiltration after heavy precipitation, provides a buffer against climate variability and allows for varied ecological niches that support the presence of different crops. Some trees can also moderate the effects of drought. Generally the trees' transpiration is higher than soil evaporation avoided thanks to the shading provided by the tree crown. Some trees are capable of drawing water from deep soil layers, releasing the excess water into more superficial layers of the soil profile (Burgess *et al*., 1998 and 2001) and making it available to plants with shallower rooting systems (Dawson, 1996; Horton and Hart, 1998). In efficient agroforestry systems, trees, shrubs and herbaceous crops are deliberately used in some form of spatial arrangement that takes advantage of their architecture and sunlight requirements (i.e. shade-tolerant and light-demanding) to allow the most efficient use of natural resources, such as land and sunlight. This diversification of commodities reduces the risks related to yield losses, including to those due to the impacts of climate change, and allows for adjustments to be made in response to market needs and labour supply. For example, in Chiapas, Mexico, coffee grown in agroforestry systems with heavy shade (60-80 percent) were kept 2 to 3°C cooler than those under light shading (10-30 percent) and lost 41 percent less water through soil evaporation and 32 percent less water through plant transpiration (Lin, 2007 and 2010). A study conducted in the United Republic of Tanzania has demonstrated that the gradual increase in minimum temperatures significantly reduce yields in arabica coffee. Over 49 years, minimum temperatures have increase by 0.31 °C per decade, and for every 1 °C rise in minimum temperatures annual yields have dropped by 120 to 150 kilograms per hectare (Craparo *et al*., 2015).

- Outside of fields, trees or shrubs planted to provide shelter from the wind and protect soil from erosion contribute to the resilience of the farming system to adverse climate events. For instance, windbreaks planted in citrus groves are used to reduce wind speeds by 80 to 95 percent, and reduced wind damage to crops by up to two times the distance of windbreak height (Tamang *et al*., 2010). Especially in mountainous areas, trees prevent soil erosion and landslides during the rainy season.
- Silvopastoral systems can help farmers adapt to increasingly drier conditions. A project implemented in Colombia, Costa Rica and Nicaragua between 2002 and 2007 showed that growing drought-tolerant, evergreen tree species that supply high-quality fodder is can safeguard farmers' production during the dry season. By providing shade and fodder, trees protect the cattle from the effects of heat stress and guarantee their feeding, which ensures stable milk and beef production throughout the year (Murgueitio and Ibrahim, 2008). Silvopastoral systems can also contribute to climate change mitigation by improving the digestibility of the forage, which can reduce methane emissions by 20 percent, increase carbon sequestration in both trees and soils (Ibrahim *et al*., 2007), and suppress the use of ?re for pasture management (Murgueitio and Ibrahim, 2008). Depending on the intensity and duration of the external shocks expected, farmers may have to adjust stocking rates and increase energy supplementation (Murgueitio *et al*., 2011). In integrated crop-livestock systems feed sources are more diversified than in specialized systems (Méndez *et al*., 2010), which allows for a better response to climate variations and reduces risks related to yield losses. For example, in case of extreme weather, with agroforestry practices, fodder production from trees and shrubs is more constant throughout the year, which curbs the reduction in pasture biomass, and its negative effects on the whole system. Legume forage trees, such as tree lucerne, also have the advantage of being a forage rich in protein, compared to non-leguminous grasses, and can increase soil nitrogen.
- Agroforestry can also improve environmental and socio-economic resilience in agricultural landscapes (see module A3) after a disturbance, such as an extreme weather event or market failure. Case study B5.1 provides an example of how agroforestry can increase resilience of disaster-affected populations.
- Non-harvested components play an important protective role (see Case Study B5.2 on how slash-and-mulch techniques can contribute to climate change adaptation).

Contribution to climate change mitigation

The proper design and management of agroforestry systems can make them effective carbon sinks that can significantly contribute to the global carbon budget. By providing products and services that would otherwise be sourced from forests (e.g. woodfuel, timber), agroforestry is also a valuable strategy for enhancing local livelihoods and reducing pressure on natural forests. Of all the land uses analysed in the Land-Use, Land-Use Change and Forestry report of the Intergovernmental Panel on Climate Change (IPCC), agroforestry offers the highest potential for carbon sequestration in non-Annex I countries to the United Nations Framework Convention on Climate Change (IPCC, 2000). The total carbon sequestration potential of agroforestry systems is estimated to be between

12 and 228 megagrams of carbon per hectare with a median value of 95 megagrams per hectare (Albrecht and Kandji, 2003). For smallholder agroforestry in the tropics, potential carbon sequestration rates range from 1.5 to 3.5 megagrams per hectare per year, with carbon stock tripling in a twenty-year period to 70 megagrams per hectare (Watson *et al*. 2000).

The climate change mitigation potential of agroforestry systems depends on:

- The amount of carbon that can be sequestered in standing woody biomass and in the soil.
- The amount of greenhouse gas released from farm operations both directly (e.g. from fuel combustion in mechanized systems) and indirectly (e.g. from the mineralization of soil organic carbon by soil disturbances, and the production and transport of agro-chemicals). For example, the use of leguminous trees (e.g. *Gliricidia sepum*) increases the availability of nitrogen in the soil and therefore decreases the need for synthetic fertilizers. Nitrogen fertilizers are associated with direct nitrous oxide emissions, as well as indirect emissions that result from ammonia volatilization, nitrate leaching, drainage, and runoff losses, and from carbon dioxide emissions for manufacturing and transport (see module B7 on sustainable soil management).
- The surface area under agroforestry.
  Although the carbon sequestration potential per unit of surface area is not high, the areas that are currently under agroforestry and those that are potentially suitable for agroforestry, including many degraded areas, are large. Over 43 percent of all agricultural land area globally (over 1 billion hectares) has a tree cover greater than 10 percent, with Southeast Asia, Central America and South America having over 50 percent of the agricultural area under agroforestry (Verchot *et al*., 2007; Smith and Olesen, 2010; Zomer *et al*., 2016).

Agroforestry also has important potential for indirect climate change mitigation as it can help decrease pressures on forests, which are the largest sink of terrestrial carbon. Agroforestry provides fuelwood and reduces or eliminates the need for shifting cultivation. In tropical latitudes it is estimated that every hectare of sustainably managed agroforestry system can provide goods and services potentially offsetting 5 to 20 hectares of deforestation (Dixon, 1995).

Agroforestry in practice

Not all tree, crop and livestock species positively interact when integrated in an agroforestry system. Foreseeing whether the interactions among components will remain positive or negative in an evolving climate requires an in-depth understanding of the direct and indirect impacts of climate change, the trade-offs among the components of the farming system, and the capacities to minimize possible negative interactions and maximize the benefits from their integration.

Agroforestry practices that can be implemented to optimize the contribution of integrated tree-crop-livestock systems towards sustainable, more productive and climate-smart agricultural systems require:

- Woody species will need be grown using a spatial design and following seasonal cycles that reduce competition with crops, and possibly contribute to increasing soil fertility and productivity. For example, the use of *Faidherbia albida* is particularly suited for intercropping with maize. This acacia-tree loses its leaves at the start of the rainy season when maize is sown, which reduces competition for light and nutrients between the crops and the trees. Because *Faidherbia* is a leguminous species it supports crop production by adding nutrients to the soil from the fallen leaves and reducting evapotranspiration (Garrity *et al*., 2010). In infertile soils in Western Sahel, *Acacia albida* intercropped with millet and sorghum has been shown to increase crop production up to 2.5 times over yields obtained in open fields (Winterbottom and Hazelhood, 1987).

- Tree species will need to be selected and their establishment planned out according to the long-term benefits expected from their integration into the farming system, so as to ensure that the supply of varied food and products will remain environmentally sustainable and economically viable under the impacts of climate change. For example, establishing an agroforestry system based on a set of fruit trees that is specifically designed to ensure a supply of fresh fruit throughout the year (known as the 'fruit tree portfolio' approach) substantially improves year-round nutrition and contributes to diet diversification for nutrition security and climate change adaptation. Also, using species that provide fodder for livestock can increase overall farm production.
- The diversification of production also makes the system more resilient to climate shocks, adverse weather conditions, and pest and diseases (Jarvis *et al*., 2007; Hajjar *et al*., 2008). For example, planting trees as wind breaks can help filter dust and air pollutants and reduce soil erosion. The shade they provide and protection they offer from prevailing winds can also lower heating and cooling requirements in homes. Trees can also provide habitat for wild species, which increases local biodiversity. Food-producing trees can also used as windbreaks to increase income opportunities and/or sustain biodiversity (Sekercioglu, 2012). Trees can also be planted around rice paddies to reduce winds speed and water percolation (FAO, 2014a; FAO, 2017a).
- When possible, suitable adapted native tree species should be selected to contribute to the conservation of local biodiversity and create habitats for beneficial species, such as pollinators and natural predators of pests. In some countries, however, locally bred adapted crops and varieties might not be available, as genetic selection is often neglected by plant breeders and the research community.
- Combining crop planting with intense pruning of existing trees in secondary forest represents a valuable climate-smart agriculture alternative to unsustainable slush-and-burn practices. This combination can almost double crop yield in some situations; reduce the labour required to establish and maintain plots; reduce water runoff and thus soil erosion; and increase water infiltration in soils, which increases fertility. Case Study B5.2 presents a smallholder production system, 'Quesungual Slash-and-mulch Agroforestry System', which is suitable for hillsides in drought-prone areas of the sub-humid tropics.

B5 - 2.2 Integrated crop-livestock systems

Integrated crop-livestock systems, which are found in all regions of the world, account for the main part of livestock production (FAO, 2017b). In 2010, integrated production systems generated close to 50 percent of the world's cereals and most of the staples consumed by poor people: 41 percent of maize, 86 percent of rice, 66 percent of sorghum, and 74 percent of millet production. These systems also produced the bulk of livestock products in the developing world (75 percent of the milk and 60 percent of the meat), and employed millions of people on farms, in formal and informal markets, at processing plants, and at other stages of the value chain (FAO, 2010b).

The interactions that are created by integrating crop and livestock production deliver multiple benefits. Livestock are often fed on crops; crop residues, such as weeds, straw and stover (which account for 19 percent of the total dry matter intake of livestock at global level); and by-products of crop processing activities, such as bran, molasses and pulps (which account for 5 percent of this total). Natural vegetation or sown pastures can also provide feed to livestock in integrated crop-livestock systems (FAO, 2001). In some integrated systems, livestock, along with producing milk, meat and off-spring, provide draught power for farm operations, transportation and pumping water. Their dung and urine are often applied to the fields, which cycles nutrients and organic matter through the system (Box B5.2) and helps maintain soil fertility and structure. Animal waste can also be used to produce energy, in the form of biogas or dung cakes that can replace charcoal and wood. Livestock also serve as a buffer against crop losses and in times of crisis, as they can be quickly sold for cash. Case study B5.4 provides an example of a smallholder integrated crop-livestock system in Kenya.

Box B5.2 Manure management and nutrient cycling

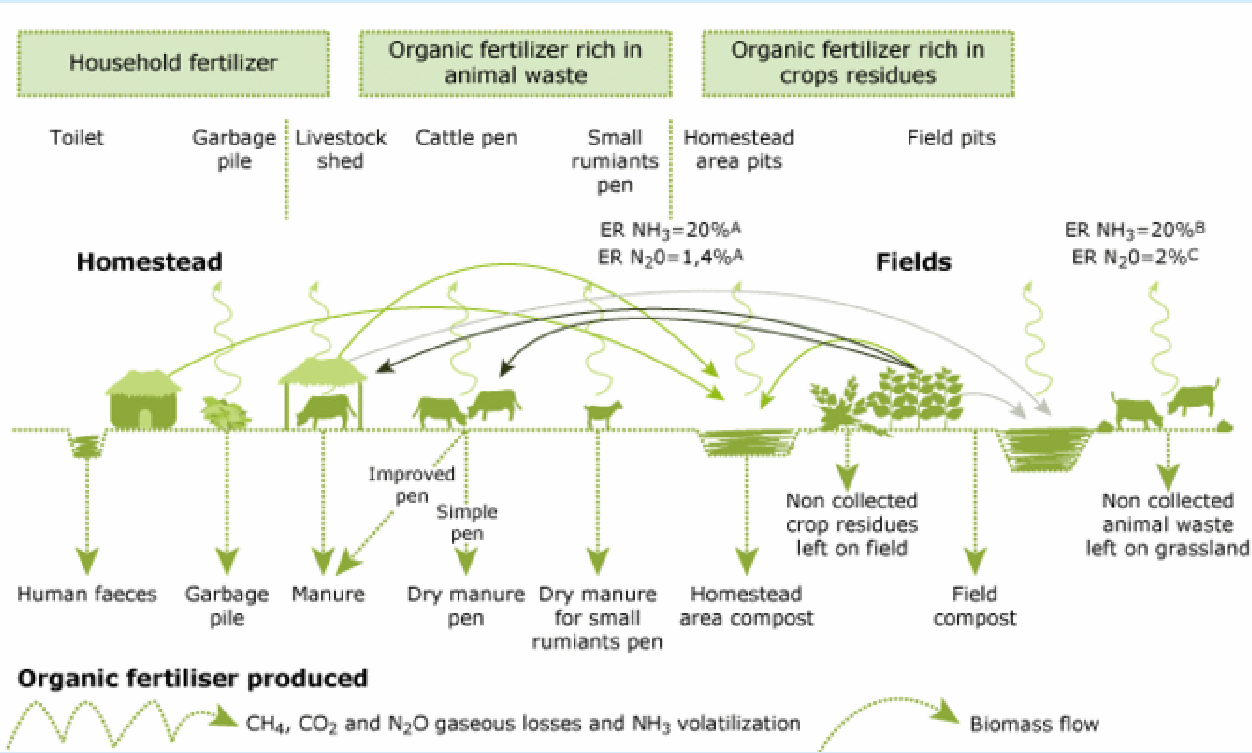
The amount and quality (as measured by the proportion of nitrogen released) of urine and dung depends on the type of animal, its size and the quality of feed, as well as storage and handling practices.

The urine and solid dung of animals fed highly digestible diets with a high protein content have much more nitrogen than excreta from diets containing greater amounts of roughage. However, much of the nitrogen in urine is lost through ammonia volatilization. Improving the recovery of nutrients and energy from animal waste can have significant impacts on the reduction of greenhouse gas emissions.

Efficiency in recycling nutrients into organic fertilizer (Figure B5.1) can be improved by increasing the collection of biomass both from crops and livestock, which can be done by keeping animals in pens for longer periods of time and collecting crop residues during harvest. Improved manure management practices (using cover pits, turning waste less often, anaerobic conditions for biogas production) can also reduce emissions. The efficiency of each practice evaluated is calculated by analysing the output/input ratio for biomass, carbon and nitrogen (Blanchard *et al.*, 2013).

Source: Authors

Figure B5.1. Classification of organic fertilizer according to local technical knowledge of farmers.



Source: Blanchard et al., 2013

Crop-livestock integrated systems can be classified in many ways, based on agro-ecological conditions, land size, type of crops and animals and their production focus, their geographical distribution, and market orientation.

Integration can happen on farms, in situations where flows of nutrients and energy occur within the limit of the farm, or between farms, in cases where manure is sold. An important type of integrated crop-livestock systems are agropastoral systems.

Agropastoral systems

Agropastoral systems are a specific case of integrated crop-livestock systems. They are found in pastoral and agro-pastoral areas and are associated with dryland or rainfed crop production. In these systems, the animals range over short distances.

In pastoral areas livestock are the primary source of subsistence. The animals, which graze on natural grasslands, are not fed cultivated fodders and grass. Pastoralists occupy arid and semi-arid regions that are not conducive to rainfed agriculture, and animals are often managed in mobile or transhumant systems (e.g. in the Sahel, Horn of Africa, central Asia and parts of South America). In some cases, as with the Fulani pastoralists in West Africa, the pastoralists manage their livestock using a transhumant system and have arrangements with crop farmers that allow the animals to graze on the stubble after harvests. The crop farmers benefit from the droppings left by the animals. In pastoral areas with higher rainfall, livestock herders also cultivate the land to produce additional food and/or income.

Contribution to sustainable production intensification and diversification

In integrated crop-livestock systems, the exchange of energy, manure and feed between the productive components can improve the efficiency in the carbon and nitrogen cycles depending on how crop residues, feed and manure are managed. This can create positive environmental, social and economic synergies.

In environments exposed to the impacts of climate change, livelihood diversification makes integrated farming systems more economically resilient as it reduces the potential of losses from specific biotic or abiotic stresses that affect genetically uniform crop monocultures or exotic livestock breeds. Keeping livestock in smaller units and potentially mixing species can avoid parasitism and emergent diseases typical of animals concentrated in big units. Where possible, including pastures in crop rotation increases seed dispersal and, in this way, the number of plant species that provide habitats for wild biodiversity, particularly pollinators. Keeping grassland short can also reduce erosion, bush fires and avalanches.

The optimization of production inputs, including labour, saves farmers’ money, recycles nutrients and organic matter, and increases farm productivity (Seo, 2010; FAO, 2011). With respect to pest management, using animals for weeding has a positive effect on the environment as it reduces herbicide use, and the droppings provide organic fertilizer. For example, goats grazing on sugar cane fields, remove weeds and dry sugar cane leaves, which reduces labour for weed removal and harvesting. Animal densities and the time the animals spend on fields always needs to be controlled to avoid overgrazing and soil compaction through trampling. With respect to nutrients management, it should be noted that organic manure from livestock may not always be available in the quantities required. This is why integrated soil fertility management, which complements organic inputs with synthetic nutrients applied in the proper dosage and at the optimal time, and good agronomic practices in general, should never be neglected when increasing inputs-use efficiency (FAO, 2015a).

Contribution to climate change mitigation

Global livestock supply chains contribute significant amounts of greenhouse gas emissions (Gerber *et al*., 2013; see module B2). However, FAO estimates that emissions of methane, nitrous oxide and nitric oxide could be reduced by 30 percent if all producers were to adopt the most efficient practices (Gerber *et al*., 2013; FAO, 2015b). An assessment of portfolios of improved practices for specific systems and regions showed that efficient production and intensification through integrated crop-livestock dairy systems could reduce enteric methane emissions by up to 17 percent in countries belonging to the Organisation for Economic Co-operation and Development (OECD); 24 percent in East Africa; and 38 percent in South Asia. These improved practices could also reduce indirect emissions by minimizing land-use change (FAO, 2012b; Mottet *et al*., 2017).

Improved crop-livestock integration and integrated manure management practices can improve the efficiency of nutrient utilization; reduce the need to import nutrients from outside the farm; and decrease emissions from crop production (Soussana *et al*., 2014). These practices include:

- Improving animal health, reproductive and herd management.
  Reducing the number of non-productive or underperforming animals can increase efficiency and reduce emissions at the herd level. For example, reducing the age at first calving from 4 to 3 years on average means that farmers would need to keep fewer non-productive heifers to maintain the stock.
- Improving animal diets by replacing roughages by more digestible feed (e.g. pasture, crop residues, fodder trees and shrubs) or by processing them (e.g. chopping or using urea treatment on crop residues). See also module B2 on livestock production.
- Where livestock's diet consists almost exclusively of the grass and shrubs grazed in grasslands or rangelands, the feed-use efficiency is in general higher in integrated crop-livestock systems relative to grazing systems in the same agroecological zone (Gerber *et al*., 2013). This means that methane emissions from enteric fermentation per unit of product are generally lower in integrated systems. Improved diets also indirectly reduces emissions as they improve soil fertility and animal health. For example, methane emissions in mixed crop-livestock dairy systems could be reduced by 30 percent in South Asia and 14 percent in East Africa through better integration of production components (Mottet *et al*., 2016).
- Improving manure management.
  Covering slurry lagoons with crop residues or applying manure in a timely manner to crop fields can directly reduce emissions of methane and nitrous oxide from manure (see Case study B5.4). Recycling energy and nutrients from manure also reduces emissions. For example, in OECD countries, improving energy use efficiency through anaerobic digestion and the use of improved practices and machinery could reduce carbon dioxide emissions from energy used on farm and in the supply chains of mixed dairy systems by up to 7 percent (Mottet *et al*., 2016).
- Improving pasture management.
  Pastures contain a high percentage of perennial grasses, which sequester and store large amounts of carbon in the soil at rates that exceed by far those of annual crops. The appropriate management of pastures (e.g. adjusting grazing pressure through appropriate planning and rotational grazing) and their restoration can further enhance their carbon storage capacity.

  Practices that reduce greenhouse gas emissions associated, *inter alia*, with the mineralization of soil organic carbon, enteric methane, nitrate leaching, waterlogging and soil erosion include: replacing exported nutrients, including through the addition of mineral fertilizer in nitrogen-deficient soils (but not in degraded soils, where the application of mineral fertilizer primes the mineralization of the scarce soil nitrogen present and it leaches off the field); practicing integrated grazing management, which involves rotating annual crops with pasture; maintaining diversity in plant species, especially legumes; avoiding the destructive intervention of soil tillage; and allowing for sufficient recovery periods between use of land for grazing or cutting. Growing legumes could sequester globally 203 teragrams of carbon dioxide equivalent per year (this includes associated nitrous oxide emissions); and improved grazing management 148 teragrams of carbon dioxide equivalent per year (Henderson *et al*., 2015). Case study B5.5 illustrates the multiple benefits of *Brachiaria* pastures.

Contribution to climate change adaptation

Climate change impacts crops, animals and grazing resources altering the interactions and resource flows between them. Integrated crop-livestock systems can contribute to climate change adaptation in different ways:

- Keeping more than one species of livestock is a risk-minimizing strategy, providing farmers with a wider range of adaptive options against climate unpredictability (Reijntjes *et al*., 1992). The advantages of mixing livestock are explained in greater detail in chapter B2 - 3.2 on risk management and system changes for climate-smart livestock production and in chapter B8 - 4.3 on the sustainable use and development of animal genetic resources for climate change adaptation.
- Changing the mix of farm activities (e.g. the proportion of crops to pasture) is a strategy for income and livelihood diversification that can be used to adapt to the short-and medium-term impacts of climate change. Modifying the mix of activities in some cases may result in radical changes in the nature and orientation of the farm system. In general terms, livestock mobility and the diversity of animal diets enable animals to take advantage of spatial and temporal variations in feed availability and can provide food and livelihoods in case of crop failure (Thomas *et al*., 2007; Thornton *et al*., 2009; FAO, 2015c; Descheemaeker *et al*., 2016). For example, to adapt to drought, farmers need solutions to overcome the reduced availability of water and feed, as well as the reduced quality of feed, as fodder tends to lose protein more quickly under drought conditions. Farmers may reassess the crops and varieties they grow, and also introduce more heat-tolerant animal breeds. During dry spells farmers may also decide to reduce their investment in crops and shift towards more livestock-oriented systems, if they can access temporally and spatially heterogeneous pastures. When climatic trends indicate unfavourable conditions for annual crops (e.g. reductions in the length of the growing period and increased rainfall variability) farmers may find growing crops too risky and, in areas where livestock mobility can compensate for low local feed availability, they may decide to convert from integrated crop-livestock systems to rangeland-based systems or focus entirely livestock production.

Integrated crop-livestock systems in practice

There are various agronomic techniques and livestock management practices that have proven to be effective in delivering benefits for food security and improved climate change adaptation and mitigation. Since integrated systems consist of different components that together act as a whole, it is a common principle that it is more important to promote the usable net primary production or the rate at which that biomass is produced (i.e. productivity) of the combination of the components rather than high yields of one component. Yield remains the most important objective, but biomass is also important for feeding livestock, sustaining and improving soil health (improved nutrient cycling, higher water infiltration and lower evaporation), and for managing weeds and pests through an integrated approach (see module B1 and B2 on agronomic management in specialized crop and livestock production systems respectively).

Two key ways to optimize primary production is to confine livestock in stalls near homesteads, which offers the opportunity to collect and distribute crop residues as needed; and adopt agronomic practices that support soil health. Generally, soil protected by a superficial layer of organic matter improves the capture and the use of rainfall. This protective layer increases water absorption and infiltration and decreases evaporation, which reduces runoff and soil erosion and builds resilience to floods or drought compared to disturbed soils left unprotected. Another important approach is to provide incentives for the functional and productive management of the whole farm. In areas where climate is expected to increasingly affect the production of sufficient above-ground biomass on farm, the mining of soil of nutrients or the excessive reliance on external inputs (e.g. herbicides and mineral fertilizers) may make some farm operations not economically viable and cause environmental damage. Sustainable farm management should be based on a number of specific activities:

- Minimizing soil disturbance continuously over time in combination with an intensive and diversified crop rotation or crop-pasture rotation to cycle nutrients, and integrated pest management.
- Seeding fields year-round, or for as much of the year as water availability will allow, in crops or desired living vegetation or intercrops that can serve as forages, instead of leaving the soil fallow.
  Adequately selected and managed cover crops can be used to help replenish soil nutrients as a substitute for some or all mineral fertilizers; prevent nutrient losses; suppress weeds; decrease soil compaction and erosion; and provide additional livestock feed. In this type of agronomic management, the main priority of cover crops is not seed production. Farmers need to become accustomed to regarding these crops as functional agronomic inputs. Cover crops may need to be terminated (e.g. grazed) before seed deposition. Also self-regenerating annual species (e.g. legumes) have significant potential to support sustainable production, whether agricultural mechanization is accessible or not. Sowing and harvesting on the whole farm in one season along with livestock keeping would result in an inefficient distribution of labour. Self-regenerating pasture-crop systems allow farmers to spread labour demand more evenly, minimize machinery capital and increase investments in supplementary feeding in case of prolonged dry spells. In these systems, low input costs reduce financial risk. On the other hand, this can also lead to lower farm output and returns.
- Keeping the soil covered as much as possible by organic residues without compromising livestock's nutritional needs.
- Good planning and the timely allocation of crop residues to minimize competition for biomass.
- Taking part of the crop residues after harvest and storing them instead of leaving them on the field, where they would otherwise degrade, increases their potential for feed.
- Adapting an integrated approach to soil fertility management.
  In most cases it is necessary to add nutrients from external sources.
- Depending on the availability of land, nutrient needs can be covered to some extent through, for example, leys or the rehabilitation of degraded pastures. This would allow for an increase in fodder production away from the fields and the transfer manure to crop fields. Also perennial crops grown outside of the fields (e.g. edible and palatable multifunctional hedgerows) offer opportunities for additional feed and biomass production for direct grazing and/or cut-and-carry.
- Where land is scarce, nutrient integration would depend on the availability of capital. The extra input would need to come from inorganic fertilizer or from concentrates, or both. Often, the price ratios of fertilizer and grains are not conducive to the utilization of fertilizers. Women producers tend to have considerably less access to these inputs than men (Farnworth et al., 2017). The cost-effective use of fertilizers and concentrates would also require the development of institutional and physical infrastructure (FAO, 2017c).

- There are three broad strategies for improving the productivity of water use (i.e. crop output per unit of water) in integrated crop-livestock systems (Descheemaeker *et al.*, 2010):
  - Agronomic management
    Practices in this area include irrigation techniques that optimize water use; the adoption of supplementary irrigation in rainfed systems and water-efficient technologies to harvest water; and the modification of cropping calendars in terms of timing or location (FAO, 2011b).
  - Feed management
    One important practice is to increase the digestibility of feed rations by improving the quality of crop residues or to supplement diets with concentrates. Feed that has low digestibility substantially limits productivity and increases methane emissions. Another feed management practice for integrated crop-livestock farming systems is reducing the number of animals in production. This lowers overall feed requirements and reduces greenhouse gas emissions (Blümmel *et al.*, 2009).

    - Animal management
      Practices include improving animal health and productivity.

- As part of a general approach to sustainable production intensification and climate change adaptation, farmers need to reassess:
    - The species, breeds and varieties they produce and introduce the right mix of crops and livestock species and breeds that are more adapted to the local impacts of climate change.
    - Animal stocking management strategies.
      For example, Himba pastoralists in Namibia reduce their number of animals before drought as a strategy to cope in semi-arid and arid regions.
    - Different crop species and varieties, and crop sequences to identify the most suitable diversified crop rotations to produce adequate biomass to satisfy competitive uses of crop residues, such as food, feed and mulch.
    - Seeding dates for different crops to identify the optimum match for each crop succession.
    - The technologies for field operations.
      Where weather unpredictability and timeliness of operations are a concern, adoption of conservation agriculture allows for flexibility of field operations and optimizes the time available during the growing season.

B5 - 2.3 Integrated rice-fish systems

The capture and culture of aquatic organisms from rice fields has a long history especially in Asia, where the availability of rice and fish has long been associated with prosperity and food security (FAO, 2012b). Rice-fish systems encompass a wide range of aquatic species, including finfish, crustaceans, mollusks, reptiles, insects, amphibians and aquatic plants, which can be raised for domestic consumption and/or sale.

Integrated rice-fish systems are practiced in various intensities of input-use ranging from the harvesting of wild fish in fields to the introduction of cultured fish species that require feed. These techniques bring triple-win benefits to farming families by increasing yields, incomes and levels of nutrition. In principle, as long as there is enough water in a rice field, it can serve as a fish production system (Halwart and Gupta, 2004).

Rice-based ecosystems provide habitats for a wide range of aquatic organisms used by local people. They also offer opportunities for the enhancement and culture of aquatic organisms. There are three different methods for integration of rice and fish farming: concurrent systems in which rice and fish are cultivated on the same plot; side-by-side systems practiced on adjacent plots where by-products of one system are used as inputs; and rotational systems. All these methods aim to increase the productivity of water, land and associated resources while contributing to increased fish production. The integration can be more or less complete depending on the general layout of the irrigated rice plots and fishponds.

There are many options for enhancing food production from fish in managed aquatic systems, which have been ingeniously realized by farmers all over the world (FAO, 2012c). Several approaches exist to modify rice fields into rice-fish cultures, ranging from trenches within the rice fields to ponds connected to the rice fields. Detailed information on various rice-fish systems, including polycultures; the best agronomic and aquaculture management practices; and potential socio-economic and environmental impacts of rice-fish cultures are provided in Halwart and Gupta (2004).

Box B5.3 addresses integrated aquaculture and hydroponics systems that are not very common or are still at a relatively pioneering stage and presents their potential for food security, climate change adaptation and mitigation.

Box B5.3 Aquaponics - Integrated aquaculture and hydroponics systems

Aquaponics is a landless system based on the symbiotic integration of two mature food production disciplines. Aquaculture (the practice of fish farming) and hydroponics (the cultivation of plants in water without soil) are combined within a closed recirculating system. In a standard recirculating aquaculture system, the organic matter ('waste') that builds up in the water needs to be filtered and removed so that the water is clean for the fish. In closed recirculating system, the nutrient?rich effluent is filtered through an inert substrate containing the rooting system of plants. Here, bacteria metabolize the fish waste, and plants assimilate the resulting nutrients. The purified water is then returned to the fish tanks.

Aquaponics aims to sustainably increase food security by increasing agricultural productivity and incomes. Producing value-added products (both fish and vegetables), aquaponics also contributes to reducing nutrient pollution from fertilizer runoff and aquaculture effluent discharge in watersheds. It has the potential to deliver higher yields of produce and protein with less labour, less land, fewer agro-chemicals and a fraction of the water usage. At the same time, aquaponics is a resilient system that can be adapted to diverse and changing conditions. Being a strictly controlled system, it combines a high level of biosecurity with a low risk of disease and external contamination, while producing high yields without the need for fertilizers and pesticides. Moreover, it is a potentially useful tool to overcome some of the challenges traditional agriculture faces with regard to water shortages, climate change and soil degradation. Aquaponics works well in places where the soil is poor and water is scarce (e.g. urban areas, arid climates and low-lying islands). Though research is scant, aquaponics produces fewer greenhouse gas emissions to generate the same amount of produce. This is due to the high efficiency of feed, the reduction of mineral fertilizer, and the lower energy expenditure, as there is no need to till, plough or work the soil. The high space efficiency means that less farm land is required to grow the same amount of food.

However, aquaponics is very knowledge- and capital-intensive as it needs high initial capital investment. Energy is also required, which, unless supplied by photovoltaic or wind sources may undermine both the profitability of the technology and the degree to which it can be considered climate smart. Commercial aquaponics is not appropriate in all locations, and many aquaponic businesses have not been successful. Large-scale systems require careful consideration before making any financial investment. It is especially important to consider the availability and affordability of production inputs (i.e. fish feed, building and plumbing supplies), the cost and reliability of electricity, and access to a significant market willing to pay premium prices for local, pesticide-free vegetables that, in some parts of the world, can be marketed as organic produce. Aquaponics combines the risks of both aquaculture and hydroponics, and thus expert assessment and consultation is essential. Aquaponics is subject to ongoing studies around the world from both research institutions and entrepreneurs who are specifically looking at ways to develop economies of scale, reduce capital expenditure, and make the systems and technology simpler and more available to small- and medium-scale farmers.

FAO is supporting aquaponic development and has published a technical manual, *Small-scale Aquaponic Food Production*, in both Arabic and English (FAO, 2014a).

Source: Authors

Contribution to sustainable production intensification and diversification

By diversifying farm activities and increasing yields of both rice and fish production, rice-fish farming provides additional food and income compared to rice monoculture. Evidence shows that although rice yields are similar, the integrated rice-fish system uses 68 percent less pesticides than rice monoculture (Xie *et al*., 2011). In rice-fish systems, the fish feed on rice pests and most broad spectrum insecticides are recognized as a direct threat to aquatic organisms and healthy fish culture. For this reason, producers using these systems are much less motivated to use pesticides. Fish farming in rice production systems and the integrated management of pests in rice production have been considered complementary activities (Halwart, 1994). Similarly, the complementary cycling of nitrogen between rice and fish can reduce the application of chemical fertilizer by 24 percent, which means that less nitrogen is released into the environment. Fertilizers and feeds used in the integrated system are more efficiently utilized and converted into food production, and nutrient discharge to the natural environment is minimized.

The potential for the sustainable intensification of integrated rice-fish production is highly dependent on the system's location and the plant and fish species cultivated. With good management and favourable local agro-ecological conditions, a one-hectare paddy field can yield from 225 to 3 000 kilograms of finfish or crustaceans a year, while sustaining rice yields of up to 7.5 to 9 tonnes (FAO, 2015d).

Rice-fish systems provide key benefits that help increase output with fewer resources.

- Rice-fish systems can increase resource efficiency because less fertilizer, land and water is required to grow the same amount of rice, while adding fish as an additional product. Fewer inputs are translated into higher production and correspondingly higher income.
- Farmers using rice-fish systems benefit from more diversified revenue streams from the same plot of land, which increases marketing opportunities, diversifies production and increases incomes.
- Revenue is higher than the added costs (fish feed and seed), so overall profits can be much higher than specialized rice production or aquaculture.
- Fish foraging activities reduce nutrient competition from weeds and damage from agricultural pests, and can be considered a type of integrated pest management. For example, a single common carp can consume in a single day up to 1 000 juvenile golden apple snails, which are an economically damaging rice pest. A major benefit is the reduced use of pesticides and associated environmental and social costs while maintaining rice yields.
- Fish manure serves as a fertilizer for the rice, and the movement of fish helps aerate and loosen the soil, which promotes fertilizer decomposition and root development.
- Compared to other potential practices for scaling up food production, costs for introducing rice-fish systems are relatively low. However, trade-offs in the use of resources between various other needs (e.g. school fees, livestock, vegetables) can occur. Priority areas for creating an enabling environment for the increased adoption of rice-fish farming (see chapter B5-3 and Halwart and Gupta, 2004), and overcoming some of the major issues and constraints include mainstreaming and popularization of rice-fish farming in a multi-stakeholder context; research and development connected to training and education; increased access to decentralized and locally available fingerling supply; and access to financing (Halwart, 2004). Care also has to be given to ensure that locations where rice-fish systems are considered have adequate rainfall, soils with good water retention and a low risk of flooding.

There are also some potential disadvantages and risks associated with integrated rice-fish production systems, including higher capital and labour costs, and the loss of stocked fish and shrimp by theft or during floods. Timely, reliable and affordable supplies of healthy and high-quality quality seed are essential. More water may be required for these systems, and stocked rice fields cannot be allowed to dry unless a refuge for the fish is provided. Fish may have to be harvested and marketed at the same time as the rice. When only small fry are stocked, the fish produced from rice paddies are often small and their economic value may be limited. On the other hand, they are more likely to be affordable to poor consumers. FAO has produced videos of examples of farmers successfully tackling these constraints:

- Indonesia Rice-Fish Farming
- China - Growing rice, raising fish for food and livelihood security

Contribution to climate change adaptation

In general, rice-fish production can help farmers to adapt to climate change through the diversification of livelihoods, which increases their resilience to external shocks.

Integrating aquaculture and rice production is a successful practice for improving water-use efficiency as a management response to increased water scarcity resulting of climate change. It reduces competition for water and other resources and provides additional income and food sources, which provides a small buffer against climate variability (Miao, 2010). Also, the shade provided by the rice plants can keep the water temperature cooler and more amenable for fish production. At the same time, it is essential to choose rice varieties and fish species that are well adapted to local conditions as well as the projected scenarios for climatic trends. For example, in Viet Nam salinity-tolerant rice varieties were included in rice-shrimp cultivation to combat the effects of sea level rise and storm surges, and farmers were supported in adapting to inundations and highly saline soils (Global Water Institute, 2016). Broadly, rice-fish farming requires about 26 percent more water than rice monoculture. In areas where water supplies are limited, the introduction of rice-fish systems is not, therefore, recommended (FAO, 2016a). Overall, the integration of rice and fish production, organized through participatory resource management planning, can help communities adapt to the effects of climate change (FAO, 2014b).

Contribution to climate change mitigation

Conversion to rice-fish systems has shown mixed results with regard to the mitigation of emissions of different greenhouse gas. Monoculture rice fields are a major source of methane and nitrous oxide emissions, owing to the heavy rates of fertilizer use and the anaerobic conditions of the soil. There are limited data on the effects of fish in rice fields.

A study by Datta *et al*. (2009) on methane and nitrous oxide emissions from an integrated rainfed rice-fish farming system of eastern India observed that adding fish to the rice fields increased methane emissions from rice-fish plots by up to 12 percent, while nitrous oxide emissions were reduced by about 10 percent. Conversely, Huang *et al*. (2001) suggests that the emission of methane from a rice field monoculture was also reduced from 4.73 to 1.71 milligrams per square metre per hour in the studied rice-fish paddy area, a decrease of about 60 percent. Interestingly, when looking at a closer spatial resolution, the fish refuge area of the plot saw a large increase in emissions to 13.10 milligrams per square metre per hour (a 175 percent increase), but, when the entire integrated system is included together (paddy and refuge) it can be tentatively concluded that the emission of methane from the rice-fish system is 34.6 percent less than that from monoculture rice fields (Lu, 2006).

It has been hypothesized that a reduced fertilizer rate and the aeration of the soil by the activity of the fish are responsible for the reduced emission, though supporting data on the precise causes are sparse. Another study in an experimental plot in China found that the conversion of rice paddies to crab-fish farming reduced methane emissions by 22 to 54 percent (Hu *et al*., 2016).

The relative costs and benefits of rice-fish culture must be weighed in regards to the increased intensification and diversification.

Integrated rice-fish systems in practice

Climate change will affect rice-fish systems in several ways. Careful management and appropriate practices can minimize these impacts.

The most significant impacts will be caused by increased water temperature, reduced water availability, waterlogging and saltwater intrusion, and extreme weather events (BFAR, 2017). In many cases, zonal or community-based adaptation strategies are essential for effective long-term management (Ahmed, 2014).

- The temperature of the water is a significant parameter influencing fish growth and health. Higher water temperatures can have devastating effects on fish health, with higher incidences of stress and disease and possible mass mortality events. Moreover, high temperatures can decrease the amount of dissolved oxygen in the water. High temperatures can also decrease the feed conversion efficiency of the fish, so that more feed is required to produce the same amount of fish. To combat the effects of temperature increase, farmers can use fish refuges and ditches dug around the perimeter of the pond. These refuges have deeper, cooler water and give the fish a place to shelter during the hottest parts of the day. Other adaption options are selecting species and varieties that are more tolerant to the warmer water; or stocking larger fish fingerlings, so that fish are more resilient and the culture period is shorter, which can make it easier to time the fish harvest before the weather becomes too hot.
- Extreme weather events can cause flooding and increased turbidity in the culture water. Flood waters can bring in pathogens, toxins and predators that attack the fish stock. At the same time, overflow of the rice field can allow the fish stocks to escape. Also, heavy rainfall can damage dikes causing erosion. High levels of sediments in the water can injure the fish by clogging gills, decrease visibility and hamper the ability of the fish to feed. To combat these impacts, the pond dikes can be raised to prevent flooding and overflow, and can be reinforced against erosion by using trees, shrubs or grasses on the dikes. Importantly, integrating agroforestry or horticulture practices on the dikes can also provide a more diversified and efficient system, as the crops can be fertilized with the remaining sediments at the end of the culture period. At the same time, some areas will also face decreased water availability. Rice-fish integrated production systems make efficient use of water, but through increased control of the irrigation and canal system the water management can be monitored and adjusted to deal with both floods and shortages.
- Saltwater intrusion and waterlogging from rising sea levels can affect the rice-fish ecosystem by poisoning the rice with salt, affecting the microbial community and making it impossible to drain the fields. Salt-tolerant varieties of both rice and fish should be chosen, and possibly the production calendar should be adjusted.

B5 - 2.4 Integrated food-energy systems

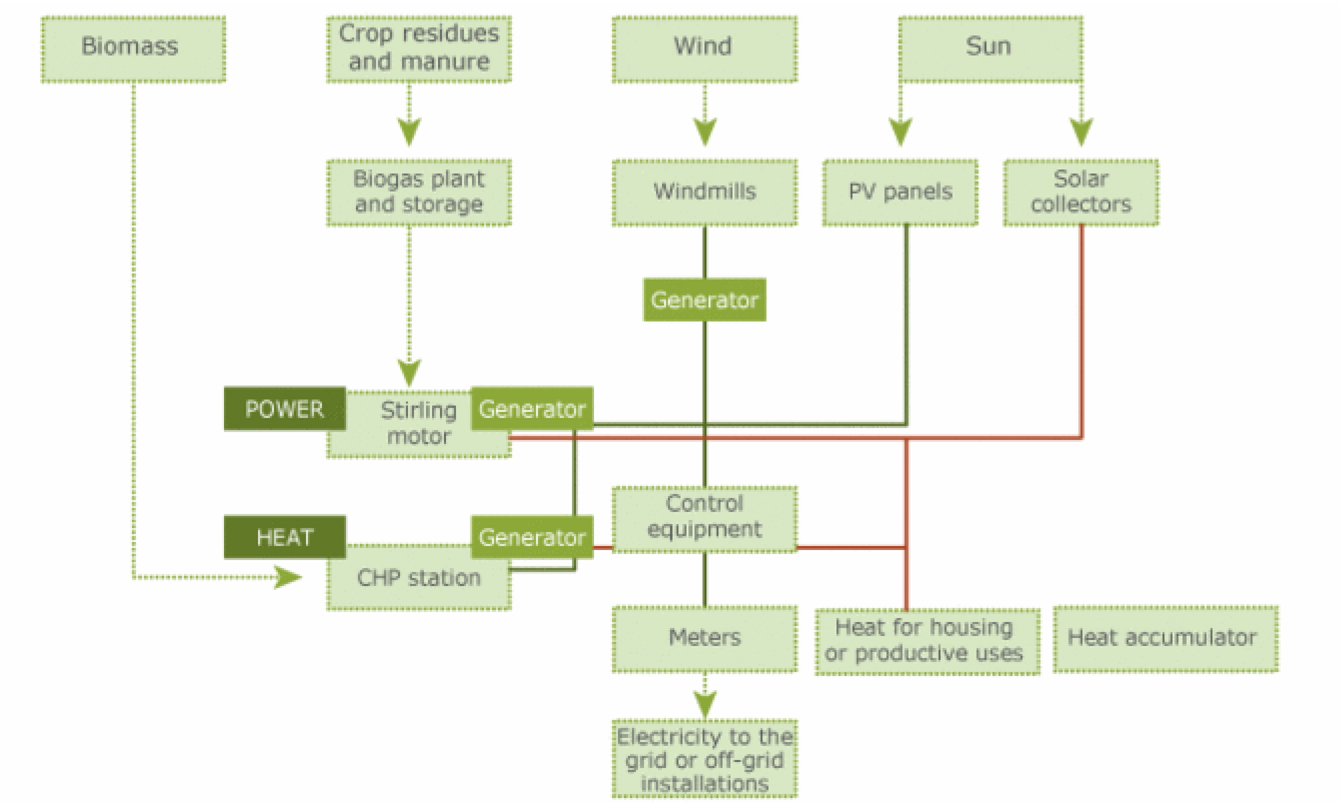
Integrated food-energy systems combine the production of energy and food.

The integration of energy and food production can be achieved in two ways:

- By optimizing land use through cropping systems that integrate energy and food crops (e.g agroforestry systems where trees are used for wood energy).
  One example is found in Malawi where pigeon peas (*Cajanus cajan*), which are grown for food, fodder and woodfuel, are cultivated in combination with maize (Bogdanski and Roth, 2012).
- By optimizing the use of biomass by using by-products or residues of food or energy production as an input to in the production process for other outputs, (see Figure B5.2).

In Asia, integrated food-energy systems that produce biogas production are relatively common. Biodigesters produce renewable energy (biogas) and a by-product that can be used as organic fertilizer (slurry). Since the slurry is liquid, transport to the fields is often complicated, and its application is typically limited to fields near the digester. Large installations (mainly in industrialized countries) separate the slurry into a liquid and a solid fraction, which can be applied on fields farther from the digester.

Figure B5.2. An integrated approach to renewable energy for farming systems



Source: Alessandro Flammini

Integrated food-energy systems can be combined in complex systems, such as the Tosoly farm in Colombia presented in Case Study B5.6.

Contribution to sustainable production intensification and diversification

Integrated food-energy systems can contribute to sustainable production intensification in several ways.

- Primarily by reducing the need for mineral fertilizers, which are costly, not always available, and whose production is associated with the use of fossil fuels and the emission of greenhouse gases. Fertilizers are partially or totally replaced by the slurry from biogas production and/or by nitrogen-fixing trees, which are also a source of fuelwood. One advantage of replacing mineral with organic fertilizer lies in savings of fossil fuels that are needed to mine and manufacture mineral fertilizers. Organic fertilizer produced on the farm is also more accessible to women producers than commercial mineral fertilizers. (Farnworth *et al.*, 2017). Nutrients cycling is addressed in detail in module B7 on sustainable soil and land management for climate-smart agriculture. The role of gender in climate-smart agriculture is discussed in module C7. Case study

B5.3 provides examples of the use of trees as fertilizers.
- Biogas produced from integrated food-energy systems can help farmers economize on fuel for cooking or for electricity (if available) for their lighting needs, and on mineral fertilizers if they use the slurry (e.g. in Viet Nam) (Teune, 2007). Farmers can also generate additional income from the sale of the energy produced on farm, for example within the ITAIPU biogas programme in Brazil.

Contribution to climate change adaptation

Integrated food-energy systems contribute to climate change adaptation in two ways:

- Increasing self-sufficiency in local modern energy services and the provision of fertilizers (e.g. the slurry from biogas production) improves farmers' resilience in that they do not have to depend on road conditions to have access to these inputs.
- Selling the excess energy produced on farm to the grid diversifies producers' income, which increases their capacity to cope with the impacts of climate change.

Contribution to climate change mitigation

Integrated food-energy systems can contribute to climate change mitigation in different ways.

- The production of sustainable bioenergy and, in some cases, the higher land and water productivity of integrated food-energy systems, can contribute to a reduction of the risk of emissions related to deforestation and forest degradation caused by the unsustainable production and use of woodfuel. An example is the synergy between pigeon peas and maize in mixed cropping systems in Malawi and Mozambique. Both crops protect each other from pests, and the pigeon pea improves soil fertility and water retention. Where integrated food-energy systems lead to increased land and water productivity, they reduce the need to expand agricultural land for food and energy production Bogdanski *et al.*, 2010; see also FAO, 2017b).
- The substitution of fossil fuel-based mineral fertilizers with the slurry can help lower the emissions associated with the production, transport and use of mineral fertilizers.
- The use of slurry as an organic fertilizer can also contribute to the sequestration of soil organic carbon.
- When mineral fertilizers are used, nitrates, which are negatively charged, can be lost by leaching in moist conditions and by denitrification, which produces the greenhouse gases nitrous oxide and nitric oxide, in anaerobic and dry conditions. Substituting mineral fertilizers with decomposing organic residues, releases nutrients slowly into the soil in a way that allows the plants to make use of them gradually, can reduce pollution and greenhouse gas emissions.

Integrated food-energy systems in practice

There are two types of integrated food-energy systems: those that optimize land use and those that optimize biomass use (chapter B5 - 2.4). Examples of adaptive management for each type are presented in Table B5.5. The Tosoly farm, which is an example of adapted integrated food-energy system that combines both land and biomass optimization, is described in Case Study B5.6.

Table B5.5. Examples of climate-smart integrated food-energy systems

Integrated food-energy system	Brief description	Notes
Integrated food-energy systems that optimize land use		
Intercropping pigeon peas with maize on the same field - Mozambique	Integration of drought-resistant pigeon peas in maize fields increases resilience and profitability in smallholder systems as it allows the simultaneous production of food (pods), fodder (leaves), fuel (wood) and fertilizer (nitrogen fixation by pigean pea).	Intercropping pigeon peas with maize is a low-risk, low-input integrated food-energy systems with a self-reinforcing synergistic positive impact on availability, accessibility and security of food, fodder, fuel and green fertilizer. It is climate-smart in that (i) it reduces the need to collect dead or live wood for cooking and (ii) as a perennial crop, the pigeon pea stores carbon. This integrated food-energy system has a high potential for country-wide replication among small-scale farmers. Agreements between supplier and buyer countries guarantee a secure market for pigeon peas. One example of these agreements is the one between Mozambique (supplier) and India (buyer). This integrated system reduces the need to cut fuelwood and the related risk of forest degradation.
Jatropha boundary planting around smallholder food crop fields - Mozambique	Integration of non-edible energy crop (Jatropha curcas) as live fencing protects food crops from free roaming/wild animals and increases food security in smallholder farming systems. For example, this sytem was introduced in Mozamique by the NGO ADPP. Furthermore, pressing of oil from Jatropha fruits generates liquid fuel that can be used to propel local engines in locations not reached by the national grid. For example, jatropha provided energy to the teacher training centre in Bilibiza before the grid reached the town. Furthermore, pure jatropha oil or blended petroleum with jatropha oil provides off-grid power to remote areas. For example, a Mozambiquan companyproduces JATfuel to power maize mills for higher quality maize flour production in remote areas. Finally, detoxified seedcake from the processing of jatropha oil can be used as bio-fertiliser.	The commercial potential lies in (i) the possibility to sell jatropha seeds to a biodiesel plant and/or (ii) the production of soap from jatropha oil after removal of phorbol esters, which are promutagenic and toxic compounds, from the seedcake through a combination of solar irradiation and ozonation. Soap can be used for own consumption, has a guaranteed local market and high-quality soap has a niche market for export. This integrated system is climate-smart because the production and uses of biodiesel reduces the need for fossil fuel.
Integrated food-energy systems that optimize biomass use		

Integrated food-energy system	Brief description	Notes
Palm oil processing utilizing oil palm residues for thermal energy generation - Ghana	Use of by-products from crude palm oil processing (fibre and palm kernel shells) as fuel generates thermal energy for those processing activities where heat is required: - Industrial processors use fibre and/or palm kernel shells to fuel a furnace which produces steam (i) to sterilize fresh fruit bunches and (ii) to power turbines that generate the electricity needed in the factory for the offices and to run the machinery for the processing activities. - Artisanal processors utilize only fibre or fibre-kernel pastes as fuel for all boiling activities during processing.	The prospects for this integrated food-energy systems are as follows: - In semi- intensive systems: palm kernel shells can be used in a top-lit up-draft microgasifier stove for home cooking. - In artisanal systems, empty palm bunches can be used for boiling activities in the oil processing chain. The stove tested by the NGO ASA Initiative produces a charred residue (by-product from the burning the oil palm biomass) that can be used as bio-fertilizer. - The residues from palm oil production can be used to produce energy and reduce the use of fossil energy.
An integrated pig-biogas-vegetable greenhouse system - China	Integration of a pigsty and a pig dung-operated biogas digester provides illumination, heat and organic manure (i.e. fermented waste) to a vegetable greenhouse.	- The use of pig manure to produce biogas reduces methane emission from manure and supports vegetable production.

Source: Authors

Creating an enabling environment and removing barriers to adoption of climate-smart integrated production systems

B5 - 3.1 Barriers to adoption

A combination of factors can create barriers to the implementation and wider uptake of integrated production systems.

- Technical knowledge
  Integrated production systems are very knowledge-intensive. Information and access to technical support (e.g. extension services) is essential, but not always available. Because of the limited experience and capacities among some national extension services, the potential for local farmers to implement agroforestry is far from being fully exploited.
- Poor access to markets, insurance and credit
  Limited access to markets and sources of financing undermines the economic viability of integrated production systems for small-scale producers. For example, in countries where aquaculture is not an important industry, fingerlings, which are a vital input in rice-fish farming, are scarce and expensive. Small-scale dairy producers also have major problems with maintaining milk hygiene during the cooling and collection process when trying to gain access to markets (see Case Study B2.4 on solar milk cooling).
- Implementation costs
  Incentives favouring specialized production systems, such as subsidized inputs, and the absence of financial incentives for integrated systems make the upfront costs of switching to an integrated production systems

less attractive for producers. For example, in agroforestry systems, the break-even point on initial investment may occur only after a number of years. Farmers may be discouraged by the initial net losses they may sustain before benefitting from their investment. Similarly, the purchase of new equipment for converting agricultural by-products to energy is prohibitive for many smallholders. This, together with the higher workload associated with integrated food-energy systems, limits the adoption of these systems by small-scale farmers. An important exception in this regard, are some national biogas programmes in Asia.

- Lack of coordination among sectors and producers
  In many countries, integrated systems fall between the agriculture, environment and forestry departments, with no institution taking a lead role in the advancement of the system or its integration in national and local policies. The only country that has adopted a national agroforestry policy is India (Government of India, 2014).
- Insecure tenure
  In the case of agroforestry or integrated crop-livestock systems, without formal land title and ownership of trees, smallholder farmers will not investments in trees or land, which pay off only in the long term.

B5 - 3.2 Creating an enabling environment for adoption

Instead of considering the barriers presented in chapter B5-4.1 as deterrents to the adoption of integrated production systems, they should be regarded as opportunities that can be exploited to help farmers, especially smallholders, use integrated systems to adapt to climate change and mitigate it. This chapter explains the ways in which an enabling environment can be fostered.

- Supporting research on impact modelling at relevant scales, particularly at the local and household levels, to allow for making appropriate decisions and ensuring an adequate understanding of the interactions between productive components

  Robust biophysical models that represent the interactions between the different productive components of integrated systems are needed to evaluate and target appropriate technological options that help farmers raise incomes, enhance food security and sustain their natural resource base; and inform policy debates on the needed policies in relation to the climate change adaptation options and mitigation potential in the different ecoregions and for each integrated production system (Thornton and Herrero, 2015).

  Adapting different technologies and management practices for each integrated system and its local biophysical and socio-economic context. Evaluating and targeting options that have the potential to meet different stakeholders' objectives is important to expand the evidence base, determine which practices and extension methods are suitable in each context, and identify the synergies and trade-offs between the various components of integrated systems. Capacity building with increased knowledge and improved management techniques will be critically important. Particular focus will need to be placed on all farming household members, men, women and children, as well as extension agents. Difficulties in accessing specialized sustainable small equipment mechanization tend to make these such systems labour-intensive. With appropriate capacity development strategies this barrier to the adoption of integrated systems can be transformed in an opportunity to create jobs attractive for young people (see also module C7 on decent rural employment). The Farmer or Pastoralist Field Schools, for example, follow a discovery-based learning approach where small groups of farmers or pastoralists meet regularly. The meetings, which are facilitated by a specially trained technician, provide a setting where producers can explore new methods, through simple experimentation and group discussion and analysis, over the course of a growing season. This approach allows farmers to modify and adapt newly introduced methods to local contexts and knowledge, which increased the likelihood of their uptake.

  The FAO document, *Evidence-based assessment of the sustainability and replicability of integrated food-energy systems. A guidance document*, presents an analytical framework for assessing integrated food-energy systems (FAO, 2014c).

The methods and approaches to support farmers with knowledge of climate-smart agriculture practices and specialized extension for different agricultural sectors are addressed in module C2.

- Strengthening institutions

Local institutions can have an important role in changing the way farmers manage their production systems and helping them cope with climate change (McCarthy *et al*., 2011; Hansen *et al*., 2011).

Beyond short-term training for agricultural extension officers, agricultural schools and universities should mainstream integrated agricultural production into their curricula. For example, efforts to promote a wider adoption of rice-fish farming should aim at developing suitable curricula for fish as pest control agents. As governments often promote integrated pest management, the culture of fish in rice fields should be promoted as part of these methods (Kamp and Gregory, 1994; Kenmore and Halwart, 1998). In the case of simple integrated food-energy systems (e.g household biogas), support services are sometimes provided through the companies or organizations that collect the feedstock (e.g. manure) from farmers and supply the biogas and biofertilizer. Tenant farming and sharecropping, whereby smallholders farm the land belonging to companies, is another type of agribusiness-smallholder partnership, which often includes provision of technical services and inputs to the farmer.

Enhanced capacity development for country-driven climate-smart agriculture is comprehensively dealt with in module C1. Generating and disseminating appropriate information (e.g. weather forecasts, extension materials and new information technologies) can build the evidence base for determining what works in which circumstances and why, and increase the ability of farmers to reduce their exposure to weather events or climate risks. Appropriate measures for evaluating the success of adaptation interventions are very much needed to guide adaptation planning and investment, and identify when the adaptation of farming system is not sufficient and more transformational approaches are needed. Vulnerability and adaptive capacity cannot be directly observed, hence the dependence on sets of indicators. Module C9 presents the criteria to define appropriate metrics for increasing programming effectiveness and outcome tracking of climate-smart agriculture interventions.

- Coordinated and informed policies are important mechanisms to mainstream the management of natural resources (communal or private) into climate adaptation and mitigation planning.

A secure framework for tenure rights (see module B7) is essential to promote long-term investments, in integrated productions systems, such as agroforestry. As discussed in module C6, translating policies into tangible benefits on the ground requires that access to resources be equally available to both men and women producers, and governments will need to pay attention to gender issues when promoting integrated production systems (Carney and Elias, 2016; Haverhals *et al*., 2016; Catacutan and Naz, 2015; Wafula *et al*., 2016). Examples of gender implications in the introduction of climate-smart agriculture approaches are provided in Box C6.2.

Ensuring secure and long-term land and tree tenure rights to farmers who invest in their farm (e.g. plant trees, raise dikes and excavate ponds or trench refuges for fish, purchase the equipment for energy conversion or for no-till) is essential to promote investments in climate-smart agriculture; enable smallholders accessing to subsidies, loans and micro credit; and provide incentives to its adoption through payments for environmental services (FAO, 2012d). Selling carbon credits could achieve multiple benefits: mitigating the impact of climate change; providing another source of income for farmers; and offering an incentive for the further diversification agricultural activities. Policy analysis has shown that, for example, in the highlands of Northern Peru at prices of USD 100 per megagram of carbon sequestration in agroforestry systems would have the potential to raise per capita incomes of farmers by up to 15 percent (Antle *et al*., 2007).

Positive incentives are particularly important to support systems where the returns on investment may take a number of years to materialize, as with agroforestry and rice-fish systems, or food-energy systems that require special equipment. Incentives may be provided in the form of grants, tax exemptions, cost-sharing programmes, microcredit or delivery in kind. In many countries, there are formal mechanisms to provide credit to small-scale farmers and entrepreneurs in rural areas. Farmer cooperatives can help increase access to micro-credit for small-scale producers where rural banks are reluctant to do so. Additionally, simple integrated food-energy systems, which have a high potential to reduce greenhouse gas emissions and are relatively easy to monitor, such as those using biogas, are good candidates for carbon finance. Financing may be required for rice-fish systems as well, since the raising of dikes and excavation of ponds or trench refuges may create extra expenses beyond what is normally required for rice farming. Often the amounts involved (USD 500 or less) are small enough to fall within the scope of micro-credit. Even if hundreds of farmers require financing in each locality, the total investment would certainly be within the capability of rural banking facilities. The more critical issue is often to get the financing body to accept rice-fish production systems as a viable venture, as aquaculture had difficulties in being seen as a low risk farming option.

Other policies specifically relevant to the energy component of integrated food-energy systems are those promoting renewable energy markets through quotas and mandates and/or feed-in tariffs.

Policy makers need to carefully consider the potential trade-offs between positive incentives aimed at one agricultural sector and the objectives for other sectors. For example, subsidies for fertilizers may create a disincentive for farmers to use manure on crops and improve their management of crop residues. Minimizing these trade-offs will require increased coordination between public institutions. Policy frameworks for climate-smart agriculture are addressed in module C3. Insurance schemes and social protection mechanisms are addressed in module C7.

Conclusions

The high efficiency of integrated agriculture production systems delivers socio-economic and ecological benefits that benefit farmers as well the whole society.

There are many ways in which integrated agriculture production systems can help producers to adapt to climate change and provide important mitigation co?benefits. However, several factors hamper the effective adaptation of integrated production systems, such as lack of data on the impacts of climate change, and high requirements in terms of knowledge and labour and initial investments that may pay off only over long time periods.

The sustainable intensification of integrated agriculture production systems requires: a better understanding of the impacts of changes in climate and climate variability on these systems; the generation and sharing of local and global knowledge, experiences and practices; capacity development through research and development, dialogue and dissemination of information; and support and coordination of policies, particularly policies that can provide incentives and create enabling institutions.

Acknowledgements

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Anne Mottet (FAO), Janie Rioux (FAO), Austin Stankus (FAO).

Reviewers: Simon Attwood (Bioversity International), Manuel Barange (FAO), Clayton Campanhola (FAO), Hans Dreyer (FAO), Gualbert Gbehounou (FAO), Jeongha Kim (FAO), Eva Muller (FAO), Ana Ocampo (FAO), Carolyn Opio (FAO), Beate Scherf (FAO), Brent Simpson (FAO), Felix Teillard (FAO), Berhe Tekola (FAO).

Notes: New module

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