Chapter 1

The challenge

To feed a growing world population, we have no option but to intensify crop production. But farmers face unprecedented constraints. In order to grow, agriculture must learn to save

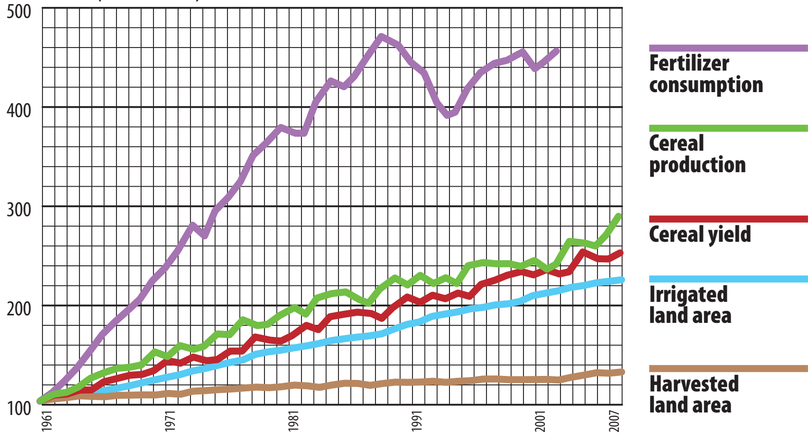
The history of agriculture can be seen as a long process of intensification[1], as society sought to meet its ever growing needs for food, feed and fibre by raising crop productivity. Over millennia, farmers selected for cultivation plants that were higher yielding and more resistant to drought and disease, built terraces to conserve soil and canals to distribute water to their fields, replaced simple hoes with oxen-drawn ploughs, and used animal manure as fertilizer and sulphur against pests.

Agricultural intensification in the twentieth century represented a paradigm shift from traditional farming systems, based largely on the management of natural resources and ecosystem services, to the application of biochemistry and engineering to crop production. Following the same model that had revolutionized manufacturing, agriculture in the industrialized world adopted mechanization, standardization, labour-saving technologies and the use of chemicals to feed and protect crops. Great increases in productivity have been achieved through the use of heavy farm equipment and machinery powered by fossil fuel, intensive tillage, high-yielding crop varieties, irrigation, manufactured inputs, and ever increasing capital intensity[2].

The intensification of crop production in the developing world began in earnest with the Green Revolution. Beginning in the 1950s and expanding through the 1960s, changes were seen in crop varieties and agricultural practices worldwide[3]. The production model, which focused initially on the introduction of improved, higher-yielding varieties of wheat, rice and maize in high potential areas[4, 5] relied upon and promoted homogeneity: genetically uniform varieties grown with high levels of complementary inputs, such as irrigation, fertilizers and pesticides, which often replaced natural capital. Fertilizers replaced soil quality management, while herbicides provided an alternative to crop rotations as a means of controlling weeds[6].

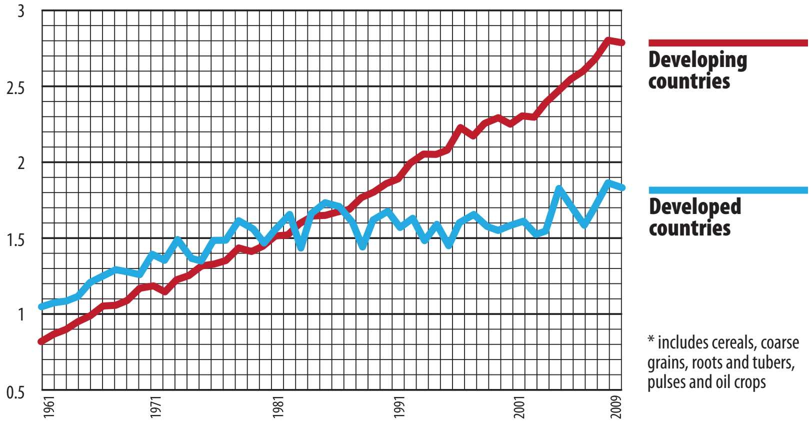
The Green Revolution is credited, especially in Asia, with having jump-started economies, alleviated rural poverty, saved large areas of fragile land from conversion to extensive farming, and helped to avoid a Malthusian outcome to growth in world population. Between 1975 and 2000, cereal yields in South Asia increased by more than 50 percent, while poverty declined by 30 percent[7]. Over the past half-century, since the advent of the Green Revolution, world annual production of cereals, coarse grains, roots and tubers, pulses and oil crops has grown from 1.8 billion tonnes to 4.6 billion tonnes[8]. Growth

Indicators of global crop production intensification, 1961-2007
Index (1961=100)



FAO. 2011. FAOSTAT statistical database (http://faostat.fao.org/).

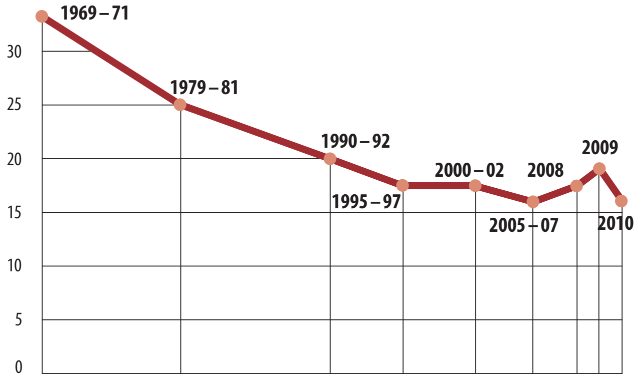
World production of major crops*, 1961-2009 (billion tonnes)



* includes cereals, coarse grains, roots and tubers, pulses and oil crops

FAO. 2011. FAOSTAT statistical database (http://faostat.fao.org/).

Undernourished in developing world population, 1969-71 to 2010
(percent)



FAO. 2010. *The State of Food Insecurity in the World: Addressing food insecurity in protracted crises.* Rome.

in cereal yields and lower cereal prices significantly reduced food insecurity in the 1970s and 1980s, when the number of undernourished actually fell, despite relatively rapid population growth. Overall, the proportion of undernourished in the world population declined from 26 percent to 14 percent between 1969-1971 and 2000-2002[9].

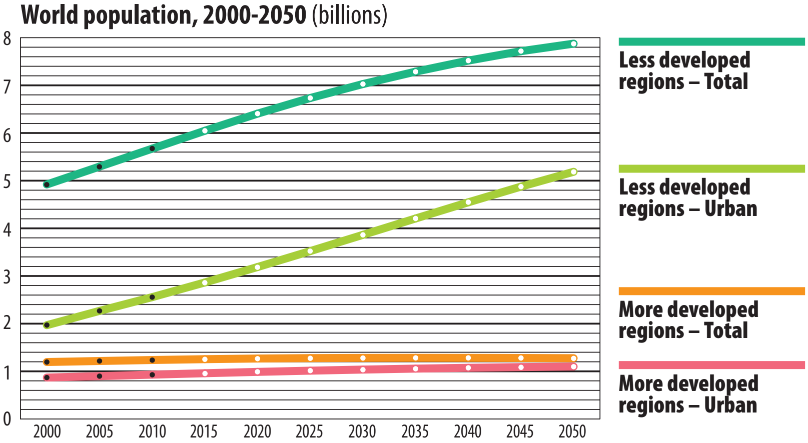
A gathering storm

It is now recognized that those enormous gains in agricultural production and productivity were often accompanied by negative effects on agriculture's natural resource base, so serious that they jeopardize its productive potential in the future. "Negative externalities" of intensification include land degradation, salinization of irrigated areas, over-extraction of groundwater, the buildup of pest resistance and the erosion of biodiversity. Agriculture has also damaged the wider environment through, for example, deforestation, the emission of greenhouse gases and nitrate pollution of water bodies[10, 11].

It is also clear that current food production and distribution systems are failing to feed the world. The total number of undernourished people in 2010 was estimated at 925 million, higher than it was 40 years ago, and in the developing world the prevalence of undernourishment stands at 16 percent[12]. About 75 percent of those worst affected live in rural areas of developing countries, with livelihoods that depend directly or indirectly on agriculture[13]. They include many of the world's half a billion low-income smallholder farmers and their families who produce 80 percent of the food supply in developing countries. Together, smallholders use and manage more than 80 percent of farmland – and similar proportions of other natural resources – in Asia and Africa[14].

Over the next 40 years, world food security will be threatened by a number of developments. The Earth's population is projected to increase from an estimated 6.9 billion in 2010 to around 9.2 billion in 2050, with growth almost entirely in less developed regions; the highest growth rates are foreseen in the least developed countries[15]. By then, about 70 percent of the global population will be urban, compared to 50 percent today. If trends continue, urbanization and income growth in developing countries will lead to higher meat

United Nations.
World urbanization prospects, the 2009 revision population database
(http://esa.un.org/wup2009/unup/).



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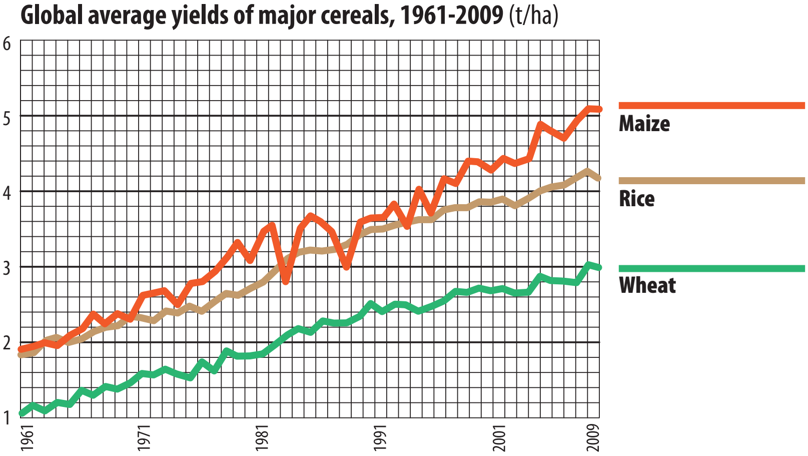

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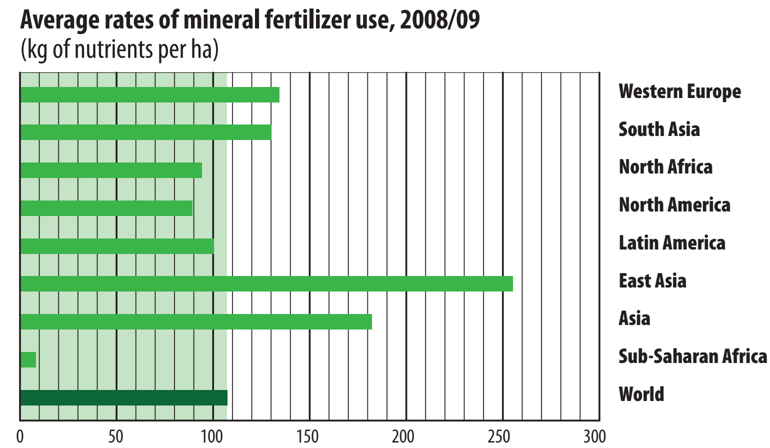


consumption, which will drive increased demand for cereals to feed livestock. The use of agricultural commodities in the production of biofuels will also continue to grow. By 2020, industrialized countries may be consuming 150 kg of maize per head per year in the form of ethanol – similar to rates of cereal food consumption in developing countries[16].

Those changes in demand will drive the need for significant increases in production of all major food and feed crops. FAO projections suggest that by 2050 agricultural production must increase by 70 percent globally – and by almost 100 percent in developing countries – in order to meet food demand alone, excluding additional demand for agricultural products used as feedstock in biofuel production. That is equivalent to an extra billion tonnes of cereals and 200 million tonnes of meat to be produced annually by 2050, compared with production between 2005 and 2007[10].

In most developing countries, there is little room for expansion of arable land. Virtually no spare land is available in South Asia and the Near East/North Africa. Where land is available, in sub-Saharan Africa and Latin America, more than 70 percent suffers from soil and terrain constraints. Between 2015 and 2030, therefore, an estimated 80 percent of the required food production increases will have to come from intensification in the form of yield increases and higher cropping intensities[17]. However, the rates of growth in yield of the major food crops – rice, wheat and maize – are all declining. Annual growth in wheat yields slipped from about 5 percent a year in 1980 to 2 percent in 2005; yield growth in rice and maize fell from more than 3 percent to around 1 percent in the same period[18]. In Asia, the degradation of soils and the buildup of toxins in intensive paddy systems have raised concerns that the slowdown in yield growth reflects a deteriorating crop-growing environment[4].

The declining quality of the land and water resources available for crop production has major implications for the future. The United Nations Environment Programme (UNEP) has estimated that unsustainable land use practices result in global net losses of cropland productivity averaging 0.2 percent a year[19]. Resource degradation reduces the productivity of inputs, such as fertilizer and irrigation. In the coming years, intensification of crop production will be required increasingly in more marginal production areas with less reliable production conditions, including lower soil quality, more limited access to water, and less favourable climates.

Efforts to increase crop production will take place under rapidly changing, often unpredictable, environmental and socio-economic conditions. One of the most crucial challenges is the need to adapt to climate change, which – through alterations in temperature, precipitation and pest incidence – will affect which crops can be grown and when, as well as their potential yields[13]. In the near term, climate variability and extreme weather shocks are projected to increase, affecting all regions[20-23], with negative impacts on yield growth and food security particularly in sub-Saharan Africa and South Asia in the period up to 2030[24]. Agriculture (including deforestation) accounts for about one third of greenhouse gas emissions; for this reason it must contribute significantly to climate change mitigation[21]. While crops can be adapted to changing environments, the need to reduce emissions will increasingly challenge conventional, resource-intensive agricultural systems[3].

Another significant source of future uncertainty is the price and availability of energy, needed to power farm operations and for the production of key inputs, principally fertilizer. As the supply of fossil fuels declines, their prices rise, driving up input prices, and consequently agricultural production costs. Fossil fuels can no longer be the sole source of energy for increasing productivity. Energy sources will have to be considerably diversified to reduce the cost of fuel for further agricultural intensification.

The challenge of meeting future demand for food in a sustainable manner is made even more daunting, therefore, by the combined effects of climate change, energy scarcity and resource degradation. The food price spike of 2008 and the surge in food prices to record levels early in 2011 portend rising and more frequent threats to world food security[25]. After examining a wide range of plausible futures – economic, demographic and climate – the International Food Policy Research Institute (IFPRI) estimated that the period 2010 to 2050 could see real price increases of 59 percent for wheat, 78 percent for rice and 106 percent for maize. The study concluded that rising prices reflect the "relentless underlying pressures on the world food system", driven by population and income growth and by reduced productivity[26].

The risk of persistent, long-term food insecurity remains most acute in low-income developing countries. The rate at which pressures are mounting on resources and the broader environment from the expansion and intensification of agriculture will be concentrated increasingly in countries with low levels of food consumption, high population growth rates and often poor agricultural resource endowments[27]. There, smallholders, who are highly dependent on ecosystem goods and services to provide food, fuel and fibre for their families and the market, are inherently more vulnerable to the declining quality and quantity of natural resources and changes in climate[14]. Without action to improve the productivity of smallholder agriculture in these countries, it is unlikely that the first Millennium Development Goal – with its targets of reducing by half the proportion of people living in hunger and poverty by 2015 – can be achieved.

Another paradigm shift

Given the current and burgeoning future challenges to our food supply and to the environment, *sustainable* intensification of agricultural production is emerging as a major priority for policy-makers[28] and international development partners[7, 14]. Sustainable intensification has been defined as producing more from the same area of land while reducing negative environmental impacts and increasing contributions to natural capital and the flow of environmental services[29].

Sustainable crop production intensification (or SCPI) is FAO's first strategic objective. In order to achieve that objective, FAO has endorsed the "ecosystem approach" in agricultural management[30]. Essentially, the ecosystem approach uses inputs, such as land, water, seed and fertilizer, to complement the natural processes that support plant growth, including pollination, natural predation for pest control, and the action of soil biota that allows plants to access nutrients[31].

There is now widespread awareness that an ecosystem approach must underpin intensification of crop production. A major study of the future of food and farming up to 2050 has called for substantial changes throughout the world's food system, including sustainable intensification to simultaneously raise yields, increase efficiency in the use of inputs and reduce the negative environmental effects of food production[32]. The International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) also called for a shift from current farming practices to sustainable agriculture systems capable of providing both significant productivity increases and enhanced ecosystem services[33].

Assessments in developing countries have shown how farm practices that conserve resources improve the supply of environmental services and increase productivity. A review of agricultural development projects in 57 low-income countries found that more efficient use of water, reduced use of pesticides and improvements in soil health had led to average crop yield increases of 79 percent[34]. Another study concluded that agricultural systems that conserve ecosystem services by using practices such as conservation tillage, crop diversification, legume intensification and biological pest control, perform as well as intensive, high-input systems[35, 36].

Sustainable crop production intensification, when effectively implemented and supported, will provide the "win-win" outcomes required to meet the dual challenges of feeding the world's population and saving the planet. SCPI will allow countries to plan, develop and manage agricultural production in a manner that addresses society's needs and aspirations, without jeopardizing the right of future generations to enjoy the full range of environmental goods and services. One example of a win-win situation – that benefits farmers as well as the environment – would be a reduction in the overuse of inputs such as mineral fertilizers along with increases in productivity.

As well as bringing multiple benefits to food security and the environment, sustainable intensification has much to offer small farmers and their families – who make up more than one-third of the global population – by enhancing their productivity, reducing costs, building resilience to stress and strengthening their capacity to manage risk[14]. Reduced spending on agricultural inputs will free resources for investment in farms and farm families' food, health and education[29]. Increases to farmers' net incomes will be achieved at lower environmental cost, thus delivering both private and public benefits[31].

Key principles

Ecosystem approaches to agricultural intensification have emerged over the past two decades as farmers began to adopt sustainable practices, such as integrated pest management and conservation agriculture, often building on traditional techniques. Sustainable crop production intensification is characterized by a more systemic approach to managing natural resources, and is founded on a set of science-based environmental, institutional and social principles.

Environmental principles

The ecosystem approach needs to be applied throughout the food chain in order to increase efficiencies and strengthen the global food system. At the scale of cropping systems, management should be based on biological processes and integration of a range of plant species, as well as the judicious use of external inputs such as fertilizers and pesticides. SCPI is based on agricultural production systems and management practices that are described in the following chapters. They include:

- maintaining healthy soil to enhance crop nutrition;
- cultivating a wider range of species and varieties in associations, rotations and sequences;
- using well adapted, high-yielding varieties and good quality seeds;
- integrated management of insect pests, diseases and weeds;
- efficient water management.

For optimal impact on productivity and sustainability, SCPI will need to be applicable to a wide variety of farming systems, and adaptable to specific agro-ecological and socio-economic contexts. It is recognized that appropriate management practices are critical to realizing the benefits of ecosystem services while reducing disservices from agricultural activities[36].

Institutional principles

It is unrealistic to hope that farmers will adopt sustainable practices only because they are more environmentally friendly. Translating the environmental principles into large-scale, coordinated programmes of action will require institutional support at both national and local levels. For governments, the challenge is to improve coordination and communication across all subsectors of agriculture, from production to processing and marketing. Mechanisms must be developed to strengthen institutional linkages in order to improve the formulation of policies and strategies for SCPI, and to sustain the scaling up of pilot studies, farmers' experiences, and local and traditional knowledge.

At the local level, farmer organizations have an important role to play in facilitating access to resources – especially land, water, credit and knowledge – and ensuring that the voice of farmers is heard[37]. Smallholder farmers also need access to efficient and equitable markets, and incentives that encourage them to manage other ecosystem services besides food production. Farmer uptake of SCPI will depend on concrete benefits, such as increased income and reduced labour requirements. If the economic system reflects costs appropriately – including the high environmental cost of unsustainable practices – the equation will shift in favour of the adoption of SCPI.

Social principles

Sustainable intensification has been described as a process of "social learning", since the knowledge required is generally greater than that used in most conventional farming approaches[14]. SCPI will require, therefore, significant strengthening of extension services, from both traditional and non-traditional sources, to support its adoption by farmers. One of the most successful approaches for training farmers to incorporate sustainable natural resource management practices into their farming systems is the extension methodology known as farmer field schools[38] (FFS)*.

* Pioneered in Southeast Asia in the late 1980s as part of an FAO regional programme on integrated pest management for rice, the FFS approach has been adopted in more than 75 countries and now covers a wide and growing range of crops and crop production issues.

Mobilizing social capital for SCPI will require people's participation in local decision-making, ensuring decent and fair working conditions in agriculture, and – above all – the recognition of the critical role of women in agriculture. Studies in sub-Saharan Africa overwhelmingly support the conclusion that differences in farm yields between men and women are caused primarily by differences in access to resources and extension services. Closing the gender gap in agriculture can improve productivity, with important additional benefits, such as raising the incomes of female farmers and increasing the availability of food[39].

The way forward

With policy support and adequate funding, sustainable crop production intensification could be implemented over large production areas, in a relatively short period of time. The challenge facing policymakers is to find effective ways of scaling up sustainable intensification so that eventually hundreds of millions of people can benefit[32]. In practical terms, the key implementation stages include:

- Assessing potential negative impacts on the agro-ecosystem of current agricultural practices. This might involve quantitative assessment for specific indicators, and reviewing plans with stakeholders at the district or provincial levels.
- Deciding at national level which production systems are potentially unsustainable and therefore require priority attention, and which areas of ecosystem sustainability (e.g. soil health, water quality, conservation of biodiversity) are priorities for intervention.
- Working with farmers to validate and adapt technologies that address those priorities in an integrated way, and use the experience to prepare plans for investment and to develop appropriate institutions and policies.
- Rolling out programmes (with technical assistance and enabling policies) based on the approaches and technologies described in this book.
- Monitoring, evaluating and reviewing progress, and making on-course adjustments where required.

This process can be iterative, and in any case relies on managing the interplay between national policy and institutions, on the one hand, and the local experience of farmers and consumers on the other. Monitoring of key ecosystem variables can help adjust and fine-tune SCPI initiatives.

In preparing programmes, policymakers may need to consider issues that affect both SCPI and the development of the agricultural sector as a whole. There is a risk, for example, that policies that seek to achieve economies of scale through value chain development and consolidation of land holdings may exclude smallholders from the process, or reduce their access to productive resources. Improving transport infrastructure will facilitate farmers' access to supplies of fertilizer and seed, both critical for SCPI, and to markets. Given the high rate of losses in the food chain – an estimated 30 to 40 percent of food is lost to waste and spoilage worldwide – investment in processing, storage and cold chain facilities will enable farmers to capture more value from their production. Policymakers can also promote small farmers' participation in SCPI by improving their access to production and market information through modern information and communication technology.

International instruments, conventions, and treaties relevant to SCPI may need to be harmonized, improved and implemented more effectively. That will require collaboration between international organizations concerned with rural development and natural resources* as well as governments, civil society organizations and farmer associations. Capacity is urgently needed to implement, at regional, national and local levels, internationally agreed governance arrangements**.

In addition, a number of non-legally binding international instruments embody cooperation for the enhancement and sustainable use of natural resources. They include guidelines and codes – such as the International Code of Conduct on the Distribution and Use of Pesticides – which aim at improving management of transboundary threats to production, the environment and human health. Finally, the United Nations Special Rapporteur on the Right to Food has produced guiding principles on land leasing and speculation in food commodity markets, and called for the scaling-up of ecological approaches in agriculture.

* Such as: FAO, the International Fund for Agricultural Development (IFAD), the United Nations Development Programme (UNDP), UNEP, the World Trade Organization (WTO) and the Consultative Group on International Agricultural Research (CGIAR).

** Such as: the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), the International Plant Protection Convention, the Convention on Biological Diversity (CBD), Codex Alimentarius, the United Nations Framework Convention on Climate Change (UNFCCC), the United Nations Convention to Combat Desertification and biodiversity related agreements.

There is no single blueprint for an ecosystem approach to crop production intensification. However, a range of farming practices and technologies, often location specific, have been developed. Chapters 2, 3, 4, 5 and 6 describe this rich toolkit of relevant, adoptable and adaptable ecosystem-based practices that enhance crop productivity and can serve as the cornerstone of national and regional programmes. Chapter 7 provides details of the policy environment and the institutional arrangements that will facilitate the adoption and implementation of SCPI on a large scale.

Chapter 2

Farming systems

Crop production intensification will be built on farming systems that offer a range of productivity, socio-economic and environmental benefits to producers and to society at large

Crops are grown under a wide range of production systems. At one end of the continuum is an interventionist approach, in which most aspects of production are controlled by technological interventions such as soil tilling, protective or curative pest and weed control with agrochemicals, and the application of mineral fertilizers for plant nutrition. At the other end are production systems that take a predominantly ecosystem approach and are both productive and more sustainable. These agro-ecological systems are generally characterized by minimal disturbance of the natural environment, plant nutrition from organic and non-organic sources, and the use of both natural and managed biodiversity to produce food, raw materials and other ecosystem services. Crop production based on an ecosystem approach sustains the health of farmland already in use, and can regenerate land left in poor condition by past misuse[1].

Farming systems for sustainable crop production intensification will offer a range of productivity, socio-economic and environmental benefits to producers and to society at large, including high and stable production and profitability; adaptation and reduced vulnerability to climate change; enhanced ecosystem functioning and services; and reductions in agriculture's greenhouse gas emissions and "carbon footprint".

These farming systems will be based on three technical principles:

- simultaneous achievement of increased agricultural productivity and enhancement of natural capital and ecosystem services;
- higher rates of efficiency in the use of key inputs, including water, nutrients, pesticides, energy, land and labour;
- use of managed and natural biodiversity to build system resilience to abiotic, biotic and economic stresses.

The farming practices required to implement those principles will differ according to local conditions and needs. However, in all cases they will need to:

- *minimize soil disturbance by minimizing mechanical tillage* in order to maintain soil organic matter, soil structure and overall soil health;
- *enhance and maintain a protective organic cover* on the soil surface, using crops, cover crops or crop residues, in order to protect the soil surface, conserve water and nutrients, promote

Contribution of sustainable intensification farming system practices to important ecosystem services

Objective	System component: Mulch cover	Minimized or zero tillage	Legumes to supply plant nutrients	Crop rotation
Simulate optimum “forest-floor” conditions	*	*		
Reduce evaporative loss of moisture from soil surface	*			
Reduce evaporative loss from upper soil layers	*	*		
Minimize oxidation of soil organic matter and loss of CO_2		*		
Minimize soil compaction	*	*		
Minimize temperature fluctuations at soil surface	*			
Provide regular supply of organic matter as substrate for soil organism activity	*			
Increase, maintain nitrogen levels in root zone	*	*	*	*
Increase cation exchange capacity of root zone	*	*	*	*
Maximize rain infiltration, minimize runoff	*	*		
Minimize soil loss in runoff and wind	*	*		
Permit, maintain natural layering of soil horizons through action of soil biota	*	*		
Minimize weeds	*	*		*
Increase rate of biomass production	*	*	*	*
Speed recuperation of soil porosity by soil biota	*	*	*	*
Reduce labour input		*		
Reduce fuel/energy inputs		*	*	*
Recycle nutrients	*	*	*	*
Reduce pest-pressure of pathogens				*
Rebuild damaged soil conditions and dynamics	*	*	*	*
Pollination services	*	*	*	*

Friedrich, T., Kassam, A.H. & Shaxson, F. 2009. Conservation agriculture. In: *Agriculture for developing countries. Science and technology options assessment (STOA) project.* European Parliament. Karlsruhe, Germany, European Technology Assessment Group.

soil biological activity and contribute to integrated weed and pest management;

- *cultivate a wider range of plant species* – both annuals and perennials – in associations, sequences and rotations that can include trees, shrubs, pastures and crops, in order to enhance crop nutrition and improve system resilience.

Those three key practices are generally associated with conservation agriculture (CA), which has been widely adopted in both developed and developing regions*. However, in order to achieve the sustainable intensification necessary for increased food production, they need to be supported by four additional management practices:

- *the use of well adapted, high-yielding varieties* with resistance to biotic and abiotic stresses and improved nutritional quality;
- *enhanced crop nutrition based on healthy soils*, through crop rotations and judicious use of organic and inorganic fertilizer;
- *integrated management of pests, diseases and weeds* using appropriate practices, biodiversity and selective, low risk pesticides when needed;
- *efficient water management*, by obtaining "more crops from fewer drops" while maintaining soil health and minimizing off-farm externalities.

Ideally, SCPI is the combination of all seven of those practices applied simultaneously in a timely and efficient manner. However, the very nature of sustainable production systems is dynamic: they should offer farmers many combinations of practices to choose from and adapt, according to their local production conditions and constraints[2-5].

Applied together, or in various combinations, the recommended practices contribute to important ecosystems services and work synergistically to produce positive outcomes in terms of factor and overall productivity. For example, for a given amount of rainfall, soil moisture availability to plants depends on how the soil surface, soil organic matter and plant root systems are managed. Water productivity under good soil moisture supply is enhanced when soils are healthy and plant nutrition is adequate. Good water infiltration and soil cover also minimize surface evaporation and maximize water

* Conservation agriculture is now practised on about 117 million ha worldwide, or about 8 percent of total crop land. Highest adoption levels (above 50 percent of crop land) are found in Australia, Canada and the southern cone of South America. Adoption is increasing in Africa, Central Asia and China.

use efficiency and productivity, in which the plants' own capacity to absorb and use water also plays a role.

One of the main requirements for ecologically sustainable production is healthy soil, creating an environment in the root zone that optimizes soil biota activity and permits root functioning to the maximum possible extent. Roots are able to capture plant nutrients and water and interact with a range of soil micro-organisms beneficial to soil health and crop performance[2, 6, 7]. Maintenance or improvement of soil organic matter content, soil structure and associated porosity are critical indicators of sustainable production and other ecosystem services.

To be sustainable in the long term, the loss of organic matter in any agricultural system must never exceed the rate of soil formation. In most agro-ecosystems, that is not possible if the soil is mechanically disturbed[8]. Therefore, a key starting point for sustainable production intensification – and a major building block of SCPI – is maintaining soil structure and organic matter content by limiting the use of mechanical soil disturbance in the process of crop establishment and subsequent crop management.

Minimized or zero tillage production methods – as practised in conservation agriculture – have significantly improved soil conditions, reduced degradation and enhanced productivity in many parts of the world. Most agricultural land continues to be ploughed, harrowed or hoed before every crop and during crop growth. The aim is to destroy weeds and facilitate water infiltration and crop establishment. However, recurring disturbance of topsoil buries soil cover and may destabilize soil structure. An additional effect is compaction of the soil, which reduces productivity[9].

One contribution of conservation agriculture to sustainable production intensification is minimizing soil disturbance and retaining the integrity of crop residues on the soil surface. CA approaches include minimized (or strip) tillage, which disturbs only the portion of the soil that is to contain the seed row, and zero tillage (also called no-tillage or direct seeding), in which mechanical disturbance of the soil is eliminated and crops are planted directly into a seedbed that has not been tilled since the previous crop[3].

Another management consideration relevant to SCPI is the role of farm power and mechanization. In many countries, the lack of farm power is a major constraint to intensification of production[10].

Using manual labour only, a farmer can grow enough food to feed, on average, three other people. With animal traction, the number doubles, and with a tractor increases to 50 or more[11]. Appropriate mechanization can lead to improved energy efficiency in crop production, which enhances sustainability and productive capacity and reduces harmful effects on the environment[12, 13].

At the same time, uncertainty about the price and availability of energy in the future suggests the need for measures to reduce overall requirements for farm power and energy. Conservation agriculture can lower those requirements by up to 60 percent, compared to conventional farming. The saving is due to the fact that most power intensive field operations, such as tillage, are eliminated or minimized, which eases labour and power bottlenecks particularly during land preparation. Investment in equipment, notably the number and size of tractors, is significantly reduced (although CA requires investment in new and appropriate farm implements). The savings also apply to small-scale farmers using hand labour or animal traction. Studies in the United Republic of Tanzania indicate that in the fourth year of implementing zero-tillage maize with cover crops, labour requirements fell by more than half[14].

Potential constraints

Some farming regions present special challenges to the introduction of specific SCPI practices. For example, under conservation agriculture, the lack of rainfall in subhumid and semi-arid climatic zones may limit production of biomass, which limits both the quantity of harvestable crops and the amount of residues available for use as soil cover, fodder or fuel. However, the water savings achieved by not tilling the soil generally lead to yield increases in the first years of adoption, despite the lack of residues. Scarcity of plant nutrients may prove to be a limiting factor in more humid areas, but the higher levels of soil biological activity achieved can enhance the long term availability of phosphorus and other nutrients[7, 15].

Low soil disturbance or zero tillage systems are often seen as unsuitable for farming on badly drained or compacted soils, or on heavy clay soils in cold and moist climates. In the first case, if bad drainage is caused by an impermeable soil horizon beyond the reach of tillage equipment, only biological means – such as tap roots, earthworms and termites – can break up such deep barriers to water percolation. Over time, these biological solutions are facilitated by minimal soil disturbance. In the second case, mulch-covered soils do take longer to warm up and dry, compared to ploughed land. However, zero tillage is practised successfully by farmers under very cold conditions in Canada and Finland, where studies have found that the temperature of covered soils does not fall as much in winter[13, 16].

Another misperception of minimized or zero tillage systems is that they increase the use of insecticides and herbicides. In some intensive systems, the integrated use of zero tillage, mulching and crop diversification has led to reductions in the use of insecticides and herbicides, in terms of both absolute amounts and active ingredient applied per tonne of output, compared with tillage-based agriculture[12, 13].

In manual smallholder systems, herbicides can be replaced by integrated weed management. For example, since conservation agriculture was introduced in 2005 in Karatu district, the United Republic of Tanzania, farmers have stopped ploughing and hoeing and are growing mixed crops of direct-seeded maize, hyacinth bean and pigeon pea. This system produces good surface mulch, so that weed management can be done by hand without need for herbicides. In some years, fields are rotated into wheat. The overall results have been positive, with average per hectare maize yields increasing from 1 tonne to 6 tonnes. This dramatic yield increase was achieved without agrochemicals and using livestock manure as a soil amendment and fertilizer[17].

Another potential bottleneck for wide adoption of conservation agriculture is the lack of suitable equipment, such as zero till seeders and planters, which are unavailable to small farmers in many developing countries. Even where this equipment is sold, it is often more expensive than conventional equipment and requires considerable initial investment. Such bottlenecks can be overcome by facilitating input supply chains and local manufacturing of equipment, and by promoting contractor services or equipment sharing schemes among farmers in order to reduce costs. Excellent examples of these approaches can be found on the Indo-Gangetic Plain. In most small farm scenarios, zero-till planters that use animal traction would meet and exceed the needs of a single farmer.

Farming systems that save and grow

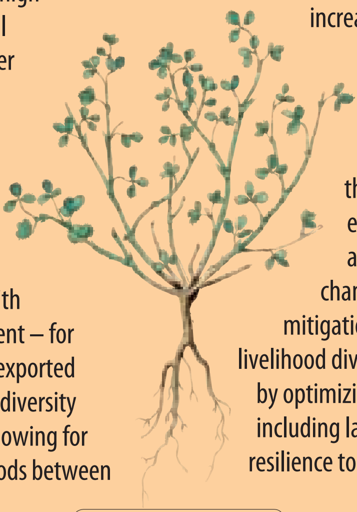
An ecosystem approach to the intensification of crop production is most effective when the appropriate, mutually reinforcing practices are applied together. Even where it is not possible to implement all recommended practices at the same time, improvement towards that goal should be encouraged. The principles of SCPI can be readily integrated into farming systems that either have features in common with ecosystem-based approaches or can be improved by underpinning them with similar principles.

Integrated crop-livestock production

Integrated crop-livestock production systems are practised by most smallholders in developing countries. Pastureland has important ecological functions: it contains a high percentage of perennial grasses, which sequester and safely store large amounts of carbon in the soil at rates far exceeding those of annual crops. That capacity can be further enhanced with appropriate management – for example, by replacing exported nutrients, maintaining diversity in plant species, and allowing for sufficient recovery periods between use of land for grazing or cutting.

In conventional farming systems, there is a clear distinction between arable crops and pastureland. With SCPI, this distinction no longer exists, since annual crops may be rotated with pasture without the destructive intervention of soil tillage. This "pasture cropping" is an exciting development in a number of countries. In Australia, pasture cropping involves direct-drilling winter crops, such as oats, into predominantly summer-growing pastures of mainly native species. Benefits suggested by field experiments include reduced risk of waterlogging, nitrate leaching and soil erosion[18].

Practical innovations have harnessed synergies between crop, livestock and agroforestry production to enhance economic and ecological sustainability while providing a flow of valued ecosystem services. Through increased biological diversity, efficient nutrient recycling, improved soil health and forest conservation, these systems increase environmental resilience, and contribute to climate change adaptation and mitigation. They also enhance livelihood diversification and efficiency by optimizing production inputs, including labour, and increase resilience to economic stresses[19].



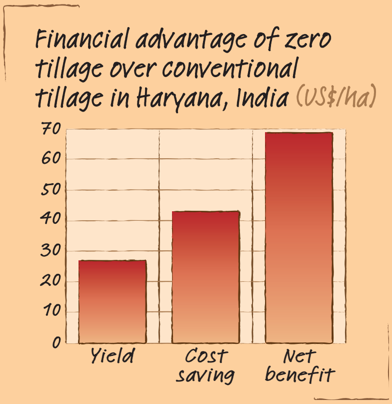
alfalfa

Sustainable rice-wheat production

Sustainable productivity in rice-wheat farming systems was pioneered on the Indo-Gangetic Plain of Bangladesh, India, Nepal and Pakistan by the Rice-Wheat Consortium, an initiative of the CGIAR and national agriculture research centres. It was launched in the 1990s in response to evidence of a plateau in crop productivity, loss of soil organic matter and receding groundwater tables[20].

The system involves the planting of wheat after rice using a tractor-drawn seed drill, which seeds directly into unploughed fields with a single pass. As this specialized agricultural machinery was originally not available in South Asia, the key to diffusion of the technology was creating a local manufacturing capacity to supply affordable zero tillage drills. An IFPRI study[21] found that zero tillage wheat provides immediate, identifiable and demonstrable economic benefits. It permits earlier planting, helps control weeds and has significant resource conservation benefits, including reduced use of diesel fuel and irrigation water. Cost savings are estimated at US$52 per hectare, primarily owing to a drastic reduction in tractor time and fuel for land preparation and wheat establishment.

wheat



Erenstein, O. 2009. Adoption and impact of conservation agriculture based resource conserving technologies in South Asia. In: Proceedings of the 4th world congress on conservation agriculture, February 4–7, 2009, New Delhi, India. New Delhi, World Congress on Conservation Agriculture.

Some 620 000 farmers on 1.8 million ha of the Indo-Gangetic Plain have adopted the system, with average income gains of US$180 to US$340 per household. Replicating the approach elsewhere will require on-farm adaptive and participatory research and development, links between farmers and technology suppliers and, above all, interventions that are financially attractive.

tagasaste

Agroforestry

Agroforestry systems, involving the cultivation of woody perennials and annual crops, are increasingly practised on degraded land, usually with perennial legumes. Conservation agriculture works well with agroforestry and several tree crop systems, and farmers in both developing and developed regions practise it in some form. These systems could be further enhanced by improved crop associations, including legumes, and integration with livestock. Alley cropping is one innovation in this area that offers productivity, economic and environmental benefits to producers[22]. Another example is the use of varying densities of "fertilizer trees" that enhance biological nitrogen fixation, conserve moisture and increase production of biomass for use as surface residues (see Chapter 3, ***Soil health***).

Ripper-furrower system in Namibia

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

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

Other production systems

Organic farming, when practised in combination with conservation agriculture, can lead to improved soil health and productivity, increased efficiency in the use of organic matter and energy savings. Organic CA farming serves mainly niche markets and is practised in parts of Brazil, Germany and the United States of America, and by some subsistence farmers in Africa. ***Shifting cultivation*** entails the clearing for crop production of forest land that is subsequently abandoned, allowing natural reforestation and the recovery of depleted plant nutrients. Although shifting cultivation is often viewed negatively, it can be adapted to follow SCPI principles. In place of slash-and-burn, shifting cultivators could adopt slash-and-mulch systems, in which diversified cropping (including legumes and perennials) reduces the need for land clearing. Other ecosystem-based approaches, such as the ***System of Rice Intensification***, have also proven, in specific circumstances, to be successful as a basis for sustainable intensification[23].

maize

The way forward

Farming systems for sustainable crop production intensification will be built on the three core technical principles outlined in this chapter, and implemented using the seven recommended management practices: minimum soil disturbance, permanent organic soil cover, species diversification, use of high-yielding adapted varieties from good seed, integrated pest management, plant nutrition based on healthy soils, and efficient water management. The integration of pastures, trees and livestock into the production system, and the use of adequate and appropriate farm power and equipment, are also key parts of SCPI.

The shift to SCPI systems can occur rapidly when there is a suitable enabling environment, or gradually in areas where farmers face particular agro-ecological, socio-economic or policy constraints, including a lack of the necessary equipment. While some economic and environmental benefits will be achieved in the short term, a longer term commitment from all stakeholders is necessary in order to achieve the full benefits of such systems.

Monitoring of progress in production system practices and their outcomes will be essential. Relevant socio-economic indicators include farm profit, factor productivity, the amount of external inputs applied per unit of output, the number of farmers practising sustainable intensified systems, the area covered, and the stability of production. Relevant ecosystem service indicators are: satisfactory levels of soil organic matter, clean water provisioning from an intensive agriculture area, reduced erosion, increased biodiversity and wildlife within agricultural landscapes, and reductions in both carbon footprint and greenhouse gas emissions.

Production systems for SCPI are knowledge-intensive and relatively complex to learn and implement. For most farmers, extensionists, researchers and policymakers, they are a new way of doing business. Consequently, there is an urgent need to build capacity and provide learning opportunities (for example, through farmer field schools) and technical support in order to improve the skills all stakeholders. That will require coordinated support at the international and regional levels to strengthen national and local institutions. Formal education and training at tertiary and secondary levels will need to upgrade their curricula to include the teaching of SCPI principles and practices.