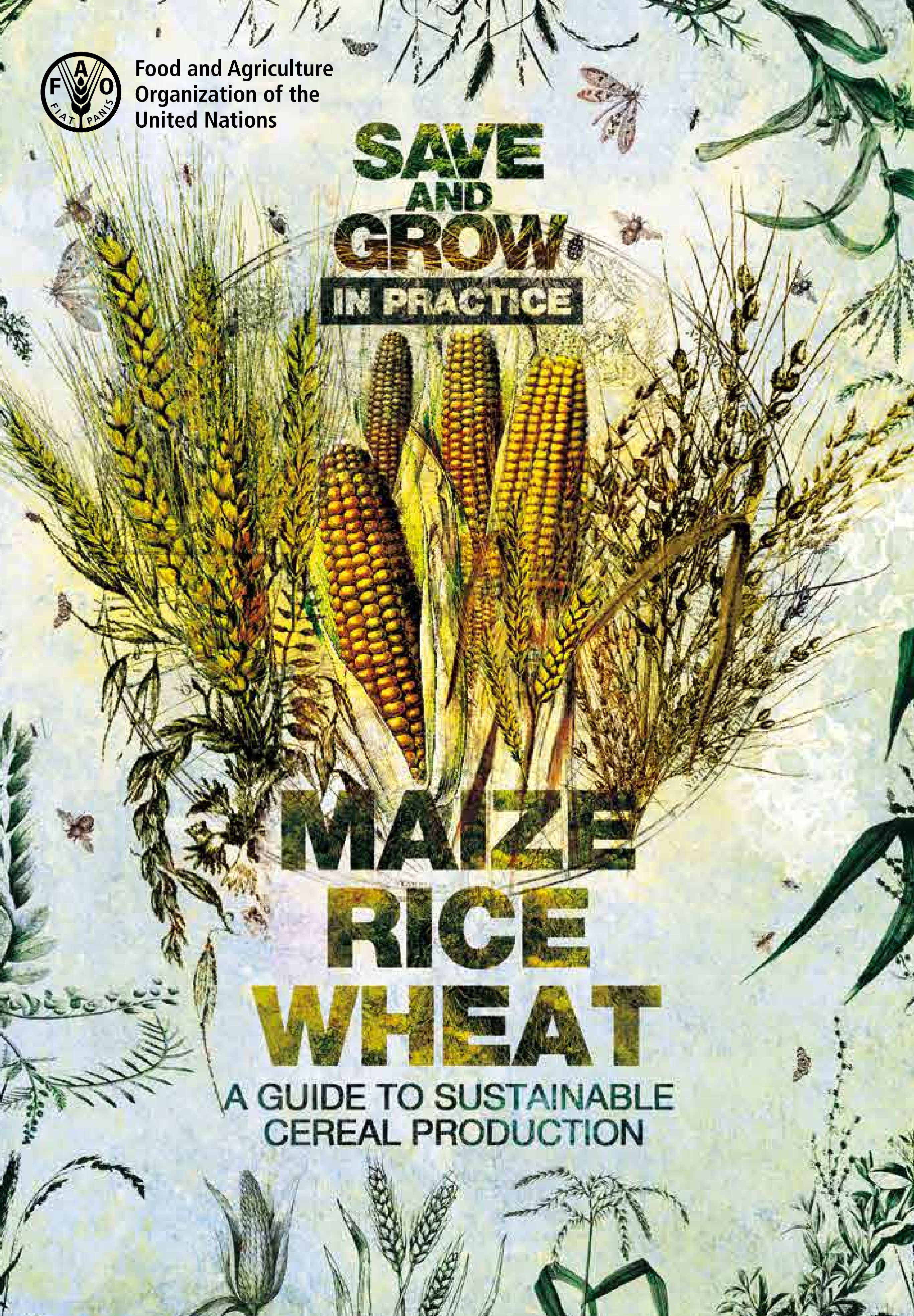
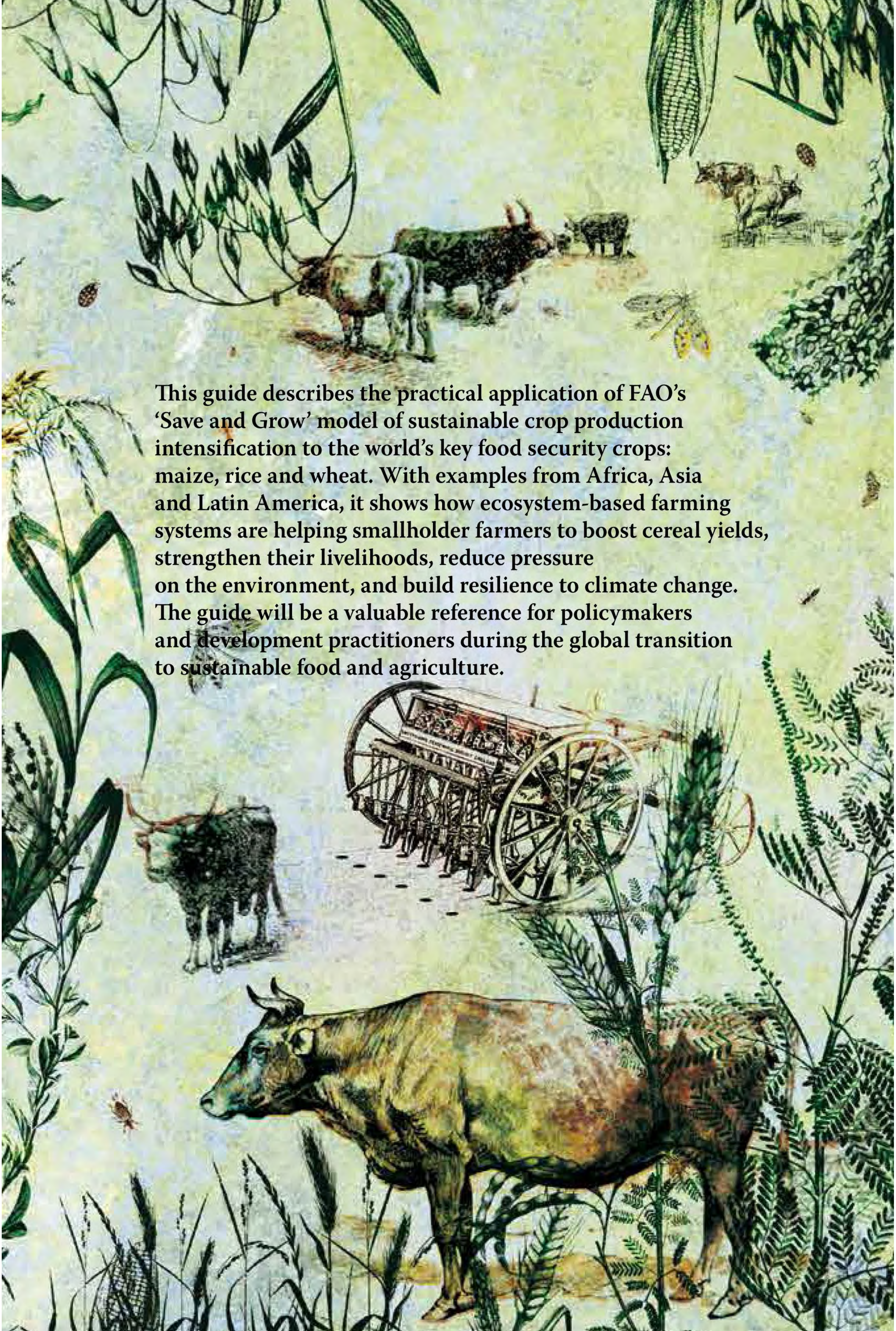
Food and Agriculture Organization of the United Nations

SAVE AND GROW IN PRACTICE

MAIZE RICE WHEAT

A GUIDE TO SUSTAINABLE CEREAL PRODUCTION





This guide describes the practical application of FAO's 'Save and Grow' model of sustainable crop production intensification to the world's key food security crops: maize, rice and wheat. With examples from Africa, Asia and Latin America, it shows how ecosystem-based farming systems are helping smallholder farmers to boost cereal yields, strengthen their livelihoods, reduce pressure on the environment, and build resilience to climate change. The guide will be a valuable reference for policymakers and development practitioners during the global transition to sustainable food and agriculture.

Save and Grow in practice maize · rice · wheat

A GUIDE TO SUSTAINABLE CEREAL PRODUCTION

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Contents

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Maps

Maps of world maize, rice, wheat and legume producing areas were prepared for this book by John Latham and Renato Cumani (FAO) from the global agro-ecological zones datasets, available at the FAO/IISA data portal: http://www.fao.org/nr/gaez

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Foreword

Let us imagine a different world in the year 2030 – a better world for our children and their children. Hunger and poverty have been eliminated. Food systems are productive and sustainable. Our societies are inclusive, our cities are safe, there is full employment, and gender equality has finally been attained.

That vision of 2030 is embodied in the Sustainable Development Goals (SDGs), the blueprint for world development recently adopted by the United Nations. Achieving those goals over the next 15 years will depend crucially on progress in agriculture. Most of the world's hungry and extremely poor live in rural areas. They include millions of smallholder farmers who are bearing the brunt of today's major global changes: widening economic inequality, relentless degradation of the ecosystems on which food production depends, and the quickening pace of climate change, which threatens crop yields worldwide.

Achieving the SDGs requires a transition to a more productive, inclusive and sustainable agriculture – one that strengthens rural livelihoods and ensures food security for all, while reducing agriculture's demands on natural resources and building resilience to climate change.

This book is a major contribution to creating the world we want. Maize, rice and wheat are fundamental to world food security. By 2050, when the global population is expected to reach 9.6 billion, demand for those cereals could total 3.3 billion tonnes a year, or 30 percent more than is produced today.

The global cereal harvest has reached record levels. However, most of it is grown in a few countries and key production areas, where farmers are paying the price of decades of intensive monocropping: soil degradation, groundwater depletion and a marked slow-down in the rate of yield increases. In vast areas of the developing world, farmers obtain barely a fraction of potential yields, owing to natural resource constraints and lack of access of the knowledge and technologies that would enhance their productivity. Climate change adds new pressures on cereals, including rising temperatures and a higher incidence of pests, diseases, droughts and floods.

We must safeguard production in the world's grain belts and rice bowls, and increase yields in countries where production has to substantially improve as populations grow. Needed is a new paradigm of cereals production, one that is both highly productive and environmentally sustainable. FAO's model of ecosystem-based agriculture, Save and Grow, meets that need, through farming systems that incorporate conservation agriculture, healthy soils, improved crops and varieties, efficient use of water, and integrated pest management.

This practical guide to sustainable cereals production reviews progress in the adoption of Save and Grow practices by smallholder farmers in the developing world. It then presents examples of Save and Grow farming systems that are producing more grain per hectare and generating significant social, economic and environmental benefits. It shows how Save and Grow practices helped restore production in wheat-growing regions of India and Kazakhstan, where Green Revolution technologies had faltered, and raised the productivity of low-input maize systems in Central America and East Africa.

The examples here highlight the rewards of integrating cereals with animal production and forestry. In Asia, farming families that raise fish in their rice fields harvest more rice and have more nourishing diets. In Brazil, a maize/livestock system is replacing unsustainable soybean monoculture. In Zambia, keeping nitrogen-rich trees in maize fields is more cost-effective than mineral fertilizer.

Save and Grow has proven itself in farmers' fields. The challenge now is to upscale the approach in national programmes. That will require a revitalized global partnership for development and major increases in investment in agriculture. With such commitment, Save and Grow will help us meet the Sustainable Development Goals. It will increase cereal production, keep ecosystems healthy, strengthen resilience to climate change, and progressively improve land and soil quality. By raising the productivity and incomes of smallholders, it will promote the inclusive economic growth needed to free millions of rural people from abject poverty. Linking smallholder production to well-designed social protection programmes will ensure food and nutrition security for the most vulnerable and help eradicate hunger forever.

Humanity has the knowledge, the technologies and the sense of common purpose needed to transform the vision of a hunger-free world into reality. There is no time to lose.

Overview

1. Cereals and us: time to renew an ancient bond

Climate change, environmental degradation and stagnating yields threaten cereal production and world food security. Sustainable crop production intensification can help to feed the world while protecting its natural resources

By 2050, world annual demand for maize, rice and wheat is expected to reach some 3.3 billion tonnes, or 800 million tonnes more than 2014's record combined harvest. Much of the increase in production will need to come from existing farmland. But one-third of that land is degraded, and farmers' share of water is under growing pressure from other sectors.

Climate change could have catastrophic effects on wheat yields and reduce maize yields in Africa by 20 percent. In Asia, rising sea levels threaten rice production in major river deltas. The potential for increases in cereal production is further constrained by stagnating yields and diminishing returns to high-input production systems.

'Business as usual' will affect disproportionately the developing world's 500 million small-scale family farmers, as well as low-income urban populations. As climate change in Asia pushes wheat into less productive rainfed areas, consumers will face steep food price increases. Population growth could deepen Africa's dependence on imported rice. Rising demand for maize and declining productivity could triple the developing world's maize imports by 2050.

Sustainably increasing the productivity of existing farmland is the best option for averting large increases in food prices, improving rural economies and farmers' livelihoods, and reducing the number of people at risk from hunger and malnutrition. The 'Save and Grow' model of crop production intensification, proposed by FAO, aims at increasing both yields and nutritional quality, while reducing costs to farmers and the environment.

This guide explains Save and Grow concepts and practices, presents examples of their practical application in the production of maize, rice and wheat, and outlines the policies, institutions, technologies and capacity-building needed to upscale lessons learned in national and regional programmes.

2. Progress toward sustainable cereal production

Farming systems need to be reconfigured worldwide for sustainable intensification. Cereal growers have already begun that transition by adopting key Save and Grow components and practices

- **Conservation agriculture.** By minimizing soil disturbance and using surface mulch and crop rotation, maize and wheat growers are reducing costs, boosting yields and conserving natural resources. Farmers in irrigated rice systems are shifting to dry-seeding without tillage. To increase their incomes and build resilience to climate change, cereal growers are diversifying crops and integrating trees, livestock and aquaculture into their production systems.
- **Soil health.** Conservation agriculture practices are improving the organic matter content and physical properties of the soil, which reduces erosion and enhances water-use efficiency. Nitrogen-fixing legumes improve soil fertility and reduce the need for mineral fertilizer. Matching crop nutrient demand and supply helps farmers to reduce fertilizer applications and harmful losses to the environment.
- **Improved crops and varieties.** Save and Grow systems use diverse, complementary groups of crops, and their improved varieties, to achieve higher productivity and strengthen food and nutrition security. Cereal varieties that are more resistant to biotic and abiotic stresses are now grown in farmers' fields. The development of more productive and nutritious cereals needs to be matched by systems for the rapid multiplication of quality seed.
- **Efficient water management.** To produce 'more crop per drop', many rice farmers have reduced the flooding of fields, which also lowers methane emissions. Growing rice without flooding cuts water use by up to 70 percent. Supplemental irrigation of wheat, using stored rainwater, has quadrupled water productivity. Furrow-irrigated, raised-bed planting saves water and produces higher yields of wheat and maize.
- **Integrated pest management.** The first line of defence against pests and diseases is a healthy agro-ecosystem. Rice farmers trained in IPM have greatly reduced insecticide applications – with no loss in yield. Planted together with maize, legumes help to smother weeds. Wheat growers have overcome rust epidemics with resistant varieties, and fight insect pests by rotating crops.

While each of those components contributes to sustainability, the maximum benefits will only be realized when all of them are integrated fully into Save and Grow farming systems.

3. Farming systems that save and grow

What does sustainable crop production intensification 'look like'? These examples, drawn from developing countries around the world, describe Save and Grow farming systems in practice

1. **In East Africa,** two of region's most serious maize pests have been overcome by growing two local plants in maize fields. The 'push-pull' system produces other benefits, including high quality cattle feed.
2. **From Madagascar,** System of Rice Intensification practices have spread to Asia, where they are helping farmers produce more rice and income using less water, less fertilizer and less seed.
3. **In Central America,** farmers have developed a 'slash-and-mulch' production system that preserves trees and shrubs, conserves soil and water, doubles yields of maize and beans, and even resists hurricanes.
4. **Worldwide,** wheat farmers grow legumes to provide a natural source of nitrogen, which boosts their wheat yields. Conservation agriculture can help realize the full benefits of wheat-legume rotation.
5. **In Latin America,** a grass native to tropical Africa has dramatically improved livestock productivity. Brazilian farmers have integrated *Brachiaria* in a direct-seeded maize system that is replacing soybean monocropping.
6. **On South Asia's Indo-Gangetic Plains,** resource-conserving technologies produce high wheat yields while reducing farmers' costs by 20 percent. A shift to conservation agriculture in rice would create positive synergies in the production of both crops.
7. **Across the developing world,** pigeon peas, cowpeas, groundnuts, soybeans and jack beans are familiar sights in farmers' maize fields. The high productivity of maize-legume systems make them especially suitable for smallholders.
8. **In Asia,** raising fish in and around paddy fields helps to control rice pests and fertilize the rice crop. Higher yields, income from fish sales and savings on agrochemicals boost farmers' income by 50 percent
9. **In Southern Africa,** leguminous trees and shrubs grown with maize provide high-quality, nitrogen-rich residues that increase soil fertility, boost yields and provide new sources of income.
10. **In Central Asia,** zero-tillage, soil cover and crop rotation would help many countries to reverse soil erosion and produce more food. Kazakhstan's wheat growers are already well advanced in the transition to full conservation agriculture.
11. **In South and Southeast Asia,** millions of rice farmers now grow maize in the dry season, using high-yielding hybrids that consume less water and generate higher incomes. Close-up: Bangladesh.

4. The way forward

The adoption of Save and Grow by smallholder farmers requires concerted action at all levels, with the participation of governments, international organizations, the private sector and civil society

Using Save and Grow, cereal growers, in often difficult farming conditions, have increased production and improved their livelihoods and income, while conserving natural resources and building resilience to climate change. But the adoption rate of sustainable practices is still relatively low, and much more needs to be done if agriculture is to deliver Save and Grow's full benefits.

The transition to sustainable crop production intensification requires fundamental changes in the governance of food and agriculture. Making those changes depends on a realistic assessment of the full costs of making the necessary transitions. It also requires the careful adaptation of sustainable farming practices and technologies to site-specific conditions.

An enabling policy, legal and institutional environment should strike the right balance between private, public and civil society initiatives, and ensure accountability, equity, transparency and the rule of law. FAO's vision of sustainable food and agriculture can guide the framing of national policies, strategies and programmes aimed at facilitating the transition to cereal production intensification that is highly productive, economically viable, environmentally sound, and based on equity and social justice.

Key challenges for policymakers, therefore, include facilitating the transition to Save and Grow within broader structural transformations; making policies that support farmer adoption of sustainable production systems; focusing investment in agriculture on the provision of public goods and encouraging farmer investment in sustainable crop production; establishing and protecting producers' rights to resources; promoting fairer and more efficient markets and value chains; increasing support to long-term agricultural research and development; promoting technological innovations adapted to smallholder needs; revitalizing agricultural education and training; strengthening formal and informal seed systems; and increasing collaboration with international organizations, instruments and mechanisms.

Chapter 1

Cereals and us: time to renew an ancient bond

Climate change, environmental degradation and stagnating yields threaten cereal production and world food security. Sustainable crop production intensification can help feed the world while protecting its natural resources

With a combined annual harvest of some 2.5 billion tonnes, maize, rice and wheat are the world's most widely cultivated crops and the foundation of world food security. Every day, humanity consumes millions of tonnes of those cereals in an almost endless variety of familiar forms – from steaming bowls of rice and plates of maize porridge to bread, tortillas, tamales, naan, chapatis, pasta, pizza, pies and pastries. Millions of tonnes more reach us by an indirect route, having been fed first to cattle, pigs and poultry that produce much of the world's meat, milk and eggs[1, 2].

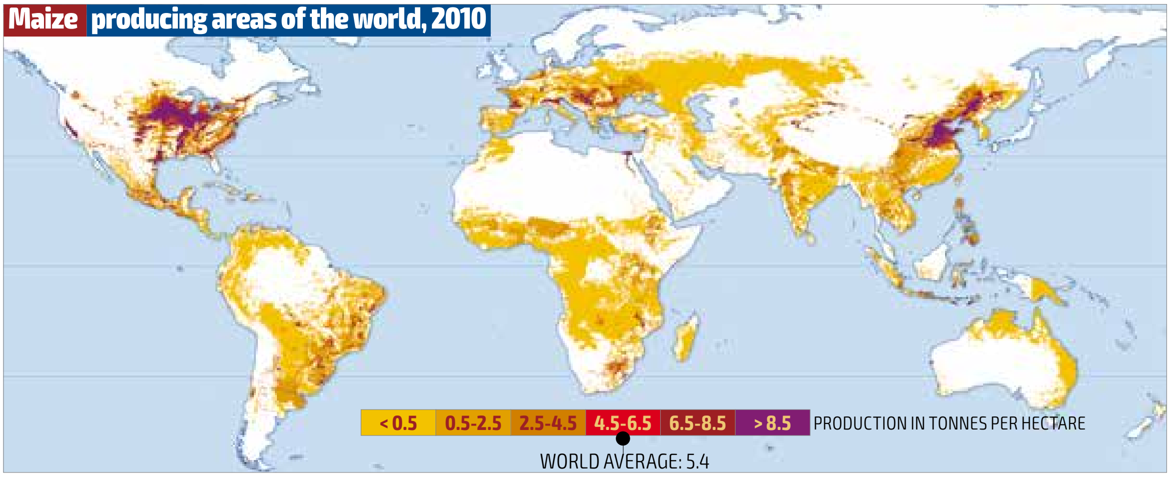
Together, maize, rice and wheat are the single most important item in the human diet, accounting for an estimated 42.5 percent of the world's food calorie supply. Globally, their contribution to our supply of protein – around 37 percent – is a close second to that of fish and livestock products. Wheat alone supplies more protein than the sum of poultry, pig and bovine meat. Maize, rice and wheat even supply 6 percent of the fat in our diets.

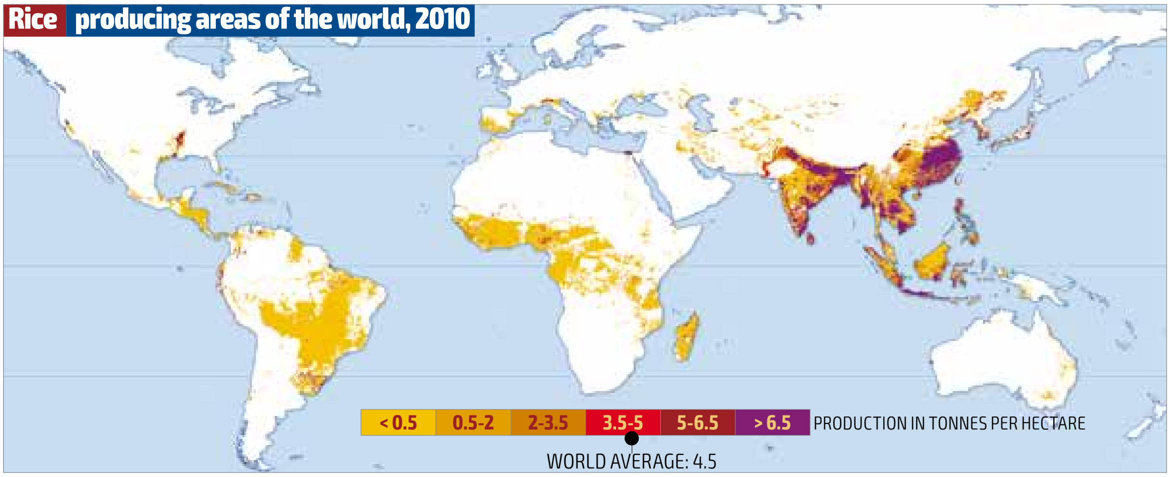
The three cereals are critical to food security in developing regions. In Southern Africa, they make up half the calorie supply. In Western Asia, wheat supplies around 40 percent of protein. In South Asia, wheat and rice account for half of all calories and protein and 9 percent of fat. In every developing region except Latin America, cereals provide people with more protein than meat, fish, milk and eggs combined.

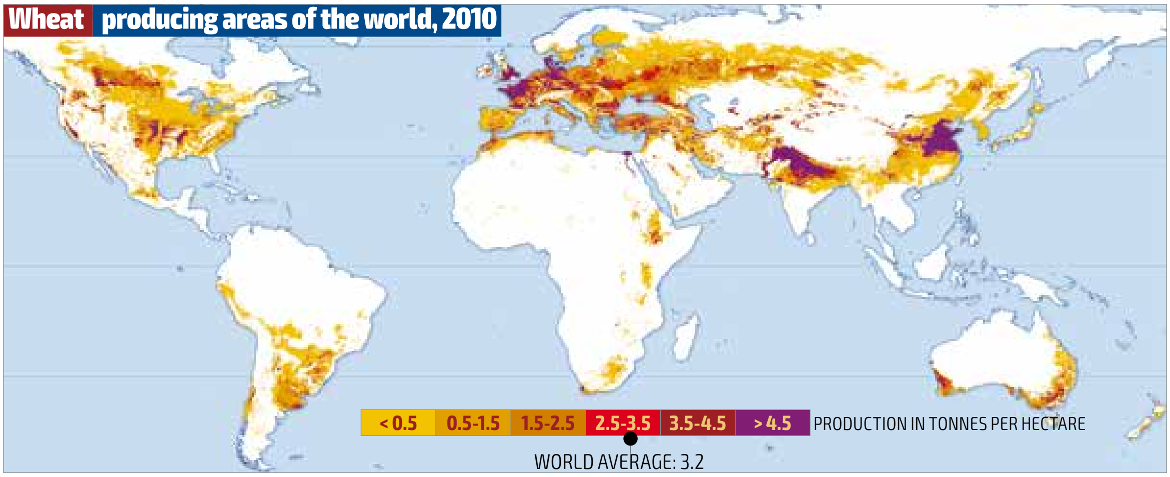
Even in North America and Western Europe, where animal products make up almost two-thirds of the protein supply, wheat still represents more than 20 percent. Indirectly, cereals account for much more: in the United States of America, around 40 percent of the domestic maize supply – equivalent to some 130 million tonnes in 2014 – is fed to livestock[2, 3].

Cereals have come to dominate human nutrition since the first farmers began to cultivate them before the dawn of history. In fact, the agricultural revolution and everything that followed – in short, the world we live in – have their origins in a curious and enduring bond first established some 10 000 years ago between communities of hunter-gatherers and abundant wild grasses of the Poaceae family. Among the first grasses to be sown and harvested, in the Middle East, were the *Triticum* species that gave rise, over a period of 2 500 years, to bread wheat[4].

What the harvested grains offered hunter-gatherers was a concentrated source of energy, protein and other nutrients that could be easily stored. The same discovery was made in East Asia and West Africa, where the rice species *Oryza sativa* and *Oryza glaberrima* were domesticated from wild progenitors between 9 000 and 3 000 years ago[5, 6]. Today's 2 500 commercial maize varieties have their origins about 7 000 years ago, in Mesoamerica, in a grass of the genus *Zea* called teosinte[4].







FAO/IISA GAEZ

The invention of irrigation in Mesopotamia 8 000 years ago was a momentous first step in the intensification of cereal production, as expanding urban populations sought to meet their food needs by raising productivity. By 3 000 years ago, intensive paddy cultivation was practised in China[4], and settlements in Mexico had developed irrigation systems for maize[7].

If cereals provided the food security that allowed the human population to grow from 10 million to 300 million in the first 8 000 years of agriculture[8], shortfalls in production or supply spelt disaster. Civilizations built on irrigated agriculture in the Indus and Tigris river valleys crumbled owing to the siltation of canals and the salinization of soils[9]. Famine devastated ancient Rome when enemies cut off shipments of grain from North Africa[10]. The Classic Mayan civilization collapsed probably owing to an epidemic of the maize mosaic virus[11]. In Europe, the end of the Medieval Warm Period 700 years ago was followed by wet summers which led to an upsurge in fungal diseases of wheat, triggering a famine that killed millions[12].

The agricultural revolution in Britain, which began in the late seventeenth century, was another milestone in cereal production intensification and food security. Improved ploughs, more productive varieties and crop rotation with legumes helped farmers to maximize the use of on-farm resources and to double wheat yields, from 1 tonne to 2 tonnes per ha, between 1700 and 1850. In the same period, the population of England increased from 5 million to 15 million[13, 14].

Population growth and agricultural intensification accelerated in the twentieth century. The years following the Second World War saw a paradigm shift in agriculture in industrialized countries, to the large-scale application of genetics, biochemistry and engineering to crop production. Great increases in productivity were achieved through the use of heavy farm machinery powered by fossil fuel, along with high-yielding crop varieties, irrigation and agrochemicals[15].

The intensification of crop production in the developing world began in earnest in the 1960s, as exponential population growth, along with serious shortfalls in cereal production, led to widespread hunger[15]. By 1970, an estimated 37 percent of the developing world's population, or almost 1 billion people, were undernourished[16, 17]. Facing the threat of a world food crisis, the international community mobilized behind agricultural research, development and technology transfer initiatives that became known as the 'Green Revolution'. The focus was on intensifying production of the three crops fundamental to the world's food security: maize, rice and wheat.

The Green Revolution, and after

The Green Revolution was driven initially by the work of the American biologist Norman Borlaug and scientists at the International Maize and Wheat Improvement Center (Cimmyt) in Mexico and the International Rice Research Institute (Irri) in the Philippines. It gathered momentum during the 1960s, with the introduction to South Asia of high-yielding, semi-dwarf rice and wheat varieties. Supported by government programmes to expand irrigation infrastructure and the supply of agrochemicals, those varieties produced, in a few short years, yield increases that had taken Britain's agricultural revolution more than a century to achieve[1].

Thanks mainly to the Green Revolution, the world witnessed a quantum leap in food production. Annual global output of cereals grew from 640 million tonnes in 1961 to almost 1.8 billion tonnes by 2000. The biggest gains were in the developing world: output of maize rose by 275 percent, of rice by 194 percent and of wheat by 400 percent. Much of the increase in Asian rice production was due to higher cropping intensities, with farmers shifting from a single crop to as many as three crops a year[18].

Although its population more than doubled between 1960 and 2000, the developing world boosted its per capita supply of cereals from domestic production, in the same period, by 50 percent[1, 17]. The proportion of undernourished fell from more than one-third of the population in 1970 to 18 percent by the end of the century[19].

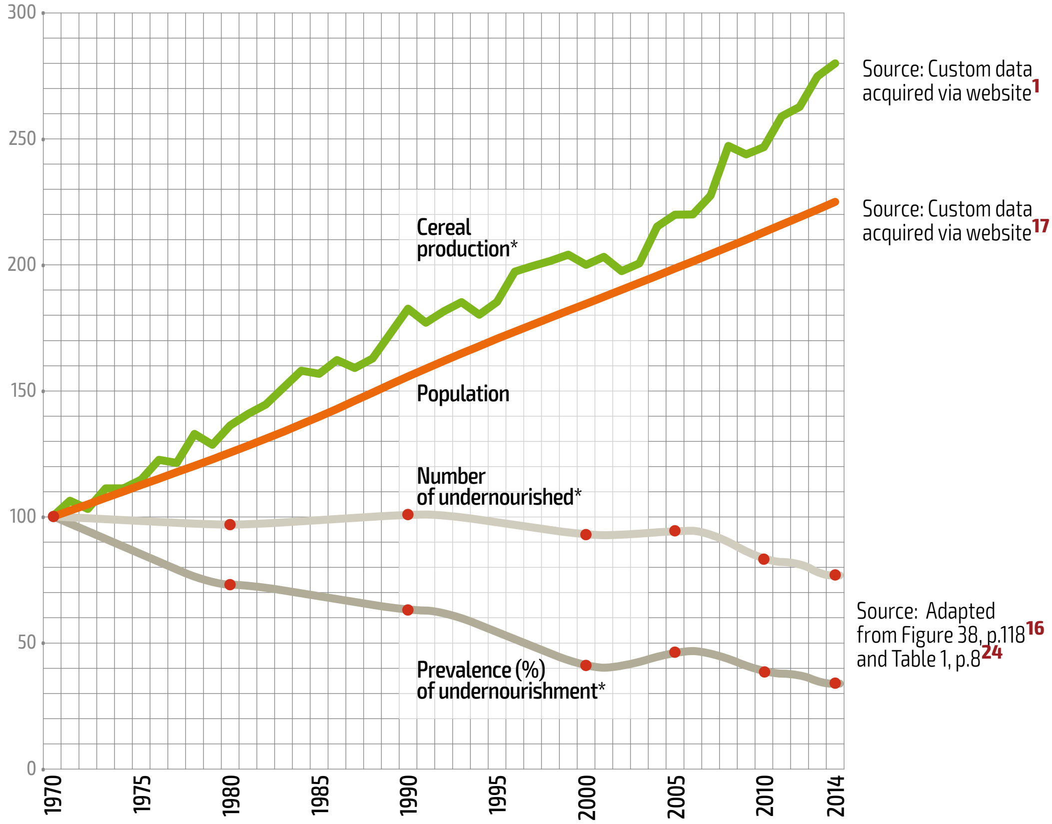
The lower unit production cost of cereals meant higher earnings for farmers, which contributed in Asia to a significant reduction in the incidence of rural poverty[20]. Urban consumers also benefited from decades of stable and relatively low cereal prices[21]. Intensification also meant that the 250 percent gain in the developing world's cereal production, between 1960 and 2000, was achieved with an expansion of the harvested area of only 44 percent, which reduced the need to convert natural habitat to farmland[1].

Today, developing countries account for two-thirds of world cereal production[1]. Improved varieties are grown on most of the wheat lands in Asia and North Africa[22], and in tropical Asia's rice fields[23]. In West Africa, early-maturing varieties have helped to double rice and maize production since 2000[1].

The contribution of the Green Revolution to food security is undeniable |Figure 1.1|. The incidence of undernutrition in the developing world's population has fallen to 12.9 percent[24]. In 2014, world cereal production reached an estimated 2.5 billion tonnes, pushing international prices well below their peak of 2011[25]. And there is potential for further production increases – in most developing regions, yields of major food crops, including cereals, are

Figure 1.1 **Cereal production, population growth, number of undernourished and prevalence of undernutrition in the developing world,** 1970-2014

Index (1970=100)



* Data for 2014 are provisional

one-half of those that would be technically possible with optimization of inputs and management[26].

The problem is that past agricultural performance is not indicative of future returns. Crop production intensification, based on monocropping and high levels of external inputs, has disrupted biodiversity and ecosystem services – including crop genetic diversity, soil formation and biological nitrogen fixation – to the point where it threatens the sustainability of food production itself[27, 28]. The Green Revolution's quantum leap in cereal production was often achieved at the cost of land degradation, salinization of irrigated areas, over-extraction of groundwater, the build-up of pest resistance, and damage to the wider environment, through increased emissions of greenhouse gases and nitrate pollution of water bodies[15].

Intensive double and triple monocropping of rice in Asia is associated with the depletion of soil micronutrients, the build-up of soil toxicity and a high incidence of pests and diseases[18]. Rice yield increases have levelled off in East and Southeast Asia, which account for 60 percent of world production[29]. Declining growth in yields has been confirmed by studies in India's main rice-growing states and in East Asia's rice bowls. Mounting evidence points to diminishing returns to modern varieties, despite the high use of inputs[20].

Yield stagnation in major wheat growing regions is seen as the result of a complex series of factors, including slowing rates of genetic enhancement, loss of soil fertility, declining input use-efficiency, and biotic and abiotic stresses[22]. The threat of wheat rusts has increased with higher cropping intensity and monocropping, while insect pests are increasingly responsible for wheat crop losses[30].

Intensive crop production often creates lush environments highly favourable to pests, leading to an ever increasing need for pesticide as insects, weeds and pathogens build up resistance. Today, agriculture uses some 2.5 million tonnes of pesticide a year[31]. As early as the 1990s, the health costs of excessive pesticide use in Asian rice fields were found to be higher than the economic benefits of pest control[32]. Globally, some 220 weed species have evolved resistance to one or more herbicides, posing a particular threat to cereals[33].

The worldwide adoption of high-yielding cereal varieties has led to the large-scale loss of plant genetic diversity and the erosion of biodiversity in general. The Green Revolution in Indonesia, for example, displaced some 1 000 local rice cultivars in favour of modern varieties which, owing to their narrow genetic base, are more vulnerable to pests and diseases. Monoculture has also reduced overall agrobiodiversity and dietary diversity, by replacing mixed farming of cereals, pulses and oilseed crops[18, 20].

Intensive crop production also contributes significantly to the greenhouse gases responsible for climate change. Emissions from agriculture, and from land cover change mainly for agriculture, have almost doubled over the past 50 years[34] and now account for up to 25 percent of total anthropogenic emissions[35]. Between 2001 and 2010, direct emissions from crop and livestock production grew from 4.7 billion to more than 5.3 billion tonnes of carbon dioxide equivalent, with most of the increase occurring in the developing countries[34].

As a major user of mineral fertilizer, cereal production contributes heavily to agriculture's emissions of nitrous oxide, which amount to 58 percent of total emissions; flooded rice cultivation, along with livestock, is the source of almost half of all methane emissions[36, 37].

Some critics say the Green Revolution benefited mainly those farmers who had better-endowed land and easier access to inputs and markets, and failed to reach the majority of small-scale, resource-poor farmers[38]. They point out the blinding paradox: that three-quarters of the world's poor and hungry live in rural areas and are employed mainly in agriculture and food production[39, 40, 41].

Another criticism of the Green Revolution model of intensive agriculture is that its heavy costs to the environment were charged to future generations. No agencies were created to collect compensation and invest it in environmental rehabilitation. If farmgate prices reflected the full cost of production – with agriculture effectively paying for the environmental damage it caused – food prices would not have remained so low for so long[15].

One thing is clear: despite the steady reduction in the proportion of undernourished in the world population, current food and agriculture systems have failed to provide everyone with the food they need for an active and healthy life. The *absolute number* of chronically undernourished in the world today is only 20 percent less than it was half a century ago[24].

Meanwhile, an estimated 2 billion people suffer from micronutrient malnutrition as a result of vitamin and mineral deficiencies in their diets. Yield increases obtained with the massive use of mineral fertilizer, which provides mainly nitrogen, phosphorus and potassium, have coincided with a decline in the nutritional content of cereals[42], and even of vegetable crops[43, 44].

Among low-income rural households especially, monotonous diets high in starchy staples are the norm, and adequate amounts of micronutrient-rich foods, such as meat, dairy products, pulses, fruit and vegetables, are generally unavailable. Fifty years of intensive production of maize, rice and wheat may have improved the supply of dietary energy, but have not brought commensurate improvements to overall human nutrition[45].

The Green Revolution model of crop production intensification was the right answer to the food crisis that faced humanity in the 1960s. But the world has now entered the 'post-Green Revolution era'.

More than three billion tonnes by 2050

World agriculture – and humanity's age-old bond with maize, rice and wheat – faces 'an unprecedented confluence of pressures'[46]. One is the demand for more food and other agricultural products than at any time in history. The global population is forecast to grow from 7.3 billion to more than 9.6 billion between now and 2050, with most of the increase in the developing regions; in the 48 least developed countries, population may double, to 1.8 billion[17]. Meanwhile, urbanization and rising affluence are driving a 'nutrition transition' in developing countries towards much higher consumption of animal protein, which will require big increases in livestock production and its intensive use of resources.

A new study by FAO and the Organisation for Economic Cooperation and Development (OECD) estimates that global consumption of cereals will increase by 390 million tonnes between 2014 and 2024. The core driver of the increase will be rising demand for animal feed, with coarse grains – of which about 70 percent is maize – accounting for more than half of the total. By 2024, developing countries will be consuming as food an additional 170 million tonnes of maize, rice and wheat[47].

In the longer term, FAO has estimated that, by 2050, annual global demand for the three cereals will reach almost 3.3 billion tonnes. Much of the increase will be needed to fuel annual production of some 455 million tonnes of meat[48], or 50 percent more than that produced in 2012[1]. The use of cereals as biofuel feedstock has been projected to grow from the current 130 million tonnes a year to 182 million tonnes by 2020[48]; under one scenario, it could reach almost 450 million tonnes by 2050[49, 50].

The demand for maize, rice and wheat does not need to be met entirely by production increases. Each year, one-third of all food produced for human consumption, including as much as 30 percent of cereals, is lost or wasted, with enormous negative effects on food availability and high environmental costs[51]. A substantial reduction in food losses and waste, along with a shift to healthier, sustainable diets less dependent on animal protein, would reduce the need to increase cereal production.

Nonetheless, the scale of future demand requires cereal farming systems that are both more productive and environmentally sustainable. Around 80 percent of future growth in crop production in developing countries will need to come from intensification; in South Asia, Western Asia and North Africa, intensification will account for between 90 and 100 percent of increases[48]. Agricultural growth will rely more than ever before on productivity gains through increased crop yields[50].

Achieving cereal yield increases will, however, be more difficult than in the past. Most of the world's agro-ecosystems have been severely depleted of their soil organic carbon, the basis of soil fertility[52]. One-third of farmland is moderately to highly degraded owing to the erosion, salinization, compaction and chemical pollution of soils[53]. If soil erosion continues at its current rate in northeastern China, cereal production on 93 million ha of farmland could fall by 40 percent within 50 years[54]. The world's irrigated wheat production areas suffer increasingly from salinization and waterlogging[22]. In Asia and Latin America, expansion of the maize producing area is considered unsustainable owing to its high environmental costs and the risk of further land degradation[55].

Meanwhile, agriculture's share of the world's freshwater withdrawals – currently around 70 percent – is under growing pressure from competing sectors. Many rainfed and irrigated cropping systems are approaching the limits of their production potential, and groundwater withdrawals exceed rates of natural replenishment in key cereal-growing areas worldwide[53]. In North Africa and Western Asia, water scarcity could be an even more important determinant of crop productivity than land scarcity[56]. Competition for water from domestic and industrial users is reducing the area under rice in some Asian countries[23]. Water scarcity is expected to lead to the diversion of irrigation from wheat to higher value crops, pushing wheat farming into less productive rainfed areas[57].

Another constraint to production increases is the marked slow-down in the rate of growth in maize, rice and wheat yields, which averaged between 2 and 3 percent annually during the Green Revolution. While the global average growth in maize yields is 1.5 percent a year, owing mainly to gains in the United States, the growth rate has slipped to 1 percent for both rice and wheat – below the minimum required, by one recent estimate, to ensure world food security in 2050[50].

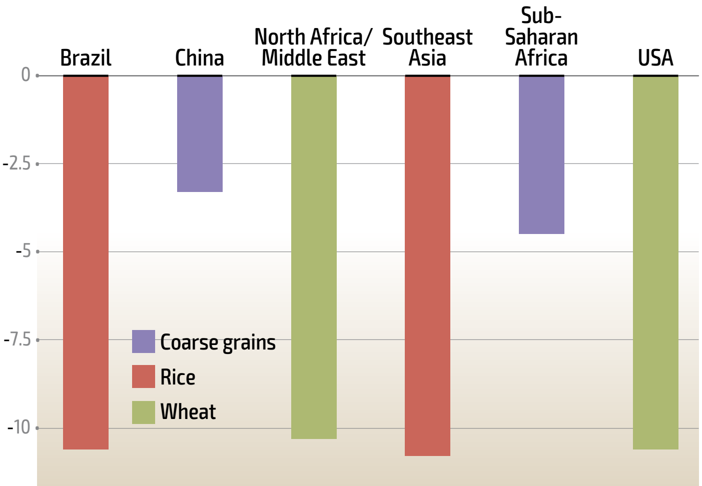
The slower growth in cereal productivity is linked to reduced incentives and demand for yield-enhancing technologies, owing to the substantial decline in the real prices of agricultural commodities from the early 1960s to the early 2000s[58]. Another factor is inadequate support to agriculture. The Green Revolution was made possible largely through research and development (R&D), input supply systems and extension services funded by governments[15]. But the growth rate of public spending on agricultural R&D in the developed world has slowed – and turned negative in the United States in 2004 – reducing technology spillovers to developing countries[59, 60].

While annual public funding for agricultural R&D increased globally by 22 percent between 2000 and 2008, to reach US$31.7 billion[61], China and India accounted for almost half of the increase; low-income countries' spending on agricultural R&D amounted to only 2.1 percent of the world total in 2009, less than in 1960[26].

The effects of climate change

Climate change, the most serious environmental challenge facing humanity, is expected to have far-reaching impacts on maize, rice and wheat. At a global level, it is estimated that higher temperatures and precipitation trends since 1980 have lowered yields of wheat by 5.5 percent and of maize by 3.8 percent below what they would have been had climate remained stable[62]. The coming decades are expected to see further increases in temperature, rising sea levels, more intense pest and disease pressures, water shortages,

Figure 1.2 Projected declines in cereal yields owing to climate change in 2050, without adaptation (%)*



* Relative to baseline values in 2050 without climate change; average result of three general circulation models

Source: Adapted from Figure 2, p.4[64]

extreme weather events and loss of biodiversity[63]. A recent study of climate change impacts on agriculture found that, without adaptation by farmers, global crop yields in 2050 would be 6.9 percent below estimated yields without climate change; cereal yields would be lower by as much as 10 percent in both developed and developing regions |FIGURE 1.2|[64].

Because maize is mainly a rainfed crop, higher rainfall variability will increase losses to drought and flooding in sub-Saharan Africa and Asia[65, 66]. Negative impacts will be felt most in areas where degraded soils no longer have the capacity to buffer crops against drought and heat stress[55]. Climate change is expected to reduce maize yields by increasing the incidence, severity and distribution of fungal diseases, which also pose threaten food safety[67].

Rice productivity in the tropics is forecast to decline. Today's high-yielding rice varieties are intolerant to major abiotic stresses that are likely to be aggravated by climate change, such as higher temperatures, drought and salinity. Rising sea levels and increased frequency of storms will pose a particular threat to rice-based systems in coastal regions[68]. Since river deltas in Bangladesh, Myanmar and Viet Nam have been responsible for half of rice production increases over the past 25 years, a serious loss of their production capacity would cause 'a major world food security crisis'[69].

Increased frequency of short-term high temperatures could have catastrophic effects on wheat yields. Wheat lands in South and Western Asia and North Africa are projected to suffer the most from heat stress and water scarcity, and from upsurges of insect pests and soil-borne pathogens. In South Asia, the Indo-Gangetic Plains are currently a favourable mega-environment for wheat; by 2050, more than half of the total area may suffer from heat stress and higher rates of fungal diseases. Climate change could also reduce the nutritional content of wheat[22, 70].

Growing pressure to reduce agriculture's own significant contribution to climate change will also affect cereal production. Climate change adaptation and mitigation will require cereal growers to limit the expansion of farmland, use less mineral fertilizer, and reduce methane emissions from rice fields by using less water[37].

To reach the target of supplying 3.3 billion tonnes of cereals, annually, by 2050, yields of maize, rice and wheat do not need to improve at the same spectacular rates recorded during the Green Revolution. The issue is how profoundly the stagnation in cereal yields and that 'unprecedented confluence of pressures' – natural resources degradation, limited room for the expansion of cultivated land, water scarcity and the potentially catastrophic effects of climate change – will impact cereal production and world food security.

Severest impacts on the most vulnerable

Future scenarios indicate that the downward pressure on cereal production will affect disproportionately the most vulnerable. They include many of the developing world's 500 million small-scale and family farmers, who produce an estimated 80 percent of the world's food[26], and the billions of low-income people who depend daily on cereals to survive.

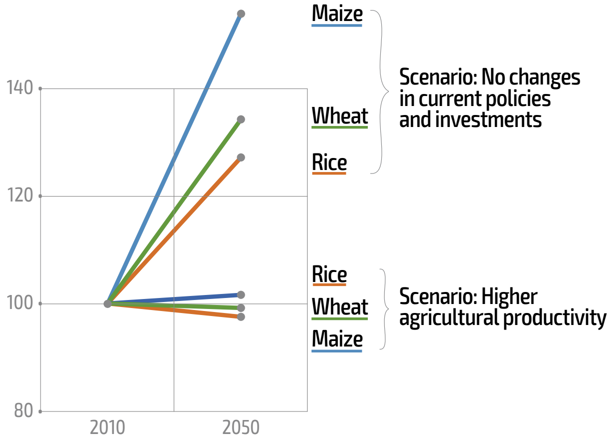
While maize is used in the developed world mainly to feed livestock and produce biofuel, in many developing countries it is primarily consumed as food. Small-scale farmers in both sub-Saharan Africa and Mesoamerica generally grow maize as a food crop for household consumption and for sale in urban markets. Maize is particularly important in the diets of the rural and urban poor in sub-Saharan Africa and Latin America[55]. Rising demand for maize and declining maize productivity could lead, by 2050, to a tripling of the developing world's maize imports, at an annual cost of US$30 billion[71].

Rice is a staple food for more than 3.5 billion people worldwide, with annual per capita consumption exceeding 100 kg in many Asian and some African countries. In both regions, rice is mainly a small farmer crop, with almost all of it produced on holdings ranging from 0.5 to 3 ha[23]. In Africa, soaring demand for rice among urban consumers is being met by imports, rather than domestic production; imports of milled rice almost tripled to 13.8 million tonnes between 2000 and 2012. West Africa alone accounts for some 20 percent of rice traded internationally[72]. Population growth will amplify the region's dependency, making African consumers ever more vulnerable to price increases[23].

Declining wheat productivity and rising wheat prices will affect most severely those countries with high rates of poverty and high dependence on wheat for their food security[30]. In South Asia, where more than 90 percent of the wheat supply is used as food, around 60 percent of the population lives on less than US$2 a day; in Central Asia, where per capita wheat consumption is 160 kg a year, poverty rates range as high as 40 percent[2,73]. African countries are increasingly dependent on wheat imports, which reached a record of 41 million tonnes in 2013/14[74]. As climate change pushes production into

Figure 1.3 Projected changes in world cereal prices, between 2010 and 2050, under two scenarios*

Index (2010=100)



* Prices adjusted for effects of inflation

Source: Adapted from Figure 2, p.92 & Figure 4, p.94[21]

more favoured higher latitudes, the risks to the livelihoods of small-scale wheat growers will also escalate[22].

The impact on the world's poorest populations of cereal price inflation in 2008 has sharpened awareness of the fragility of the global food system[23]. Wheat price hikes, for example, sparked urban riots in the Middle East and North Africa[30]. The current downward trend in cereal prices is expected to be short-term, with prices destined to stabilize above the relatively low levels recorded before 2008[47].

A study by the International Food Policy Research Institute (IFPRI) found that under a 'business as usual' scenario, with no change in current agricultural policies and investments, the real price of cereals could rise considerably between 2010 and 2050, slowing the reduction in the number of people at risk of hunger in many regions.

But the study offered another, more optimistic scenario: with sufficient levels of investment in *increasing yields sustainably on existing farmland,* the resulting higher productivity would keep inflation-adjusted cereal prices in 2050 very close to those of 2010 |Figure 1.3|. Lower prices for maize would lead to a drop in the cost of milk and meat, while the lower cost of rice would relieve burdens on net food importers. Overall, productivity gains would improve food security in all regions, reducing the population at risk of hunger globally by around 40 percent[21].

Save and Grow: Producing more with less

Raising yields sustainably on existing farmland is the essence of FAO's 'Save and Grow' model of crop production intensification. Save and Grow aims at overcoming today's intersecting challenges: boosting crop productivity and ensuring food and nutrition security for all, while reducing agriculture's demands on natural resources, its negative impacts on the environment, and its major contribution to climate change[15]. A solid body of evidence has shown that farm practices that conserve natural resources also increase crop productivity and enhance the flow of ecosystem services[75-77].

The Save and Grow approach recognizes that food security will depend as much on ensuring sustainability as it will on raising crop productivity[78]. It seeks to achieve both objectives by promoting farming practices and technologies that protect the environment, make more efficient use of natural resources, reduce the momentum of climate change, contribute to rural livelihoods and benefit human health[31, 79].

Ecosystem-based crop production is inherently climate-smart. It helps smallholders adapt to climate change by making their production systems more resilient to environmental stresses, such as drought, higher temperatures and upsurges in pests and diseases[37]. By maintaining and using a diversity of kingdoms, species and genepools in agro-ecosystems, it increases both productivity and resilience[27].

Save and Grow also has great potential for mitigating climate change: by capitalizing on natural biological processes, it reduces the use of mineral fertilizer and cuts nitrous oxide emissions 'at source'; through more efficient use of water, it can help cut methane emissions from irrigated rice fields[37]. Management practices that restore soil health could sequester in the soil some 1.8 tonnes of carbon per ha annually[80]. Carbon sequestration has the potential to offset fossil fuel emissions by up to 1.3 billion tonnes of carbon a year, equivalent to 15 percent of global fossil fuel emissions[81].

Much more attention needs to be given not only to the quantity, but also to the *quality* of the foods produced and consumed. Save and Grow promotes the diversification of smallholder production to include foods with a high content and bioavailability of nutrients – meat, dairy products, poultry and fish – which address multiple nutrient deficiencies, as well as pulses, fruit and leafy vegetables. Diversification increases the availability of a wider range of nutritionally dense foods, contributing directly to household food and nutrition security[31].

Finally, higher productivity in smallholder agriculture is the key to equitable, broad-based socio-economic development in rural areas. It increases producers' incomes and demand for labour, diversifies sources of household income, improves access to food, and fosters rural industries.

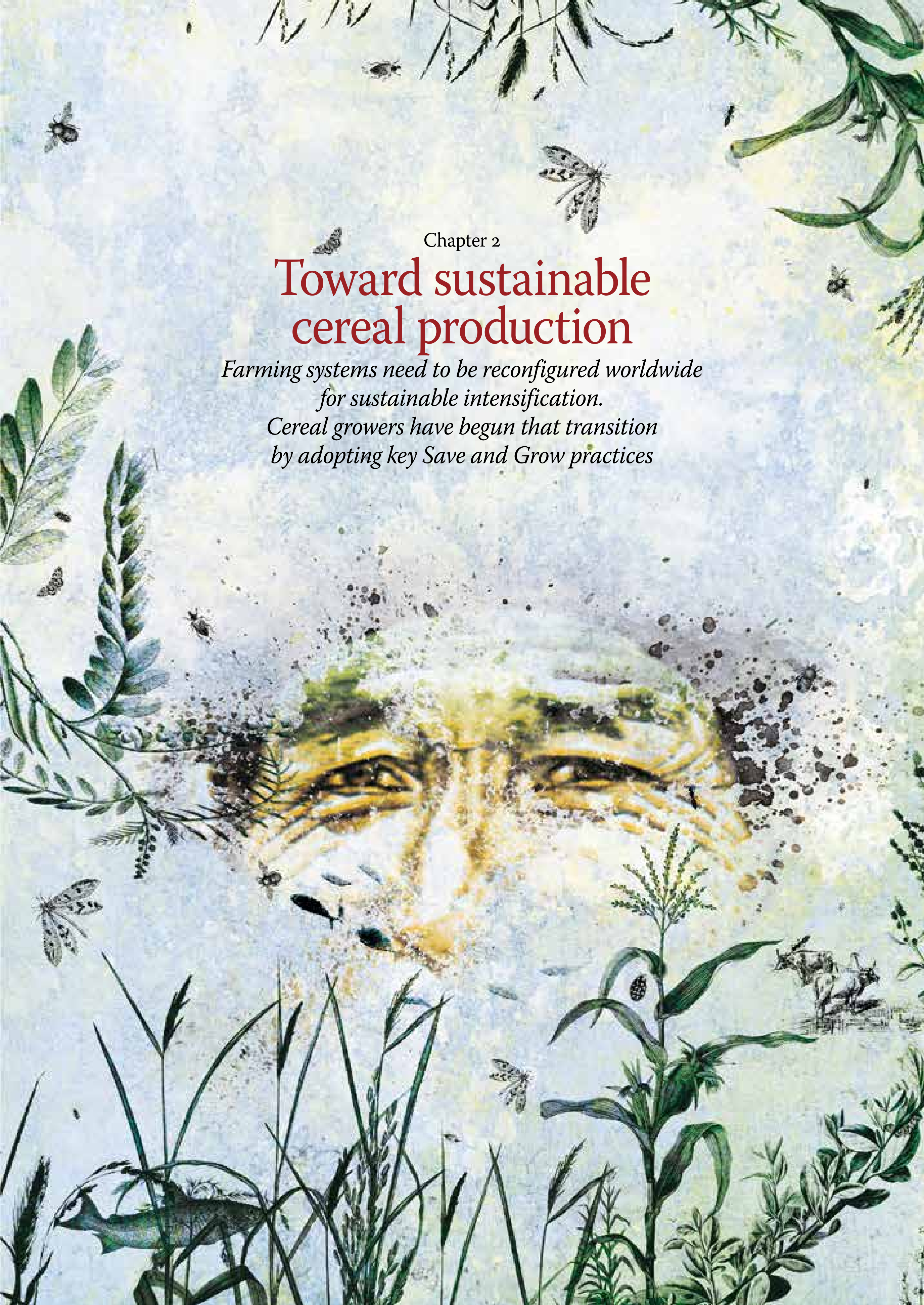
Empirical evidence shows that agricultural growth in many resource-poor, low-income countries can be five times more effective in reducing hunger and poverty than growth in other sectors[82].

It is time to renew the bond between humanity and cereals. The Food and Agriculture Organization believes that Save and Grow is the way forward – indeed, the only viable option – for increasing maize, rice and wheat production sustainably. *Chapter 2* of this book describes Save and Grow farming system components, practices and technologies, and reviews progress in their adoption by smallholder cereal growers in developing countries. *Chapter 3* presents examples of integrated Save and Grow farming systems, in practice, from across the developing world. *Chapter 4* concludes with an outline of the policy and institutional frameworks, and the innovations in technologies, education and capacity-building, needed to upscale the lessons learned in national and regional programmes.

Chapter 2

Toward sustainable cereal production

Farming systems need to be reconfigured worldwide for sustainable intensification. Cereal growers have begun that transition by adopting key Save and Grow practices



Save and Grow farming systems increase crop productivity and diversify food production, while simultaneously restoring and enhancing natural capital and ecosystem services. They do so by achieving higher rates of efficiency in the use of farm inputs – including water, nutrients, energy and labour – and strengthening resilience to abiotic, biotic and economic stresses, and to climate change.

Sustainable intensification, through Save and Grow, offers a range of productivity, socio-economic and environmental benefits to smallholder farmers and to society at large, including: high and stable production and profitability; higher farmer income and improved rural livelihoods; increased availability and consumption of the diverse range of foods necessary for a healthy diet; adaptation and reduced vulnerability to climate change and other shocks; enhanced ecosystem functioning and services; and reductions in agriculture's greenhouse gas emissions and carbon footprint[1].

Moreover, Save and Grow will contribute to the global transition to sustainable food and agriculture – one that ensures world food security, provides economic and social opportunities, and protects and enhances the ecosystem services upon which agriculture depends[2].

Save and Grow farming systems are based on five complementary components and their related practices[1]:

- **Conservation agriculture** (CA)**,** through minimal soil disturbance, the use of surface mulches and crop rotation, and the integrated production of crops, trees and animals;
- **Healthy soil,** through integrated soil nutrition management, which enhances crop growth, bolsters stress tolerance and promotes higher input-use efficiency;
- **Improved crops and varieties** adapted to smallholder farming systems, with high yield potential, resistance to biotic and abiotic stresses and higher nutritional quality;
- **Efficient water management** that obtains 'more crop per drop', improves labour and energy-use efficiency, and helps reduce agricultural water pollution; and
- **Integrated pest management** (IPM) based on good farming practices, more resistant varieties, natural enemies, and judicious use of relatively safer pesticides when necessary.

For this publication, FAO conducted an extensive review of progress in the adoption of sustainable, resource-conserving practices by smallholder producers of maize, rice and wheat in the developing world. The review confirmed recent findings that, over the past two decades, some of the most significant steps in the transition to sustainable intensification have been taken by smallholders in developing countries[3].

This chapter describes each of the Save and Grow farming system components and their related practices, and provides examples of their successful application by smallholder cereal producers. However, the individual components and practices should be seen only as the *building blocks* for the sustainable production of the three crops. While each contributes to sustainability, the maximum benefits will only be realized when all of the components, described below, are integrated fully in Save and Grow farming systems (see Chapter 3).

Conservation agriculture

Save and Grow incorporates the three core practices of conservation agriculture (CA), an approach that has been adopted on some 155 million ha of farmland worldwide[4].

First, farmers avoid or limit mechanical disturbance of the soil. Excessive land preparation with ploughs, harrows and hoes buries the soil's protective cover, kills soil biota, causes the rapid decomposition of organic matter, depletes soil fertility and degrades soil structure. Second, cover crops or mulches are retained permanently on the soil surface to reduce erosion, increase water infiltration, conserve soil moisture, suppress weeds and encourage the proliferation of soil biota that promote soil health and crop performance. Third, farmers maintain crop nutrient supply, reduce pest and disease loads and bolster overall system stability by growing a wider range of plant species and varieties in associations and rotations, and – where appropriate – by integrating forestry, animal husbandry and aquaculture in their production systems[1].

By improving soil health, reducing pest and pathogen pressure, reducing erosion, increasing the availability of water and nutrients, and increasing soil carbon storage, conservation agriculture enhances crop resilience to higher temperatures, drought and flooding, enhances ecosystem services, and helps to mitigate climate change. It also lowers production costs through savings on machinery, labour, fossil fuel, irrigation, mineral fertilizer and pesticide. However, conservation agriculture is not a 'one-size-fits-all' approach – the methods used to realize its key practices vary according to crops and local conditions[5-9].

Over the past two decades, tillage has been significantly reduced, and in some cases eliminated altogether, across large areas used for wheat and maize production. On the Indo-Gangetic Plains, wheat farmers using zero- and minimum tillage have reaped the benefits of higher grain yields and enhanced conservation of soil and water. Zero-tillage is considered the most successful resource-conserving technology on the plains[10,11] (see Chapter 3, p.58). As well as increasing average yields by 7 percent, it has saved farmers up to 30 days of labour and Us$52 in land preparation costs per hectare, and increased their average net incomes by Us$97 per ha |Figure 2.1|[12].

In Morocco, where intensive agriculture with deep tillage and soil inversion caused rapid soil degradation and loss of fertility, conservation agriculture systems for wheat production are now found across a range of field conditions, resulting in improved grain yields and input-factor productivity. Zero-tillage is practised for other winter crops, rotations with pulses and oilseed crops, and field crops under irrigation[13].

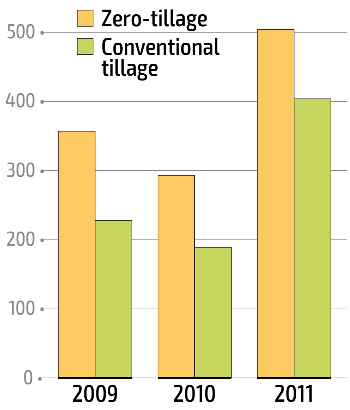
The success of zero-, or reduced, tillage in maize production is exemplified by the widespread adoption of direct-seeded, mulch-based cropping systems in Latin America. Areas permanently established under this system have increased in recent decades, reaching more than 50 percent of the total cropped area in Brazil, Paraguay and Argentina[4,14]. In sub-Saharan Africa, maize systems under conservation agriculture retain more soil moisture during seasonal dry spells and are more productive than systems based on conventional tillage using ploughs, harrows and hoes[15].

Much of tropical Asia's rice will continue to be produced in the wet season, when soil is too saturated for other staple crops. However, the traditional practice in Asia of transplanting rice into puddled soil is labour-, water-, and energy-intensive. In rice-wheat systems, it also delays the planting of wheat, and damages soil structure. With the decreasing availability of labour and water, many farmers in irrigated rice systems are shifting to the dry-seeding of rice with zero-tillage, which eliminates soil puddling. Numerous studies have shown that, compared with production in puddled fields, dry-seeding uses 33 percent less irrigation water and lowers production costs by as much as Us$125 per ha[16].

Adoption of dry-seeding of rice remains highly variable in Asia, but adoption rates were found to exceed more than 50 percent of farmers in one area of northeast India[17]. Efforts to promote conservation agriculture in rice in India are drawing on new technologies, developed in the region, for land levelling, weed control and drill-seeding, which places fertilizer and rice seed at optimal depth[16].

In Save and Grow farming systems, cereals are regarded not as monocultures but as components of crop rotations and of mixed farming. Smallholder farmers in highly stressed environments have traditionally rotated crop and forage tree species, and have integrated crop and livestock production, in order to reduce the risk of crop failure. On larger scales, diversification makes farming systems more resilient by limiting losses to specific biotic or abiotic stresses that affect genetically uniform monocultures[18].

Figure 2.1 **Net return from wheat cultivation under zero-tillage and conventional tillage,** Haryana, India (US$/ha)



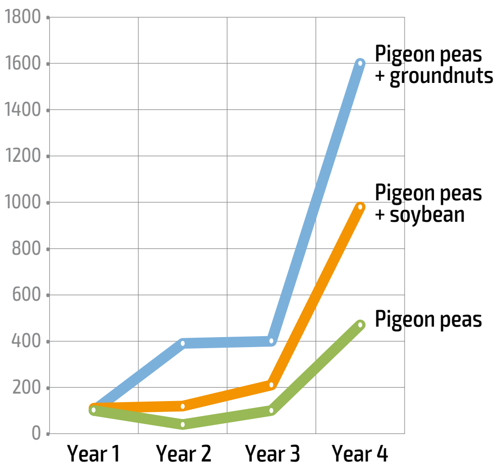
Source: Adapted from Table 5, p.13[12]

Diversified production has other benefits: it increases the availability of plant residues for use as surface mulch, and recycles on-farm nutrients and organic matter through animal manure. Provided markets are available for the other commodities produced, it also allows cereal growers to diversify their sources of income.

Wheat is grown in rotation with other crops in all production regions. An irrigated wheat-cotton rotation system is practised on an estimated 1.4 million ha in India and 2.6 million ha in Pakistan[19]. Similar systems are important in Egypt, Tajikistan, Turkey and Uzbekistan. Traditionally, the late harvesting time of cotton has pushed wheat planting in South Asia late into December, which, in turn, exposes the wheat crop to heat stress as the kernels mature in late April and May. That bottleneck has been overcome through relay planting of wheat in the standing cotton crop, without tillage, which advances wheat sowing by up to 44 days and boosts yields by as much as 40 percent[20, 21].

A wheat-maize rotation system on the North China Plain produces more than 50 percent of the country's wheat, and about 33 percent of its maize[22]. In India, the most productive and profitable wheat-maize systems are based on untilled, permanent raised beds which are drill-seeded through crop residues[23]. Rotation of wheat with grain legumes – including chickpeas, lentils and faba beans – is practised increasingly in rainfed wheat production areas, especially in soils with low levels of nitrogen, typical of Western Asia and North Africa. Legumes diversify production, enrich the soil through biological nitrogen fixation, enhance water-use efficiency, and disrupt the life cycle of weeds, pests and disease agents.

Figure 2.2 Number of farmers adopting legumes in maize production following trials, Ekwendeni, Malawi



Source: Adapted from Figure 2, p.446[24]

In recent years, many smallholder farmers in Southern Africa have revived the traditional practice of growing legumes, such as groundnuts, soybeans and pigeon peas, along with maize |Figure 2.2|[24-26]. Often, the legumes are valued more as sources of food and income than for their contribution to soil fertility – annual legumes used solely as green manure find few adopters.

The rotation of maize with other crops – and its integration into agroforestry and livestock production systems – is well established, and holds particular promise in increasing resource-use efficiency[27]. In savanna regions of Africa, farmers often grow maize under the canopy of an acacia, *Faidherbia albida*, which deposits nitrogen-rich leaves that serve as a surface mulch, a natural fertilizer and livestock feed (see Chapter 3, p.71). The development of

'CA with trees' has helped to advance the diffusion of conservation agriculture in crop-livestock systems in sub-Saharan Africa[28].

In Brazil, the introduction of zero-tilled maize in rotation with soybeans helped drive the widespread adoption of CA. In the country's tropical savanna region, maize is grown between rows of trees for the first two or three years after the trees have been planted. The area is then planted with forages intercropped with maize. Once the pasture is established, it is grazed by livestock until the trees are ready for harvest[29, 30] (see Chapter 3, p.55). This diversification mitigates the impact on farm income of both climate and market variability. It also reduces the clearing of forest for agriculture, protects biodiversity, checks soil erosion and improves soil structure and fertility[31-32].

Rice-based systems are becoming increasingly diverse. Over the past two decades, rice-maize rotation has expanded rapidly in Bangladesh[33]. Zero-tillage production of potatoes is expanding in lowland rice-growing areas of Viet Nam, where the paddies are drained using furrows, and potato seed tubers are placed on the resulting raised beds. After adding fertilizer to the soil around the tubers, the beds are covered with straw left over from the rice harvest[34]. Farmers in the inland valleys of West Africa are also diversifying their rice systems with vegetable production[35].

Rice is integrated with fish and livestock production in Asia. Aquaculture in trenches dug around rice fields boosts rice productivity by increasing the supply of nutrients to the plants, and provides farmers with an extra source of nutritious food for the household[36]. Farmers in Bangladesh are growing maize and Napier grass between the two main rice-growing seasons as an efficient way of producing food, cash income and fodder for livestock, especially in land-scarce areas. In one district, the rice-forage system has generated an average net economic return to farmers of US$2 630 per ha, compared to US$1 815 when they grow rice alone[37].

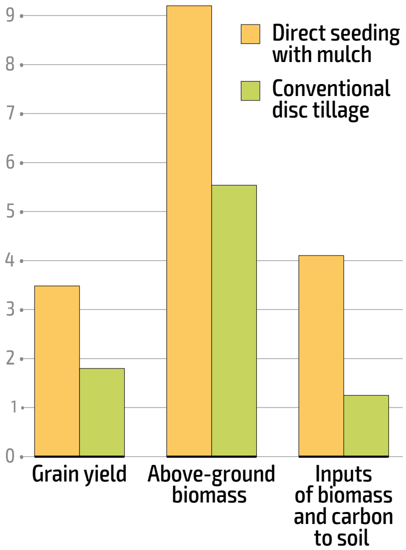
Soil health

'Soil health' is defined as the capacity of soil to function as a living system that sustains plant and animal productivity, maintains or enhances water and air quality, and promotes plant and animal health[38]. In Save and Grow, soil health is essential to the efficient use by plants of natural and external production inputs. It bolsters crops' resilience to the abiotic and biotic stresses that will be accentuated by climate change.

For agricultural soils to be considered healthy, soil biota must be managed in ways that allow the soil to support sound root development and plant growth, and to offer most of the ecosystem services that it would provide in its natural state. Excessive, intensive cultivation destroys soil structure by breaking up soil aggregates, reducing organic matter content and porosity, and disrupting the related soil functions of moisture and nutrient infiltration, retention and release[6].

A number of good agricultural practices promote soil health, improve soil fertility and enhance both crop productivity and long-term sustainability. They include judicious application of mineral and organic fertilizers, and conservation agriculture practices, including zero-tillage and the use of crop residue mulch and cover crops of mixed species.

Figure 2.3 **Effect of tillage and residue management on maize yields, biomass and soil carbon stocks,** La Tinaja, Mexico (t/ha)



Source: Adapted from Tables 4-6, p.429[44]

All of those practices are urgently needed in many key rice, wheat and maize producing regions, in order to correct macro- and micronutrient deficiencies and to increase levels of soil organic carbon (SOC)[39, 40]. Building carbon stocks is costly, in terms of the time and the inputs – such as organic amendments – that are required. It is vital, therefore, that viable SOC thresholds are protected through Save and Grow soil health recommendations.

Studies in the wheat-growing areas of Morocco found that zero-tillage and the retention of crop residues on the soil surface led to higher soil organic carbon content and increased water-stable soil aggregates, compared to ploughed land[13, 41, 42]. In the intensive rice-wheat and maize-wheat systems of the Indo-Gangetic Plains, studies have found a significant improvement in the physical and chemical properties of soil under CA[43].

In maize-based production systems in western Mexico, direct-seeded maize cropping – using crop residues as surface mulch – has had substantial benefits for soil health, mainly by reducing water runoff losses and soil erosion. Over a five-year period, soil carbon levels increased by almost 30 percent and maize yields almost doubled |Figure 2.3|[44].

Legumes have long been grown before, or with, cereal crops as a means of improving soil health and productivity. Through biological nitrogen fixation, legumes add to the soil up to 300 kg of nitrogen per ha per year, which is why wheat grown after legumes produces higher yields (see Chapter 3, p.52). In Mexico, legumes in rotation with maize contribute organic matter and nitrogen that help boost maize yields by 25 percent (see Chapter 3, p.64).

In Lombok, Indonesia, rice bunds are planted with *Sesbania grandiflora* trees which, among tree legumes, have the highest nutritive value. The falling leaves of the trees are rich in nitrogen and help improve soil nutrient levels and crop productivity. The practice is becoming widespread in other parts of Asia[45]. In Uganda, where a lack of soil nitrogen is the most limiting factor in farming systems, growing velvet beans before the rice crop boosted rice grain yields from 1.5 tonnes to 2.3 tonnes per ha, equal to the improvement obtained with mineral fertilizer[46].

Both organic and inorganic fertilizers play important roles in maintaining healthy, productive soils. Eight years of research in a rice-wheat system in India showed that the combined use of farmyard manure (a mix of animal manure and crop residues) and green manure at rates of 5 to 6 tonnes per ha, together with 90 kg of nitrogen applied as mineral fertilizer, sustained wheat productivity while reducing mineral fertilizer applications by half[47].

Since mineral fertilizer is often too expensive for smallholders in sub-Saharan Africa, many have adopted ‘integrated soil fertility management’, which complements synthetic nutrients with organic inputs obtained through: improved waste recycling and crop residue composting; the use of animal manure; and the incorporation of grain legumes, trees and shrubs through intercropping, rotations and agroforestry[48, 49].

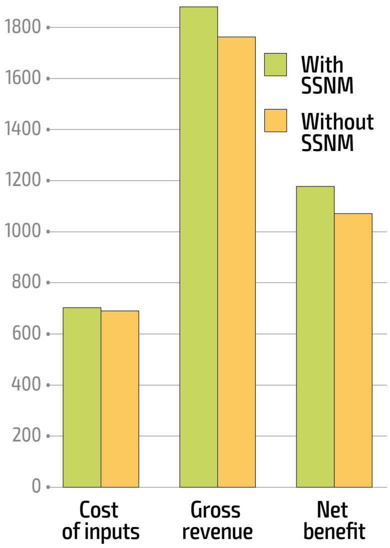
In farming systems that combine crop and animal production, livestock are often fed on local resources, such as pasture, crop residues, fodder trees and shrubs. Livestock dung and urine recycle nutrients and organic matter, which help to maintain soil fertility and structure. Mixed farming increases farm productivity and saves farmers’ money by intensifying nutrient and energy cycles.

However, organic manures may not always be available in the quantities required, and wide variations in nutrient content make it difficult for farmers to calculate application rates. In Zimbabwe, where large areas are inherently deficient in soil nitrogen and phosphorus, a study of 450 maize farms concluded that the yield benefits of conservation agriculture could only be fully realized when mineral fertilizer is also applied[50]. Better management of mineral fertilizer – including the correct dosage and timing of applications – and improvements in agronomic practices are urgently needed to increase fertilizer-use efficiency, or the output of grain per unit of fertilizer applied.

In Malawi, maize farmers with access to extension advice on weed management, crop rotation, intercropping and the timing of fertilizer applications often achieve, with the same amount of fertilizer, grain yields more than double the national average[51].

Fertilizer-use efficiency has also been markedly improved in rice production with site-specific nutrient management (SSNM), a strategy that optimizes use of existing soil nutrients and fills deficits with mineral fertilizer[52]. In field trials, per hectare rice yields increased by 0.2 tonnes in Viet Nam, 0.3 tonnes in the Philippines and 0.8 tonnes in India. The net benefit per hectare to rice growers who used SSNM in the Philippines was 10 percent more than those who did not |Figure 2.4|[53].

Figure 2.4 **Economics of site specific nutrient management (SSNM) in irrigated rice production,** Central Luzon, the Philippines (US$/ha/yr)



Source: Adapted from Table 9, p.19 & Table 10, p.21[53]

In Southern India, SSNM allowed wheat farmers to reduce fertilizer applications while achieving grain yields that were 23 percent higher than those obtained using recommended fertilizer rates[54]. Site-specific nutrient management has also been shown to benefit maize production. In Indonesia, the Philippines and Viet Nam, farmers recorded yield increases of from 0.9 to 1.3 tonnes per ha[53].

Micronutrients, such as calcium, magnesium, sulphur, iron and zinc, play an important role in improving soil health, crop productivity and the nutritional content of cereals. There is evidence that the use of fertilizer containing micronutrients significantly enhances crop nutritional quality, as well as crop yield, biomass production and resilience to pests, diseases and drought[55].

Recent technological innovations are supporting improved nutrient management in maize, rice and wheat production systems. As part of the SSNM approach, IRRI and partners helped to introduce in Bangladesh a low-cost plastic 'leaf colour chart', which allows rice farmers to determine when to apply urea for optimum benefit. Instead of broadcasting urea fertilizer several times, and in large quantities, during the growing season, the farmers compare the colour of rice leaves with colour panels corresponding to specific crop nitrogen deficits. The charts are credited with reducing urea use by around 20 percent while producing yield increases of up to 31 percent. Total benefits are estimated at US$22.8 million[52, 56].

Further efficiencies have been achieved in Bangladesh using more precise 'deep placement' of urea fertilizer in briquettes, at depths of 7 to 10 cm. By 2012, more than 400 000 rice farmers were following the practice, which resulted in average yield increases of 250 kg per ha, reduced fertilizer use by 7 000 tonnes, and saved the government US$1.6 million in fertilizer subsidies[57].

Fertilizer-use efficiency has been notably improved using a hand-held optical sensor and a crop algorithm which measure, in real time, the vigour of a wheat crop, and match nitrogen applications to requirements. In Mexico, sensor-based nitrogen management helped moderate fertilizer applications at planting and during early growth, and guided applications during later development stages[58]. On the Indo-Gangetic plains, the same system was used with conservation agriculture to save on fertilizer applications while producing higher wheat yields and reducing off-farm environmental impacts[59].

Improved crops and varieties

The use of improved varieties is another important means of increasing the productivity of maize, rice and wheat. Save and Grow farming systems require varieties that are more productive, use nutrients and water more efficiently, have greater resistance to insect pests and diseases, and are more tolerant to drought, flooding and higher temperatures. Needed are varieties that are adapted to less favoured areas and production systems, produce food with higher nutritional value, and help improve the provision of ecosystem services.

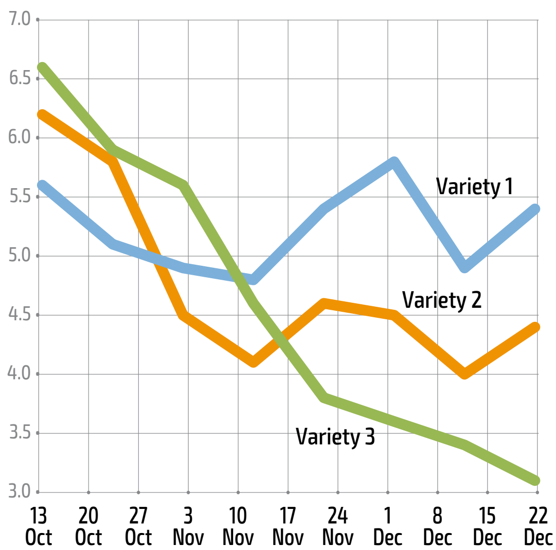
Those new crops and varieties will be deployed in diverse agro-ecologies where associated biodiversity – such as livestock, pollinators, pest predators, soil organisms and nitrogen fixing trees – is also important. Varieties suitable for Save and Grow need to be adaptable to changing production practices and to integrated pest management[1].

With climate change, tolerance to heat and drought will become a very important trait in cereals, especially in the tropics[60]. The CIMMYT-led Drought Tolerant Maize for Africa project has developed varieties, including hybrids, which out-yield commercial varieties by 25 percent under specific drought conditions. Some are also heat-tolerant, producing yields 27 percent higher than commercial varieties[61]. Heat-tolerant wheat, based on germplasm held at CIMMYT and the International Centre for Agricultural Research in the Dry Areas (ICARDA), has been released in several countries. A CIMMYT-sponsored wheat improvement network is exploring the development of high-yielding wheat varieties that can cope with Kazakhstan's increasingly hot summers (see Chapter 3, p.75).

Cultivars that are high-yielding in a shorter growing season reduce exposure to late season heat stress and have been instrumental in the development of rotations for all three cereals. In South Asia, the planting of earlier maturing rice varieties in the monsoon season has allowed earlier planting of subsequent wheat, maize and other dry season crops. Breeders are also identifying wheat cultivars that are suited to earlier planting |FIGURE 2.5|[62].

In Bangladesh, the cultivation of high-yielding hybrid maize as a dry season crop has proved to

Figure 2.5 **Grain yields of elite wheat cultivars by planting date,** Bihar and Madhya Pradesh, India (t/ha)



Source: Adapted from Figure 16, p.23[62] be a good strategy for adapting to higher temperatures and growing water scarcities (see Chapter 3, p.79).

Another expected impact of climate change is an increased incidence of flooding, which poses a particular threat to rice production in Asia[63]. The 'Sub-1' varieties developed recently by Irri, which tolerate submergence for up to 18 days, have been adopted by farmers at unprecedented speed, thanks to strong government support[52]. Maize tolerant to multiple stresses has been developed for the Indo-Gangetic Plains, where it performs well under both drought and waterlogging[61].

Varieties with resistance or tolerance to biotic stresses offer the most economical and environmentally friendly means of controlling upsurges in pest and disease problems. To combat the threat of Ug99, a highly virulent race of stem rust in wheat, Cimmyt, Icarda and national agricultural research systems identified resistant materials that have been incorporated in high-yielding varieties and deployed in many countries[64]. The International Atomic Energy Agency (Iaea) and Fao have worked together with several countries to develop mutant wheat varieties resistant to the same rust[65].

AfricaRice has developed and helped to distribute widely 'New Rice for Africa' (Nerica) varieties, which combine the high yield and other traits of Asian rice with the African species' resistance to the parasitic weed *Striga*, a serious pest of both rice and maize in the region[66, 67]. To confer resistance to a major rice pest, the blast fungus, Irri is combining different race-specific genes into the same rice type. Inter-planting different rice varieties can also be an effective tool in blast management. In China, planting glutinous rice with a blast-resistant hybrid prevents the build-up of fungus inoculum, leading to a significant reduction in pesticide use[68].

Another area of breeding that shows great promise is biofortification, which increases the nutrient content of food crops through genetic improvement. The Harvest Plus programme of the Consultative Group on International Agricultural Research (Cgiar) has promoted the biofortification of seven crops, including maize, rice and wheat. Bangladesh has released the world's first zinc-enriched rice, and maize varieties rich in vitamin A have reached more than 500 000 households in Africa[69]. Nutritional value has been greatly improved in Quality Protein Maize, which contains nearly twice as much usable protein as conventional maize[70, 71].

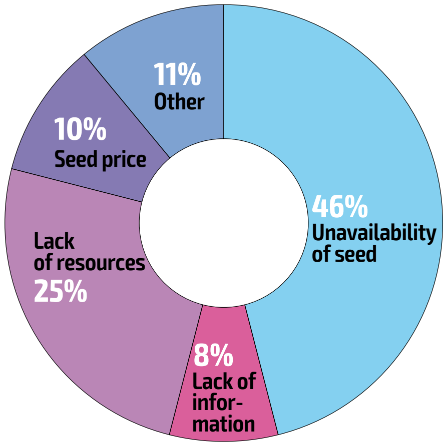
To develop varieties suitable for Save and Grow farming systems, plant breeders need access to the widest possible sources of desirable traits, which are found in cereal collections in genebanks, in landraces in farmers' fields and in wild crop relatives. More intense characterization of cereal genetic resources is needed in order to identify traits suitable for ecosystem-based agriculture and to integrate them in crop breeding[72]. For example, wheat landraces can provide important traits for tolerance to drought and heat, such as higher biomass, which would greatly improve the cereal's adaptation to climate change worldwide[73].

Another emerging thrust in breeding is improving the components of cereal-based intercropping systems. Recent research has provided a better understanding of interactions between crop genotypes and species, including mechanisms for pest and disease avoidance. With breeding that combines the traits of different plants to improve overall performance, intercropping could bolster the long-term sustainability of food production under low inputs in many parts of the world[74, 75].

Interest is also growing in the genetic improvement of the nutritional quality of cereal plant residues. After the maize grain harvest, smallholder farmers in Central America and sub-Saharan Africa commonly use most of the plant leaves and stalks to feed livestock. Studies in Mexico suggest that germplasm collections hold vast untapped potential for improving the feed value of maize stover, which would allow farmers to retain more residues in the field as soil cover[76].

Combining practices such as conservation agriculture with improved cultivars that make more efficient use of water and nutrients would enhance the overall productivity and profitability of most cropping systems. Varieties with higher fertilizer-use efficiency could help to reduce losses of fertilizer nutrients from fields, currently estimated at up 50 percent of applied nitrogen and 45 percent of phosphorus[77, 78].

Figure 2.6 **Main barriers to smallholder adoption of drought tolerant maize** in Ethiopia*



* Results of farm household survey

Source: Adapted from Fisher, M., Abate, T., Lunduka, R., Asnake, W., Alemayehu, Y. & Madulu, R. 2015. Drought tolerant maize for farmer adaptation to drought in sub-Saharan Africa: Determinants of adoption in eastern and southern Africa. *Climate change*. DOI 10.1007/s10584-015-1459-2. Figure 2.

The breeding of more productive, efficient and nutritious cereals needs to be matched by formal seed systems that ensure the rapid multiplication and supply of improved seed to smallholders, and by support to farmers' own initiatives to conserve and enhance local agrobiodiversity. Both formal and community-based seed systems will be essential in the distribution of cereal varieties suitable for Save and Grow production[1].

In many countries, the lack of efficient seed systems prevents farmers from adopting new varieties |Figure 2.6|. Seed production is especially critical for hybrids of cross-pollinated crops, such as maize. There is a growing trend toward public-private partnerships to improve seed supply. The private sector in China produces and markets the seed of hybrid rice developed by the public sector[79], and the private sector is now beginning to produce and sell wheat seed in India and other countries.

The Brazilian Agricultural Research Corporation (Embrapa) has pioneered partnerships with the private sector in order to market its maize hybrids and, in the process, generate resources for further R&D[80]. In 2014, the Drought Tolerant Maize for Africa project facilitated production and delivery of about 40 000 tonnes of improved maize seed in partnership with some 110 private and public seed companies, NGOs and farmer organizations[81].

As wheat is a self-pollinated crop, seed saved from previous harvests continues to dominate, and varietal replacement rates are low, particularly in rainfed and remote areas. To increase access to improved varieties, Icarda has helped national partners to fast-track the testing and release of rust-resistant varieties. Accelerated seed multiplication and large-scale production, in collaboration with country programmes and farmer groups, helped deliver to cereal growers 80 000 tonnes of certified seed[82].

Community seed banks and networks complement formal seed systems by conserving and improving seed from a variety of sources, including farmer-to-farmer exchanges and local markets. Community-based breeding and multiplication of cereal varieties that are competitive in yield and well adapted to local conditions give smallholder farmers access to a wider range of planting material than is normally available, contributing to both food security and the conservation of agrobiodiversity. Farmers' varieties also provide base materials for formal crop improvement programmes – some community seed banks have been established in partnership with plant breeding institutes[83].

In West Africa, where varietal development is slow, a women farmers' organization specializes in the production of foundation and certified seed of aromatic rice varieties grown in the Senegal River Valley[52]. Maize seed production and delivery have been accelerated through community-based seed producers in Nepal[84] and in Timor-Leste[85].

Efficient water management

Competition for water resources is becoming intense in many of the world's cereal producing areas. Inefficient use of water for crop production has depleted aquifers and reduced river flows, and many river basins no longer have sufficient water to meet the demands of agriculture, industry and urban centres. In addition, excessive use of mineral fertilizer and pesticide has polluted rivers, lakes and coastal areas, harming terrestrial and aquatic ecosystems and human health[86].

As competing demands for fresh water intensify, cereal growers will need to considerably improve the water productivity of their farming systems, and reduce the negative impacts of cereal production on the quality of ground and surface waters.

No single approach can overcome the challenge of producing more food, feed, fodder and fibre with the declining availability and quality of water. Needed is a combination of water-saving technologies in irrigation, a balanced use of surface- and groundwater resources, and good agronomic and soil management practices, such as zero-tillage, crop residue retention, raised-bed planting and crop diversification[87].

The International Crops Research Institute for the Semi-Arid Tropics (Icrisat) has promoted in rainfed areas a set of water management practices that includes water harvesting and storage, re-vegetation and other soil cover strategies, and better land and soil nutrient management. In India, rainwater harvesting structures, which are refilled during monsoons, reduce runoff by 40 percent and soil losses by 50 percent, and increase cropping intensity by 180 percent[88, 89]. In Honduras, the introduction of mulching and other soil conservation techniques doubled maize yields in shifting agriculture systems, reduced soil erosion and increased the quality and availability of water for downstream users (see Chapter 3, p.48).

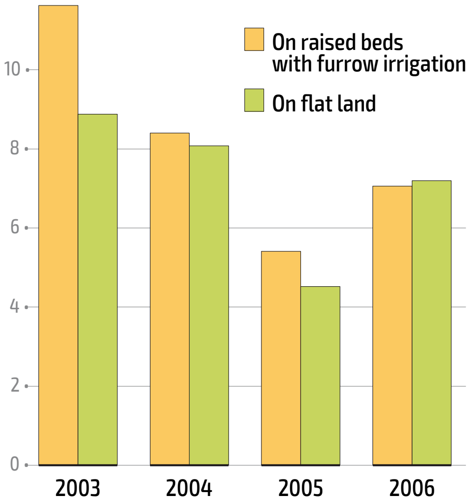
Raised-bed systems enhance the water productivity of maize in rainfed areas. The 'broad bed and furrow' system, promoted by Icrisat, is an *in situ* soil and moisture conservation and drainage technology suitable for clay soils, which are frequently waterlogged during the rainy season. Up to four rows of crops can be sown with precision seeders on sloping beds, which conserve water in the soil profile and channel excess runoff to small tanks for later use[90].

Several strategies can improve water-use efficiency in rainfed areas. They include the application of conservation agriculture practices that reduce evaporation losses from the soil and enhance the soil's water-holding capacity. Although it is not easy to increase that capacity, small but long-term improvements can be achieved with good soil and crop management. Wheat varieties with early vigour, which extract deeper soil water, tolerate some soil water stress and carry a higher percentage of grain at harvest, are usually more water-use efficient[64, 91]. More efficient rice and maize varieties, as well as hybrids, are now widely available. Adequate levels of crop nutrients, especially potassium, also enhance water-use efficiency[92].

Where precipitation is inadequate, harvesting and storing run-off water, then applying it in limited amounts during critical crop growth stages, is a viable option. In the Syrian Arab Republic, this 'supplemental irrigation' one to three times in the spring, at rates of 100 to 300 mm, has increased wheat yields from 2 to 6 tonnes per ha and quadrupled water productivity: a very large return for a small amount of water[64].

The same strategy facilitates earlier planting of wheat to avoid drought and frost later in the growing season. Research in Turkey and the Islamic Republic of Iran has shown that early wheat sowing, assisted by the application of 50 to 70 mm of supplemental irrigation, increases yields by more than 2 tonnes per ha[93].

Figure 2.7 **Water-use efficiency of irrigated chickpeas intercropped with maize,** Madhya Pradesh, India (kg/ha per mm)



Source: Adapted from Table 7, p.469[98]

Water-use efficiency in irrigation is commonly 50 percent or less. Applying the optimal amount of water required for a specific crop or variety, combined with good management practices, has the greatest potential to enhance water-use efficiency[94].

A recent study estimated average rice output on the Indo-Gangetic Plains at 0.7 kg of grain for every cubic metre of irrigation water used. However, in the Indian state of Punjab, with appropriate irrigation and drainage infrastructure and good management practices, water productivity averaged 1.5 kg per cubic metre[95].

Raised-bed planting with furrow irrigation, which feeds water to the soil between two rows of crops, significantly increases soil porosity, carbon content and infiltration rates, thereby improving the water-use efficiency of wheat and other crops[64]. The benefits of raised beds may be further enhanced when they are not tilled. In Egypt, ICARDA and national institutes have promoted raised beds as part of an integrated production system in the Nile Delta. After the introduction of seed drills and improved crop management, wheat yields increased overall by 25 percent and water-use efficiency by more than 50 percent[96].

In Pakistan, farmers reported maize yield increases of from 30 to 50 percent on untilled raised beds with furrow irrigation, compared to irrigated flat land[97]. In India, the system allowed farmers to raise productivity per unit of land by intercropping maize with chickpeas, pigeon peas and soybeans |FIGURE 2.7|[98].

To increase the efficiency of water use in irrigated rice production, farmers are using a variety of Save and Grow techniques. On an estimated 4 million ha of irrigated land in South Asia, farmers have adopted laser-assisted precision land levelling, which – compared to traditional levelling of fields with wooden boards – leads to water savings and productivity increases of 16 percent[12, 43].

Other water-saving technologies for irrigated rice include peripheral bunding, which improves rainwater use and reduces dependence on canal water supplies, dry-seeding with zero-tillage, alternate wetting and drying (AWD), intermittent irrigation and early transplanting of seedlings[16, 99].

In West Africa, where most rice is grown on slopes and valley bottoms without adequate irrigation and drainage, AfricaRice is promoting a low-cost 'smart valleys' development approach that uses simple earthen structures such as bunds, along with basic irrigation and drainage infrastructure.

Besides increasing resilience to drought, bunding and land levelling reduce the risk of applied fertilizer being washed away by heavy rain[100, 101].

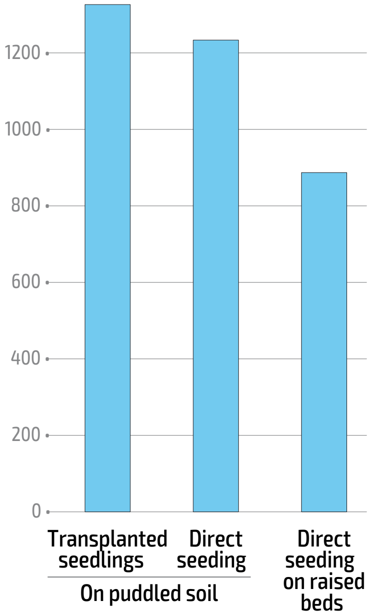
Average yields are between 3.5 and 4 tonnes per ha, which has led to improvements in farmers' incomes. The 'smart valleys' approach, which was developed and validated with the full participation of farmers in Benin and Togo, has been incorporated into Benin's national strategy for inland valley development[52].

In Asia, alternate wetting and drying, in which a rice field can be left unwatered for up 10 days, has reduced water needs by 15 to 30 percent, with no loss in yield[102]. Suitable for lowland rice areas with reliable water supplies, AWD reduces spending on fuel for pumping water; it also lowers methane emissions from rice fields by up to 70 percent[103]. The practice has been integrated into national programmes in Bangladesh, Myanmar, the Philippines and Viet Nam. With optimum implementation, AWD could allow a shift in some areas from a single rice crop to double cropping[52].

System of Rice Intensification practices reduce water consumption, per hectare, to almost half that of flooded rice fields by allowing dry periods between irrigations and lowering considerably the level of flooding (see Chapter 3, p.44).

In many areas, the practice of transplanting rice seedlings into puddled soil has been replaced by direct-seeding – seeds may be broadcast on wet or puddled fields, or drill-seeded with no prior tillage. Compared with transplanting, direct-seeding produces similar yields while reducing irrigation water applications by up to one-third |Figure 2.8|[16].

Figure 2.8 **Irrigation water applied in transplanted and direct seeded rice production systems** (mm)*



* Derived from 44 country studies

Source: Adapted from Table 8, p.339[16]

Another practice, suitable for dry season rice production, is 'aerobic rice', which is grown in dry soil with irrigation applied only as necessary. Tested and adopted by farmers in the Philippines and northern China, the technology uses varieties adapted to well drained, non-puddled and non-saturated soils in rainfed and water-scarce areas[104].

With good management, aerobic rice yields can be around 75 to 80 percent of those obtained from flooded rice, but using 50 to 70 percent less water. Labour requirements are also lower[52]. On black soils in India, the pre-monsoon dry-seeding of rice through surface mulch has provided a profitable alternative for farmers whose normal practice has been to leave the land fallow[62].

Integrated pest management

Insect pests, diseases and weeds cause substantial losses – in the range of 20 to 50 percent – in the maize, rice and wheat fields of smallholder farmers[105]. They can also lead to reduced grain quality and to post-harvest losses from infestation and spoilage. In the case of weeds, manual control is one of the most time-consuming tasks faced by smallholders, and a job usually carried out by women.

The first line of defence against pests and diseases is a healthy agro-ecosystem. Save and Grow uses integrated pest management (IPM), a 'problem-avoiding' crop protection strategy that draws on and enhances the biological processes and crop-associated biodiversity that underpin crop production. The approach was developed in response to the widespread over-use of pesticides, which reduces populations of pests' natural enemies, leads to outbreaks of secondary pests, creates pesticide resistance, and increases the risks to both people and the environment. A recent study found that at least 50 percent of the pesticide used is simply not needed in most agro-ecosystems[106].

In IPM programmes, farmers are trained to base their pest management decisions on an economic threshold, which establishes an acceptable level of damage below which the cost of control measures is not compensated by any increase in productivity. The basic strategy is to foresee and avoid problems and, if they are unavoidable, to detect them early enough so that they can be controlled by natural means, with smaller quantities of relatively safer pesticides being used only as a last resort[1].

Integrated pest management was first applied in Asian rice fields to combat the brown planthopper, a major cause of crop losses. Outbreaks of planthoppers were triggered by indiscriminate spraying of wide-spectrum insecticide, which killed the pest's natural enemies and allowed rapid growth of its populations[107,108].

In response to one such outbreak in Viet Nam, FAO supported community-based management of the pest and its associated diseases using IPM. Among the measures put in place were farmer monitoring of the numbers of planthoppers and natural predators in rice fields, the removal of infected plants, the optimization of seeding times and fertilizer use, and the planting of more resistant varieties[52]. Vietnamese farmers have reduced their use of insecticide by as much as 70 percent and, with strong government support, the rice-growing area under IPM in one province has expanded exponentially |Figure 2.9|[109].

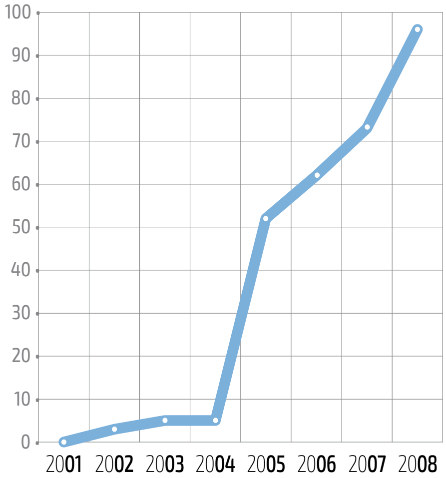
Where rice production is integrated with aquaculture, fish feed on insect pests, disease-causing fungi and weeds, reducing the need for chemical controls. Rice-fish farmers apply up to 68 percent less pesticide per hectare than farmers producing rice alone (see Chapter 3, p.68).

Studies throughout Asia have highlighted the advantages of conducting training in IPM through farmer field schools, a form of adult education that encourages rice growers to tailor IPM practices to diverse and changing ecological conditions. Farmers attending field schools typically reduce insecticide applications per season from three to one, and report a general increase in yields. In one area of Indonesia, farmers virtually eliminated insecticides and achieved yield increases of 21 percent. They also gained social skills and improved relations with service providers[110, 111].

Intensive training of farmers can significantly reduce the use of pesticide in maize production. In Nicaragua, trained farmers sprayed their crops far less often than untrained farmers, and used less than 10 percent the normal amount of insecticide |FIG 2.10|[112]. Highly effective non-chemical approaches are also available for maize pest control. In the Andes of Peru, Ecuador and Bolivia, smallholder farmers apply mineral or edible oil to maize whorls and silks to reduce infestations of insect pests by up to 76 percent[113-115]. To combat the fall armyworm, scientists in Brazil have developed two highly effective biopesticides, which are less toxic and better targeted than wide-spectrum synthetic pesticide. Their active ingredients are isolates of a bacterium and a virus that can reduce armyworm numbers by more than 95 percent[116-118].

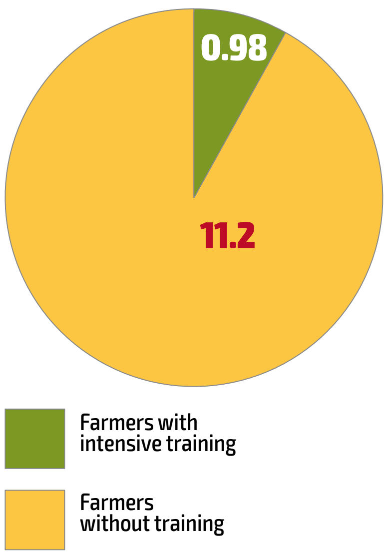
In African maize fields, crop rotation and better soil management have been used to control the parasitic weed *Striga*, which causes substantial crop losses on small farms[119]. In Madagascar, maize is planted with a leguminous cover crop, which stimulates germination of *Striga* seeds, then out-shades emerging weeds[52]. Rice is sown later through the legume residues. Direct-seeding helps prevent the mixing of weed seeds into the root zone, increases the overall resilience and stability of the system, and is particularly effective when combined with upland NERICA rice varieties[66, 67, 120]. In East Africa, a novel IPM system harnesses chemical interactions between two local plants to impede the growth of *Striga* weed and destroy maize stem borers (see Chapter 3, p.40).

Figure 2.9 Adoption of integrated pest management in rice-growing area of An Giang Province, Viet Nam (% of total area)



Source: Adapted from Figure 6, p.218[109]

Figure 2.10 Effects of training on maize farmers' average insecticide applications, Nicaragua (litres/ha)



Source: Adapted from Table 1, p.196[112]

In wheat production, IPM is based mainly on crop management practices and the use of resistant cultivars. Wheat is affected by a range of diseases. Powdery mildew causes crop losses of up to 45 percent[121], while the fungus *Septoria tritici* has cut grain harvests by half[122]. In Central and Western Asia and North Africa, losses of up to 80 percent have been caused by stripe rust[64].

The development and rapid deployment of resistant wheat varieties helped Ethiopia to overcome an outbreak of stem rust which, in the Bale region, had virtually wiped out the wheat crop. Resistant varieties have been planted on an estimated 80 percent of the national wheat area and are credited with enabling a record wheat harvest in 2014[64].

While resistant varieties, along with early planting, are effective in controlling the Hessian fly, a more complex IPM strategy is needed to control other insect pests. Recommendations for Sunn pest include targeted ground spraying, planting medicinal plants that attract natural predators, and using fungal preparations that kill the pest in its winter refuges. Control of wheat stem sawfly has been improved through the use of resistant varieties, delayed planting, crop rotation and parasitoids[64].

Participatory approaches such as farmers' field schools are also widely used to disseminate IPM options for wheat pests. Following its successful introduction to control Sunn pest infestations, IPM through farmer field schools has become the Islamic Republic of Iran's mainstream plant protection strategy[123].

Controlling weeds is also an important component of Save and Grow for cereals, and will become even more so as herbicide resistance in weeds increases. Avoiding soil disturbance, maintaining soil cover, practising crop rotation and preventing weed seeding are all effective measures for reducing weed pressure on crop production.

As the above review has shown, cereal growers worldwide have increased their productivity through the application of one or more of the Save and Grow farming system components, such as conservation agriculture, the use of improved varieties, better soil health management, increased water-use efficiency and integrated pest management. Many have made their production systems more resilient by diversifying crops and integrating crop, forestry and animal production. In the following *Chapter 3*, we present 11 examples of 'Save and Grow in practice' – cereal farming systems that have integrated all or most of the Save and Grow components and recommendations.

Chapter 3

Farming systems that save and grow

What does sustainable crop production intensification 'look like'? These examples, drawn from developing countries around the world, describe Save and Grow farming systems in practice

Key points

1

Maize/livestock, East Africa. 'Push-pull' fights maize pests, boosts milk production. A novel system of integrated pest management harnesses chemical interactions between two local plants to destroy maize stem borers and impede the growth of *Striga* weed. As well as providing year-round soil cover, the system produces high quality fodder, making 'push-pull' the basis for sustainable, low-input crop/livestock production. Page 40

2

Rice, Asia. Higher yields from healthy plants in healthy soil. From widely-spaced plants in aerated soil, the System of Rice Intensification has produced yields double those of flooded rice fields. Its focus on soil health improves the rice plant's access to nutrients, while its reduced irrigation needs help cut methane emissions. The system's higher labour requirements could be lowered with technological innovation. Page 44

3

Maize/forestry, Central America. More maize, less erosion on tropical hillsides. The 'slash-and-mulch' system grows maize and beans on untilled soil enriched with tree prunings. It builds soil nutrient stocks, reduces the time needed for land preparation and weeding, and produces yields double those of traditional shifting cultivation. Many 'slash-and-mulch' farmers have diversified production into home gardens and livestock. Page 48

4

Wheat/legumes, worldwide. The extra benefits of legumes before wheat. Legume residues add to soil up to 300 kg of nitrogen per hectare. As a result, wheat grown after legumes produces higher grain yields, with higher protein content. In addition, some legumes secrete acids that make phosphorus more readily available to the wheat's roots, and a gas that improves the plant's overall development. Page 52

5

Maize/livestock, Latin America. 'Nutrient pumps' feed cattle, nourish maize. A key component of sustainable maize-livestock systems is *Brachiaria* pasture, which prevents soil compaction and is more nourishing than native savanna grasses. Zero-tillage systems that use the grass produce up to three cereal crops a year. Relay cropping *Brachiaria* with maize makes optimal use of land resources and reduces land degradation. Page 55

See the **Glossary** on the inside back cover for terms used in this chapter

6 Rice/wheat, Indo-Gangetic Plains. Conservation agriculture the key to food security. In South Asia's breadbasket, farmers practise zero-tillage to reduce costs and grow more wheat. Alternate wetting and drying of rice fields helps cut water consumption by up to 50 percent. Yields of both cereals improve after laser-assisted land-levelling. Farmers save on fertilizer with 'needs-based' nitrogen management and use legumes to suppress weeds. Page 58

9 Maize/forestry, Southern Africa. Where trees and shrubs cost less than fertilizer. Leguminous shrubs and trees are an integral part of maize production systems in Zambia and Malawi. Over two years, they increase levels of soil nitrogen by as much as 250 kg per hectare, which helps quadruple maize output. The maize/forestry system is resilient to drought and more profitable than growing maize with fertilizer. Page 71

7 Maize/legumes, worldwide. Traditional system makes more productive use of land. Rotation, intercropping and relay cropping of legumes with maize lead to higher land productivity, making maize-legume systems especially suitable for smallholders. Legume rotation can increase maize yields by 25 percent. Maize intercropped with legumes under conservation agriculture produces 33 percent more grain than monocropping. Page 64

10 Wheat, Central Asia. Farmers stop ploughing on Kazakhstani steppe. Kazakhstan is one of the world's leading adopters of conservation agriculture. Direct-seeded, untilled land produces higher wheat yields than ploughed land, and carries lower production costs. Rotating wheat with other crops generates extra income and leaves residues that conserve soil moisture and block the germination of weed seeds. Page 75

8 Rice/aquaculture, Asia. A richer harvest from paddy fields. A one-hectare paddy can yield up to 9 tonnes of rice and 750 kg of fish a year. Fish raised in rice fields improve family diets and provide a natural source of plant nutrients and pest control. Thanks to higher rice yields, fish sales and savings on agrochemicals, the income from rice-fish farming is up to 400 percent more than that from rice monoculture. Page 68

11 Rice/maize, Asia. High-yielding hybrids help adapt to climate change. By growing maize instead of rice in the dry season, farmers reduce pressure on groundwater and double their profits. Many have increased their incomes further by intercropping maize with vegetables. Maize farmers trained in resource-conserving crop management use less mineral fertilizer and obtain yields twice the national average. Page 79

Agro-ecological zone Tropical rainfed
Main cereal Maize
Other crops/products Meat, milk, fodder, legumes, vegetables

1 · Maize/livestock East Africa

'Push-pull' fights pests, boosts milk production

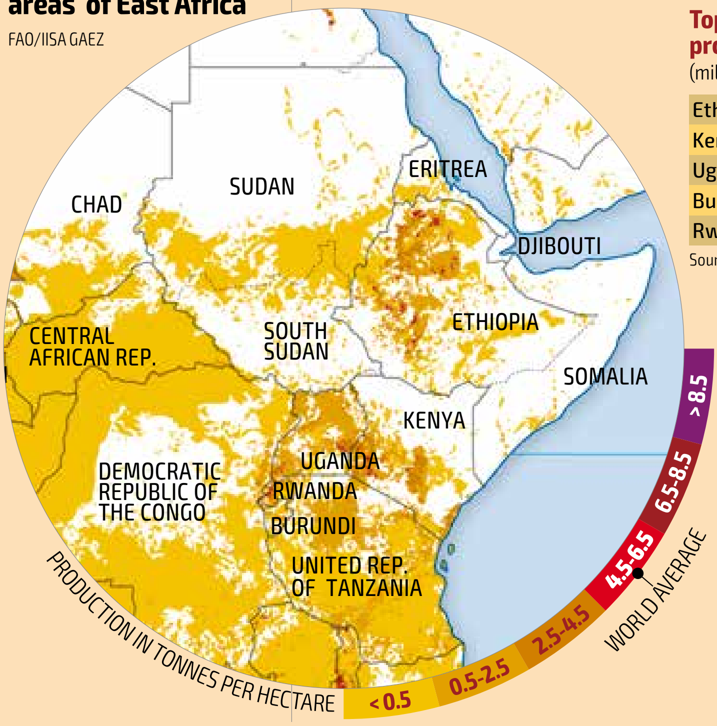
Two of Africa's most serious maize pests have been overcome by growing two local plants in maize fields. The 'push-pull' system produces other benefits, including high quality cattle fodder

Stem borers and the parasitic weed *Striga* are the bane of maize fields in Africa. The larvae of an indigenous moth, stem borers eat into the succulent stalks of maize and devour them from within, causing crop losses of from 20 to 80 percent. Ministries of agriculture often recommend the use of synthetic pesticide to control stem borers, but most smallholder farmers cannot afford it[1].

Striga, a parasitic plant that attaches itself to the roots of cereal crops and siphons off water and nutrients, grows on some 40 percent of sub-Saharan Africa's arable land. In western Kenya, it infests as much as 76 percent of land planted to maize and sorghum, causing annual losses valued at more than US$40 million. Sometimes, *Striga* infestations can lead to complete crop failure. Control of *Striga* is extremely difficult, as each plant produces thousands of tiny seeds that can remain viable in the soil for many years. As farmers abandon heavily infested areas to cultivate new land, *Striga* follows them[1].

In 1993, the International Centre of Insect Physiology and Ecology (ICIPE), in Nairobi, began working with the Kenya Agricultural Research Institute, Rothamsted Research (United Kingdom) and other partners to find affordable, environmentally friendly ways of controlling stem borers. What emerged from their work is now known as the 'push-pull' system of integrated pest management, which controls the borers by harnessing complex chemical interactions among

Maize producing areas of East Africa
FAO/IISA GAEZ



Top 5 maize producers, 2013
(million tonnes)

Ethiopia	6.67
Kenya	3.39
Uganda	2.75
Burundi	0.16
Rwanda	0.67

Source: FAOSTAT

Napier grass (at left) and *Desmodium* (at right) protect maize from borers and weeds

plants and insects in a biologically diverse agro-ecosystem[1].

In push-pull, maize is intercropped with the leguminous plant *Desmodium*, while a popular fodder crop, Napier grass, is planted as a border around the field. *Desmodium* produces volatile chemicals that attract predators of maize pests. More importantly, by giving a false distress signal to the moths that the area is already infested, these chemicals 'push' the egg-laying moths to seek out habitats where their larvae will face less competition for food[1].

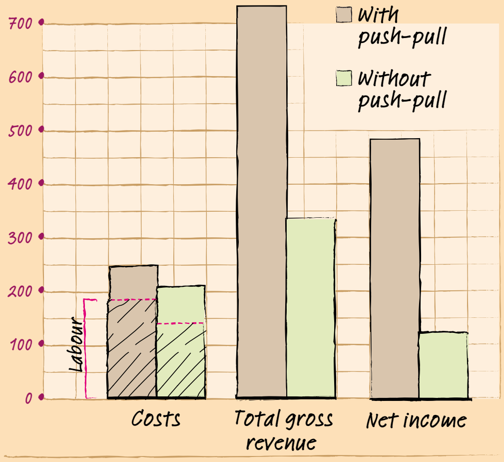
That's where the Napier grass comes in. It also produces volatile chemicals that 'pull' the moths towards them, and then exudes a sticky substance that traps the stem borer larvae as they feed on its stems. Few larvae survive to adulthood. Napier grass also attracts stem borer predators, such as ants, earwigs and spiders[1]. In trials, the number of stem borer eggs, and plant damage caused by stem borer feeding, have been found to be significantly higher in monocropped maize plots than in push-pull fields[2].

During the course of their work, Icipe researchers made a startling discovery: *Desmodium* also acts as a 'false host' to *Striga*, first exuding chemicals that induce germination of its seeds, then releasing other chemicals that inhibit the weed's root growth[1]. Trials of the push-pull system showed that maize plots not only suffered little stem borer damage, but were almost completely *Striga*-free after two seasons[3].

THE SYSTEM HARNESSES COMPLEX CHEMICAL INTERACTIONS AMONG PLANTS AND INSECTS

The push-pull system of pest control delivers other benefits. Both *Desmodium* and Napier grass are peren-

Figure 3.1 Economics of maize production, Kisii district, Kenya (US$/ha)



Source: Adapted from Table 1, p.6[1]

nial crops that provide year-round soil cover, which helps retain soil moisture, improves soil structure, prevents erosion, and makes the agro-ecosystem more resilient to drought and other extreme weather events. Since it is a leguminous plant, *Desmodium* also fixes nitrogen in the soil and makes it available to the maize crop.

Beginning in 1997, ICIPE and its partners introduced the push-pull system to maize and sorghum farmers in Kenya and eastern Uganda, using 'farmer teachers' to help them spread the word. By 2010, more than 25 000 farmers around Lake Victoria had adopted it. An impact assessment conducted in 24 villages found that 19 percent of farmers had adopted push-pull primarily to control pests, especially *Striga*, and to increase crop productivity. Seventy-five percent of those farmers said their yields were three to four times higher than before. Some were harvesting 5 tonnes of maize per ha from fields that had previously produced less than 1 tonne[3]. In Kisii district, the income of push-pull maize farmers, per hectare, was three times that of their neighbours |FIGURE 3.1|[1].

Almost half of the push-pull farmers had adapted the system to allow for the intercropping of maize with beans and other grain legumes, such as groundnuts, soybeans and cowpeas, and vegetables such as kale. Integrating beans in the system does not reduce *Desmodium*'s effect on *Striga* and stem borers[3].

The voracious maize stem borer causes crop losses of up to 80 percent

As well as helping farmers to increase food production, the Napier grass used in the system has boosted the supply of feed for livestock. In fact, the ICIPE assessment found that fodder production was an important factor motivating farmers to adopt push-pull[3]. For example, farmers in one district on Lake Victoria could satisfy only half of local milk demand owing to the lack of good quality feed. After 700 farmers adopted the push-pull system, milk production increased from 7 million to 8 million litres a year[1].

More livestock fodder means more manure is available for farmers to apply to their fields, which reduces the need for mineral fertilizer. Push-pull farmers have been able to diversify their production in other ways as well – for example, by selling organic produce and raising poultry. Farmers interviewed for the Icipe assessment said they used the extra income from higher production for a variety of purposes, including paying their children's school fees and improving their housing[3].

The assessment found, however, that some farmers had not adopted push-pull because they did not have enough information about it. Although push-pull saves on labour by reducing the need for weeding, some farmers did not have enough household labour – or enough cash to hire extra help – to establish the system in their fields.

In addition, farmers with one-year land leases were reluctant to invest in a technology that did not produce rapid benefits. The lack of *Desmodium* seeds and their high cost also limited rates of adoption[3].

By 2014, as many as 70 000 smallholder farmers in Ethiopia, Kenya, the United Republic of Tanzania and Uganda – of whom more than half are women – were controlling *Striga* with *Desmodium* intercropping[4].

The International Centre of Insect Physiology and Ecology and partners have adapted push-pull to drier areas and to climate change by identifying and incorporating into the system two drought-tolerant companion plants: Greenleaf desmodium as an intercrop, and *Brachiaria* grass as a border plant[5].

Push-pull is now seen as the basis of an integrated crop-livestock production system that does not require high levels of external inputs and could significantly improve food security in East Africa. A recent survey of 900 farmers in Ethiopia, Kenya and the United Republic of Tanzania found a high potential for adoption of the system, especially among women and those who were aware of the damage caused by *Striga* and had good access to inputs[6].

Establishing push-pull as a permanent part of agriculture in the region will require continued support from government extension services and the use of community-based extension strategies, such as farmer field schools, farmer-teacher events and local public meetings[3].

It will also require an assured supply of *Desmodium* and *Brachiaria* seed, along with the seed of improved maize varieties and hybrids.

THANKS TO PUSH-PULL, MILK PRODUCTION INCREASED BY 1 MILLION LITRES A YEAR

Agro-ecological zone Tropical monsoon, irrigated and upland systems
Main cereal Rice

2. Rice Asia

Higher yields from healthy plants in healthy soil

Rice farmers are adopting crop, soil and water management practices which, together, produce more rice and income using less water, less fertilizer and less seed

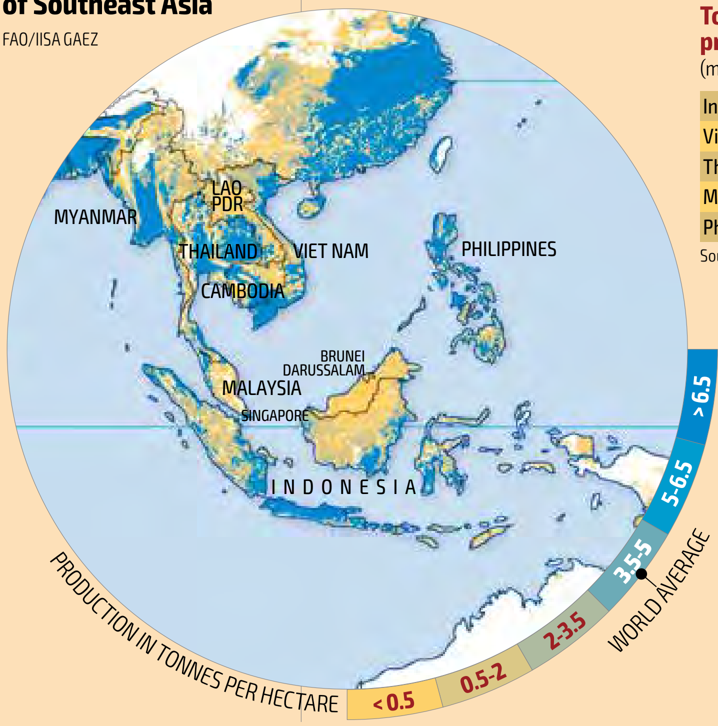
Traditionally, rice has been cultivated in most of Asia as follows: fields are first flooded then ploughed to create soft, muddy soil often overlying a dense, compacted layer that restricts downward loss of water[1]. Rice seedlings 20 to 60 days old are then transplanted to the fields in clumps of two to four plants, randomly distributed or in narrowly spaced rows. To suppress weeds, the paddy is continuously flooded with 5 to 15 cm of water until the crop matures[2, 3].

That system has enabled the cultivation of rice for millennia at low, but relatively stable yields[4]. When the Green Revolution introduced high-yielding varieties, mineral fertilizer and chemical pest control, per hectare productivity in many Asian rice fields doubled in the space of 20 years[5].

A set of crop, soil and water management practices known as the System of Rice Intensification (SRI) takes a strikingly different approach. Seedlings 8 to 15 days old are transplanted singly, often in grid patterns with spacing of 25 x 25 cm between plants. To promote moist, but aerated, soil conditions, intermittent irrigation is followed by dry periods of 3 to 6 days. Weeding is done at regular intervals, and compost, farmyard manure and green manure are preferred to mineral fertilizer. Once the plants flower, the field is kept under a thin layer of water until 20 days before the harvest[3, 6].

Since SRI was first developed in Madagascar in the 1980s, numerous trials have shown that the system out-

Rice producing areas of Southeast Asia
FAO/IISA GAEZ



Top 5 rice producers, 2013
(million tonnes)

Indonesia	71.3
Viet Nam	44.0
Thailand	38.8
Myanmar	28.0
Philippines	18.4

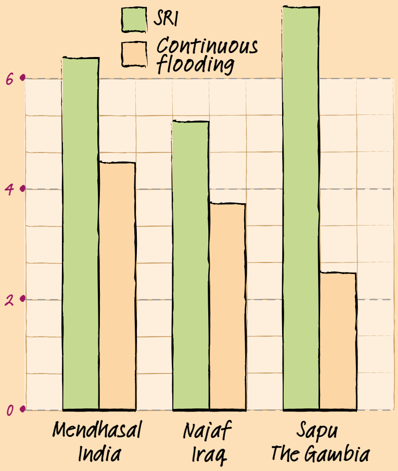
Source: FAOSTAT

yields traditional flooded-rice production, while reducing the use of water, seed, fertilizer and pesticide[2]. The system was found to improve grain yields above those obtained under flooded systems by 40 percent in India[7] and Iraq[8] and almost 200 percent in The Gambia[9] |Figure 3.2|. In comparison trials with current improved practices in China, Sri methods increased rice yields by more than 10 percent[10]. Rice grown using Sri consumed 25 to 47 percent less water than flooded systems in India[11] and China[12, 13], and required 10 to 20 percent less seed than traditional systems in Nepal[14].

The Governments of Cambodia, China, Indonesia and Viet Nam – where much of the world's rice is produced – have endorsed Sri methods in their national food security programmes, and millions of rice farmers have adopted Sri practices[2]. More than one million Vietnamese rice farmers are reported to be applying Sri; their per hectare incomes have increased by an average of Us$110, thanks to a 40 percent reduction in production costs[15]. Farmers who were trained in site-specific nutrient management in Viet Nam benefited from additional annual income of up to Us$78 per ha[16].

In Morang district, Nepal, a group of farmers reported that Sri had often doubled their yields. In addition, their rice was maturing up to four weeks earlier, which saved water, reduced the risk of crop losses and made land available for other crops[14]. In Mali's Timbuktu region, farmers using Sri produced twice as much rice per hectare as their neighbours. Since Sri plots could be harvested 10 to 15 days earlier, farmers had switched from lower yielding, short-cycle varieties to medium-duration varieties, which produce more grain[2].

Figure 3.2 Grain yields of rice grown under continuous flooding and System of Rice Intensification (t/ha)



Source: Adapted from Table 3, p.84[7]; Table 9, p.127[8]; Table 1, p.9[9]

The System of Rice Intensification could help to overcome many of the challenges facing the rice sector. With its emphasis on organic sources of plant nutrition and high fertilizer-use efficiency, Sri offers a means of reducing the environmental pollution caused by nitrate losses from rice fields[17]. It may allow farmers to continue to cultivate rice in rainfed areas, such as northeast Thailand, which are increasingly affected by drought, and in major irrigated rice areas of China, Pakistan and India, where, by

2025, water supply is forecast to be insufficient to meet demand[18].

The system could also dramatically reduce emissions of methane from irrigated systems[19]. At present, more than 90 percent of the world's rice is harvested from flooded fields, which emit methane totalling some 625 million tonnes of carbon dioxide equivalent annually[20]. Emissions could be reduced by almost one-sixth if all continuously flooded rice fields were drained at least once during the growing season[21]. The System of Rice Intensification does that several times during the growing season[6].

TECHNICAL INNOVATIONS COULD REDUCE THE LABOUR REQUIREMENTS OF SRI CULTIVATION

Scientists are looking for rigorous explanations of SRI's lower resource use and higher productivity, as well as examining the ways in which SRI guidelines are followed by farmers[3].

An important focus of SRI systems is improved soil health. Intermittent irrigation and the application of organic compost and mulch significantly increase the number of beneficial soil bacteria in the root zone[22, 23]. Since SRI rice is planted singly in healthy, aerated soil with more room to absorb solar energy, it can develop larger root systems, which would lead to a higher number of stems[24]. The plants may also have longer panicles, more grains per panicle, and a higher percentage of mature grains[7].

Higher yields may be due to increased nutrient availability and superior growing conditions, which enhance the plant's physiological development[9]. A more general explanation offered is that SRI exploits more fully the genetic potential of the rice plant[2, 6]. However, a recent review of SRI's reported high yields found a 'substantial diversity' in SRI practices, making it difficult to draw general conclusions about the impact of SRI as a 'singular technological package'[3].

Much of the debate around SRI centres on the increased demand for labour in SRI production. In The Gambia, labour costs of transplanting were two to three times higher than those of conventional flooded rice[9]. A recent

study in India found that because it was very labour-intensive, the system carried much higher production costs and was 'really uneconomical'[25].

However, proponents of SRI respond that it generates employment. In Tamil Nadu (India), SRI production was found to be the most suitable option for employing otherwise idle family labour during the dry season[11].

The labour requirements of SRI cultivation could be lowered with technical innovations, such as seedling trays that simplify seedling preparation and transplanting[9]. Another option is replacing transplanting altogether with direct-seeding, which in Nepal produced yields 50 percent higher than those obtained from transplanted rice[14]. In Sichuan province, China, seedlings are being planted on zero-tilled, furrow-irrigated, permanent raised beds under organic mulch or plastic film[26].

More than one million Vietnamese rice farmers are applying SRI practices

Agro-ecological zone Tropical hillside, rainfed
Main cereal Maize
Other crops/products Meat, milk, timber, fuelwood, fruit, legumes, vegetables

3 • Maize/forestry Central America

More maize, less erosion on tropical hillsides

Farmers have developed a slash-and-mulch production system that preserves trees and shrubs, conserves soil and water, doubles yields of maize and beans, and even resists hurricanes

On the steep hillsides of south-western Honduras, traditional 'slash-and-burn' cultivation of maize, beans and other food crops has led to widespread deforestation and environmental degradation. Many farmers have abandoned the age-old practice of allowing cleared fields to lie fallow long enough for tree cover to grow back and for the soil to recover. Without trees to anchor the depleted soil, erosion has increased, reducing the quality of water and its availability to downstream users. As agricultural productivity declines, rates of rural poverty and malnutrition have risen[1,2].

Recognizing that slash-and-burn cultivation was unsustainable, farmers in the Honduran department of Lempira developed a low-cost, resource-

Maize producing areas of Central America
FAO/IISA GAEZ

Top 5 maize producers, 2013
(million tonnes)

Mexico	22.66
Guatemala	1.73
El Salvador	0.87
Honduras	0.60
Nicaragua	0.55

Source: FAOSTAT

conserving system for growing their crops[1]. Instead of clearing the forest and burning vegetation, they adopted a 'slash-and-mulch' approach. They begin by broadcasting sorghum or beans in an area of well-developed, naturally regenerated secondary forest. After planting, they selectively cut and prune the trees and shrubs, and spread the leaves and small branches on the soil surface to create a layer of mulch. High-value timber, fruit and fuelwood trees are left to grow[1, 2].

Once the sorghum and beans have been harvested, maize is planted (maize is not used as a 'pioneer crop' because mulch slows the emergence of its seedlings). Farmers continue to prune trees to ensure that the crops have sufficient sunlight, while leaves, branches and crop residues are used to maintain a semi-permanent soil cover. The soil is not tilled, and fertilizer is applied only when needed[2].

In the early 1990s, the Food and Agriculture Organization began working closely with local farmers and farmers' groups to develop and disseminate those practices, which have become known as the Quezungual Slash-and-Mulch Agroforestry System, or QSMAS[1]. The system has since been adopted by more than 6 000 low-income farmers in southwestern Honduras[2].

Using QSMAS, those farmers have been able to double the productivity of shifting cultivation – maize yields have risen from 1.2 tonnes to 2.5 tonnes per ha, and bean yields from 325 to 800 kg[1]. Increased productivity has improved food security and has allowed farmers to set aside space in their fields to explore different options for producing food. Almost half of the farmers who have adopted QSMAS use some part of their land, and their additional income, to diversify production, primarily to home gardens and livestock[2].

Honduran farmers have embraced the system because it is founded on

The slash-and-mulch system has been adopted by more than 6 000 smallholder farmers

Using QSMAS, farmers increased bean yields from 325 to 800 kg per hectare

familiar, indigenous farming practices, is more productive and profitable than slash-and-burn agriculture, and delivers many other benefits. By retaining soil moisture and preventing erosion, QSMAS has made farms more resilient to extreme weather events, such as a drought in 1997 and Hurricane Mitch in 1998. The system also reduces the time required to prepare the land and control weeds – an important consideration in an area where labour scarcity is a major constraint to improving farm productivity.

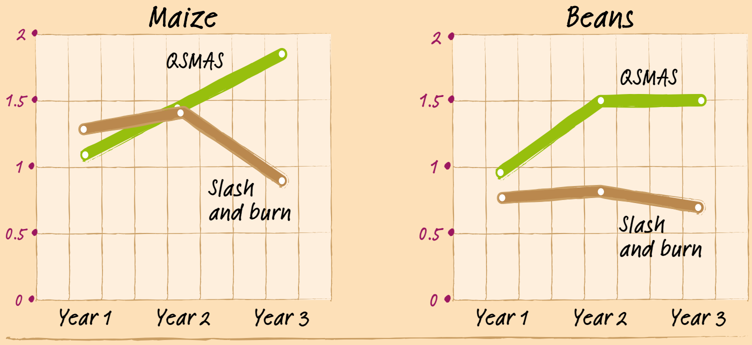
Rural communities also benefit from improved water quality, as well as increased water availability during the November to April dry season. The trees retained on QSMAS farms meet around 40 percent of households' fuelwood needs[2].

The success of QSMAS was also due to the fact that local communities and extension workers were encouraged to share ideas and learn from each other. Thanks to that participatory process, the impact of QSMAS has reached beyond the farmers' fields. Once they became more aware of the problems created by deforestation, community institutions banned the use of slash-and-burn[2].

In 2005, the International Center for Tropical Agriculture (CIAT) undertook a four-year project with the goal of furthering the development of QSMAS and improving the livelihoods of the rural poor. The Center sought to identify the main principles behind QSMAS management, the biophysical benefits that make the system resilient, the social factors that lead to its acceptance, and other maize-producing areas where it could be adopted.

During trials on 15 plots, the differences between slash-and-burn and slash-and-mulch emerged clearly in measures of sustainability and resilience. A QSMAS production cycle allows for around 10 to 12 years of cultivation of annual crops, followed by

Figure 3.3 Average grain yields obtained under slash-and-burn and QSMAS systems, Somotillo, Nicaragua (t/ha)



Source: Adapted from Table 3.4, p.48[2]

seven years of fallow. In contrast, slash-and-burn yields begin to decline from the second year of cropping |Figure 3.3|. In slash-and-burn agriculture, the nitrogen content of the soil decreases over time, but it increases significantly on QSMAS plots. By measuring methane and nitrous oxide emissions and carbon stocks sequestered in the soil and trees, CIAT also found that the global warming potential of QSMAS is only a quarter that of slash-and-burn agriculture[2].

The maize production system has spread to other regions of Honduras and to El Salvador, Guatemala and Nicaragua, where farmers have often adapted its basic practices – progressive pruning, permanent soil cover, minimal soil disturbance and efficient use of mineral fertilizer – to local conditions[3].

In trials in Guatemala, maize yields rose by 11 to 25 percent in soils enriched with the prunings of *Gliricidia sepium* trees. Adoption rates reached 88 percent in areas where the system was promoted[2].

In Nicaragua, where farmers learned about slash-and-mulch from visiting Honduran farmers, maize yields at validation sites were more than double those under slash-and-burn, while profitability increased by 83 percent. As a result, by 2010 more than half of the farmers in one Nicaraguan community had adopted QSMAS. Nicaragua's Institute of Agricultural Technology is now promoting the system[4].

The Quezungual Slash-and-Mulch Agroforestry System is seen as an alternative to slash-and-burn agriculture for sub-humid hillside areas of the tropics[3]. It is estimated that in 18 countries of Africa, Asia and Latin America there is a 50 percent probability of finding similar conditions to QSMAS test sites, with the largest areas in Brazil, El Salvador and the Democratic Republic of the Congo[4].

THE SYSTEM IS SEEN AS SUITABLE FOR SUB-HUMID HILLSIDE AREAS ACROSS THE TROPICS

Agro-ecological zone Temperate, sub-tropical rainfed and irrigated
Main cereal Wheat
Other crops Grain and forage legumes

4 • Wheat/legumes Worldwide

The extra benefits of legumes-before-wheat

Wheat farmers grow legumes to improve the health of soil and provide a natural source of nitrogen, which boosts wheat yields. Conservation agriculture is needed to realize the full benefits of wheat-legume rotation

Growing legumes can be a very good investment in its own right. Since they derive 70 to 80 percent of their nitrogen needs from the atmosphere, through biological nitrogen fixation in their root nodules, grain and forage legumes generally do not require nitrogen fertilizer to achieve optimum yields[1]. Grain legumes, such as lentils, are high in protein, dietary fibre, vitamins, minerals, antioxidants and phyto-estrogens[2] and can be sold to generate income. Forage legumes, such as alfalfa, can be used on the farm to feed livestock.

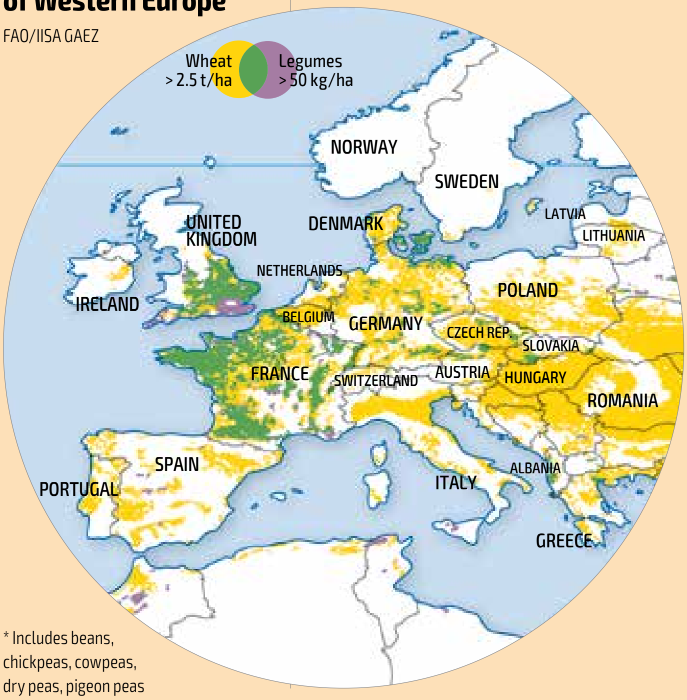
When grown before wheat, legumes produce another significant benefit – nitrogen in legume residues reduces the need to apply nitrogen fertilizer to the wheat crop[3]. It is estimated that globally, some 190 million ha of grain legumes contribute around 5 to 7 million tonnes of nitrogen to soils[4]. Thanks to that 'natural fertilization', wheat grown after legumes produces higher grain yields and has higher protein content than wheat grown after another wheat crop[5].

The high productivity of wheat-legume rotations has long been recognized by wheat farmers, and for as far back as 2 000 years ago in Western Asia and North Africa. Typical rainfed wheat-based rotations include grain legumes, such as chickpeas, lentils and faba beans, and the forage legumes vetch, berseem clover and *Medicago* species[6-8].

Choosing the right legume for a specific wheat farming system is extremely important, as different legume

Wheat and legume* producing areas of Western Europe

FAO/IISA GAEZ



* Includes beans, chickpeas, cowpeas, dry peas, pigeon peas

Top 5 wheat producers, 2013
(million tonnes)

France	38.61
Germany	25.01
United Kingdom	11.92
Belgium	1.80
Austria	1.59

Source: FAOSTAT

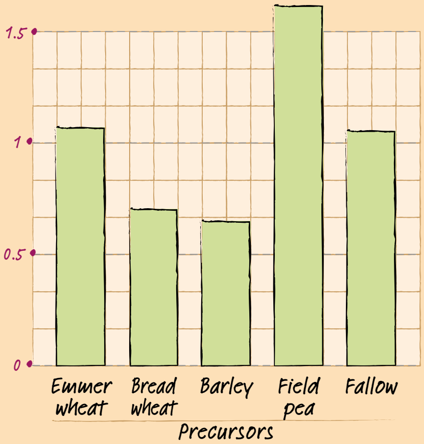
species and varieties growing in the same location can differ significantly in dry matter production, nitrogen fixation and accumulation, and residue quality. Residual nitrogen values from grain legumes vary greatly, but can cover between 20 and 40 percent of wheat's nitrogen needs[3]. While grain legumes can add to the soil from 30 to 40 kg of nitrogen per ha, legumes grown as green manure crops or as forage for livestock build up nitrogen much faster, and can fix as much as 300 kg of nitrogen per ha[9].

Legumes enhance wheat's uptake of other nutrients. Wheat grown after legumes tends to have a healthier root system than wheat-after-wheat, making it better able to use other available nutrients. The roots of chickpeas and pigeon peas secrete organic acids which can mobilize fixed forms of soil phosphorus and make it more readily available[5].

Legumes also release hydrogen gas into the soil, at rates of up to 5 000 litres per ha per day. A by-product of nitrogen fixation, hydrogen is oxidized by soil microbes surrounding the root system of the plant, leading to changes in the soil biology that improve the development of the wheat plant[1, 5]. Deep-rooting legumes such as pigeon peas, lablab and velvet beans help build soil structure and biopores, which improve drainage and aeration[10].

Wheat sown in the autumn and followed by a summer fallow is the predominant production system in dry areas. In the Middle East and North Africa, fields are commonly left fallow

Figure 3.4 Yields of bread wheat grown as a second crop following selected precursors, Bale Region, Ethiopia (t/ha)



Source: Adapted from Table 4, p.140[17]

owing to the lack of sufficient moisture to sustain reliable production of rainfed summer crops. However, with the development of early maturing legume varieties, farmers can now replace long fallows with legume crops, which make more productive use of land[11, 12]. Growing food legumes in summer not only helps enhance soil fertility and water-use efficiency, but boosts yields of the subsequent wheat crop[13].

In the highlands of Ethiopia, pulses are grown in rotation with cereals, or as intercrops, to spread the risks of drought and to improve soil fertility[14-16]. In the Bale region, wheat after field peas significantly out-yields wheat-wheat and wheat-barley rotations |FIGURE 3.4|[17]. A faba bean-wheat rotation system resulted in wheat yield increases of up to 77 percent while reducing the need for nitrogen fertilizer[18]. In the Islamic Republic of Iran,

After a crop of field peas, wheat yields improve significantly

Soybeans planted into standing wheat are more productive

DRILL-SEEDING WHEAT THROUGH LEGUME RESIDUES CONSERVES SOIL STRUCTURE, MOISTURE AND NUTRIENTS

cereal-legume intercropping has been shown to be more productive and profitable than wheat monocropping[19].

Managing legumes to achieve 'win-win' outcomes – a profitable legume and maximum benefits for the subsequent wheat crop – is complex for many farmers. Legumes are generally seen as more risky to grow than wheat or other cereals. This is partly because legumes are often more susceptible to biotic and abiotic stresses, which can reduce yields and plant biomass. If the legume fails to produce enough biomass to yield well and also leave residual nitrogen in straw and root residues, the smallholder loses income in one growing season without compensation in the next. In addition, prices for grain legumes are often more volatile than for cereals.

Due to their shorter growing season, some legume crops do not remove as much soil water as wheat, and leave more residual moisture for the wheat crop. However, this moisture can be easily lost if the legume residues are heavily grazed or removed for other purposes. It is recommended, therefore, that residues are left as a surface cover and wheat is drill-seeded with minimum soil disturbance[5].

To manage risk, farmers are advised to plant legumes only when there is sufficient moisture stored in the soil profile, or available as irrigation. While early planting enhances biomass production and nitrogen fixation, it can also increase susceptibility to pathogens. To realize the full benefits of wheat-legume rotation, residues should be retained on the soil surface, and both legumes and wheat crops should be established with zero-tillage to conserve soil structure, soil water and soil nutrients.

5 · Maize/livestock **Latin America**

'Nutrient pumps' feed cattle, nourish maize

A grass native to tropical Africa has dramatically increased livestock productivity in Latin America. Brazilian farmers have now integrated *Brachiaria* in a direct-seeded maize system that is replacing soybean monocropping

Agro-ecological zone Tropical savanna
Main cereal Maize
Other crops/products Meat, milk, forage, rice, millet, sorghum

Livestock production is particularly important in smallholder farming systems on the savanna grasslands of Latin America. However, output per animal unit in tropical areas is far below that achieved in temperate regions. A major constraint is the quantity and quality of forage, a key feed source in ruminant systems. Overgrazing, farming practices that deplete soil nutrients, and a lack of forage species that are better adapted to biotic and abiotic stresses – all contribute to low productivity. Improving pasture forage quality and productivity would help to boost production of meat and milk[1].

Many livestock farmers in Latin America have adopted a sustainable livestock production system that integrates forages with cereals. A key component of the system is *Brachiaria*, a grass native to sub-Saharan Africa, which grows well in poor soils, withstands heavy grazing and is relatively free from pests and diseases.

Thanks to its strong, abundant roots, *Brachiaria* is very efficient in restoring soil structure, and helps prevent soil compaction, which reduces rainwater infiltration and stifles root growth. It also has the ability to convert residual soil phosphorus into organic, readily available forms for a subsequent maize crop[2].

Recent CIAT research has identified another special characteristic of *Brachiaria*: a chemical mechanism found in the roots of one *Brachiaria* species inhibits emissions from the

Top 5 maize producers, 2013
(million tonnes)

Brazil	80.54
Argentina	32.12
Paraguay	4.12
Venezuela (Bolivarian Republic of)	2.25
Colombia	1.77

Source: FAOSTAT

Maize producing areas of South America
FAO/IISA GAEZ

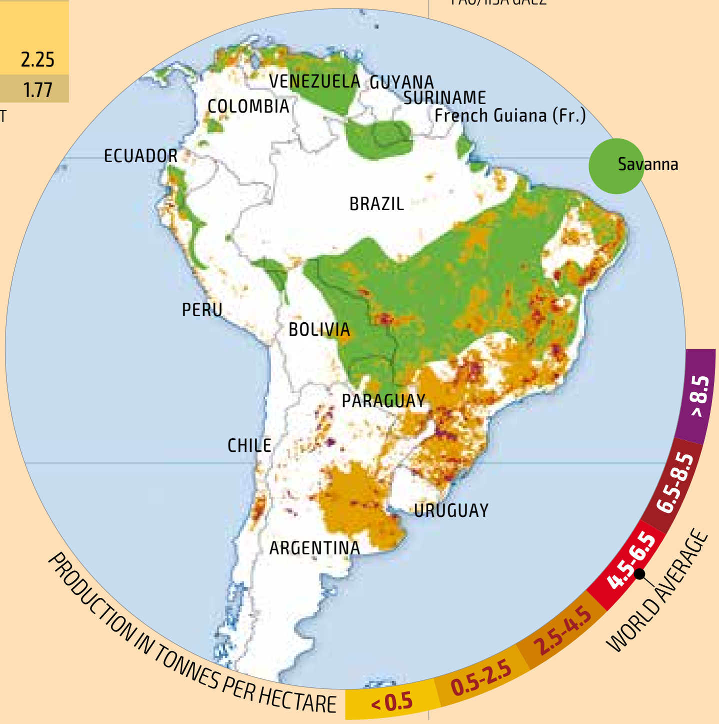
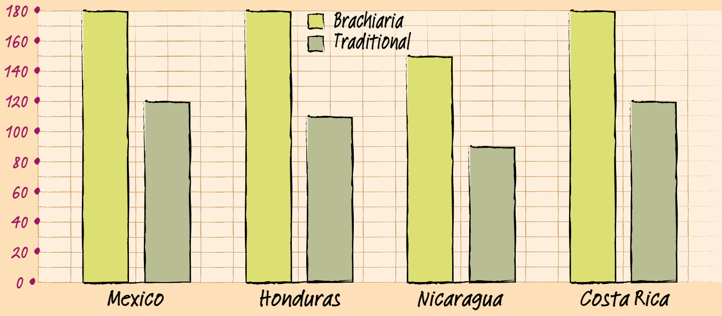


Figure 3.5 Levels of beef productivity on traditional and *Brachiaria* pastures (kg/ha/yr)



Source: Adapted from Table 1[5]

FOLLOWING INTENSIVE SOYBEAN MONOCULTURE, SOILS ARE LEFT COMPACTED AND SUSCEPTIBLE TO EROSION

soil of nitrous oxide, which is derived mainly from mineral fertilizer and is one of the most potent of the greenhouse gases causing climate change[3].

The versatile grass is now grown on an estimated 80 million ha of land in Latin America[4]. While the adaptation of *Brachiaria* to low-fertility soils has led to its use for extensive, low-input pastures, it is also suitable for intensively managed pastures[1].

In Mexico and Central America, the productivity of animals feeding on *Brachiaria* pastures is up to 60 percent higher than those feeding on native vegetation |Figure 3.5|. The value of the additional production has been estimated at US$1 billion a year[5]. In Brazil, annual economic benefits have been put at US$4 billion[6].

Rotation of annual crops with grazed pasture is increasing in the Cerrados eco-region of Brazil, where beef cattle are a major source of income for many farmers. Years of poor herd management, overgrazing and lack of adequate soil nutrient replacement have led to declining productivity and reduced profitability in traditional livestock production systems[1,7,8].

Where natural ecosystems have been replaced by intensive soybean monoculture, much of the soil is compacted and susceptible to erosion from heavy rainfall. Under those conditions, traditional techniques of soil erosion control, such as contour planting, have proved to be ineffective[9].

In response, many farmers have adopted zero-tillage systems, which increase soil cover and bring other environmental benefits. In the early 1990s, less than 10 percent of the Cerrados was under zero-tillage; by 1996, it had risen to 33 percent. Including expansion of the harvested area, the total area under zero-tillage in the Cerrados increased 17 times over[10].

It has been estimated that around 50 percent of the total cropped area in Brazil is under direct-seeded, mulch-based cropping (DMC) systems, which usually support three crops a year, all under continuous direct-seeding[11]. In the Cerrados, more than 4 million ha are cultivated using diversified DMC systems, which have replaced inefficient, tillage-based soybean monoculture. A typical sequence is maize (or rice), followed by another cereal, such as millet or sorghum, or the grass *Eleusine*, intercropped with a forage species such as *Brachiaria*[11,12].

The forages function as 'nutrient pumps', producing large amounts of biomass in the dry season that can be grazed or used as green manure. Combining maize and *Brachiaria* at the end of the rainy season taps soil

Brachiaria grass restores soil structure and helps prevent compaction

water from levels deeper than 2 m, and promotes active photosynthesis later during the dry season. It results in vigorous vegetative re-growth after the first rains of the following season, or after rain during the dry season, thus ensuring permanent soil cover[13].

Because *Brachiaria* provides excellent forage, farmers can then choose to convert the area into pasture, or keep it in grain production for another year. Such systems are found under irrigation and in wetter regions with frequent, heavy rains that recharge deep water reserves. In the best DMC systems, total annual dry matter production, above and below the soil, averages around 30 tonnes per ha, compared to the 4 to 8 tonnes found under monocropping[14].

To reduce crop competition, novel intercropping systems have been developed. In the 'Santa Fé' system for maize and *Brachiaria*, developed in Brazil, the grass is made to germinate after the maize crop, either by delaying its planting or by planting it deeper. The young *Brachiaria* plants are shaded by the maize and provide little competition for the cereal. At maize harvest, however, shading is reduced and the established pasture grows very quickly over the maize residues[15].

This tight integration between forage and grain crops leads to a better use of the total farm area and a more intensive use of the pastures, with less pasture degradation. Similar DMC systems are being tested in other parts of the world, including sub-Saharan Africa[11].

Agro-ecological zone Sub-tropical monsoon and irrigated
Main cereals Rice, wheat
Other crops Maize, potatoes, sugar cane, cotton, legumes

6 · Rice/wheat Indo-Gangetic Plains

Conservation agriculture the key to food security

Resource-conserving technologies produce high wheat yields while reducing farmers' costs by 20 percent. A shift to conservation agriculture in rice would create positive synergies in the production of both crops

Stretching 2.25 million sq km across South Asia, from Bangladesh, through India and Nepal to Pakistan, the Indo-Gangetic Plains are both the rice bowl and breadbasket of 1.8 billion people[1, 2]. Over the past 30 years, thanks mainly to Green Revolution improved varieties and technology packages, farmers there have developed a crop rotation system that produces rice during the summer monsoon, and wheat during the short winter. Today, that rice-wheat system covers around 13.5 million ha and produces annually an estimated 80 million tonnes of rice and 70 million tonnes of wheat[3, 4].

In the most productive part of the plains – the northwestern Indian states of Punjab, Haryana and western Uttar Pradesh – the expansion of the rice-wheat area and yield increases of 3 percent a year allowed India to boost wheat production from 20 million tonnes in 1970 to 65 million tonnes by 1995. Around that time, however, rice and wheat productivity began to stagnate, with yields between 30 and 70 percent below their potential. The decline was blamed on 'soil fatigue' caused by decades of intensive cultivation, a continuous drop in input-use efficiency, the depletion of groundwater, and rising temperatures[5, 6].

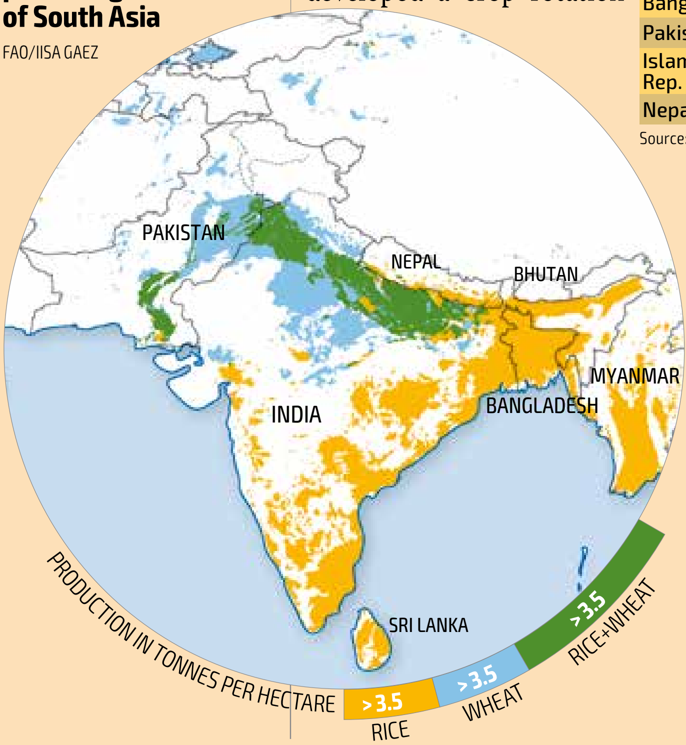
In response, the Rice-Wheat Consortium, an eco-regional initiative of national agricultural research systems and the CGIAR, launched a concerted effort in 1995 to promote resource-conserving technologies for cereal

Top 5 rice and wheat producers, 2013
(million tonnes)

India	252.71
Bangladesh	52.76
Pakistan	34.03
Islamic Rep. of Iran	16.54
Nepal	6.23

Source: FAOSTAT

Rice and wheat producing areas of South Asia
FAO/IISA GAEZ



The Indo-Gangetic Plains rice-wheat system produces 150 million tonnes of cereals a year

production. The technologies included zero-tillage, laser-assisted levelling of land, retention of crop residues, permanent bed planting, dry-seeding of rice and surface-seeding of wheat[3].

In India and Pakistan, the rate of adoption of many of those technologies has been 'exponential'[1, 5]. In Haryana state, for example, the wheat area under zero-tillage rose from nil to 300 000 ha between 1997 and 2002. In India as a whole, zero- and reduced-tillage for wheat production was practised on an estimated 1.6 million ha by 2005[7].

A major constraint to wheat productivity, on the eastern plains, is late sowing. Rice transplanting starts in July but often continues until late August, owing to the uncertainty of rains, the high cost of pumping groundwater, and labour shortages. Those delays result in a late rice harvest, which in turn postpones the sowing of the subsequent wheat crop well past the optimal planting date. Precious time is also lost owing to the farmers' practice of thoroughly ploughing the harvested rice fields, which are often seriously compacted by repeated puddling and the weight of combine harvesters[1, 6].

In many areas, the planting date of wheat has now been brought forward by direct-seeding – sowing is done after the rice harvest with no prior tillage operations[6, 8]. Seed and fertilizer are placed at appropriate spacing and soil depths, with minimal soil disturbance, using locally manufactured, tractor-mounted seed drills[1].

Zero-tillage contributes to higher wheat yields, in the range of 6 to 10 percent, because it allows for timely sowing, leads to a better crop stand, and generates big savings on tractor

Running parallel to the Himalayan mountains, the Indo-Gangetic Plains are the breadbasket and rice bowl of 1.8 billion people

operations, time and fuel |Figure 3.6|[9]. Farmers also save an estimated US$50 to US$70 per ha on water[6,10]. In some areas, irrigation water productivity has improved by as much as 65 percent above that obtained under conventional practices[2].

Water productivity improves even more when wheat is planted on zero-tilled raised beds[6]. Irrigating alternate furrows between the beds saves water and also allows the use of more saline water – salt accumulates on the sides of dry furrows, keeping the root zone relatively salt-free[11]. Other advantages of growing wheat on raised beds include reduced waterlogging, reduced seed rates, and more room for precise fertilizer placement, mechanical weeding, intercropping and relay planting of mungbeans[12].

On the western Indo-Gangetic plains, the adoption of zero-tillage in wheat production has reduced farmers' costs per hectare by 20 percent and increased net income by 28 percent, while reducing greenhouse gas emissions[13].

On the eastern plains, where drainage is poor, some farmers now broadcast or drum-seed pre-soaked wheat seeds, without tillage. This 'surface-seeding' is a low-cost technology particularly suited to smallholder farmers, who lack the resources for land preparation; it allows them to grow wheat in fields that would otherwise remain fallow[6,11]. Although yields are no higher than those of wheat broadcast on conventionally-tilled land, there is an income gain thanks to savings on tillage costs[14].

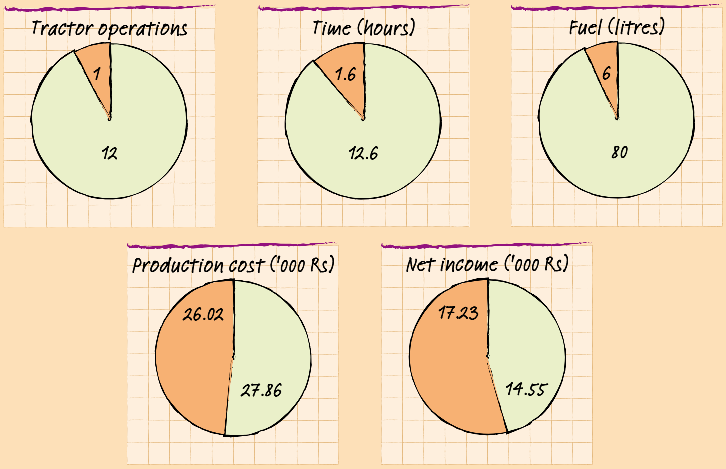
Dry-seeding of rice reduces water use, energy costs and labour requirements

For rice, the Consortium promoted the substitution of long-season cultivars with short-seasons ones, and direct dry-seeding which, by eliminating the need for transplanting, reduces water use, energy costs and labour requirements. In dry-seeding, fields are prepared in June and a short-season rice crop is sown after irrigation to establish it before the onset of the monsoon in July[6].

During crop growth, various approaches are being promoted to help farmers increase rice output with the same amount of water, or use less water without reducing yields. One approach is alternate wetting and drying, in which the paddy is flooded and the water is allowed to dry out before re-flooding. Another is aerobic rice, where seeds are sown directly into the dry soil, then irrigated. Both approaches result in water savings of 30 to 50 percent[6]. Raised-bed planting also produces significantly higher rice yields[12].

Another resource-conserving technology introduced to the Indo-Gangetic Plains is laser-assisted land-levelling. Many fields have uneven surfaces, which lead to wasted water, sub-optimal germination and lower yields. Traditionally, farmers have levelled their fields using scrapers and wooden boards. Now, laser-guided tractors, operated by private contractors, offer more precise levelling of fields at prices smallholders can afford. Recent studies in northwest India found that the technology is far more efficient than traditional levelling, reducing water applications by as much as 40 percent, improving the efficiency of fertilizer, and boosting rice and wheat yields by from 5 to 10 percent. It is equally profitable on all farm sizes[1, 14-16].

Figure 3.6 Economics of zero-tillage and conventional tillage in wheat production, Haryana, India (per ha)



Source: Adapted from Tables 1 & 2, p.93[9]

Farmers have also introduced new crop rotations that disrupt the life cycles of insect pests and weeds, and promote soil health. In Pakistan's Punjab province, smallholder farmers rotate rice with berseem clover, a fodder that improves soil fertility and suppresses weeds that might otherwise infest subsequent cereal crops[17]. On the eastern plains, where fields generally remain fallow for 80 days after the wheat harvest, a summer mungbean crop planted on zero-tilled soil produces 1.45 tonnes per ha, worth US$745. Mungbeans also add nitrogen to the soil through biological nitrogen fixation[14].

To reduce the wasteful use of fertilizer, the Rice-Wheat Consortium promoted 'needs-based' nitrogen management by introducing a leaf colour chart indicating the best times for fertilization. The charts were originally designed for rice, but were spontaneously adapted to wheat by farmers[18]. Using the charts, farmers have reduced fertilizer applications by up to 25 percent with no reduction in yield[1].

PRIVATE CONTRACTORS PROVIDE LASER-GUIDED LAND LEVELLING AT PRICES SMALLHOLDERS CAN AFFORD

Village surveys conducted across the plains in 2009 found that one in three farm households had adopted at least one resource-conserving technology, with the highest rates – of almost 50 percent – in the northwest. Farmers learned about the technologies from a variety of sources, including other farmers and equipment manufacturers, and most had integrated them into their traditional crop management practices. In northwest India, zero-tillage seed drills were the most common item of agricultural machinery after tractors[18]. Their high adoption rate was made possible by the ready availability of seed drills developed by the private sector, with strong support from state and local governments[7].

The impact of Save and Grow practices and technologies is reflected in recent increases in wheat production in India. Following poor yields from 2003 to 2007 in Punjab state, for example, wheat productivity has increased steadily, and average output exceeded 5 tonnes per ha in 2012[19]. In 2014, India's overall wheat production reached a record 96 million tonnes[4].

Much more needs to be done to achieve a full transition to the sustainable intensification of cereal production on the Indo-Gangetic Plains, but the potential rewards are enormous. To date, zero-tillage has been adopted mainly for the wheat component of the rice-wheat system. Applied to rice, it would lead to further, urgently needed, reductions in the use of irrigation water[7]. Numerous trials of zero-till, dry-seeded rice have shown that puddling is not essential for high yields[12].

Several strategies have been proposed to increase the uptake of dry-

Zero-tillage in action: the 'Happy Seeder' drills wheat seeds through heavy loads of rice crop residues seeding in rice production, including intercropping with *Sesbania*, which reduces weed infestations and boosts yields in unpuddled rice fields[9]. However, the large-scale adoption of dry-seeding is held back by lack of farmer access to suitable equipment. A recent study in northeast India found that 57 percent of farmers practised dry-seeding in 2012. However, since only 10 percent of farmers owned drill-seeders, most relied on service providers. Many farmers were unable to carry out dry-seeding because demand for services exceeded the supply[20].

A decisive shift to conservation agriculture practices in rice – particularly the retention of crop residues – would create positive synergies in production of the two cereals. While many farmers have adopted the drill-seeding of wheat into residues of the preceding rice crop, most continue to burn rice straw after the harvest, which leads to serious air pollution[19]. To discourage burning-off, and encourage mulch-based zero-tillage, the Governments of Punjab and Haryana states are now upscaling a new technology, the 'Happy Seeder', which can drill wheat seed through heavy loads of rice residues[21, 22].

Accelerated uptake of resource-conserving technologies also depends on improvements in policy support, technical knowledge, infrastructure and access to input and output markets. Needed is a systems approach, rather than commodity-centric technologies which make intensive, and unsustainable, use of labour, water and energy. A convergence among proven technologies and practices would harness the full benefits of conservation agriculture[23].

Finally, it may be time for farmers on the Indo-Gangetic Plains to further diversify production, away from just rice and wheat. Diversification from cereal monocropping to other high-value crops would reduce biotic and abiotic pressures on the system and conserve soil and water[6, 24]. Crop diversification also offers smallholder farmers higher income opportunities[7].

In the northwest, sugar cane, mungbeans, mint, maize and potatoes are now cultivated as part of rotations in the rice-wheat system. On the eastern plains, where winters are shorter, there is a growing trend towards replacing wheat entirely with potato and maize, which offer higher economic returns[1].

CROP DIVERSIFICATION OFFERS SMALLHOLDER FARMERS HIGHER INCOME EARNING OPPORTUNITIES

Agro-ecological zone Temperate, sub-tropical rainfed and irrigated
Main cereal Maize
Other crops Grain and forage legumes

7 • Maize/legumes **Worldwide**

Traditional system makes more productive use of land

Pigeon peas, cowpeas, groundnuts and jack beans are familiar sights in farmers' maize fields. The high productivity of maize-legume systems make them especially suitable for smallholders

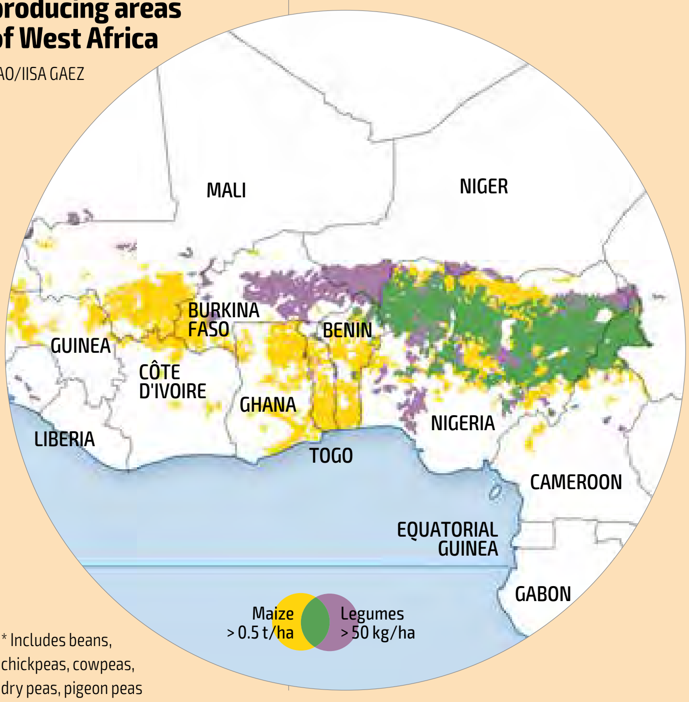
Maize-legume systems come in three basic configurations. One is intercropping, in which maize and legumes are planted simultaneously in the same or alternating rows. Another approach is relay cropping, where maize and legumes are planted on different dates and grow together for at least a part of their life cycle. Maize and legumes may also be grown as monocultures in rotation, with maize being planted in the same field after the legume harvest.

Such systems are common throughout the developing world. Commonly planted legumes include beans, pigeon peas, cowpeas, groundnuts and soybean, which are grown mainly for food, and non-edible legumes, such as velvet beans and jack beans, which are used as feed for livestock. All fix nitrogen in the soil and are useful as sources of residues that can be retained on the soil surface as mulch.

Maize-bean intercropping is a traditional practice among smallholder farmers in Latin America, especially in the land-scarce highlands. In Peru, practically all beans, and in Ecuador about 80 percent, are planted along with maize. In areas of Central America where land is limited and rainfall low, maize is often intercropped with field beans[1,2].

When maize and beans are intercropped, their yields are generally lower than those of maize or beans grown in monoculture. Studies have found that maize yielded 5.3 tonnes per ha when monocropped, 5.2 tonnes

Maize and legume* producing areas of West Africa
FAO/IISA GAEZ



* Includes beans, chickpeas, cowpeas, dry peas, pigeon peas

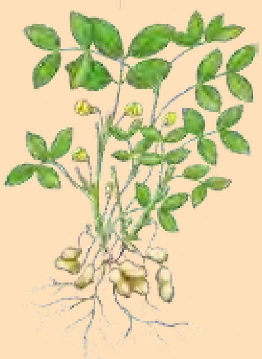
Top 5 maize producers, 2013
(million tonnes)

Nigeria	10.40
Ghana	1.76
Burkina Faso	1.71
Mali	1.50
Benin	1.35

Source: FAOSTAT

when intercropped with bush beans, and 3.7 tonnes when intercropped with climbing beans[3]. However, under intercropping, production costs per unit of output are usually lower and, because beans sell for up to four times the price of maize, farmers' income is higher and more stable[4].

Being drought-tolerant, pigeon pea is often intercropped with cereals in smallholder farming systems in Asia, Africa and the Caribbean. Pigeon pea is also deep-rooting, so it does not compete with maize for water, and is slow-growing in its early stages, which allows maize to establish properly.



As with maize and beans, both maize and pigeon pea, when planted together, yield slightly less than they do when cultivated alone. However, the overall yield from intercropping exceeds that which would have been produced by the corresponding monocrops – a comprehensive study of maize-pigeon pea intercropping in South Africa found that the system was nearly twice as productive as monocrops per unit of area[5]. In maize-pigeon pea systems in India and Sri Lanka, planting four rows of maize to two rows of pigeon pea provided the highest net returns[6].

A three-year study conducted in central Malawi found that intercropping maize and pigeon peas under conservation agriculture produced almost double the vegetative biomass, and in drier years 33 percent more maize grain than conventionally tilled maize monocropping[7]. In Mozambique, long-term maize-legume intercropping and zero-tillage improved rainfall infiltration five times over, thanks to good quality biomass production, which provided mulch[8]. In Panama, planting maize on jack bean mulch saved farmers 84 kg per ha in nitrogen applications[9].

Relay cropping is practised in Brazil, Colombia and Central America, where maize is planted in May-June and beans are sown between the maize plants in August-September. This allows the maize to develop enough to provide a support for the climbing beans[3]. In northern Ghana, planting fields with cowpeas, from three to six weeks before maize, yields a nutritious food at a time when other crops are not yet mature and, with the retention of residues, provides nitrogen to the soil[10].

Maize-legume rotations also help to maintain soil fertility. In Mexico, smallholder farmers have developed a system that grows velvet beans in the maize 'off-season', and leads to significantly higher levels of soil pH, organic matter and nitrogen. That, in turn, contributes to a 25 percent increase in the yield of the subsequent maize crop. The study concluded that the rotation system was more effective than intercropping[11].

A CIMMYT-led programme for the sustainable intensification of maize-

Each year, African farmers harvest an estimated 11.5 million tonnes of groundnuts

PER UNIT OF LAND AREA, MAIZE-PIGEON PEA INTERCROPPING IS NEARLY TWICE AS PRODUCTIVE AS MONOCROPPING

MAIZE-SOYBEAN ROTATION REDUCES SOIL EROSION AND ALLEVIATES PEST PRESSURE ON BOTH CROPS

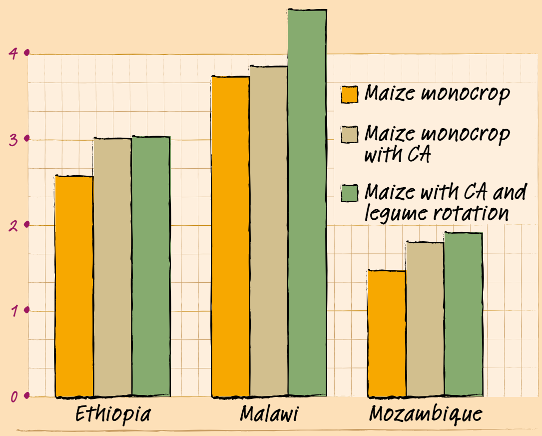
legume cropping systems in Eastern and Southern Africa found that, under conservation agriculture, the highest maize yield increases were achieved when the cereal was rotated with legumes such as beans, cowpeas and soybeans. In Malawi, farmers' normal practice obtained maize yields of 3.7 tonnes per ha; with CA, yields rose to 3.9 tonnes; with CA and after soybeans, yields reached 4.5 tonnes |FIGURE 3.7|[12].

A highly productive maize-soybean rotation system is practised in Nigeria. Planted before maize, the soybeans reduce *Striga* infestations by inducing premature germination of its seeds. The soybeans produce about 2.5 tonnes of grain and 2.5 tonnes of forage per ha, and residues that supply 10 to 22 kg of nitrogen per ha. Nitrogen is utilized by the subsequent maize crop, which produces yields up to 2.3 times higher than those under monocropping.

Nigerian farmers' soybean output rose from less than 60 000 tonnes in 1984 to 600 000 tonnes in 2013[13], encouraged by gross income that is 50 to 70 percent higher than that obtained from continuous maize. Increases in soybean yields and the planted area in Nigeria's dry savanna generated additional fixed nitrogen that has been valued at US$44 million a year[14].

Soybeans are often rotated with maize in Brazil. In the southern states of Mato Grosso and Paraná, maize is a second-season crop that is planted on the mulch of early maturing soybeans, which improves moisture availability for the maize and reduces soil erosion. The rotation allows two harvests from the same field and alleviates pest pressure on both crops, leading to more sustainable production and improvements in farmers' income and livelihoods[15].

Figure 3.7 Impact of conservation agriculture (CA) and legume rotation on maize yields (t/ha)



Source: Adapted from Tables 1-3, p.380[12]

Strong-stalk maize varieties support greater weights of climbing beans

While the benefits of maize-legume systems are well known, smallholder farmers who rely on food crops for household food security – especially in Africa – are often reluctant to occupy their fields with non-edible legumes for half or a full year, regardless of the long-term benefits[16]. Adoption of these systems in Africa is also constrained by dysfunctional markets for rotational crops, the unavailability of seed and the farmer's perception of risk[17].

Governments may invest in the development of smallholder maize-legume systems as a means of ensuring food security, improving farmer incomes and improving soil health. Since non-edible legumes such as velvet bean have very high carbon sequestration potential, climate change mitigation funding may be available to encourage smallholder adoption.

Maize and legume varieties that produce high yields in monoculture generally also have high yields when intercropped. However, differences in the suitability of certain varieties for maize-legume systems have been observed. Breeding efforts should exploit productive interactions, such as strong-stalk maize that supports higher weights of beans. Generally, maize-legume systems also exhibit considerable site specificity. Therefore, the system and its variations require extensive validation in farmers' fields.

Agro-ecological zone
Monsoon paddy systems
Main cereal Rice
Other products
Finfish, crustaceans, snails

8 · Rice/aquaculture Asia

A richer harvest from paddy fields

Many rice farmers raise fish around paddy fields to produce food, control pests, and fertilize their rice crop. Result: lower costs, higher yields and improved household nutrition

A field of rice in standing water is more than a crop – it is an ecosystem teeming with life, including ducks, fish, frogs, shrimp, snails and dozens of other aquatic organisms. For thousands of years, rice farmers have harvested that wealth of aquatic biodiversity to provide their households with a wide variety of energy- and nutrient-rich foods. The traditional rice-fish agro-ecosystem supplied micronutrients, proteins and essential fatty acids that are especially important in the diets of pregnant women and young children[1].

During the 1960s and 1970s, traditional farming systems that combined rice production with aquaculture began to disappear, as policies favouring the cultivation of modern high-yielding rice varieties – and a corresponding increase in the use of agrochemicals – transformed Asian agriculture. As the social and environmental consequences have become more apparent, there is renewed interest in raising fish in rice fields[2,3].

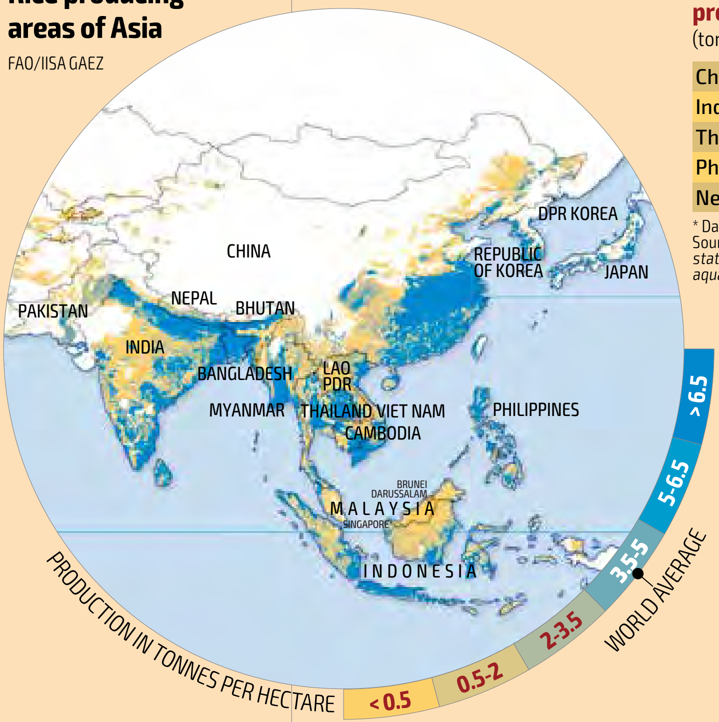
There are two main rice-fish production systems. The most common is concurrent culture, where fish and rice are raised in the same field at the same time; rotational culture, where the rice and fish are produced at different times, is less common. Both modern short-stem and traditional long-stem rice varieties can be cultivated, as can almost all the important freshwater

Ricefield aquaculture production, 2010
(tonnes)

China	1 200 000
Indonesia	92 000
Thailand	21 000*
Philippines	150
Nepal	45

* Data for 2008
Source: FAO, 2012. *The state of world fisheries and aquaculture 2012.* Rome.

Rice producing areas of Asia
FAO/IISA GAEZ



A one-hectare paddy yields up to 750 kg of fish and 9 tonnes of rice a year

aquaculture fish species and several crustacean species[2,4].

In China, rice farmers raise fish in trenches up to 100 cm wide and 80 cm deep, which are dug around and across the paddy field and occupy about 20 percent of the paddy area. Bamboo screens or nets prevent fish from escaping. While fish in traditional rice-fish systems feed on weeds and by-products of crop processing, more intensive production usually requires commercial feed. With good management, a one-hectare paddy field can yield from 225 to 750 kg of finfish or crustaceans a year, while sustaining rice yields of 7.5 to 9 tonnes[5].

The combination of different plant and animal species makes rice-fish systems productive and nutritionally rich. Equally important are the interactions among plant and animal species, which improve the sustainability of production. Studies in China found that the presence of rice stem-borers was around 50 percent less in rice-fish fields. A single common carp can consume up to 1 000 juvenile golden apple snails every day; the grass carp feeds on a fungus that causes sheath and culm blight[2].

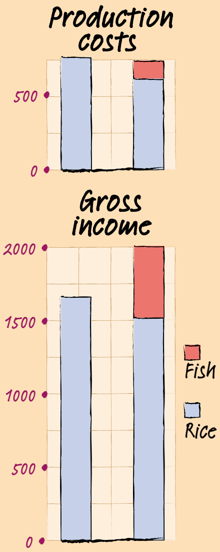
Weed control is generally easier in rice-fish systems because the water levels are higher than in rice-only fields. Fish can also be more effective at weed control than herbicides or manual weeding[2]. By using fish for integrated pest management, rice-fish systems achieve yields comparable to, or even higher than, rice monoculture, while using up to 68 percent less pesticide. That safeguards water quality as well as biodiversity[6].

The interactions among plant and animal species in rice-fish fields also improve soil fertility. The nutrients in fish feed are recycled back into fields through excreta and made immediately available to the rice crop. Reports from China, Indonesia and the Philippines indicate that rice-fish farmers' spending on fertilizer is lower[2].

Cultivating fish reduces the area available for planting rice. However, higher rice yields, income from fish

Snails harvested from Indonesian rice fields are a local delicacy

Figure 3.8 Economics of rice-fish farming and rice monoculture, Indonesia (US$/ha)



Source: Adapted from Table 15, p.50[2]

sales and savings on fertilizer and pesticide lead to returns higher than those of rice monoculture |Figure 3.8|[2]. Profit margins may be more than 400 percent higher for rice farmers culturing high-value aquatic species[6].

Raising fish in rice fields also has community health benefits. Fish feed on the vectors of serious diseases, particularly mosquitoes that carry malaria. Field surveys in China found that the density of mosquito larvae in rice-fish fields was only a third of that found in rice monocultures. In one area of Indonesia, the prevalence of malaria fell from 16.5 percent to almost zero after fish production was integrated into rice fields[2].

Combining rice and aquaculture also makes more efficient use of water. However, rice-fish farming requires about 26 percent more water than rice monoculture[2]. In areas where water supplies are limited, the introduction of rice-fish systems is not, therefore, recommended. However, FAO has estimated that almost 90 percent of the world's rice is planted in environments that are suitable for the culture of fish and other aquatic organisms[6].

In China, aquaculture in rice fields has increased steadily over the last two decades, and production reached 1.2 million tonnes of fish and other aquatic animals in 2010[6]. New opportunities for diversifying production are opening up in Indonesia, where the *tutut* snail, a traditional item in rural diets, is becoming a sought-after health food for urban consumers[4]. The resurgence in rice-fish farming is being actively promoted by the Government of Indonesia, which recently launched a 'one-million hectare rice-fish programme'[7].

While there is compelling evidence of the social, economic and environmental benefits of aquaculture in rice farming systems, its rate of adoption remains low outside of China. Elsewhere in Asia, the area under rice-fish production is only slightly more than 1 percent of the total irrigated rice area. Interestingly, the rice-fish farming area is proportionally largest outside Asia, in Madagascar, at nearly 12 percent[2].

There are many reasons for the marginality of rice-fish farming, including lack of awareness of its benefits, the availability of low-cost pesticides and smallholder farmers' limited access to credit for investment in fish production[2]. Overcoming those barriers is difficult because multi-sectoral policymaking is involved.

Rice-fish farming needs to be championed by agricultural policymakers and agronomists who recognize the benefits of integrating aquaculture and rice, and can deliver that message to rice-growing communities. Just as agricultural development strategies once promoted large-scale rice monoculture, they can now help to realize the potential of intensive, but sustainable, rice-fish production systems.

9 · Maize/forestry **Southern Africa**

Where trees and shrubs cost less than fertilizer

Leguminous trees and shrubs grown with maize provide high-quality, nitrogen-rich residues that improve soil fertility, boost yields and provide new sources of income

Agro-ecological zone Tropical, rainfed
Main cereal Maize
Other crops/products Meat, milk, fodder, fuelwood

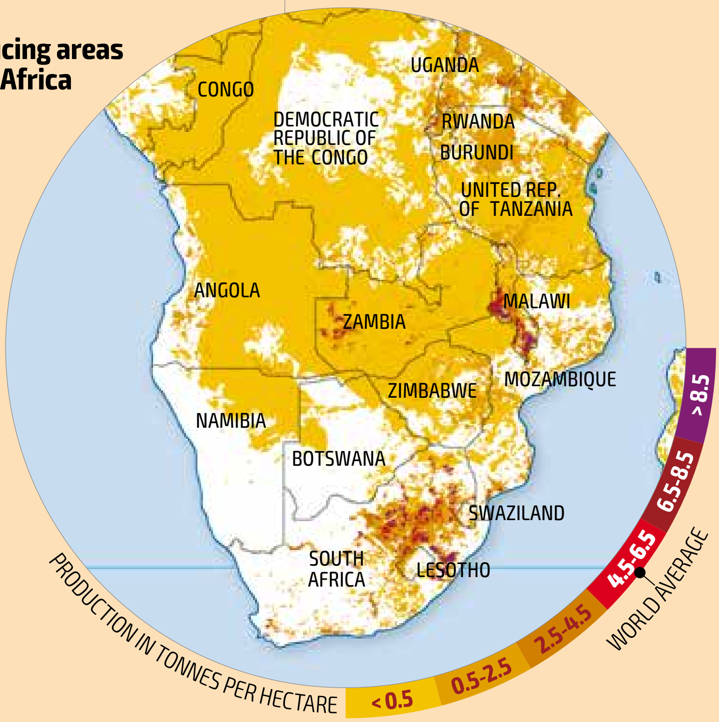
Food security in Malawi and Zambia depends on maize production. However, in both countries, yields average a low 1.2 tonnes per ha. Only about one in four smallholder farmers in Zambia and one in five in Malawi grow enough maize to sell in markets. Since maize production is almost entirely rainfed, the crop is highly vulnerable to fluctuations in rainfall and temperatures, and that vulnerability is likely to increase as climate changes.

In Malawi, a drought in 2004–2005 caused average maize yields to drop to just 0.76 tonnes per ha, and five million Malawians, nearly 40 percent of the population, needed food aid[1].

One of the main obstacles farmers face in increasing maize production is low soil fertility. Many maize farmers can neither afford mineral fertilizer nor obtain sufficient amounts of organic fertilizer, such as animal manure. Decades of intensive cultivation

Maize producing areas of Southern Africa

FAO/IISA GAEZ



Top 5 maize producers, 2013
(million tonnes)

South Africa	12.37
United Republic of Tanzania	5.36
Malawi	3.64
Zambia	2.53
Mozambique	1.63

Source: FAOSTAT

without fertilization have drained nutrients, particularly nitrogen, from the soil[1].

To address the problem, the Zambia National Farmers' Union has explored ways of integrating nitrogen-fixing trees into maize production systems[2]. The most promising candidate was found to be *Faidherbia albida*, an African acacia species, which has an unusual growth habit. The tree is dormant in the early rainy season and loses its leaves just as field crops are being established; the leaves only grow back at the end of the wet season. Maize can be grown directly under the leafless *Faidherbia* canopy, as the trees do not compete with the crop for light, nutrients or water while the maize is growing[3].

The falling leaves of *Faidherbia* enrich the soil with nitrogen and organic matter

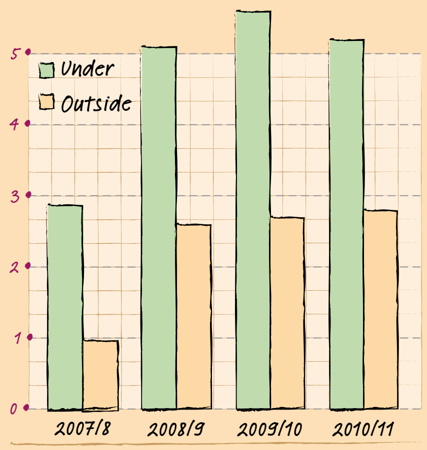
Thanks to the decaying leaves, the soil under the trees contains up to twice as much organic matter and nitrogen as soil outside the canopy. There is also a marked increase in soil microbiological activity, and an increase in water holding capacity[4].

Numerous studies have noted increases in yields when maize is grown in association with *Faidherbia*, and those increases tend to be higher where soil fertility is low. In Zambia, maize planted outside the tree canopy produced average yields of 1.9 tonnes per ha, compared to 4.7 tonnes when the crop was grown under the canopy |Figure 3.9|[5]; in Malawi, maize yields increased by 100 to 400 percent when the crop was grown with *Faidherbia*[1].

Both countries promote *Faidherbia* as part of conservation agriculture systems that offer smallholder farmers a means of increasing maize productivity and earning higher incomes from sales. National recommendations are to grow 100 trees per ha in a 10 m x 10 m grid pattern[1].

Faidherbia is now grown in conservation agriculture maize systems covering some 300 000 ha in Zambia.

Figure 3.9 Average yields of maize under and outside Faidherbia albida canopy (t/ha)



Source: Adapted from Figure 3, p.11[4]

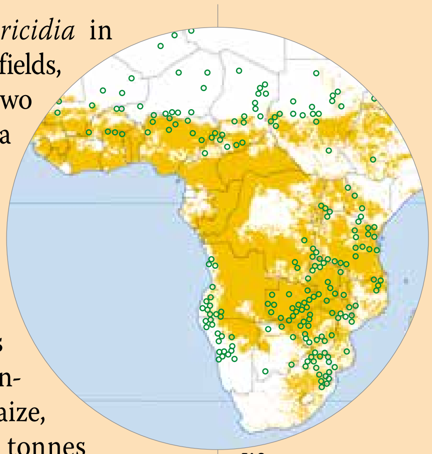
In Malawi, there are about half a million farms with the trees. Farmers have been able to establish most of the *Faidherbia* stands simply by assisting the natural regeneration of tree seedlings on their land[6].

Although *Faidherbia* is one of the fastest growing acacia species, it is not a quick fix for low soil fertility. In a survey of 300 Zambian farmers, one-third said that yields increased over a period of one to three years, while 43 percent said that it took up to six years before they saw benefits in production[6].

Planting leguminous coppicing trees, such as *Gliricidia sepium*, which take less time to establish, is another way of increasing maize production sustainably. On small landholdings in southern Malawi, the World Agroforestry Centre is promoting a system in which farmers plant *Gliricidia* in rows in their maize fields, prune them back two or three times a year, and mix the leaves into the soil. Findings from a decade-long study indicate that on unfertilized plots where *Gliricidia* is intercropped with maize, yields average 3.7 tonnes per ha, and reach 5 tonnes per ha in good years. On unfertilized plots without *Gliricidia*, average yields were only 0.5 to 1.0 tonne per ha[1].

In areas where land holdings are larger than 1 ha, growing leguminous shrubs such as *Sesbania sesban* on fallow fields is another option for revitalizing the soil and increasing maize yields. Leguminous trees and shrubs add from 100 to 250 kg of nitrogen per ha to the soil in fields that are left fallow for two or three years. Even though fields are unproductive for two out of every five years, overall production and returns on investment are higher when maize is grown in rotation with nitrogen-fixing shrubs and trees[1].

In eastern Zambia, one study found the average net profit was US$130 per ha when farmers cultivated maize without fertilizer; US$309 when it was grown in rotation with *Sesbania*; and US$327 when it was intercropped with *Gliricidia*. For each unit of investment, farmers who integrated trees with maize benefited from higher returns than those who used mineral



FAO

Distribution of *Faidherbia albida* sites across maize-growing areas of Africa

The leguminous shrub *Sesbania sesban* revitalizes soil and boosts maize yields

LOW-INCOME FARMERS ARE OFTEN QUICKER TO EMBRACE AGROFORESTRY THAN THOSE WHO ARE BETTER OFF

fertilizer, subsidized or unsubsidized, for continuous maize production[7]. The study confirmed that maize production in agroforestry-based systems is both socially profitable and financially competitive, compared to maize production using only mineral fertilizer[8].

Adopting agroforestry practices has helped smallholder farmers in East and Southern Africa to overcome one barrier to the adoption of conservation agriculture: the lack of crop residues to maintain a constant soil cover. Because most African smallholders also raise livestock, they often use crop residue biomass as animal fodder. With trees growing on their farms, there is now enough biomass to both meet livestock needs and improve maize yields.

The trees also provide fuel for rural households – in Zambia, farmers were able to gather 15 tonnes of fuelwood per ha after the second year of fallow with *Sesbania* and 21 tonnes after the third year[1].

Agroforestry improves soil structure and water filtration, which makes farms, especially those that rely on rainfall, more resilient to drought and the effects of climate change. Moreover, it can play an important role in climate change mitigation. Conservation agriculture with trees sequesters from 2 to 4 tonnes of carbon per ha per year, compared to 0.2 to 0.4 tonnes under CA without trees. In addition, by increasing maize production and the supply of fuelwood, farming systems that integrate trees with maize can reduce the need for converting forests to farmland, which is a major source of greenhouse gas emissions.

In Sahelian countries, such as Burkina Faso and Niger, agroforestry has been shown to improve the yields of other cereals, such as millet and sorghum. With further research and farmer engagement, conservation agriculture with trees could be expanded into a much broader range of food cropping systems throughout Africa[1].

Agroforestry does not require large financial investment. In fact, low-income farmers are often quicker to embrace it than farmers who are better off. Although more labour is required during the initial shift to a maize-forestry system, farm labour can be used more efficiently once farmers master the new practices. However, incorporating trees into crop production is a knowledge-intensive activity. Policy support, continued research and rural advisory services that engage smallholder farmers are crucial for the long-term expansion of farming systems that integrate maize, shrubs and trees[1].

10 · Wheat Central Asia

Farmers stop ploughing on Kazakhstani steppe

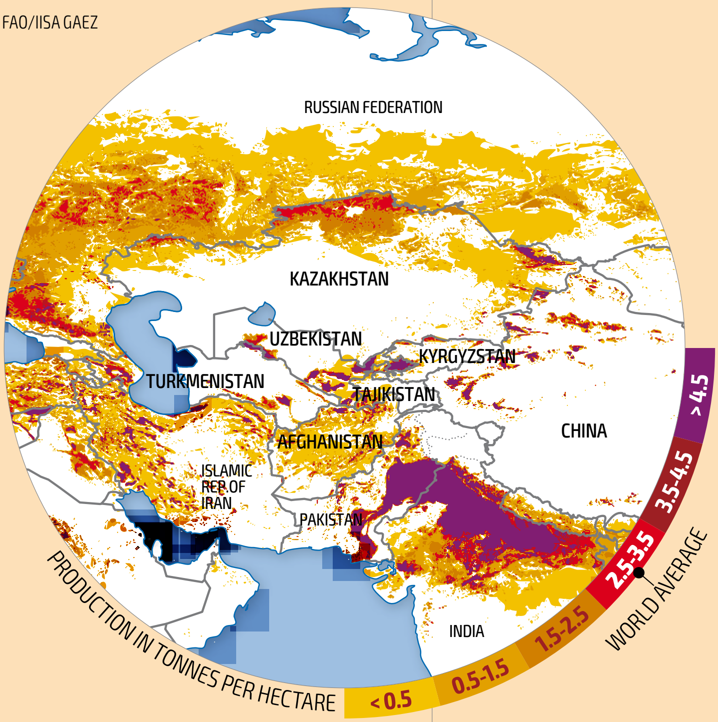
Zero-tillage, soil cover and crop rotation would help many countries to reverse land degradation and produce more food. Kazakhstan's wheat growers are already well advanced in the transition to full conservation agriculture

Agro-ecological zone Temperate continental, rain- and snow-fed
Main cereal Wheat
Other crops Oats, buckwheat, sorghum, oilseeds, legumes

In the spring of 2012, as farmers across the semi-arid steppes of northern Kazakhstan were sowing their annual wheat crop, the region entered one of its worst droughts on record. In many areas, no rain fell between April and September. To make matters worse, daily summer temperatures rose several degrees above normal[1]. That year, many farmers lost their entire crop and Kazakhstan's wheat harvest, which had reached 23 million tonnes in 2011, plummeted to less than 10 million tonnes[2].

Some farmers, however, did not lose their crops. They were among the growing number of Kazakhstani wheat growers who have fully adopted conservation agriculture (CA), including zero-tillage, retention of crop residues on the soil surface and crop rotation[1]. Those practices have increased levels of soil organic carbon and improved soil structure in their fields, allowing better infiltration and conservation of moisture captured from melting winter snow[3]. As a result, some farmers in Kostanay province achieved yields in 2012 of 2 tonnes per hectare, almost double the national average of recent years[1].

Wheat producing areas of Central Asia
FAO/IISA GAEZ



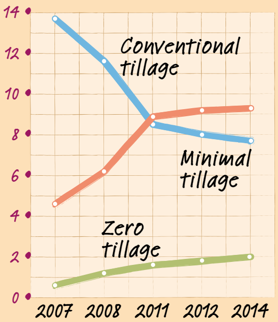
Around 2 million of Kazakhstan's 19 million ha of crop land are under full conservation agriculture. On 9.3 million ha, farmers have adopted minimal tillage, which uses narrow chisel ploughs at shallow depths |Figure 3.10|[4, 5]. The widespread adoption of conservation agriculture in

Top 5 wheat producers, 2013
(million tonnes)

Kazakhstan	13.94
Uzbekistan	6.84
Afghanistan	5.16
Turkmenistan	1.25
Tajikistan	0.92

Source: FAOSTAT

Figure 3.10 Changes in crop area under different tillage technologies in Kazakhstan (million ha)



Source: Adapted from Table 2, p.4[4]

northern Kazakhstan's wheat belt has been driven by necessity. While the country has vast land resources for wheat production, and is one of the world's leading producers and exporters of high-quality wheat and flour[6], the crop relies entirely on precipitation and is, therefore, very vulnerable to the loss of soil moisture[1].

Wheat farmers began reducing tillage in the 1960s to cope with high losses of soil to wind erosion. By the end of the twentieth century, minimal tillage was a common practice. In 2000, CIMMYT and FAO, together with Kazakhstani scientists and farmers, launched a programme to introduce conservation agriculture in rainfed areas, and raised-bed planting of wheat under irrigation in the south of the country[7].

Trials in the north showed zero-tilled land produced wheat yields 25 percent higher than ploughed land, while labour costs were reduced by 40 percent and fuel costs by 70 percent. The trials also demonstrated the advantages of growing oats in summer instead of leaving land fallow. With an oat crop, the total grain output from the same area of land increased by 37 percent, while soil erosion was much reduced[7].

Today, Kazakhstan ranks among the world's leading adopters of zero-tillage. The area of land that is no longer ploughed at all rose from nil in 2000 to 1.4 million ha by 2008[8]. That increase is attributed to very high adoption rates on large farming enterprises of more than 50 000 ha, where managers are striving to increase production while reducing costs[9]. However, the approach has also been taken up on small to medium-sized farms, a category which, in sparsely populated Kazakhstan, ranges from 500 to 2 500 ha[10]. The adoption rate has been particularly high on farms with rich black soils, where high returns provide the capital needed for investment in CA machinery[7].

In zero-tilled areas, weeds are often controlled with herbicides[11]. However, many farmers have found that combining zero-tillage with permanent soil cover also helps to suppress weeds. Without tillage, the natural store of weed seeds in the soil diminishes over time, and decomposing residues release humic acids, which block the seeds' germination. While zero-tillage usually requires increased use of herbicides in the first few years of adoption, after four or five years the incidence of weeds – and herbicide use – decreases considerably[5].

Another advantage of retaining crop residues in northern Kazakhstan is that it increases the availability of water to the wheat crop. Annual precipitation ranges from 250 to 350 mm, and winter snow accounts for around 40 percent of it; when the snow is blown away by wind, the soil surface is left bare and dry. Retaining the stubble of the previous wheat crop traps the snow which, when the weather warms, melts into the soil. That has two benefits: more moisture is available along the soil profile and erosion is reduced or even eliminated. On-farm research has found that the use of residues to

Kazakhstan is one of the world's leading producers and exporters of high-quality wheat and flour

capture snow, along with zero-tillage, can increase yields by 58 percent[9].

Progress in the adoption of the third pillar of CA, diverse crop rotations, which would increase land productivity and help farmers to better manage wheat pests and diseases, has been slower. The vegetation period on the northern steppes in summer is short, with a high frequency of dry years[12].

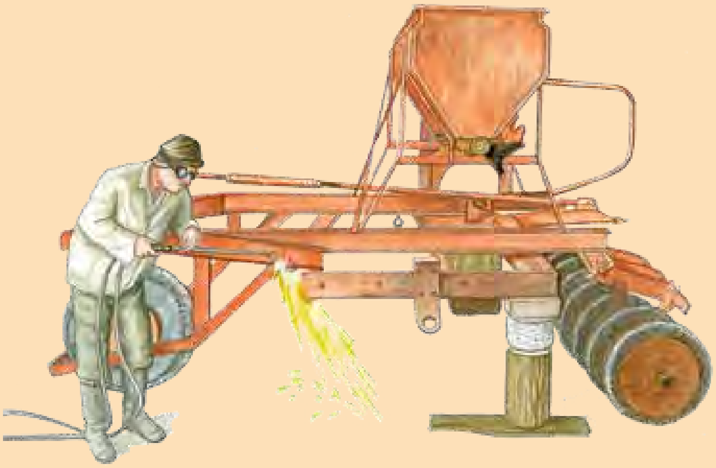
However, areas of traditional summer fallows are declining, as farmers take advantage of available – and sometimes abundant – rainfall to grow oats, sunflower and canola[7]. Studies have shown the high potential of other rotational crops, including field peas, lentils, buckwheat and flax[13].

A three-year study found that forage sorghum sown late in May and harvested in August provided not only fodder for sale or silage, but also left a durable post-harvest stubble that was very effective in trapping that precious winter snow[9].

The adoption of conservation agriculture in Kazakhstan has enabled an increase in annual wheat production of almost 2 million tonnes, sufficient to feed some 5 million people[10]. Further increases will be possible with the development of high-yielding wheat varieties better suited to zero-tillage and the north's harsh winters and increasingly hot summers. That option is being explored through a programme with CIMMYT, which crosses in Mexico local Kazakhstani wheat varieties with Mexican, Canadian and US cultivars[4].

ZERO-TILLAGE AND CROP RESIDUES THAT CAPTURE WINTER SNOW CAN INCREASE WHEAT YIELDS BY 58 PERCENT

Conservation agriculture is considered highly suitable for all of Central Asia's major cropping systems, from north Kazakhstan's wheat belt down to the irrigated wheat, rice and cotton fields of Uzbekistan and Tajikistan. By reducing erosion and building healthy soils, it would help combat the desertification and land degradation



Kazakhstani wheat growers have invested US$200 million in zero-tillage equipment

MOST CENTRAL ASIAN COUNTRIES STILL HAVE NO POLICIES TO PROMOTE CONSERVATION AGRICULTURE

that costs Central Asian countries an estimated $2.5 billion annually. By optimizing water-use efficiency, it could be particularly beneficial in irrigated areas – salinization, caused mainly by over-use of irrigation, affects 11 percent of irrigated land in the Kyrgyz Republic, 50 percent in Uzbekistan and 96 percent in Turkmenistan[14].

In recent years, information on conservation agriculture has reached farmers across the region and some CA practices are appearing in their fields. In Uzbekistan, for example, winter wheat is planted into standing cotton on some 600 000 ha. In Tajikistan, direct-seeding of winter wheat after the cotton harvest, with minimum soil disturbance, is practised on some 50 000 ha[5]. Trials conducted recently by an FAO project in Azerbaijan convinced smallholder farmers to adopt conservation agriculture on 1 800 ha of irrigated land[15].

However, full conservation agriculture remains limited outside of northern Kazakhstan. Even in the south of Kazakhstan, the adoption of zero-tilled, raised bed planting of wheat under irrigation is held back by a lack of suitable seeding equipment and farmers' general lack of knowledge of CA technologies. Most Central Asian countries have no policies that promote conservation agriculture. Quite the contrary: farmers often have little incentive to adopt water-saving practices because they do not pay for irrigation water[3]. Some countries even have tillage regulations that prevent farmers from leaving crop residues on the field[5]. While drill-seeders have been successfully tested in Uzbekistan, none are commercially available[11].

A transition to conservation agriculture in Central Asia should start by increasing the awareness of its benefits among all stakeholders, including farmers, researchers, extensionists and policymakers[14]. Governments can support the transition by facilitating the development of a local capacity for manufacturing CA equipment, particularly seed drills that are adapted to local soil and climatic conditions[15].

Many governments could learn from the example of Kazakhstan, where state policy promotes conservation agriculture, and the top priority in agricultural research is the development and dissemination of water-saving technologies. In 2011, Kazakhstan introduced subsidies on CA equipment that are three to four times higher than those on conventional technologies[3]. Government support has encouraged farmers in northern Kazakhstan to invest an estimated US$200 million to equip their farms with zero-tillage machinery[16].

11 · Rice/maize Asia

High yielding hybrids help adapt to climate change

Many rice farmers have switched to growing maize in the dry season, using hybrids that reduce water consumption and generate higher incomes. Close-up: Bangladesh

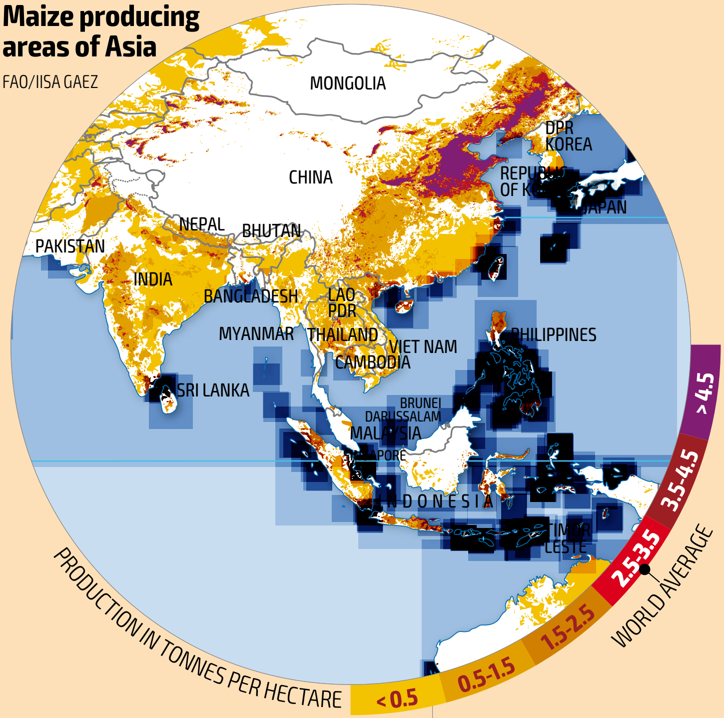
Agro-ecological zone Monsoon rainfed and winter irrigated
Main cereals Rice, maize
Other crops/products Vegetables, potatoes, legumes, meat, eggs

Traditionally, many Asian rice farmers have maintained year-round production by growing either wheat or rice in the dry winter season, after the monsoon rice crop. Over the past two decades, however, rice-maize farming systems have expanded rapidly throughout Asia, driven by a strong demand for maize and by the development of maize hybrids suited to areas with insufficient water for continuous rice cultivation[1].

At last count, rice-maize systems were practised on more than 3.3 million ha of land in Asia, with the largest production areas found in Indonesia (1.5 million ha), India (0.5 million) and Nepal (0.4 million). Recent expansion of the area under rice-maize rotation has been most rapid in Bangladesh, where farmers began growing maize to sell as feed to the country's booming poultry industry. Between 2000 and 2013, maize production increased from just 10 000 tonnes to 2.2 million tonnes, and the harvested area from 5 000 ha to 320 000 ha[1, 2].

Maize grows well in Bangladesh's fertile alluvial soils and yields there are among the highest in the region. The crop is sown at the start of the cool *Rabi* season, which runs from November to April, after the harvesting of the rice crop grown during the July-December *Aman* monsoon season. While *Rabi* maize is generally cultivated as a sole crop, many farmers have begun to intercrop it with potatoes and with early maturing vegetables, such as red amaranth, spinach, radish, coriander and French beans. Peas are also intercropped with

Maize producing areas of Asia
FAO/IISA GAEZ

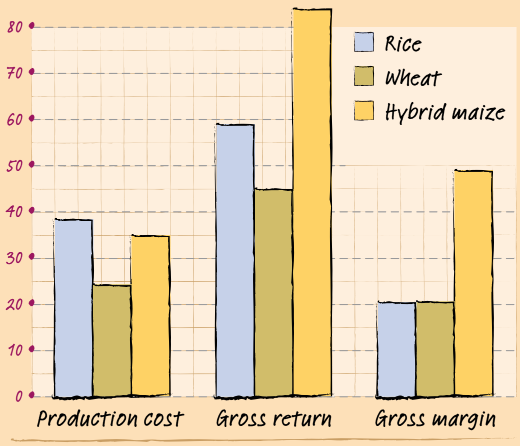


Top 5 maize producers, 2013
(million tonnes)

China	217.7
India	23.3
Indonesia	18.5
Philippines	7.4
Viet Nam	5.2

Source: FAOSTAT

Figure 3.11 Economics of dry season rice, wheat and hybrid maize production in Bangladesh ('000 Taka/ha)



Source: Adapted from Table 2, p.41[3]

maize because they do not compete for sunlight, nutrients or space[3].

Farmers typically use high-yielding hybrid maize, which requires significant inputs of nutrients. The cost of maize production is actually higher than that of other traditional winter cereals and, as a result, poorer farmers often plant maize on only a small area of land. However, the gross margin from maize sales, per hectare, is 2.4 times greater than that of wheat or rice |Figure 3.11|. Maize also has fewer pest and disease problems[3].

The diversification to maize could also be a good strategy for climate change adaptation, because maize is more tolerant of high temperatures, which are a growing problem for wheat, and is less thirsty for water – in Bangladesh, 850 litres of water produces a kilogram of maize grain, compared with 1 000 litres per kg of wheat and more than 3 000 litres for the same amount of rice. By reducing the extraction of groundwater for irrigation, maize production also helps reduce arsenic contamination of the soil, a severe problem in many areas of Bangladesh[3].

Farmers and agronomists in Bangladesh have noted that grain yields tend to decline in fields where maize has been cultivated as a dry season crop for five or more years. To ensure the sustainability of rice-maize systems, farmers need to carefully time the planting and harvesting of each crop, improve their soil and water management practices, and use quality seed[3].

UNTILLED RAISED BEDS PRODUCE HIGHER YIELDS OF RICE AND MAIZE THAN PLOUGHED LAND

The soil requirements of rice and maize are very different, which makes the timing of maize planting tricky. Transplanted *Aman* rice is usually grown in well-puddled, wet clay soils, while maize grows best in well-aerated loamy soils[3]. After the rice harvest, therefore, conventional preparation of fields for maize often involves three to five passes of a rotary tiller behind a two-wheel tractor. Ploughing requires considerable investments of time, fuel and labour, and farmers need to wait for up to three weeks before the rice fields are dry enough to be tilled[4]. Late planting of maize, in turn, can lower yields by as much as 22 percent[3].

Areas identified as suitable for maize production in Bangladesh

Conservation agriculture practices are reducing the need for ploughing and, with it, delays in maize planting. Establishing rice and maize on untilled permanent beds, using straw as mulch, has produced higher grain yields, using fewer inputs, than crops sown on ploughed land. Increased productivity has been attributed to higher levels of soil nitrogen and generally better soil conditions. In India, research showed that permanent beds not only produced higher yields than ploughed land, but did so using up to 38 percent less irrigation water[4]. In Bangladesh, saving water is crucial during the dry months from February to May, when shallow tube wells often run dry[3].

The Bangladesh Agricultural Research Institute and CIMMYT have adapted and promoted drill-seeders originally developed for wheat, so that they can be used to sow maize and

FARMER TRAINING IS CRITICAL TO THE RAPID AND WIDESPREAD ADOPTION OF SUSTAINABLE MAIZE PRODUCTION

rice without tillage. In northwest Bangladesh, farmers using these seeders obtained rice yields similar to those of transplanted rice, but using less water and labour, and were able to harvest the crop two weeks earlier[3].

A study in Bangladesh compared yields and profitability under ploughing and zero-tillage. With permanent bed planting of maize, the combined productivity of rice and maize was 13.8 tonnes per ha, compared to 12.5 tonnes on tilled land. The annual costs of rice-maize production on permanent beds was US$1 532 per ha, compared with US$1 684 under conventional tillage[4].

Hybrid maize requires large amounts of nitrogen to produce high yields. But Bangladesh's reserves of natural gas, which is used to produce urea fertilizer, are finite and non-renewable. One promising solution to soil nutrient depletion is the application of poultry manure, which is becoming abundant – Bangladesh's poultry sector now produces about 1.6 million tonnes of manure every year[3].

Good maize yields have been obtained by replacing with poultry manure 25 percent of the mineral fertilizer normally applied. Soil nitrogen can also be partially replenished by growing legumes, such as mungbeans, after the maize harvest[3]. In tropical monsoon climates, a summer mungbean crop also mops up residual nitrogen and prevents nitrate pollution of aquifers[5].

Planting short duration rice varieties would allow farmers to plant maize earlier. However, those rice varieties produce lower yields, and farmers are generally unwilling to sacrifice the production of their main food crop. The Bangladesh Rice Research Institute is, therefore, developing higher-yielding, shorter duration *Aman* rice varieties. The future of sustainable rice-maize farming in South Asia also hinges on the development of high-yielding maize hybrids that mature quickly and tolerate both waterlogging and drought[3].

Maize farming in Bangladesh is still new territory for many farmers, and it will take time for them to fully integrate it into cropping systems that optimize production and improve soil health. Critical to the rapid and widespread adoption of sustainable maize production is the training of farmers in the precise timing of sowing and more effective management of irrigation and mineral fertilizer[6,7].

Domestic maize production has reduced Bangladesh's dependence on imports. The shift to maize has also provided farmers with a means of diversifying their income and their diets. Many farmers do not sell their entire maize harvest – they feed some to their own poultry and sell eggs and meat at local markets. Increasingly, maize is being consumed as food, not just fed to poultry. As the price of wheat flour has increased, many families are mixing maize flour into their chapatis[8].

Chapter 4

The way forward

The widespread adoption of Save and Grow will require concerted action at all levels – by governments, international organizations, the private sector and civil society

The profiles of Save and Grow in practice, presented in *Chapter 3*, have demonstrated how integrated, resource-conserving farming systems, when adapted to specific agro-ecological and socio-economic contexts, generate significant social, economic and environmental benefits. Smallholder farmers have increased cereal production and productivity and improved their livelihoods and income, while conserving natural resources, enhancing ecosystem services, and adapting to and mitigating the effects of climate change. Save and Grow farming systems are often most effective under difficult farming conditions of water scarcity, soil nutrient depletion and climate extremes.

Sustainable crop production intensification, through Save and Grow, must now be scaled up, as a matter of urgency, in order to face the 'unprecedented confluence of pressures' that threatens the world's environment, socio-economic development and long-term food security.

Today, almost 800 million people are chronically hungry[1] and 2 billion suffer from micronutrient deficiencies[2]. Agricultural activities are depleting the very natural resources on which our food systems depend. Globally, one-third of all farmland is moderately to highly degraded through loss of organic matter, forest clearing, nutrient depletion and erosion[3]. Agriculture's share of the world's freshwater withdrawals faces intense competition: by 2025, two-thirds of the world's population could be living under conditions of water stress[4]. An estimated 75 percent of crop biodiversity has been lost and the remainder is at risk, while the increasingly narrow genetic base of major crop varieties exposes them to the impacts of climate change[5].

The 'confluence of pressures' is not felt uniformly. It is felt more by some countries and communities than by others, and particularly so in the rural areas of developing countries, where at least 70 percent of the world's very poor people live[6]. Poverty itself has been shown to be a major cause of natural resource degradation. The distribution of land suitable for cropping is also skewed against countries that have the greatest need to raise production[3].

The challenge we face is to meet today's demands for more food and other agricultural products than at any time in history, and to do it in a way that conserves natural resources and does not jeopardize the capacity of future generations to meet their own needs. At stake is not only global food security but prospects for global peace and stability.

The transition to sustainability – to ensure world food security, provide economic and social opportunities, slow the rate of climate change, and protect natural resources and ecosystem services – requires fundamental changes in the governance of food and agriculture[7]. It calls for striking a balance between the needs of both human and natural systems, between agriculture's multiple objectives, and between agriculture and other sectors.

That requires, in turn, a realistic assessment of the full costs of making transitions, including the need for building enabling policies and institutions. It also requires careful targeting of integrated farming systems that are adapted to site-specific conditions. Achieving sustainability hinges on an enabling policy, legal and institutional environment that strikes the right balance between private and public sector initiatives, and ensures accountability, equity, transparency and the rule of law[8].

Some lessons learned

We review first some of the 'lessons learned' from the Save and Grow farming systems presented in *Chapter 3*. The aim is to identify the actors, and the policy and institutional measures, that enabled and sustained the adoption of ecosystem-based cereal production, as well as the constraints that have impeded progress.

National and international organizations have played an important role in the development of sustainable farming systems. For example, FAO promoted the introduction of conservation agriculture in Kazakhstan and supported farmer training in Sustainable Rice Intensification (SRI) practices in Viet Nam. Conservation agriculture on the Indo-Gangetic Plains has been supported by an eco-regional programme of the CGIAR and national research institutes in four countries. Similar long-term partnerships have provided funding, research and technical advice for the development of maize agroforestry systems in Central America and Southern Africa.

Farmers and farmers' organizations have often led innovation in ecosystem-based production. In Honduras, smallholder farmers pioneered 'slash-and-mulch' production of maize, which has since been adopted in neighbouring countries. Farmers have introduced conservation agriculture practices, such as zero-tillage, to the System of Rice Intensification. In India, they adapted to wheat a nitrogen management tool originally developed for rice, while farmers in Kenya have adapted the 'push-pull' system of integrated pest management to grow beans and provide feed for livestock.

Government support, at all levels, has been crucial in upscaling sustainable crop production initiatives. Kazakhstan is one of the world's leading adopters of zero-tillage thanks to a national policy that promotes conservation agriculture. With the support of FAO, the Government of Indonesia has launched a 'one-million hectare rice-fish programme', which will make an important contribution to nutrition and rural development. State governments have funded the diffusion of zero-tillage maize systems in Brazil and supported the supply of zero-tillage equipment for wheat in India.

The private sector has also been a key facilitator of more sustainable and productive farming in some countries. In India, local factories manufacture zero-tillage seed drills and private contractors provide laser-assisted land levelling services. In Kazakhstan, conservation agriculture equipment, such as tractor-drawn seed drills, is readily available from dealers in agricultural machinery. Public-private partnerships are improving the seed supply in Brazil, China and India.

At the same time, constraints to the adoption of sustainable crop production intensification have been identified. While conservation agriculture would help to increase cereal production in Central Asia, most governments in the region have no policies to promote it, suitable equipment is generally unavailable, and farmers have few incentives to increase water productivity.

Despite the positive impact of 'push-pull' IPM on production, income and sustainability in East Africa, its adoption is hampered by insecure land tenure, which discourages farmer investment. The introduction of legume crops would improve maize yields and soil health in sub-Saharan Africa, but farmers lack access to seed and profitable markets for their produce.

Many governments continue to subsidize the price of pesticide and mineral fertilizer, tilting the comparative economic advantage against more sustainable systems, such as integrated rice and aquaculture production, which use fish to control weeds and insect pests, and cereal-legume systems, which capitalize on natural sources of nitrogen. In general, the private sector has under-invested in the development of sustainable technologies, and has often actively opposed measures to promote integrated pest management.

An important precondition for the adoption of Save and Grow practices is their adaptation to specific agro-ecological and socio-economic conditions, including labour availability. Labour costs have emerged, for example, as a factor limiting the wider adoption of the System of Rice Intensification in some areas.

Another major constraint is the time needed to realize the benefits of moving to sustainable production practices and restoring ecosystem services. In Kazakhstan, weed problems in wheat fields decline over a period of four to five years after adoption of zero-tillage and the retention of crop residues. In Zambia, it took up to six years for farmers to see the production benefits of growing maize with *Faidherbia albida*. This underscores the need for strong institutional commitment – including but not limited to financing – in support of the transition to Save and Grow, for a sustained period[9,10].

Making the transition to Save and Grow: Ten recommendations

Drawing on the lessons learned from the Save and Grow farming systems presented in *Chapter 3*, and other ecosystem-based approaches being applied in the developing world, the following 10 actions are recommended for consideration by countries making the transition to the sustainable intensification of maize, rice and wheat production.

1 Promote Save and Grow in structural transformation

A key challenge for policymakers in managing the transition to sustainable agriculture – and the broader structural transformation of economies and societies – is building and strengthening institutions and partnerships and harmonizing their actions. A multi-sector policy framework is needed that considers agriculture and agricultural growth within the context of natural resources management, urbanization policies, patterns of public investment, reduction in food waste, a shift to more sustainable diets, and the creation of non-farm employment in rural areas.

In this vision of sustainability, Save and Grow becomes part of the global transition to 'green economies', which aim at improving human well-being and social equity, while significantly reducing environmental risks, ecological scarcities and the pace of climate change. The greening of agriculture is expected to increase yields and farmers' incomes, while creating additional positive effects and synergies in social, economic and environmental spheres, such as improved nutrition, reduced dependence on food imports, and reduced environmental pollution[11]. Such an approach will require cooperation and integration among government ministries in order to ensure the compatibility of sectoral policies and programmes[12, 13].

In many developing countries, the institutions necessary for the transition to Save and Grow – in agricultural education, research, extension, policymaking, and seed production and certification – are either weak or non-existent. They must be created or strengthened. In most countries, ministries and national institutions often do not coordinate actions that have impacts on agricultural productivity and sustainability. In fact, they frequently promote contradictory policies and actions.

Ministries critical to the promotion of sustainable crop production – such as those for agriculture, livestock, environment, natural resources, forestry, fisheries, food processing and marketing, and labour – need to align their strategies and actions for maximum benefit and impact. Policymakers must also develop and strengthen the capacity to analyse and balance the trade-offs among agricultural sectors, and often within the crops subsector.

Many non-governmental agencies are also involved in the production, processing and marketing of cereals. Civil society organizations (CSOs) represent a range of constituencies, including farmers, agricultural workers, the landless, women, youth and indigenous peoples. They reach the most vulnerable groups of society, and bring their concerns into the policy dialogue and the design of programmes and projects. The CSOs, including social movements of smallholder farmers, have succeeded in establishing a dialogue with governments and other actors at regional and global levels, and have contributed to the development of new governance models. They should be part of multi-stakeholder national dialogues, and fully engaged in the planning and implementation of public policies.

The private sector, including farmer organizations, small- and medium-sized enterprises, international corporations and private foundations, is also an important partner. Since agriculture is a core private enterprise activity, the sector can support smallholder farming initiatives and help ensure food security through responsible, productive investment and employment creation.

Partnerships between CSOs and the private sector, and between them and national institutions, should be strengthened, and their actions aligned for efficient implementation of Save and Grow. To derive maximum benefit, national development plans should be formulated in consultation with key stakeholders, using participatory processes, in order to ensure their support and commitment and to facilitate harmonized actions.

2 Promote policies that facilitate farmer adoption of Save and Grow

Policymakers have a key role to play in creating the enabling environment for sustainable crop production intensification. They need to support appropriate research and extension, access to credit and input/output markets, and capacity building for stakeholders throughout the maize, rice and wheat value chains. They should create incentives for farmers to diversify their production systems by strengthening markets for rotational crops and for animal and forestry products[5]. Timely access to fertilizer is consistently found to have a major positive impact on crop yields, while the availability of, and access to, quality seeds of adapted varieties facilitates diversification[14, 15].

Appropriate policies and investments can reduce the risk farmers may face in the transition to Save and Grow[16]. They include: tax breaks to financial institutions that provide services in rural areas in support of sustainable agriculture; agricultural insurance policies; social protection to mitigate risk and strengthen resilience; payments for environmental services; and public funding of agricultural research, development and extension[17].

The adoption of Save and Grow will have positive impacts on the environment that should be recognized and rewarded. Payments for environmental services in agriculture are still relatively new, but considerable work has been done on the topic in recent years. For example, China is linking resource-conserving farming systems to funding for climate change mitigation. With Fao's support, Viet Nam is developing funding strategies that would provide payment for environmental services[13].

Through institutional procurement programmes, governments can improve the food and nutrition security of vulnerable groups, and integrate smallholders into markets as suppliers. Thanks to management training, bulk purchases of inputs and collective marketing, some smallholder farmers' organizations in Kenya are able to compete with larger enterprises in tenders for the supply of maize to the World Food Programme[18]. Well-designed social protection programmes can stimulate smallholder food production, creating a 'win-win' situation for both consumers and producers[19, 20]. For example, Brazil purchased in 2013 some 270 000 tonnes of food, from 95 000 family farmers, for free distribution to food insecure people and the country's social assistance network[21].

Policies may also need to address labour shortages in rural areas. Lifting people out of poverty through agriculture also requires increased returns to labour, not just higher yields. It is unlikely that farmers will adopt Save and Grow practices if they do not provide returns that are competitive with those in other sectors. A successful transition to Save and Grow will depend on technologies and policies that strengthen the environmental, economic and social pillars of sustainability, reduce risk and save labour[13].

Countries may also need to review their current programmes of support to agriculture with a view to eliminating 'perverse subsidies' that encourage harmful practices – such as overuse of fertilizer, pesticide and water, and deforestation that leads to further loss of biodiversity – and provide instead incentives for the adoption of sustainable practices.

3 Increase investment in agriculture

The Food and Agriculture Organization has called for a new agricultural investment strategy that focuses public resources, at all levels, on the provision of public goods and encourages farmer investment in sustainable intensification. Farmers are already the biggest investors in agriculture. However, in the absence of good governance, appropriate incentives and essential public goods, they do not invest enough and, often, do not invest in sustainable production systems[17, 22].

Investment by governments and development partners, when properly targeted at sustainably enhancing agricultural productivity and returns to farmers, is an important means of promoting economic growth and poverty reduction, food and nutrition security, and environmental sustainability. Investment in rural infrastructure, in credit services, in education, extension and training, and in research and development specific to smallholder agriculture, can help drive increases in food supply and improvements in the efficiency of agricultural markets[17].

Investment is especially needed in roads, cold chains, processing, packaging, storage and marketing, in order to reduce food losses and waste amounting to an estimated one-third of global production. In the long term, such investments would yield much higher returns – in terms of productivity and economic growth – than other expenditures, such as input subsidies[17].

Making the transition to Save and Grow may require significant investment by countries in building an enabling environment, and by farmers in adopting practices that may take several years to realize positive returns. With the acceleration of climate change, the need to adequately address farmers' increased exposure to risk calls for investment strategies that give higher priority to risk management[9, 10, 14].

4 Establish and protect farmers' rights to natural resources

The transition to Save and Grow also requires action to protect and strengthen smallholders' access to natural resources, especially land, water and agrobiodiversity. Weak and unequal land tenure arrangements persist in large parts of the world, and can lead to expropriation, displacement and eviction[23]. Clear tenure rights are necessary to promote equitable access to productive resources as well as their sustainable management. Farmers will adopt Save and Grow practices only if they can benefit, for a sufficiently long period, from the increase in the value of natural capital[7].

Often, farmers' rights are poorly defined, overlapping or not formalized. Improving the land and water rights of farmers – especially those of women, who are increasingly the ones making production decisions – is a key incentive to the adoption of sustainable crop production. Land tenure programmes in many developing countries have focused on formalizing and privatizing rights to land, with little regard for customary and collective systems of tenure. Governments should give greater recognition to such systems, as growing evidence indicates that, where they provide a degree of security, they can also provide effective incentives for investment[5].

Governments and their development partners should make use of the Committee on World Food Security's *Voluntary guidelines on the responsible governance of tenure of land, water, fisheries and forests in the context of national food security*[24], as appropriate, in their policies and strategies to promote sustainable crop production. The guidelines serve as an authoritative reference for law-making and policy-setting related to access and tenure rights. They provide investors and developers with clear indications on best practices, and provide civil society organizations with benchmarks that they can use in their work on behalf of rural communities.

Other useful guidelines include *Principles for responsible investment in agriculture and food systems*[22], also developed by the Committee on World Food Security, and *Principles for responsible agricultural investment that respects rights, livelihoods and resources*[25], developed in 2009 by Fao, the International Fund for Agricultural Development (Ifad), the United Nations Conference on Trade and Development (Unctad) and the World Bank.

Access to and sustainable use of biodiversity is also essential to Save and Grow. Farmers need access not only to a range of species for diversification of their farming systems, but also to improved genetic resources within species, in order to produce more with less and meet the challenges of climate change. Countries should strengthen their programmes for the conservation and sustainable use of biodiversity, join international instruments such as the Convention on Biodiversity, the International Treaty on Plant Genetic Resources for Food and Agriculture (It-Pgrfa) and the Commission on Genetic Resources for Food and Agriculture, and collaborate closely with the Cgiar centres.

5 Promote more efficient value chains and markets

Efficient value chains are vital to food security, poverty reduction and the sustainability of food and agriculture systems. To be economically, socially and environmentally sustainable, value chains need to create added value and higher incomes, facilitate more equitable distribution of benefits, and reduce ecological footprints throughout the chain[26].

Sustainable food value chains are built on collaboration among all stakeholders, including smallholder farmers, agribusiness, governments and civil society. Initially, food value chain development should focus mainly on efficiency improvements – including reduction of post-harvest losses – that lead to lower food prices and greater food availability, allowing households to buy more food. Changing consumer demand then becomes a core driver for innovation and value creation, leading to continuous improvement in the food supply and increasing benefits to consumers[26].

Governments can support 'inclusive business models' through legal frameworks that establish, for example, good practices in contract farming. In the United Republic of Tanzania, where demand for rice is soaring, smallholders and large private rice growers are collaborating through out-grower schemes[27]. However, reducing sub-Saharan Africa's dependence on imported rice requires improvements in quality as well as quantity. A recent study found that Africa's urban consumers are 'willing to pay' for a quality upgrade of domestically produced rice through varietal improvements and better processing[28].

A legal and institutional environment that promotes and supports cooperation among smallholder farmers would allow them to take advantage of economies of scale in such activities as purchasing inputs and processing, transporting and selling outputs[7]. The marketing of smallholder produce can also be facilitated by certification schemes that reward producers who adopt sustainable production systems.

6 Increase support to agricultural research and development

The locus of agricultural research and development has shifted from the public to the national and multinational private sector. As private investment increases, public investment in R&D has fallen in almost half of the world's low-income countries[29]. Private companies tend to concentrate on commodities and short-term profit margins[30] and, in many cases, to promote technologies – such as chemical pest control – that rely on external inputs, without regard for sustainability[31].

Longer-term public sector initiatives are needed in areas relating to natural resources management, including research on soils, water, genetic resources and sustainability[30]. Many governments will need to maintain or strengthen their capacity to conduct research. That may involve not only investing in research facilities and equipment, but also ensuring that scientific capacity is relevant and adequate to address the policy and technology needs of agriculture, in general, and the smallholder sector in particular.

In most developing countries, research capacity is especially weak in areas such as biotechnology, modelling and forecasting. The use of satellite remote sensing and modern telecommunications is essential for making quick and efficient responses to rapidly changing demands on agriculture and to the mounting effects of climate change.

To generate technology options that are attractive to farmers, science-based innovation needs to be built on farmers' traditional knowledge. Research should address the needs of marginal farming areas, and work to benefit smallholders by increasing agricultural productivity and natural resources conservation, and by helping to diversify cereal farming systems to higher value products.

Research must be linked more closely with extension and other sources of knowledge. Strengthening deployment and implementation capacity will support the further development of Save and Grow farming systems and their adoption by small-scale farmers. International agricultural research organizations, as well as funding agencies, have an important role in supporting those national efforts.

7 Promote technological innovation

Smallholder cereal growers are at the forefront of efforts to ensure food and nutritional security from household to global levels. They will need access to the full range of technologies required for sustainable crop production intensification. For example:

Mechanization. Conservation agriculture (CA) requires implements and machinery suited to all technology levels. In Brazil, a flourishing domestic industry produces CA equipment suited to different soils, climates and farming systems[32]. Some of those technologies have been transferred to Africa and Asia, where local manufacturers produce manual and animal traction zero-tillage planters and tractor-drawn direct-seeding equipment[33, 34]. Governments need to adopt strategies for upscaling conservation agriculture and other sustainable practices, identifying clear roles for the private sector in manufacturing, distribution, servicing and repair and for the public sector in research, capacity building and support to business development[35, 36].

New crops and varieties. Accelerated development of improved crop varieties is critical to meeting future challenges, especially for smallholder farmers. Crop diversity underpins diversification of their farming systems and contributes to greater resilience to climate change and other stresses. New approaches to plant breeding, such as molecular markers, could improve cereal yields, nutrient content, and pest and disease resistance, and reduce the time needed for the development and release of new varieties[37]. Higher yielding maize hybrids are of growing importance in smallholder farming systems and hybrid rice and wheat could become more common. Crop breeding should address genetic improvement of the components of intercropping systems and the nutritional quality of cereal plant residues that are used to feed livestock. Support to on-farm conservation and enhancement of farmers' varieties is crucial.

Improved water-use efficiency. Major producers of irrigated maize, rice and wheat either do not have, or soon will not have, access to enough water to maintain per capita food production. The use of more water-efficient crop varieties, the adoption of water-conserving practices, such as zero-tillage and cover crops, and increased investment in water-efficient technologies, such as land levelling, drip irrigation and rainwater harvesting, will be critical for production under climate change. Cultivation of rice and wheat on irrigated raised beds has significantly improved water-use efficiency and boosted yields in Egypt, India and Mexico. Raised-bed systems also enhance water productivity, with big yield gains, in rainfed maize production. Improved irrigation technologies will work best when water is valued and priced appropriately[38]. Smallholders' rights to water, as well as land, need to be protected.

Innovative fertilizers. There has been virtually no investment in fertilizer research and development over the past five decades. Taking plant physiological and soil processes, rather than chemistry, as a starting point, the redesign of 'packaging' and 'delivery' nutrients can result in rapid nutrient uptake by plants. Innovative fertilizers – targeted at feeding crops, rather than the soil – would provide multiple benefits, including higher content of multiple nutrients in cereals, the restoration of soil fertility, and increased system resilience and sustainability. Improvements in nitrogen fertilizer would safeguard ecosystem health by reducing emissions of nitrous oxide to the environment[39].

Integrated pest management. Because insect pests, weeds and diseases evolve and are easily carried to new locations, meeting the emerging challenges to cereal production requires continuous development of IPM technologies. Some recent innovations include: breeding to restore the natural pest-repellent capacity of maize root systems; a biopesticide derived from seeds of the neem tree that eliminates brown planthoppers on rice crops; and fungi and nematodes that are highly effective against wheat stem sawfly[31, 40]. Innovation in IPM requires strong policy support and the active participation of farmers through farmer field schools.

Improved post-harvest management. Post-harvest grain losses to pests and rodents are high in smallholder production systems. In humid climates, drying facilities are particularly important to control the risk of fungal diseases[41]. Analysis of traditional post-harvest systems can identify gaps and provide appropriate solutions. In Afghanistan, replacing clay silos with metal silos for grain storage has helped some 76 000 farmers reduce losses from 20 percent of the harvest to less than 2 percent[42]. In Africa, FAO has promoted grain storage management – including simple ways measuring moisture content, and non-chemical control of pests and diseases – adapted to the needs of small farmers affected by droughts and floods[43].

New generation technologies. A smartphone-based 'rice crop manager' developed by IRRI calculates crop and nutrient management recommendations based on local conditions and sends them to the farmer via SMS. The recommendations have increased per hectare yields by an average of 0.4 tonnes and income by US$100[44]. The widespread diffusion of mobile phones in sub-Saharan Africa offers similar opportunities for linking researchers and farmers, as well as farmers and markets. Other innovations now available to smallholders are relatively low-cost, especially when provided through cooperatives or hiring services. They include laser-assisted land-levelling, leaf colour charts to help time mineral fertilizer applications, and electronic sensors that detect plant nitrogen deficits and nutrient levels in cereal residues. Before being recommended, however, proposed innovations should be assessed for their likely social, economic and environmental impacts.

8 Improve communication with farmers and help build their capacities

Much less is known about agro-ecological and resource-conserving technologies than about the use of external inputs in intensive crop production[45]. The lack of information on ecosystem-based approaches, and on the need to adapt them to specific agro-ecological and socio-economic conditions, is a major barrier to the successful upscaling of Save and Grow.

Sustainable crop production intensification is generally more knowledge and management intensive. It is important, therefore, to support farmers in strengthening their capacities to understand ecosystem functions and to build on their traditional knowledge in order to identify and adapt appropriate practices and technologies.

Agricultural extension, training and education need to place far greater emphasis on integrated production systems. This change needs to occur at all levels of learning to ensure that all stakeholders are better informed and more knowledgeable about the principles of sustainable crop production and its practical application through Save and Grow.

Advisory services to support Save and Grow will need to collaborate closely with farmer organizations and networks, and in public-private partnerships. Participatory methodologies can help producers and their advisers to share their experiences, knowledge and skills in farming systems management. Farmer field schools, for example, provide a platform for experimentation and farmer-to-farmer communication and exchange. Since women are the mainstay of agriculture in many countries, they should be placed at the centre of training and extension efforts, and supported in meeting their broader needs for gender equity, sustainable livelihoods and access to resources.

Support to capacity building, education and training should be seen as part of a broader effort to develop social capital – i.e. the value generated by social bonds, rules, norms and sanctions that gives farming communities the confidence to invest in collective activities, and makes them less likely to engage in unfettered private actions with negative outcomes, such as natural resource degradation[46]. For example, because IPM is knowledge-intensive, farmer field schools and other participatory forms of knowledge-sharing help to build social capital, as well as human and natural capital[31].

9 Strengthen seed systems

Save and Grow farming systems need varieties that are higher yielding, more resilient and better adapted to ecosystem-based production practices, and make more efficient use of inputs. Ensuring smallholder farmers' access to the quality seed of improved varieties requires action to strengthen national seed systems.

In many developing countries, seed systems are either non-existent or ineffective, owing to weak regulatory frameworks, lack of funding and limited technical and managerial capacity. While seed supply is sometimes regarded as a private sector activity, the private sector often produces and sells only the seed of crops and varieties that allow it to maximize profits, and ignores many crops and varieties critical to food security and to the productivity and sustainability of smallholder agriculture.

National seed systems need to be strengthened through capacity building, fast-track variety release, accelerated seed multiplication and support to on-farm seed conservation and community seed banks. Action is also needed to strengthen public capacity, encourage private sector investment and involve civil society organizations and farmers in the formulation and implementation of national seed policy[5, 47].

In the wheat seed sector, mechanisms to increase the rate of seed production could include pre-release and off-season seed multiplication of early generations, where feasible. Without such efficiency gains, the dominance of vulnerable 'mega-varieties' will be exacerbated[48]. The same approaches would also be effective for rice.

The seed of maize hybrids is normally produced and marketed by the private sector, and the seed of the open-pollinated varieties by NGOs and community-based organizations. Some innovative public-private partnerships have been pioneered by Brazil, China and CIMMYT. They involve the provision of improved maize lines to the private sector for the production and marketing of hybrid seed, in exchange for funding or other research support. However, no effective collaboration is in place for the production and marketing of seed of open-pollinated varieties of maize, which are grown largely by smallholders.

Participatory approaches that recognize the potential of the informal seed sector, and the important role of women within it, can strengthen the seed systems for all three crops. In sub-Saharan Africa, community-based seed producers – many of them run by women – are multiplying quality seed of maize varieties; in West Africa they produce up to 20 tonnes of seed annually. Upscaling the approach will be an important step towards seed self-sufficiency in under-serviced rural areas.

10 Work with international organizations, instruments and mechanisms

Countries should make use of global, regional and sub-regional organizations, instruments and mechanisms for the efficient implementation of Save and Grow. The Food and Agriculture Organization has unique expertise and extensive experience in supporting countries in the development of policies, strategies and technologies for the sustainable intensification of cereal production. It hosts international instruments, such as the IT-PGRFA, the International Plant Protection Convention, the Rotterdam Convention and the Committee on World Food Security, which provide opportunities for countries to share experiences and build collaboration.

Other global organizations that influence maize, rice and wheat include several CGIAR centres, IAEA, OECD, UNCTAD, the United Nations Department of Economic and Social Affairs, the United Nations Environment Programme and the World Bank. Many regional and sub-regional organizations* also offer valuable support to sustainable agricultural development through the provision of technologies, capacity-building, enhanced information exchange and the facilitation of trade. A number of developing countries have considerable experience in the implementation of sustainable food and agriculture, offering opportunities for enhanced South-South cooperation.

* For example: the Inter-American Institute for Cooperation on Agriculture (IICA) and the Regional Fund for Agricultural Technology (FONTAGRO) in Latin America; the Asia-Pacific Association of Agricultural Research Institutions (APAARI); the New Partnership for Africa's Development (NEPAD), the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), the Southern African Centre for Cooperation in Agricultural Research (SACCAR) and the West and Central African Council for Agricultural Research and Development (CORAF).

There is no single blueprint for Save and Grow and its ecosystem-based approach to crop production intensification. No magic seeds or technologies exist that will improve the social, economic and environmental performance of cereal production across all landscapes, in all regions. Save and Grow represents a major shift from a homogenous model of crop production to knowledge-intensive, often location-specific, farming systems. That is why its application requires time, increased support to farmers and firm commitment to strengthening national programmes[9, 10].

The widespread adoption of Save and Grow requires concerted action at all levels, with the active participation of governments, international organizations, civil society and the private sector. The challenge is enormous, but so, too, will be the rewards. Save and Grow will help drive the global transition to sustainable food and agriculture, and help to build the hunger-free world we all want.

References

Chapter 1. Cereals and us: time to renew an ancient bond

1. FAO. 2015. FAOSTAT. Online statistical database: Production (available at http://faostat3.fao.org/download/Q/QC/E).

2. FAO. 2015. FAOSTAT. Online statistical database: Food balance (available at http://faostat3.fao.org/download/FB/*/E).

3. United States Department of Agriculture. 2015. *World agricultural supply and demand estimates, January 2015.* Washington, DC.

4. Murphy, D. 2007. *People, plants and genes: the story of crops and humanity.* Oxford, UK, Oxford University Press.

5. Molina, J., Sikora, M., Garud, N., Flowers, J., Rubinstein, S., Reynolds, A., Huang, P., Jackson, S., Schaal, B., Bustamante, C., Boyko, A. & Purugganan, M. 2011. Molecular evidence for a single evolutionary origin of domesticated rice. *Proceedings of the National Academy of Sciences,* USA, 108: 8351–8356.

6. Wang, M., Yu, Y, Haberer, G., Marri, P.R., Fan, C., Goicoechea, J.L., Zuccolo, A., Song, X., Kudrna, D., Ammiraju, J.S.S., Cossu, R.M., Maldonado, C., Chen, J., Lee, S, Sisneros, N., de Baynast, K., Golser, W., Wissotski, M., Kim, W., Sanchez, P., Ndjiondjop, M-N., Sanni, K., Long, M., Carney, J., Panaud, O., Wicker, T., Machado, C.A., Chen, M., Mayer, K.F.X., Rounsley, S. & Wing, R.A. 2014. The genome sequence of African rice (*Oryza glaberrima*) and evidence for independent domestication. *Nature Genetics* 46, 982–988.

7. Landon, A.J. 2008. The 'How' of the Three Sisters: The Origins of Agriculture in Mesoamerica and the Human Niche. *Nebraska Anthropologist* 23. Paper 40. Lincoln (USA), University of Nebraska-Lincoln.

8. Leakey, R. & Lewin, R. 1977. *Origins: the emergence and evolution of our species and its possible future.* London, Macdonald James Publishers.

9. Wolman, M.G. 1993. Population, land use and environment: A long history. *In* C. Jolly & B. Boyle Torrey, eds. *Population and land use in developing countries: Report of a workshop.* Washington, DC, The National Academies Press.

10. Burns, T.S. 1994. *Barbarians within the gates of Rome.* Indianapolis (USA), Indiana University Press.

11. Brewbaker, J. 1979. Diseases of maize in the wet lowland tropics and the collapse of the Classic Maya civilization. *Economic Botany,* 33 (2): 101–118.

12. Jordan, W. 1996. *The great famine: Northern Europe in the early fourteenth century.* Princeton (USA), Princeton University Press.

13. Pretty J. N. 1991. Farmers' extension practice and technology adaptation: Agricultural revolution in 17–19th century Britain. *Agriculture and Human Values* VIII, 132–148.

14. Apostolides, A., Broadberry, S., Campbell, B., Overton, N. & van Leeuwen, B. 2008. *English agricultural output and labour productivity, 1250–1850: some preliminary estimates.* Coventry (UK), University of Warwick.

15. FAO. 2011. *Save and Grow. A policymaker's guide to the sustainable intensification of smallholder crop production.* Rome.

16. FAO. 2005. *The State of Food and Agriculture 2005: Agricultural trade and poverty – can trade work for the poor?* Rome.

17. United Nations, Department of Economic and Social Affairs, Population Division. 2015. *World Population Prospects: The 2015 Revision* (available at http://esa.un.org/unpd/wup/DataQuery/).

18. FAO. 2010. *The Green Revolution in Asia: Lessons for Africa*, by H. Jhamtani. Rome.

19. FAO. 2009. *The State of Food Insecurity in the World: Economic crises – impacts and lessons learned.* Rome.

20. Hazell, P.B.R. 2010. Asia's Green Revolution: past achievements and future challenges. *In* S. Pandey, D. Byerlee, D. Dawe, A. Dobermann, S. Mohanty, S. Rozelle & B. Hardy, eds. *Rice in the global economy: strategic research and policy issues for food security*, pp 61–92. Los Baños, Philippines, International Rice Research Institute.

21. Rosegrant, M., Tokgoz, S., Bhandary, P. & Msangi, S. 2013. Scenarios for the future of food. In *2012 Global food policy report.* Washington, DC, IFPRI.

22. Shiferaw B., Smale, M, Braun H-J., Duveiller, E., Reynolds M. & Muricho, G. 2013. Crops that feed the world 10. Past successes and future challenges to the role played by wheat in global food security. *Food Security,* 5: 291–317.

23. Seck, P.A., Diagne, A., Mohanty, S. & Wopereis, M.C.S. 2012. Crops that feed the world 7: Rice. *Food Security*, 4: 7–24.

24. FAO, IFAD & WFP. 2015. *The State of Food Insecurity in the World 2015. Meeting the 2015 international hunger targets: taking stock of uneven progress.* Rome.

25. FAO. 2015. World food situation: Food price index (retrieved: 7 September 2015) (available at http://www.fao.org/fileadmin/templates/worldfood/Reports_and_docs/Food_price_indices_data.xls).

26. FAO. 2014. *The State of Food and Agriculture 2014. Innovation in family farming.* Rome.

27. Frison, E.A., Cherfas, J. & Hodgkin, T. 2011. Agricultural biodiversity is essential for a sustainable improvement in food and nutrition security. *Sustainability,* 3: 238–253.

28. Tscharntke, T, Yann Clough, T.C., Wanger, L.J., Motzke, I., Perfecto, I., Vendermeer, J. & Whitbread, A. 2012. Global food security, biodiversity conservation and the future of agricultural intensification. *Biological Conservation,* 151: 53–59.

29. FAO. 2010. *Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture.* Rome.

30. Solh, M., Braun, H-J. & Tadesse, W. 2014. *Save and Grow: Wheat.* Paper prepared for the FAO Technical Consultation on Save and Grow: Maize, Rice and Wheat, Rome, 15–17 December 2014. Rabat, ICARDA. (mimeo).

31. Pretty, J.N. & Bharucha, Z.P. 2014. Sustainable intensification in agricultural systems. Invited Review. *Annals of Botany,* 114 (8): 1571–1596.

32. Pingali, P., Hossain, M. & Gerpacio, R. 1997 *Asian Rice Bowls – The returning crisis?* In association with IRRI. Wallingford, UK, CAB International.

33. Heap, I. 2014. Global perspective of herbicide-resistant weeds. *Pest Management Science.* Special issue: Global herbicide resistance challenge. Vol. 70, Issue 9, pp.1306–1315. September 2014.

34. FAO. 2014. *Agriculture, forestry and other land use emissions by sources and removals by sinks. 1990–2011 Analysis.* FAO Statistics Division Working Paper Series, No. 14–02. Rome.

35. Vermeulen, S.J., Campbell, B.M. & Ingram, J.S. 2012. Climate Change and Food Systems. Annual *Review of* Environment *and* Resources, 2012.37:195–222. DOI: 10.1146/annurev-environ-020411-130608.

36. IPCC (Intergovernmental Panel on Climate Change). 2014. *Climate Change 2014: Mitigation of Climate Change.* Final draft Report of Working Group III. Contribution to the Fourth Assessment Report of the IPCC.

37. FAO. 2013. *Climate-smart agriculture sourcebook.* Rome.

38. Altieri, M. 2002. Agroecology: the science of natural resource management for poor farmers in marginal environments. *Agriculture, Ecosystems and Environment,* 93: 1–24.

39. ILO (International Labour Organization). 2012. *Global Employment Trends 2012. Preventing a deeper job crisis.* Geneva, Switzerland.

40. FAO. 2012. *Decent rural employment for food security: a case for action.* Rome.

41. FAO. 2014. *The State of Food Insecurity* *in the World 2014. Strengthening the enabling environment to improve food security and nutrition.* Rome.

42. Fan, M.S., Zhao, F.J. & Fairweather-Tait, S.J. 2008. Evidence of decreasing mineral density in wheat grain over the last 160 years. *Journal of Trace Elements in Medicine and Biology,* 22:315–324.

43. Mayer, A.M. 1997. Historical changes in the mineral content of fruits and vegetables. *British Food Journal,* 99:207–211.

44. Davis, D.R., Epp, M.D. & Riordan, H.D. 2004. Changes in USDA food composition data for 43 garden crops. *Journal of the American College of Nutrition,* 23:669–682.

45. FAO. 2012. *Sustainable nutrition security: Restoring the bridge between agriculture and health.* Traore, M., Thompson, B. & Thomas, G. Rome.

46. Foresight. 2011. *The future of food and farming: Challenges and choices for global sustainability.* Final Project Report. London, Government Office for Science.

47. OECD (Organisation for Economic Co-operation and Development) & FAO. 2015. *Agricultural Outlook 2015–2024.*Paris and Rome.

48. FAO. 2012. *World agriculture towards 2030/2050 - The 2012 revision.* ESA Working Paper No. 12-03, June 2012. Rome.

49. Fischer, G. 2011. How can climate change and the development of bioenergy alter the long-term outlook for food and agriculture? *In* P. Conforti, ed. *Looking ahead in world food and agriculture: perspectives to 2050.* Rome, FAO.

50. Fischer, R.A., Byerlee, D. & Edmeades, G.O. 2014. *Crop yields and global food security: will yield increase continue to feed the world?* ACIAR Monograph No. 158. Australian Centre for International Agricultural Research, Canberra.

51. FAO. 2013. *Food wastage footprint. Full cost accounting: Final report.* Rome.

52. Lal, R. 2014. Abating climate change and feeding the world through soil carbon sequestration. *In* D. Dent, ed. *Soil as world heritage,* pp 443–457. Berlin: Springer.

53. FAO. 2011. *The State of the World's Land and Water Resources for Food and Agriculture. Managing systems at risk.* Rome.

54. FAO. 2013. *Guidelines to control water pollution from agriculture in China – Decoupling water pollution from agricultural production.* Rome.

55. Shiferaw, B., Prasanna B.M., Hellin, J. & Bänziger, M. 2011. Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. *Food Security,* 3: 307–327.

56. Funk, C.C. & Brown, M.E. 2009. Declining global per capita agricultural production and warming oceans threaten food security. *Food Security,* 1:271–289.

57. CIMMYT (International Maize and Wheat Improvement Center). 2009. *Wheat facts and futures 2009.* Dixon, J., H.-J. Braun, P. Kosina & J. Crouch, eds. Mexico, D.F., CIMMYT.

58. FAO. 2011. *The State of Food Insecurity in the World 2011. How does international price volatility affect domestic economies and food security?* Rome.

59. Pardey, P., Alston, J. & Piggott, R. 2006. *Agricultural R&D in the developing world.* Washington, DC, IFPRI.

60. Pardey, P., Alston, J. & Chan-Kang, C. 2013. Public agricultural R&D over the past half century: an emerging new world order. *Agricultural Economics,* 44(1): 103–113.

61. Beintema, N., Stads, G.J., Fuglie K. & Heisey, P. 2012. *ASTI global assessment of agricultural R&D spending: Developing countries accelerate investment.* IFPRI, ASTI & GFAR, Rome. 24pp.

62. Lobell D.B., Schlenker, W.S. & Costa-Roberts, J. 2011. Climate trends and global crop production since 1980. *Science,* 333:616–620.

63. Padgham, J. 2009. *Agricultural development under a changing climate: opportunities and challenges for adaptation.* Washington D.C., The World Bank.

64. Wiebe, K., Lotze-Campen, H., Sands, R., Tabeau, A., van der Mensbrugghe, D., Biewald, A., Bodirsky, B., Islam, S., Kavallari, A., Mason-D'Croz, D., Müller, C., Popp, A., Robertson, R., Robinson, S., van Meijl, H. & Willenbockel, D. 2015. Climate change impacts on agriculture in 2050 under a range of plausible socioeconomic and emissions scenarios. *Environmental Research Letters,* 10 (2015) 085010.

65. Prasanna, B.M. 2014. Maize research-for-development scenario: challenges and opportunities for Asia. *In* B.M. Prasanna et al., eds. Book of extended summaries, 12th Asian Maize Conference and Expert Consultation on Maize for Food, Feed, Nutrition and Environmental Security. Bangkok, Thailand, 30 October – 1 November 2014. CIMMYT, Mexico D.F. and APAARI, Bangkok, pp.2–11.

66. Tesfaye, K., Gbegbelegbe, S., Cairns, J.E., Shiferaw, B., Prasanna, B.M., Sonder, K,. Boote, K.J., Makumbi, D., Robertson, R. 2015. Maize systems under climate change in sub-Saharan Africa: potential impacts on production and food security. *International Journal of Climate Change Strategies and Management*, Vol. 7 Issue 3, pp.247–271.

67. Paterson, R. R. M., & Lima, N. 2010. How will climate change affect mycotoxins in food? *Food Research International*, 43(7): 1902–1914.

68. Mackill, D. J., Ismail, A. M., Pamplona, A.M., Sanchez, D.L., Carandang, J.J. & Septiningsih, E.M. 2010: Stress-tolerant rice varieties for adaptation to a changing climate. *Crop Environment and Bioinformatics.* 7: 250–259.

69. Zeigler, R. 2014. *IRRI 2035: Investing in the future.* Based on a presentation by the Director General to the IRRI community, 30 May 2013. Los Baños, Philippines.

70. Ortiz, R., Sayre, K.D., Govaerts, B., Gupta, R., Subbarao, G.V., Ban, T. , Hodson, D., Dixon, J.M., Ortiz-Monasterio, J.I. & Reynolds, M. 2008. Climate change: can wheat beat the heat? *Agriculture, Ecosystems & Environment* 126:45–58.

71. Rosegrant, M. R., Ringler, C., Sulser, T. B., Ewing, M., Palazzo, A. & Zhu, T. 2009. *Agriculture and food security under global change: Prospects for 2025/2050.* Washington, D.C., International Food Policy Research Institute.

72. FAO. 2015. FAOSTAT. Online statistical database: Trade. (available at http://faostat3.fao.org/download/T/*/E).

73. World Bank. 2015. Poverty and Equity Database (available at http://povertydata.worldbank.org/poverty/home/).

74. FAO. 2014. *Food Outlook. Biannual report on global food markets.* Rome.

75. Pretty, J.N., Noble, A.D., Bossio, D., Dixon, J., Hine, R.E., de Vries, F. & Morrison, J.I.L. 2006. Resource-conserving agriculture increases yields in developing countries. *Environmental science & technology*, 40: 1114–1119.

76. Power, A.G. 2010. Ecosystem services and agriculture: Tradeoffs and synergies. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 365(1554): 2959– 2971.

77. Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappell, M., Aviles-Vazquez, K., Samulon, A. & Perfecto, I. 2007. Organic agriculture and the global food supply. *Renewable Agriculture and Food Systems*, 22: 86–108.

78. Garnett, T., Appleby, M.C., Balmford, A., Bateman, I.J., Benton, T.G., Bloomer, P., Burlingame, B., Dawkins, M., Dolan, L., Fraser, D., Herrero, M., Smith, P., Thornton, P.K., Toulmin, C., Vermeulen, S.J. & Godfray, H.C.J. 2013. Sustainable Intensification in agriculture: premises and policies. *Science* 341: 33–34.

79. FAO. 2010. *Sustainable crop production intensification through an ecosystem approach and an enabling environment: Capturing efficiency through ecosystem services and management.* Rome.

80. FAO. 2012. *Soil organic carbon accumulation and greenhouse gas emission reductions from Conservation Agriculture: a literature review.* Integrated Crop Management, Vol.16–2012. Rome.

81. Lal, R. 2004. Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. *Science.* 304, 1623 (2004). DOI: 10.1126/science.1097396.

82. Christiaensen, L., Demery, L. & Kuhl, J. 2011. The (evolving) role of agriculture in poverty reduction: an empirical perspective. *Journal of Development Economics*, 96: 239–254.

Chapter 2. Toward sustainable cereal production

1. FAO. 2011. *Save and Grow. A policymaker's guide to the sustainable intensification of smallholder crop production.* Rome.

2. FAO. 2014. *Building a common vision for sustainable food and agriculture: Principles and approaches.* Rome.

3. Pretty, J.N. & Bharucha, Z.P. 2014. Sustainable intensification in agricultural systems. Invited Review. *Annals of Botany,* 114 (8): 1571–1596.

4. Kassam, A., Friedrich, T., Derpsch, R. & Kienzle, J. 2014. *Worldwide adoption of Conservation Agriculture.* Paper presented at the 6th World Congress on Conservation Agriculture, 22–25 June 2014, Winnipeg, Canada.

5. Baker, C.J., Saxton, K.E., Ritchie, W.R., Chamen,W.C., Reicosky, D.C., Ribeiro, M.F.S., Justice, S.E. & Hobbs, P.R. 2007. No-tillage seeding in conservation agriculture (Second Edition). C.J. Baker & K.E. Saxton, eds. Rome, FAO & Cambridge, USA, CAB International.

6. Kassam, A., Friedrich, T., Shaxson, F. & Pretty, J. 2009. The spread of Conservation Agriculture: Justification, sustainability and uptake. *International Journal of Agricultural Sustainability* 7(4) 2009, pp.292–320.

7. Friedrich, T., Derpsch, R. & Kassam, A. 2012. Global overview of the spread of Conservation Agriculture. *Field Actions Science Reports Special Issue (Reconciling Poverty Alleviation and Protection of the Environment),* 6: 1–7.

8. FAO. 2014. *Managing soils for food security and climate change adaptation and mitigation*. Rome.

9. Sun, L., Chang, S.X., Feng, Y.S., Dyck, M.F. & Puurveen, D. 2015. Nitrogen fertilization and tillage reversal affected water-extractable organic carbon and nitrogen differentially in a Black Chernozem and a Gray Luvisol. *Soil and Tillage Research*, 146: 253–260.

10. Shiferaw, B., Smale, M., Braun, H-J., Duveiller, E., Reynolds, M. & Muricho, G. 2013. Crops that feed the world 10. Past successes and future challenges to the role played by wheat in global food security. *Food Security,* 5: 291–317.

11. Sayre, K.D., & Govaerts, B. 2009. Conservation agriculture for sustainable wheat production. *In.* J. Dixon, H. J. Braun, P. Kosina, & J. Crouch, eds. *Wheat facts and futures 2009.* Mexico International Maize and Wheat Improvement Center (CIMMYT).

12. Aryal, J.P., Sapkota, T.B., Jat, M.L. & Bishnoi, D. 2015. On-farm economic and environmental impact of zero-tillage wheat: a case of north-west India. *Experimental Agriculture, 51:* 1–16., Cambridge University Press 2014. doi:10.1017/S001447971400012X.

13. Moussadek, R. 2012. Impacts de l'agriculture de conservation sur les propriétés et la productivité des vertisols du Maroc Central. *Afrika focus,* 25(2): 147–151.

14. Scopel, E., Triomphe, B., dos Santos Ribeiro, MdeF., Séguy, L., Denardin, J.E. & Kochhann, R.A. 2004. Direct seeding mulch-based cropping systems (DMC) in Latin America. *In* R.A. Fischer, ed. *New directions for a diverse planet.* Proceedings of the 4th International Crop Science Congress, Brisbane, Australia.

15. Thierfelder, C. & Mupangwa, W. 2014. *Identifying new sustainable intensification pathways for smallholder farmers in Southern Africa.* Paper presented at the World Congress of Conservation Agriculture (WCCA6), June 22–25, 2014, Winnipeg, Canada.

16. Kumar V. & Ladha J.K. 2011. Direct seeding of rice: recent developments and future research needs. *Advances in Agronomy,* 111: 297–413.

17. Yamano, T., Baruah, S., Sharma, R., & Kumar, A. 2013. *Factors affecting the adoption of direct-seeded rice in the northeastern Indo-Gangetic Plain.* CSISA Socioeconomics Policy Brief. New Delhi: International Rice Research Institute.

18. Frison, E.A., Cherfas, J. & Hodgkin, T. 2011. Agricultural biodiversity is essential for a sustainable improvement in food and nutrition security. *Sustainability* 3: 238–253.

19. Mayee, C.D., Monga, D., Dhillon, S.S., Nehra, P.L. & Pundhir, P. 2008. *Cotton-wheat production system in South Asia: a success story.* Asia-Pacific Association of Agricultural Research Institutions, Bangkok, Thailand.

20. Buttar, G.S., Sidhu, H.S, Singh, V., Gupta, N., Gupta, R., Jat, M.L. & Singh, B. 2011. Innovations for relay planting of wheat in cotton: a breakthrough for enhancing productivity and profitability in cotton-wheat systems of South Asia. . *Experimental Agriculture* (2013), Vol. 49 (1), pp.19–30 (doi:10.1017/S0014479712001032).

21. Kukal S.S., Singh, Y., Jat, M.L. & Sidhu, H.S. 2014. Improving Water Productivity of Wheat-Based Cropping Systems in South Asia for Sustained Productivity. *In* Donald L Sparks, ed. *Advances in Agronomy,* (127): 159–230. University of Delaware, USA.

22. He, Ping, Lia, S., Jina, J., Wang, H., Li, C., Wang, Y. & Cuie, R. 2009. Performance of an optimized nutrient management system for double-cropped wheat-maize rotations in North-Central China. *Agronomy Journal* 101(6): 1489–1496.

23. Sepat, S. & Rana, D.S. 2013. Effect of Double No-till and Permanent Raised Beds on Productivity and Profitability of Maize (*Zea mays* L.) –wheat (*Triticum aestivum* (L.) Emend. Flori & Paol) Cropping System under Indo-Gangetic Plains of India. *International Journal of Agriculture and Food Science Technology,* 4 (8): 787–790.

24. Bezner-Kerr, R., Snapp, S.S., Chirwa, M., Shumba, L. & Msachi, R. 2007. Participatory research on legume diversification with Malawian smallholder farmers for improved human nutrition and soil fertility. *Experimental Agriculture,* 43: 437–453.

25. Giller, K.E., Murwira, M.S., Dhliwayo, D.K.C., Mafongoya, P.L., & Mpepereki, S. 2011. Soyabeans and sustainable agriculture in southern Africa. *International Journal of Agricultural Sustainability,* 9: 50–58.

26. Kamanga, B.C.G., Kanyama-Phiri, G.Y., Waddington, S.R., Almekinders, C.J.M. & Giller, K.E. 2014. The evaluation and adoption of annual legumes by smallholder maize farmers for soil fertility maintenance and food diversity in central Malawi. *Food Security,* 6(1): 45–59.

27. Wilkins, R.J. 2008. Eco-efficient approaches to land management: a case for increased integration of crop and animal production systems. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 363(1491): 517–525.

28. Garrity, D.P. 2011. *Making Conservation Agriculture ever green.* Keynote presentation 5th World Congress on Conservation Agriculture and 3rd Farming Systems Design Conference (WCCA5 and FSD3), 26–29 September 2011, Brisbane Australia.

29. Kluthcouski, J., Cobucci, T., Aidar, H., Yokoyama, L.P., Oliveira I.P. de, Costa, J.L. da S., Silva, J.G. da, Vilela, L., Barcellos, A. de O. & Magnobosco, C.de U. 2000. *Sistema Santa Fé - Tecnologia Emprapa: Integração lavoura-pecuária peolo consórcio de culturas anuais com forragerira, em áreas de lavoura, nos sistemas direto e convencional.* Santo Antônio de Goiás, Brazil: Embrapa Arroz e Feijão, 28pp. Embrapa Arroz e Feijão. Circular Técnica 38.

30. Pacheco, A.R., de Queiroz Chaves, R. & Lana Nicoli, C.M. 2013. Integration of crops, livestock, and forestry: A system of production for the Brazilian Cerrados, pp.51–60. *In* C.H. Hershey & P. Neate, eds. *Eco-efficiency: From vision to reality (Issues in Tropical Agriculture series)* Cali, CO: Centro Internacional de Agricultura Tropical (CIAT), 2013.

31. Vilrla, L., Macedo, M.C.M., Júnior, G.B.M. & Kluthcouski, J. 2003. Crop-livestock integration benefits. *In*: J. Kluthcouski, L.F. Stone & H. Aidar, eds. *Integraçã lavoura-pecuária. Embrapa Arroz e Feijão*, Santo Antônio de Goiás, Goiás, Brazil.

32. FAO. 2007. *Tropical crop–livestock systems in conservation agriculture: the Brazilian experience* by Landers, J.N. 2007 Integrated Crop Management 5. Rome. 92pp.

33. Timsina, J., Jat, M.L. & Majumdar, K. 2010. Rice-maize systems of South Asia: current status, future prospects and research priorities for nutrient management. *Plant Soil,* 335:65–82.

34. FAO. 2012. *Farmer Field Schools as a vehicle to help vulnerable smallholder farmers develop climate resilient farming systems: experiences based on FAO's work in South and Southeast Asia.* Presentation to the Second World Bank-FAO Expert Meeting, 14–16 May 2012, Bangkok, Thailand.

35. Sounkoura, A., Ousmane, C., Eric, S., Urbain, D., Soule, A., Sonia, P. & Joel, H. 2011. Contribution of rice and vegetable value chains to food security and incomes in the inland valleys of southern Benin and Mali: Farmers' Perceptions. In: *Agricultural Innovations for Sustainable Development. Contributions from the Finalists of the 2009/2010 Africa-wide Women and Young Professionals in Science Competitions. 3(2): 51–56.* CTA & FARA.

36. FAO. 2004. *Culture of fish in rice fields.* M. Halwart & M. Gupta, eds. Rome.

37. Khaleduzzaman, A.B.M., Akbar, M.A. & Shamsuddin, M. 2011. Integration of forage production with high-yielding rice variety cultivation in Bangladesh. In: H.P.S. Makkar, ed. *Successes and failures with animal nutrition practices and technologies in developing countries.* Proceedings of the FAO Electronic Conference, 1–30 September 2010, Rome. FAO Animal Production and Health Proceedings. No. 11. Rome.

38. Doran, J.W. & Zeiss, M.R. 2000. *Soil health and sustainability: managing the biotic component of soil quality. Agronomy & Horticulture - Faculty Publications, Paper 15.* Lincoln (USA), University of Nebraska.

39. Lal, R. 2010. Eco-efficiency in agro-ecosystems through soil carbon sequestration. *Crop Science*, Vol. 50 no. Supplement_1. Crop Science Society of America, Madison, WI. DOI: 10.2135/cropsci2010.01.0012.

40. Lal, R. 2015. World water resources and achieving water security. *Agronomy Journal*, 107: 4: pp.1526–1532.

41. Mrabet, R., Moussadek, R., Fadlaoui, A. & van Ranst, E. 2012. Conservation agriculture in dry areas of Morocco. *Field Crops Research*, 132: 84–94.

42. Moussadek, R., Mrabet, R., Dahan, A., Zouahri, M., Mourid, E. & Van Ranst, E. 2014. Tillage System Affects Soil Organic Carbon Storage and Quality in Central Morocco. *Applied and Environmental Soil Science*, 2014. Article ID 654796 doi:10.1155/2014/654796.

43. Jat, M.L., Gathala, M.K., Ladha, J.K., Saharawat, Y.S., Jat, A.S., Kumar, V., Sharma, S.K., Kumar, V. & Gupta, R. 2009. Evaluation of precision land leveling and double zero till systems in the rice–wheat rotation: water use productivity, profitability and soil physical properties. *Soil & Tillage Research,* 105, 112–121.

44. Scopel, E., Findeling, A., Chavez Guerra, E. & Corbeels, M. 2005. Impact of direct sowing mulch-based cropping systems on soil carbon, soil erosion and maize yield. *Sustainable Development*, 25: 425–432 doi: 10.1051/agro:2005041.

45. Hasniati, D. & Shelton, M. 2005. *Sesbania grandiflora*: a successful tree legume in Lombok, Indonesia. *Tropical Grasslands Journal,* Vol. 39. 2005. p. 217.

46. Kaizzi, C.K., Ssali, H., Nansamba, A. & Vlek, P. 2007. The potential benefits of *Azolla*, Velvet bean (*Mucuna pruriens* var. *utilis*) and N fertilizers in rice production under contrasting systems in eastern Uganda. *In* A. Bationo, B. Waswa, J. Kihara & J. Kimetu, eds. *Advances in Integrated Soil Fertility Management in Sub-Saharan Africa: Challenges and Opportunities,* pp 423–433.

47. Singh, M., Singh, V.P. & Reddy, K.S. 2001.Effect of integrated use of fertilizer N and FYM or green manure on transformation of NK and S and productivity of rice-wheat system on Vertisols. *Journal of the Indian Society Soil Science*, 49: 430–435.

48. Snapp, S.S., Mafongoya, P.L. & Waddington, S. 1998. Organic matter technologies for integrated nutrient management in smallholder cropping systems of southern Africa. *Agriculture, Ecosystems and Environment,* 71: 185–200.

49. Vanlauwe, B., Bationo, A., Chianu, J., Giller, K.E., Merckx, R., Mokwunye, U., Ohiokpehai, O., Pypers, P., Tabo, R., Shepherd, K.D., Smaling, E.M.A., Woomer, P.L. & Sanginga, N. 2010. Integrated soil fertility management: Operational definition and consequences for implementation and dissemination. *Outlook on Agriculture,* 39(1): 17–24.

50. Nyamangara, J., Nyaradzo Masvaya, E., Tirivavi, R. & Nyengerai, K. 2013. Effect of hand-hoe based conservation agriculture on soil fertility and maize yield in selected smallholder areas in Zimbabwe. *Soil & Tillage Research* 126 (2013) 19–25.

51. Snapp, S., Jayne, T.S., Mhango, W., Benson, T. & Ricker-Gilbert, J. 2014. *Maize yield response to nitrogen in Malawi's smallholder production systems.* Malawi Strategy Support Program Working Paper No. 9. Washington, DC, IFPRI.

52. Buresh, R.J. & Wopereis, M. 2014. *Save and Grow: Rice.* Paper prepared for the FAO Technical Consultation on Save and Grow: Maize, Rice and Wheat, Rome, 15–17 December 2014. Rome, FAO. (mimeo).

53. Pampolino, M.F., Manguiat, J., Ramanathan, S., Gines, H.C., Tan, P.S., Chi, T.T.N., Rajendran, R. & Buresh, R.J. 2007. Environmental impact and economic benefits of site-specific nutrient management (SSNM) in irrigated rice systems. *Agricultural Systems,* 93(1): 1–24 doi:10.1016/j.agsy.

54. Biradar D.P., Aladakatti, Y.R., Rao, T.N. & Tiwari, K.N. 2006. Site-Specific Nutrient Management for maximization of crop yields in Northern Karnataka. *Better Crops,* 90(3): 33–35.

55. Bindraban, P.S., Dimkpa, C., Nagarajan, L., Roy, A. & Rabbinge, R. 2015. Revisiting fertilizers and fertilization strategies for improved nutrient uptake by plants. *Biology and Fertility of Soils.* DOI: 10.1007/s00374-015-1039-7.

56. Asaduzzaman, M. 2011. *Technology transfer and diffusion: Simple to talk about not so easy to implement.* A presentation made in WIPO Conference on Innovation and Climate Change, 11–12 July 2011. Geneva.

57. World Bank. 2012. *Agricultural innovation systems: An investment sourcebook.* Washington DC. DOI: 10.1596/978-0-8213-8684-2.

58. Ortiz-Monasterio J. & Raun, W. 2007. *Reduced nitrogen and improved farm income for irrigated spring wheat in the Yaqui Valley, Mexico, using sensor based nitrogen management.* Paper presented at the International Workshop on Increasing Wheat Yield Potential. CIMMYT, Obregon, Mexico, 20–24 March 2006. *Journal of Agricultural Science*, 145: 215–222.

59. Sapkota, T.B., Majumdar, K., Jat, M.L., Kumar, A., Bishnoi, D.K., McDonald, A.J. & Pampolino, M. 2014. Precision nutrient management in conservation agriculture based wheat production of Northwest India: Profitability, nutrient use efficiency and environmental footprint. *Field Crops Research,* 155:233–244.

60. Lobell, D.B., Hammer, G.L., McLean, G., Messina, C., Roberts, M.J. & Schlenker, W. 2013. The critical role of extreme heat for maize production in the United States. *Nature Climate Change,* 3: 397–501.

61. Edmeades, G.O. 2015. *Maize – Improved varieties.* Paper prepared for FAO for Save and Grow: Maize, Rice and Wheat. Rome. (mimeo).

62. Borlaug Institute for South Asia. 2015. *Major Accomplishments 2012–2014.* BISA Report Series 1. New Delhi, India. 38pp.

63. Mackill, D. J., Ismail, A. M., Pamplona, A.M., Sanchez, D.L., Carandang, J.J. & Septiningsih, E.M. 2010. Stress-tolerant rice varieties for adaptation to a changing climate. *Crop, Environment & Bioinformatics,* 7: 250–259.

64. Solh, M., Braun, H-J. & Tadesse, W. 2014. *Save and Grow: Wheat.* Paper prepared for the FAO Technical Consultation on Save and Grow: Maize, Rice and Wheat, Rome, 15–17 December 2014. Rabat, ICARDA. (mimeo).

65. IAEA (International Atomic Energy Agency). 2010. *Mass screening techniques for selecting crops resistant to diseases.* IAEA-TDL-001, Vienna.

66. Cissoko, M., Boisnard, A., Rodenburg, J., Press, M.C. & Scholes, J.D. 2011. New Rice for Africa (NERICA) cultivars exhibit different levels of post-attachment resistance against the parasitic weeds *Striga hermonthica. New Phytologist,* 192: 952–963.

67. Jamil, M., Rodenburg, J., Charnikhova, T. & Bouwmeester, H.J. 2011. Pre-attachment *Striga hermonthica* resistance of New Rice for Africa (NERICA) cultivars based on low strigolactone production. *New Phytologist*, 192: 964–975.

68. IRRI (International Rice Research Institute). 2015. Disease and pest resistant rice (available at http://irri.org/our-work/research/better-rice-varieties/disease-and-pest-resistant-rice).

69. HarvestPlus. 2014. *Biofortification progress briefs.* August 2014 (available at http://www.harvestplus.org/sites/default/files/Biofortification_Progress_Briefs_August2014_WEB_0.pdf).

70. Atlin, G.N., Palacios, N., Babu, R., Das, B., Twumasi-Afriyie, S., Friesen, D., De Groote, H., Vivek, B. & Pixley, K. 2011. Quality Protein Maize: Progress and Prospects. *In* J. Janick, ed. *Plant Breeding Reviews, 34: 83–31.* Willey-Blackwell.

71. Babu, R., Palacios, N. & Prasanna, B.M. 2013. Biofortified maize – a genetic avenue for nutritional security. *In* R.K. Varshney & R. Tuberosa, eds. *Translational genomics for crop breeding: Abiotic stress, yield, and quality.* John Wiley & Sons, pp.161–176.

72. Mahmood, T. & Trethowan, R. 2015. Crop breeding for conservation agriculture. *In* M. Farooq & K.H.M. Siddique, eds. *Conservation agriculture,* pp159–179.

73. Lopes, M., El-Basyoni, I., Baenziger, P.S., Singh, S., Royo, C., Ozbek, K., Aktas, H., Ozer, E., Ozdemir, F., Manickavelu, A., Ban, T. & Vikram, P. 2015. Exploiting genetic diversity from landraces in wheat breeding for adaptation to climate change. *Journal of Experimental Botany,* 2015 Jun;66(12):3477–3486. Epub 2015 Mar 28.

74. George, T.S., Hawes, C., Newton, A.C., McKenzie, B.M., Hallett, P.D. & Valentine, T.A. 2014. Field phenotyping and long-term platforms to characterise how crop genotypes interact with soil processes and the environment. *Agronomy* 4, no. 2: 242–278.

75. Brooker, R.W., Bennett, A. E., Cong, W.-F., Daniell, T.J., George, T.S., Hallett, P.D., Hawes, C., Iannetta, P.P.M., Jones, H.G., Karley, A.J., Li, L., McKenzie, B.M., Pakeman, R.J., Paterson, E., Schöb, C., Shen, J., Squire, G., Watson, C.A., Zhang, C., Zhang, F., Zhang, J. & White, P.J. 2015. Improving intercropping: a synthesis of research in agronomy, plant physiology and ecology. *New Phytologist,* 206: 107–117. doi: 10.1111/nph.13132.

76. Hellin, J., Erenstein, O., Beuchelt, T., Camacho, C. & Flores, D. 2013. Maize stover use and sustainable crop production in mixed crop–livestock systems in Mexico. *Field Crops Research.* Volume 153, September 2013, pp.12–21.

77. Tilman D., Cassman K.G., Matson P.A., Naylor R. & Polasky S. 2002. Agricultural sustainability and intensive production practices. *Nature,* 418: 671–677. doi:10.1038/nature01014.

78. Trethowan, R., Manes, Y. & Chattha, T. 2009. *Breeding for improved adaptation to conservation agriculture improves crop yields.* Paper presented at the 4th World Congress on Conservation Agriculture, February 4–7, 2009, New Delhi, India.

79. Global Rice Science Partnership (GRiSP). 2013. *Rice almanac*, 4th edition. IRRI, Los Baños, Philippines, 283pp.

80. Smith, J.S., Jones, E. S., Nelson, B.K., Phillips, D.S. & Wineland, R.A. 2014. Genomic approaches and intellectual property protection for variety release: A perspective from the private sector. *Genomics of Plant Genetic Resources.* Springer Netherlands, 2014. pp.27–47.

81. Prasanna, B.M. 2015. *Climate-resilient maize development and delivery in the tropics through public-private partnerships: CIMMYT's experiences and perspective.* 5th International Workshop on Next Generation Genomics and Integrated Breeding for Crop Improvement (February 18 – 20, 2014), ICRISAT, Patancheru, India.

82. Joshi, A. K., Azab, M., Mosaad, M., Moselhy, M., Osmanzai, M., Gelalcha, S., Bedada, G., Bhatta, M. R., Hakim, A., Malaker, P. K., Haque, M. E., Tiwari, T. P., Majid, A., Jalal Kamali, M. R., Bishaw, Z., Singh, R. P., Payne, T. & Braun, H. J. 2011. Delivering rust resistant wheat to farmers: a step towards increased food security. *Euphytica* 179:187–196.

83. Lewis, V. & Mulvany, P.M. 1997. *A typology of community seed banks.* Natural Resources Institute (NRI), University of Greenwich, Central Avenue and Intermediate Technology Development Group, Myson House, U.K.

84. Gadal, N., Bhandari, D.B., Pandey, A., Dilli Bahadur, K.C. & Dhami, N.B. 2014. Strengthening the local seed systems and disadvantaged communities: success and evolution of the first community-managed seed production company in the hills of Nepal. *In* B.M. Prasanna *et al.*, eds. Book of Extended Summaries, 12th Asian Maize Conference and Expert Consultation on Maize for Food, Feed, Nutrition and Environmental Security. Bangkok, Thailand, October 30 – November 1, 2014. CIMMYT, Mexico D.F. and APAARI, Bangkok, pp.238–242.

85. Lopes, M., Nesbitt, H., Spyckerelle, L., Pauli, N., Clifton, J. & Erskine, W. 2015. Harnessing social capital for maize seed diffusion in Timor-Leste. *Agronomy for Sustainable Development,* 35:847–855.

86. Comprehensive Assessment of Water Management in Agriculture. 2007. *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture.* London: Earthscan, and Colombo: International Water Management Institute.

87. Yadvinder-Singh, Kukal, S.S., Jat, M.L. & Sidhu, H.S. 2014. Improving Water Productivity of Wheat-Based Cropping Systems in South Asia for Sustained Productivity. *Advances in Agronomy*, 127: 157–258.

88. Garg, K.K., Karlberg, L., Barron, J., Wani, S.P. & Rockstrom, J. 2012. Assessing impact of agricultural water interventions at the Kothapally watershed, Southern India. *Hydrological Processes*, 26(3): 387–404.

89. Singh, R., Garg, K.K., Wani, S.P., Tewari, R.K. & Dhyani, S.K. 2014. Impact of water management interventions on hydrology and ecosystem services in Garhkundar-Dabar watershed of Bundelkhand region, Central India. *Journal of Hydrology,* 509:132–149.

90. El-Swaify, S.A., Pathak, P., Rego, T.J. & Singh, S. 1985. Soil management for optimized productivity under rainfed conditions in the semi-arid tropics. *Advances in Soil Science,* 1: 1–64.

91. Molden, D., Oweis T., Steduto, P., Bindraban, P., Hanjra, M. & Kijne, J. 2010. Improving agricultural water productivity: between optimism and caution. *Agricultural Water Management*, 97(4): 528–535.

92. Amberger A. 2006. *Soil fertility and plant nutrition in the tropics and subtropics.* International Fertilizer Industry Association & International Potash Institute, France.

93. Ilbeyi, A., Ustun, H., Oweis T., Pala, M. & Benli, B. 2006. Wheat water productivity in a cool highland environment: Effect of early sowing with supplemental irrigation. *Agricultural Water Management,* 82: 399–410.

94. IAEA. 2012. *Greater agronomic water use efficiency in wheat and rice using carbon isotope discrimination.* IAEA-TEC-DOC-1671, Vienna, Austria.

95. Sharma, P.C., Jat, H.S., Kumar, V., Gathala, M.K., Datta, A., Yaduvanshi, N.P.S., Choudhary, M., Sharma, S., Singh, L.K., Saharawat, Y., Yadav, A.K., Parwal, A., Sharma, D.K., Singh, G., Jat, M.L., Ladha, J.K. & McDonald, A. 2015. *Sustainable intensification opportunities under current and future cereal systems of North-West India.* Technical Bulletin: CSSRI/Karnal/2015/e. Central Soil Salinity Research Institute, Karnal, India.

96. ICARDA (International Center for Agricultural Research in the Dry Areas). 2013. *ICARDA Annual Report.* Beirut, Lebanon.

97. Marino, M. 2013. Raised beds prove their worth. *Partners magazine.* Winter 2013. Australian Center for International Agricultural Research. Canberra.

98. Mandal, K.G., Hati, K.M., Misra, A.K., Bandyopadhyaym, K.K. & Tripathi, A.K. 2013. Land surface modification and crop diversification for enhancing productivity of a Vertisol. *International Journal of Plant Production* 7 (3). July 2013.

99. Gupta, R., Jat, R.K., Sidhu, H.S., Singh, U.P., Singh, N.K., Singh, R.G. & Sayre, K.D. 2015. *Conservation Agriculture for sustainable intensification of small farms.* Compendium of Invited Papers presented at the XII Agricultural Science Congress 3–6 February 2015, ICAR-National Dairy

Research Institute, Karnal, India. pp.15.

100. Djagba, J.F., Rodenburg, J., Zwart, S.J., Houndagba, C.J. & Kiepe, P. 2014. Failure and success factors of irrigation system developments: a case study from the Ouémé and Zou valleys in Benin. *Irrigation and Drainage,* 63(3): 328–329.

101. Rodenburg, J., Zwart, S.J., Kiepe, P., Narteh, L.T., Dogbe, W. & Wopereis, M.C.S. 2014. Sustainable rice production in African inland valleys: seizing regional potentials through local approaches. *Agricultural Systems,* 123: 1–11.

102. Richards, M. & Ole Sander, B. 2014. *Alternate wetting and drying in irrigated rice.* Practice brief – Climate-smart agriculture, April 2014 (available at https://cgspace.cgiar.org/rest/bitstreams/34363/retrieve).

103. Lampayan, R.M., Rejesus, R.M., Singleton, G.R. & Bouman, B.A.M. 2015. Adoption and economics of alternate wetting and drying water management for irrigated lowland rice. *Field Crops Research,* 170: 95–108.

104. Kreye, C., Bouman, B.A.M., Reversat, G., Fernandez, L., Vera Cruz, C., Elazegui, F., Faronilo, J.E. & Llorca, L. 2009. Biotic and abiotic causes of yield failure in tropical aerobic rice. *Field Crops Research,* 112: 97–106.

105. Oerke, E.C. 2006. Crop losses to pests. *Journal of Agricultural Science*, 144: 31–43.

106. Pretty, J.N. & Bharucha, Z.P. 2015. Integrated Pest Management for Sustainable intensification of agriculture in Asia and Africa. *Insects* 2015, *6*(1), 152–182; doi:10.3390/insects6010152.

107. Gould. F., Kennedy, G.G. & Johnson, M.T. 1991. Effects of natural enemies on the rate of herbivore adaptation to resistant host plants. *Entomologia Experimentalis et Applicata*, 58: 1–14.

108. Gallagher, K.D., Kenmore, P.E. & Sogawa, K. 1994. Judicial use of insecticides deter planthopper outbreaks and extend the life of resistant varieties in southeast Asian rice. pp 599–614. *In* R.F. Denno & T.J. Perfect, eds., *Planthoppers-their ecology and management.* New York, Chapman and Hall.

109. Heong, K.L., Escalada, M.M., Huan, N.H., Chien, H.V. & Quynh, P.V. 2010. Scaling out communication to rural farmers: lessons from the "Three Reductions, Three Gains" campaign in Vietnam. *In* F.G. Palis, G.R. Singleton, M.C. Casimero & B. Hardy, eds. *Research to impact: case studies for natural resource management for irrigated rice in Asia,* pp.207–220. Los Baños (Philippines), International Rice Research Institute. 370pp.

110. Gallagher, K.D. 1998. *Farmer Field Schools for Integrated Pest Management in Africa with Special Reference to East Africa. Proceedings of the National Pre-Season Planning Workshop on the Implementation of Field School Groups for Integrated Production and Pest Management.* 31 August–1 September, 1998. ZIPAM, Darwendale. Government of Zimbabwe and FAO Global IPM Facility. Rome.

111. FAO. 2004b. *IPM Farmer Field Schools: A synthesis of 25 impact evaluations.* Rome, Global IPM Facility.

112. Hruska, A.J. & Corriols, M. 2002. The impact of training in integrated pest management among Nicaraguan maize farmers: increased net returns and reduced health risk. *International Journal of Occupational and Environmental Health.* Vol. 8, Issue 3 (01 July 2002), pp.191–200.

113. Tejada, T. 1990. Uso de aceite en el control de *Heliothis zea* y *Euxesta* sp. en el cultivo de maize. *Memorias de la XIV Reunion de Maiceros de la Zona Andina y la I Reunion Suramericana de los Maiceros*. Maracay, Venezuela. 7pp.

114. Abanto, W., Narro, L. & Chavez, A. 1998. Control del gusano mazorquero (*Heliothis zea*, Boddie) en maiz amilaceo mediante la aplicacion de aceite de consume humano. p. 530–538. *In* C. De Leon, L. Narro & S. Reza, eds. *Memorias IV Reunión Latinoamericana y XVII Reunión de la Zona Andina de Investigadores en Maíz.* Agosto 10–17, 1997. CORPOICA, Ceres, Colombia.

115. Tapia, I., Bermeo, D.B., Silva, E. & Racines, M. 1999. Evaluación de cuatro métodos de aplicación de aceite comestible vegetal en el control de *Heliothis zea* y *Euxesta* sp. en la sierra del Ecuador. Proc. XVIII Reunión Latinoamericana del Maíz. Sete Lagoas, Brazil. pp.671–675.

116. Valicente, F.H. 2008. Controle biológico da lagarta do cartucho, *Spodoptera frugiperda*, com *Bacillus thuringiensis.* Sete Lagoas: Embrapa Milho e Sorgo. Embrapa Milho e Sorgo. Circular Técnica, 105; 9pp.

117. Valicente, F. H., Tuelher, E. De S. & Barros, E.C. 2010. Processo de formulação do *Baculovirus spodoptera* em pó molhável. Embrapa Milho e Sorgo, Circular técnica, 156; 5pp. Sete Lagoas, Brazil.

118. Cruz, I., Figueiredo, M.L.C., Silva, R.B. & Foster, J.E. 2010. Efficiency of chemical pesticides to control *Spodoptera frugiperda* and validation of pheromone trap as a pest management tool in maize crop. *Revista Brasileira de Milho e Sorgo*, Vol.9, n.2, p.107–122, 2010.

119. Oswald, A. & Ransom, J. 2001. *Striga* control and improved farm productivity using crop rotation. *Crop Protection,* Vol. 20, Issue 2, March 2001, pp.113–120.

120. Rodenburg, J., Cissoko, M., Kayeke, J., Dieng, I., Khan, Z.R., Midega, C.A.O., Onyuka, E.O. & Scholes, J.D. 2015. Do NERICA rice cultivars express resistance to *Striga hermonthica* (Del.) Benth. and *Striga asiatica* (L.) Kuntze under field conditions? *Field Crops Research,* 170 (2015): 83–94.

121. Conner, R. L., Kuzyk, A. D. & Su, H. 2003.Impact of powdery mildew on the yield of soft white spring wheat cultivars. *Canadian Journal of Plant Science*, 83(4): 725–728.

122. Duveiller, E., Singh, R. P. & Nicol, J. M. 2007. The challenges of maintaining wheat productivity: pests, diseases, and potential epidemics. *Euphytica*, 157(3): 417–430.

123. FAO. 2011. *History of IPM/FFS in Iran.* FAO project GTFS/REM/070/ITA Regional Integrated Pest Management (IPM) Programme in the Near East. Rome.

Chapter 3. Farming systems that save and grow

'Push-pull' fights pests, boosts milk production

1. Khan, Z. & Pickett, J. 2009. *Push-pull strategy for insect pest management.* Nairobi. ICIPE.

2. Midega, C.A.O., Khan, Z.R., Van den Berg, J., Ogol, C.K., Bruce, T.J. & Pickett, J.A. 2009. Non-target effects of the 'push-pull' habitat management strategy: Parasitoid activity and soil fauna abundance. *Crop Protection* 28 (2009) 1045–1051.

3. International Centre of Insect Physiology and Ecology (ICIPE). 2010. *Impact assessment of push–pull technology developed and promoted by ICIPE and partners in eastern Africa.* Nairobi.

4. Khan, Z., Midega, C., Pittchar, J., Murage, A., Birkett, M., Bruce, T. & Pickett, J. 2012. Achieving food security for one million sub-Saharan African poor through push–pull innovation by 2020. *Philosophical Transactions of the Royal Society London B: Biological Sciences* 2014 Apr 5; 369(1639).

5. ICIPE. 2013. *Climate-smart push–pull: resilient, adaptable conservation agriculture for the future.* Nairobi.

6. Murage, A.W., Midega, C.A.O., Pittchar, J.O., Pickett, J.A. & Khan, Z.R. 2015. Determinants of adoption of climate-smart push-pull technology for enhanced food security through integrated pest management in eastern Africa. *Food Security* 7(3), 709–724.

Higher yields from healthy plants in healthy soil

1. Sharma, P.K. & De Datta, S.K. 1986. Physical properties and processes of puddled rice soil. *Advances in Soil Science* 5: 139–178.

2. Africare, Oxfam America, WWF-ICRISAT Project. 2010. *More Rice for People, More Water for the Planet.* WWF-ICRISAT Project, Hyderabad, India.

3. Berkhout, E., Glover, D. & Kuyvenhoven, A. 2015. On-farm impact of the System of Rice Intensification (SRI): Evidence and knowledge gap. *Agricultural Systems* 132: 157–166.

4. Buresh, R.J. 2015. Nutrient and fertilizer management in rice systems with varying supply of water. *In* P. Drechsel, P. Heffer, H. Magen, R. Mikkelsen & D. Wichelns, eds. *Managing water and fertilizer for sustainable agricultural intensification.* International Fertilizer Industry Association (IFA), International Water Management Institute (IWMI), International Plant Nutrition Institute (IPNI), and International Potash Institute (IPI). Paris.

5. FAO. 2015. FAOSTAT. Online statistical database: Production (available at http://faostat3.fao.org/download/Q/QC/E).

6. Uphoff, N. 2008. *Farmer innovations improving the System of Rice Intensification (SRI)* (available at http://www.future-agricultures.org/farmerfirst/files/T1a_Uphoff.pdf).

7. Thakur, A., Uphoff, N. & Antony, E. 2009. An assessment of physiological effects of System of Rice Intensification (SRI) practices compared with recommended rice cultivation practices in India. *Experimental Agriculture* (2010), Vol. 46 (1), pp.77–98.

8. Hameed, K., Mosa, A. & Jaber, F. 2011. Irrigation water reduction using System of Rice Intensification compared with conventional cultivation methods in Iraq. *Paddy Water Environment* (2011) 9:121–127.

9. Ceesay, M., Reid, W., Fernandes, E. & Uphoff, N. 2006. The effects of repeated soil wetting and drying on lowland rice yield with system of Rice Intensification (SRI) methods. *International Journal of Agricultural Sustainability*, 4:1, 5–14.

10. Wu, W., Ma, B.-L. & Uphoff, N. 2015. A review of the system of rice intensification in China. *Plant and Soil*, *August 2015, Vol. 393, Issue 1, pp.361–381.*

11. Barah, B. 2009. Economic and ecological benefits of System of Rice Intensification (SRI) in Tamil Nadu. *Agricultural Economics Research Review.* Vol. 22, July-December 2009, pp.209–214.

12. Zhao, L., Wu, L., Li, Y., Lu, X., Zhu, D. & Uphoff, N. 2009. Influence of the System of Rice Intensification on rice yield and nitrogen and water use efficiency with different n application rates. *Experimental Agriculture* (2009), Vol. 45, pp.275–286.

13. Zhao, L., Wu, L., Wu, M. & Li, Y. 2011. Nutrient uptake and water use efficiency as affected by modified rice cultivation methods with reduced irrigation. *Paddy Water Environment* (2011) 9:25–32.

14. Dhital, K. 2011. *Study on System of Rice Intensification in transplanted and direct-seeded versions compared with standard farmer practice in Chitwan, Nepal.* Tribhuvan University Institute of Agriculture and Animal Science, Rampur, Chitwan, Nepal.

15. Dzung, N.T. 2011. *Simple and effective-SRI and agriculture innovation.* System of Rice Intensification website. (available at http://sri.ciifad.cornell.edu/countries/vietnam/VN_SRI_booklet_Eng2012.pdf).

16. Nga, N., Rodriguez, D., Son, T. & Buresh, R.J. 2010. Development and impact of site-specific nutrient management in the Red River Delta of Vietnam. pp.317–334. *In* F.G. Palis, G.R. Singleton, M.C. Casimero & B. Hardy, eds. *Research to impact. case studies for natural resource management for irrigated rice in Asia.* International Rice Research Institute. Los Baños, Philippines.

17. Choi, J.D., Kim, G.Y., Park, W.J., Shin, M., Choi, Y.H., Lee, S., Kim, S.J. & Yun, D.K. 2014. Effect of SRI water management on water quality and greenhouse gas emissions in Korea. *Irrigation & Drainage,* 63: 266–270.

18. Tuong, T. & Bouman, B. 2003. Rice production in water-scarce environments. *In* J.W. Kijne, R. Barker and D. Molden, eds. *Water productivity in agriculture: limits and opportunities for improvement.* CAB International.

19. Gathorne-Hardy, A., Narasimha Reddy, D., Venkatanarayana, M. & Harriss-White, B. 2013. A life-cycle assessment (LCA) of greenhouse gas emissions from SRI and flooded rice production in S.E. India. *Taiwan Water Conservancy,* 61:110–125.

20. Wassmann, R., Hosen, Y. & Sumfleth, K. 2009. *Reducing methane emissions from irrigated rice.* Focus 16(3). Washington, DC, IFPRI.

21. Yan, X., Akiyama, H., Kazuyuki, Y. & Akimoto, H. 2009. Global estimations of the inventory and mitigation potential of methane emissions from rice cultivation conducted using the 2006 Intergovernmental Panel on Climate Change Guidelines. *Global Biogeochemical Cycles*, Vol. 23, Issue 2, June 2009.

22. Anas, I., Rupela, O.P., Thiyagarajan, T.M. & Uphoff, N. 2011. A review of studies on SRI effects on beneficial organisms in rice soil rhizospheres. *Paddy Water Environment,* 9:53–64.

23. Lin, Xianqing, Zhu, D. & Lin, Xinjun. 2011. Effects of water management and organic fertilization with SRI crop practices on hybrid rice performance and rhizosphere dynamics. *Paddy Water Environment* (2011) 9:33–39.

24. Uphoff, N., Kassam, A. & Thakur, A. 2013. Challenges of Increasing Water Saving and Water Productivity in the Rice Sector: Introduction to the System of Rice Intensification (SRI) and this issue. 2013. *Taiwan Water Conservancy* Vol. 61, No. 4.

25. Borlaug Institute for South Asia. 2015. *Major accomplishments 2012–2014.* BISA Report Series 1, pp.13. New Delhi.

26. Lu, S.H., Dong, Y.J., Yuan, J., Lee, H. & Padilla, H. 2013. A high-yielding, water-saving innovation combining SRI with plastic cover on no-till raised beds in Sichuan, China. *Taiwan Water Conservancy*, 61: 4, 94–109.

More maize, less erosion on tropical hillsides

1. Ayarza, M. & Welchez, L. 2004. Drivers Affecting the Development and Sustainability of the Quesungual Slash and Mulch Agroforestry System (QSMAS) on Hillsides of Honduras. *In* A. Noble, ed. *Comprehensive assessment "bright spots" project final report.* Cali, Colombia. CIAT.

2. CIAT. 2009. *Quesungual slash and mulch agroforestry system (QSMAS): Improving crop water productivity, food security and resource quality in the subhumid tropics.* CPWF Project Report. Cali, Colombia.

3. Gangloff, G., Marohn, C., Tellez, O. & Cadisch, G. 2015. *Land use change: Identifying biophysical and socio-economic factors determining adoption of the Quesungual agroforestry system.* Paper prepared for the Tropentag Conference 2015, Management of land use systems for enhanced food security: conflicts, controversies and resolution. Humboldt-Universität, Berlin.

4. CIAT. 2009. *Quesungual slash and mulch agroforestry system: an eco-efficient option for the rural poor.* Cali, Colombia.

The extra benefits of legumes-before-wheat

1. Dong, Z., Wu, L., Kettlewell, B., Caldwell, C. & Layzell, D. 2003. Hydrogen fertilization of soils – is this a benefit of legumes in rotation? *Plant, Cell and Environment* (2003) 26, 1875–1879.

2. Pulse Australia. 2008. *Australian Pulse Bulletin.* PA 2008 (4). 5pp. Melbourne, Australia.

3. Evans J., McNeill A.M., Unkovich M. J., Fettell N.A. & Heenan D.P. 2001. Net nitrogen balances for cool-season grain legume crops and contributions to wheat nitrogen uptake: a review. *Australian Journal of Experimental Agriculture* 41: 347–359.

4. Peoples, M.B., Brockwell, J., Herridge, D.F., Rochester, I.J., Alves, B.J.R., Urquiaga, S., Boddey, R.M., Dakora, F.D., Bhattarai, S., Maskey, S.L., Sampet, C., Rerkasem, B., Khan, D.F., Hauggaard-Nielsen, H. & Jensen, E.S. 2009. The contributions of nitrogen-fixing crop legumes to the productivity of agricultural systems. *Symbiosis* 48: 1–17.

5. Griffiths, J. 2009. Legumes – benefits beyond nitrogen. *Farming Ahead,* 211:57–58.

6. Pala, M., Van Duivenbooden, N., Studer, C. & Bilders, C.L. 1999. Cropping systems and crop complementarity in dryland agriculture. *In* N. Van Duivenbooden, M. Pala, C. Studer & C.L. Bilders, eds. *Efficient soil water use: the key to sustainable development in the dry areas of West Asia, and North and Sub-Saharan Africa*. Proceedings of the 1998 (Niger) and 1999 (Jordan) workshops of the Optimizing Soil Water Use (OSWU) Consortium. ICARDA, Aleppo and ICRISAT, Patancheru, pp.299–330.

7. Cooper, P.J.M., Gregory, P.J., Tully, D. &

Harris, H.C. 1987. Improving Water use Efficiency of Annual Crops in the Rainfed Farming Systems of West Asia and North Africa. *Experimental Agriculture*, 23: 113–158. doi:10.1017/S001447970001694X.

8. Ryan, J., Masri, S., Ibriçki, H, Singh, M., Pala, M. & Harris, H.C. 2008. Implications of cereal-based crop rotations, nitrogen fertilization, and stubble grazing on soil organic matter in a Mediterranean-type environment. *Turkish Journal of Agriculture and Forestry,* 32: 289–297.

9. Fischer R.A., Byerlee D. & Edmeades G.O. 2014. *Crop yields and global food security: will yield increase continue to feed the world? ACIAR Monograph No. 158.* Canberra. Australian Centre for International Agricultural Research: Canberra.

10. Kassam, A. 2014. *Save and Grow: Soil health.* Paper presented at the FAO Technical Consultation on Save and Grow: Maize, Rice and Wheat, Rome 15–17 December 2014. Rome.

11. Tutwiler, R., Haddad, N. & Thomson, E.F. 1997. Crop-livestock integration in the drier areas of west Asia and north Africa. *In*: N. Haddad, R. Tutwiler & E.F. Thomson, eds. *Improvement of crop- livestock integration systems in west Asia and north Africa.* Proceedings of the Regional Symposium, 6–8 November, 1995, pp.5–22 Amman, Jordan. ICARDA, Aleppo.

12. Pala, M., Ryan, J., Zhang, H., Singh, M. & Harris, H.C. 2007. Water-use efficiency of wheat-based rotation systems in a Mediterranean environment. *Agricultural Water Management* 93(3): 136–144. doi:10.1016/j.agwat.2007.07.001.

13. Gan, Y.T., Liang, C., Chai, Q., Lemke, R.L., Campbell, C.A. & Zentner, R.P. 2014. Improving farming practices reduce the carbon footprint of spring wheat production. *Nature Communications 5,* Article number:5012.

14. Hailu, G., Tarekegn, A. & Asmare, E. 1989. Beneficial break crops for wheat production. *Ethiopian Journal of Agricultural Science,* 11(1): 15–24.

15. Higgs, R., Arthur, L., Peterson, E. & Paulson, W.H. 1990. Crop rotations: sustainable and profitable. *Journal of Soil and Water Conservation,* 45: 68–70.

16. Amanuel, G., Kühne, R.F., Tanner, D.G. & Vlek, P.L.G. 2000. Biological nitrogen fixation in faba bean (*Vicia faba* L.) in the Ethiopian highlands as affected by P fertilization and inoculation. *Biology and Fertility of Soils,* 32: 353–359.

17. Tanner, D.G., Yilma, Z., Zweie, L. & Gebru, G. 1994. Potential for cereal-based double cropping in Bale Region of Ethiopia. *African Crop Science Journal,* 2:135–143.

18. Asefa T., Tanner, D.G., Kefyalew, G. & Gorfu, A. 1997. Grain yield of wheat as affected by cropping sequence and fertilizer application in southeastern Ethiopia. *African Crop Science* 1, 5:147–159.

19. Moradi, H., Noori, M., Sobhkhizi, A., Fahramand, M. & Rigi, K. 2014. Effect of intercropping in agronomy. *Journal of Novel Applied Sciences,* 3 (3): 315–320, 2014.

'Nutrient pumps' feed cattle, nourish maize

1. Rao, I., Peters, M., van der Hoek, R., Castro, A., Subbarao, G., Cadisch, G. & Rincón, A. 2014. Tropical forage-based systems for climate-smart livestock production in Latin America. *Rural 21* 04/2014: 12–15.

2. Resende, Á.V., Furtini Neto, A.E., Alves, V.M.C., Curi, N., Muniz, J.A., Faquin, V., & Kinpara, D.I. 2007. Phosphate efficiency for corn following *Brachiaria* grass pasture in the Cerrado Region. *Better Crops.* 91(1): 17–19.

3. CGIAR (Consultative Group for International Agricultural Research). 2013. *'Grassroots action' in livestock feeding to help curb global climate change.* Research Program on Livestock and Fish (available at http://livestockfish.cgiar.org/2013/09/14/bni/).

4. CIAT. 2010. *Livestock, climate change and Brachiaria.* CIAT Brief No. 12.

5. Holmann, F., Rivas L., Argel, P. & Pérez E. 2004. Impact of the adoption of *Brachiaria* grasses: Central America and Mexico. *Livestock Research for Rural Development* 16 (12) 2004.

6. CIAT. 2013. *The impacts of CIAT's collaborative research.* Cali, Colombia.

7. Klink, C.A. & Moreira, A.G. 2002. Past and current human occupation, and land use. pp.69–88. *In* P.S. Oliveira & R.J. Marquis, eds. *The cerrados of Brazil: ecology and natural history of a neotropical savanna.* New York, USA. Columbia University Press.

8. Diniz-Filho, J.A.F., de Oliveira, G., Lobo, F., Ferreira, L.G, Bini, L.M. & Rangel, T.F.L.V.B. 2009. Agriculture, habitat loss and spatial patterns of human occupation in a biodiversity hotspot. *Scientia Agricola,* 66(6):764–771.

9. Pacheco, A. R., de Queiroz Chaves, R. & Lana Nicoli, C.M. 2013. Integration of Crops, Livestock, and Forestry: A System of Production for the Brazilian Cerrados. pp.51–60. *In* C.H. Hershey & P. Neate, eds. *Eco-efficiency: From vision to reality (Issues in Tropical Agriculture series)* Cali, Colombia. Centro Internacional de Agricultura Tropical (CIAT), 2013.

10. Marouelli, R.P. 2003. *O desenvolvimento sustentável da agricultura no cerrado brasileiro.* Ecobusiness School of the Instituto Superior de Administração e Economia – Fundação Getulio Vargas (ISEA-FGV). Brasilia, Brazil. (MBA Thesis).

11. Scopel, E., Triomphe, B., dos Santos Ribeiro, MdeF., Séguy, L., Denardin, J.E. & Kochhann, R.A. 2004. Direct seeding mulch-based cropping systems (DMC) in Latin America. *In* R.A. Fischer, ed. *New directions for a diverse planet.* Proceedings of the 4th International Crop Science Congress. Brisbane, Australia.

12. Kluthcouski, J., Cobucci, T., Aidar, H., Yokoyama, L.P., Oliveira I.P. de, Costa, J.L. da S., Silva, J.G. da, Vilela, L., Barcellos, A. de O. & Magnobosco, C.de U. 2000. *Sistema Santa Fé – Tecnologia Emprapa: Integração lavoura-pecuária peolo consórcio de culturas anuais com forragerira, em áreas de lavoura, nos sistemas direto e convencional.* Santo Antônio de Goiás: Embrapa Arroz e Feijão. 28pp. (Embrapa Arroz e Feijão. Circular Técnica 38).

13. Séguy, L., Bouzinac, S., Scopel, E. & Ribeiro, M.F.S. 2003. *New concepts for sustainable management of cultivated soils through direct seeding mulch based cropping systems: the CIRAD experience, partnership and networks.* Proceedings of the II World congress on Sustainable Agriculture "Producing in harmony with nature", Iguaçu, Brazil, 10–15 August 2003.

14. Séguy, L., Bouzinac, S., Maronezzi, A.C., Belot, J.L. & Martin, J. 2001. *A safrinha de algodão - opção de cultura arriscada ou alternativa lucrativa dos sistemas de plantio direto nos trópicos úmidos – Boletim técnico 37* da COODETEC CP 301 85806-970 Cascavel – PR / Brazil.

15. Kluthcouski, J. & Pacheco-Yokoyama, L. 2006. Crop-livestock integration options. *In* J. Kluthcouski, L.F. Stone & H. Aidar, eds. *Integraçã Lavoura-Pecuária* EMBRAPA Arroz e Feijáo. Santo Antônio de Goiás, Brazil.

Conservation agriculture the key to food security

1. Gupta, R. & Sayre, K. 2007. Conservation agriculture in South Asia. Paper presented at the International Workshop on Increasing Wheat Yield Potential, CIMMYT, Obregon, Mexico, 20–24 March 2006. *Journal of Agricultural Science*, 145, 207–214.

2. Sharma, B.R., Amarasinghe, U., Cai, X., de Condappa, D., Shah,T., Mukherji, A., Bharati, L., Ambili, G., Qureshi. A., Pant, D., Xenarios, X., Singh & R. & Smakhtin, V. 2010. The Indus and the Ganges: river basin under extreme pressure. *Water International*, 35, 493–521.

3. Ladha, J., Yadvinder-Singh, Erenstein O. & Hardy B., eds. 2009. *Integrated crop and resource management in the rice-wheat system of South Asia.* Los Baños (Philippines), International Rice Research Institute.

4. FAO. 2015. FAOSTAT. Online statistical database: Production (available at http://faostat3.fao.org/download/Q/QC/E).

5. Chauhan, B.S., Mahajan, G., Sardana, V., Timsina, J. & Jat, M.L. 2012.Productivity and Sustainability of the Rice-Wheat Cropping System in the Indo-Gangetic Plains of the Indian subcontinent: Problems, Opportunities, and Strategies. *Advances in Agronomy* 117: 316–355.

6. Gautam, P. 2008. Emerging issues and

strategies in the rice-wheat cropping system in the Indo-Gangetic Plains. *In* Y. Singh, V. Singh, B. Chauhan, A. Orr, A. Mortimer, D. Johnson & B. Hardy, eds. *Direct Seeding of rice and weed management in the irrigated rice-wheat cropping system of the Indo-Gangetic Plains.* Los Baños (Philippines), International Rice Research Institute & Pantnagar, India, Directorate of Experiment Station, G.B. Pant University of Agriculture and Technology.

7. Erenstein, O. 2009. Reality on the ground: Integrating germplasm, crop management, and policy for wheat farming system development in the Indo-Gangetic Plains in. 2009. *In* J. Dixon, H. Braun, P. Kosina & J. Crouch, eds. *Wheat facts and futures 2009.* Mexico, D.F., CIMMYT.

8. Malik, R. K., Singh, S. & Yadav, A. 2007. Effect of sowing time on grain yield of wheat (*Triticum aestivum* L.) in rice–wheat cropping system. *Haryana Agricultural University Journal of Research,* 37: 103–105.

9. Singh, S., Sharma, R.K., Gupta, R.K. & Singh, S.S. 2008. Changes in rice-wheat production technologies and how rice-wheat became a success story: lessons from zero-tillage wheat. *In Direct Seeding of rice and weed management in the irrigated rice-wheat cropping system of the Indo-Gangetic Plains.* Y. Singh, V. Singh, B. Chauhan, A. Orr, A. Mortimer, D. Johnson & B. Hardy, eds. Los Baños (Philippines), International Rice Research Institute, and Pantnagar, India, Directorate of Experiment Station, G.B. Pant University of Agriculture and Technology.

10. Erenstein, O. & Laxmi, V. 2008. Zero tillage impacts in India's rice–wheat systems. *Soil Tillage Research,* 100, 1–14.

11. Gupta, R., Jat, R.K., Sidhu, H.S., Singh, U.P., Singh, N.K., Singh, R.G. & Sayre, K.D. 2015. *Conservation Agriculture for sustainable intensification of small farms.* Compendium of Invited Papers presented at the XII Agricultural Science Congress 3–6 February 2015, ICAR-National Dairy Research Institute, Karnal, India. pp 15.

12. ACIAR (Australian Centre for International Agricultural Research). 2008. Permanent beds and rice-residue management for rice-wheat systems in the Indo-Gangetic Plain. *In* E. Humphreys & C.H. Roth eds. Proceedings of a workshop, Ludhiana, India, 7–9 September 2006. Canberra.

13. Aryal, J.P., Sapkota, T.B., Jat, M.L. & Bishnoi, D. 2015. On-farm economic and environmental impact of zero-tillage wheat: a case of north-west India. *Experimental Agriculture, 51:* 1–16., *Cambridge University Press 2014.* doi:10.1017/S001447971400012X.

14. IRRI. 2009. *Revitalizing the rice-wheat cropping systems of the Indo-Gangetic Plains: Adaptation and adoption of resource-conserving technologies in India, Bangladesh, and Nepal.* Final report submitted to the United States Agency for International Development. Los Baños (Philippines), International Rice Research Institute.

15. Jat, M.L. 2006. Land levelling: a precursor technology for resource conservation. *Rice-wheat consortium Technical Bulletin,* Series 7. New Delhi. Rice-wheat Consortium for the Indo-Gangetic plains.

16. Aryal, J., Bhatia, M., Jat, M.L. & Sidhu, H.S. 2014. Impacts of laser land leveling in rice-wheat rotations of the North-western Indo-Gangetic Plains of India. Paper presented at the World Congress of Environmental and Resource Economists, 28 June–2 July 2014, Istanbul, Turkey.

17. Hussain, I., Hassnain Shah, M., Khan, A., Akhtar, W., Majid, A. & Mujahid, M. 2012. Productivity in rice-wheat crop rotation of Punjab: an application of typical farm methodology. *Pakistan Journal of Agricultural Research,* Vol. 25, No. 1, pp 1–11.

18. Singh, R., Erenstein, O., Gatdala, M., Alam, M., Regmi, A., Singh, U., Mujeeb ur Rehman, H. & Tripathi, B. 2009. Socioeconomics of integrated crop and resource management technologies in the rice-wheat systems of South Asia: Site contrasts, adoption, and impact using village survey findings. *In* J. Ladha, Yadvinder-Singh, O. Erenstein & B. Hardy, eds. *Integrated crop and resource management in the rice-wheat system of South Asia.* Los Baños (Philippines), International Rice Research Institute.

19. Fischer, R.A., Byerlee, D. & Edmeades, G.O. 2014. *Crop yields and global food security: Will yield increase continue to feed the world?* ACIAR Monograph No. 158. Canberra, Australian Centre for International Agricultural Research.

20. Yamano, T., Baruah, S., Sharma, R. & Kumar, A. 2013. *Factors affecting the adoption of direct-seeded rice in the northeastern Indo-Gangetic Plain.* CSISA Socioeconomics Policy Brief. New Delhi: International Rice Research Institute.

21. Gathala, M.K., Kumar, V., Sharma, P.C., Saharawat, Y.S., Jat, H.S., Singh, M., Kumar, A., Jat, M.L., Humphreys, E., Sharma, D.K., Sharma, S. & Ladha, J.K. 2013. Optimizing intensive cereal-based cropping systems addressing current and future drivers of agricultural change in the north-western Indo-Gangetic Plains of India. *Agriculture, Ecosystems and Environment* 177: 85–97.

22. Sidhu, H.S., Singh, Manpreet, Yadvinder-Singh, Blackwell, J., Lohan, S.K., Humphreys, E., Jat, M.L., Singh, V. & Sarabjeet-Singh, 2015. Development and evaluation of the Turbo Happy Seeder for sowing wheat into heavy rice residues in NW India. *Field Crops Research.* In Press.

23. Sharma, P.C., Jat, H.S., Kumar, V., Gathala, M.K., Datta, A., Yaduvanshi, N.P.S., Choudhary, M., Sharma, S., Singh, L.K., Saharawat, Y., Yadav, A.K., Parwal, A., Sharma, D.K., Singh, G., Jat, M.L., Ladha, J.K. & McDonald, A. 2015. *Sustainable intensification opportunities under current and future cereal systems of North-West India.* Technical Bulletin: CSSRI/Karnal/2015/e. Central Soil Salinity Research Institute, Karnal, India. 46pp.

24. Jat, M.L., Gupta, R.K., Erenstein, O. & Ortiz, R. 2006. Diversifying the intensive cereal cropping systems of the Indo-Ganges through horticulture. *Chronica Horticulturae* 46 (3), 27–31.

Traditional system makes more productive use of land

1. Cerrate, A. & Camarena, F. 1979. Evaluación de ocho variedades de maíz en sistema asociado con frijol en el Callejón de Huaylas, Perú. pp.151–155. *Informativo del Maíz.* Univ. Nac. Agraria. Numero Extraordinario, Vol. III, Lima, Perú.

2. Gordon, R., Franco, J., Gonzalez A. & de Garcia, N. 1997. Evaluación de variedades de Vigna (*Vigna unguiculata*) para asociación con el cultivo de maíz en Azuero, Panamá. pp.146–148. *In* J. Bolaños, ed. *Programa Regional de Maíz para Centro América y el Caribe, Síntesis de resultados experimentales 1993–1995,* CIMMYT, PRM, Guatemala.

3. Francis, C.A. 1981. Development of plant genotypes for multiple cropping systems. *In* K.J. Frey, ed. *Plant Breeding II.* The Iowa State University Press, Ames. 497pp.

4. Laing, D.R. 1978. *Competencia en los sistemas de cultivos asociados de maíz-frijol.* pp.174-178. Proc. VIII Reunión de Maiceros de la Zona Andina. I Reunión Latinoamericana de Maíz, Lima, Perú.

5. Mathews, C., Jones, R.B. & Saxena, K.B. 2001. Maize and pigeonpea intercropping systems in Mpumulanga, South Africa. *International Chickpea and Pigeonpea Newsletter,* 8:53.

6. Marer, S.B., Lingaraju, B.S. & Shashidhara, G.B. 2007. Productivity and economics of maize and pigeonpea intercropping under rainfed condition in northern transitional zone of Karnataka. *Karnataka Journal of Agricultural Science,* 20:1–3.

7. Ngwira, A., Aune, J. & Mkwinda, S. 2012. On-farm evaluation of yield and economic benefit of short term maize legume intercropping systems under conservation agriculture in Malawi. *Field Crops Research,* 132 (2012) 149–157

8. Rusinamhodzi, L., Corbeels, M., Nyamangarad, J. & Giller, K. 2012. Maize–grain legume intercropping is an attractive option for ecological intensification that reduces climatic risk for smallholder farmers in central Mozambique. *Field Crops Research,* 136 (2012) 12–22.

9. Herrera, A.P., Gordon, R., Franco, J., Garcia, N., Martinez, L., Gonzalez, A. & Sain, G. 1993. Análisis económica de la aplicación de nitrógeno en maíz en rotación con leguminosas bajo dos tipos

de labranza, Rio Hato, Panama, 1992–93. pp.167–169. *In* J. Bolaños, G. Sain, R. Urbina & H. Barreto, eds. *Programa Regional de Maíz para Centro América y el Caribe, Síntesis de resultados Experimentales 1992.* CIMMYT, PRM, Guatemala.

10. Marinus, W. 2014. *Cowpea-maize relay cropping. A method for sustainable agricultural intensification in northern Ghana?* Plant production systems. Wageningen University. Wageningen, The Netherlands.

11. Ortiz-Ceballos, A., Aguirre-Rivera, J., Salgado-Garcia, S. & Ortiz-Ceballos, G. 2015. Maize-velvet bean rotation in summer and winter *milpas*: a greener technology. *Agronomy Journal*, 107: 1: 330–336.

12. Mekuria, M., Kassie, M., Nyagumbo, I., Marenya, P. & Wegary, D. 2014. Sustainable intensification of maize-legume based systems: Lessons from SIMLESA. *In* B.M. Prasanna *et al.*, eds. Book of Extended Summaries, 12th Asian Maize Conference and Expert Consultation on Maize for Food, Feed, Nutrition and Environmental Security. Bangkok, Thailand, October 30 – November 1, 2014. CIMMYT, Mexico D.F. and APAARI, Bangkok, pp.379–386.

13. FAO. 2015. FAOSTAT. Online statistical database: Production (available at http://faostat3.fao.org/download/Q/QC/E).

14. Sanginga, N., Dashiell K.E., Diels, J., Vanlauwe, B., Lyasse, O., Carsky, R.J., Tarawali, S., Asafo-Adjei, B., Menkir, A., Schulz, S., Singh, B.B., Keatinge, D. & Ortiz, R. 2003. Sustainable resource management coupled to resilient germplasm to provide new intensive cereal-grain-legume-livestock system in the dry savanna. *Agriculture, Ecosystem and Environment,* 100: 305–314.

15. Landau, E. C., Cruz, J.C., Hirsch, A. & Guimaraes, D.P. 2012. Expansão potencial do plantio de 2a safra de milho no Brasil no sistema de rotação soja-milho considerando o zoneamento de risco climático. *Boletim de Pesquisa e Desenvolvimento.* Sete Lagoas: Embrapa Milho e Sorgo. 36pp.

16. Kerr, R. B., Snapp, S., Chirwa, M., Shumba, L. & Msachi, R. 2007. Participatory research on legume diversification with Malawian smallholder farmers for improved human nutrition and soil fertility. *Experimental Agriculture,* 43:437–453.

17. Thierfelder, C., Cheesman, S. & Rusinamhodzi, L. 2012. Benefits and challenges of crop rotation in maize-based conservation agriculture (CA) cropping system of Southern Africa. *International Journal of Agricultural Sustainability.* DOI:10.1080/14735903.2012. 703894:1–17.

A richer harvest from paddy fields

1. Halwart M. 2013. Valuing aquatic biodiversity in agricultural landscapes. *In* J. Fanzo, D. Hunter, T. Borelli & F. Mattei, eds. *Diversifying food and diets – using agricultural biodiversity to improve nutrition and health.* Bioversity International, pp.88–108.

2. FAO. 2004. *Culture of fish in rice fields.* M. Halwart & M. Gupta, eds. Rome

3. FAO. 2014. *Aquatic biodiversity in rice-based ecosystems: Studies and reports from Indonesia, LAO PDR and the Philippines.* M. Halwart & D. Bartley, eds. The Asia Regional Rice Initiative: Aquaculture and fisheries in rice-based ecosystems. Rome.

4. FAO. 2014. *Aquaculture and fisheries in rice-based ecosystems.* The Asia Regional Rice Initiative factsheet. Rome.

5. FAO. 2007. Analysis of feeds and fertilizers for sustainable aquaculture development in China. Miao, W.M. & Mengqing, L. 2007. *In* M. Hasan, T. Hecht & S. De Silva, eds. *Study and analysis of feeds and fertilizers for sustainable aquaculture development.* FAO Fisheries Technical Paper 497. Rome.

6. FAO. 2012. *The state of world fisheries and aquaculture 2012.* Rome.

7. Suryana, A. *Regional Rice Initiative Implementation in Indonesia: Progress and lessons learned.* Presentation at a Side Event of the 149th Session of the FAO Council, Rome, 18 June 2014.

Where trees and shrubs cost less than fertilizer

1. Garrity, D., Akinnifesi, F., Ajayi, O., Weldesemayat, S., Mowo, J., Kalinganire, A. Larwanou, M. & Bayala, J. 2010. Evergreen Agriculture: a robust approach to sustainable food security in Africa. *Food Security* (2010) 2:197–214.

2. Haggblade, S. & Tembo, G. 2003. *Early evidence on conservation farming in Zambia.* EPTD Discussion Paper 108. Washington DC: International Food Policy Research Institute.

3. Barnes R. & Fagg, C. 2003. *Faidherbia albida.* Monograph and Annotated Bibliography. Tropical Forestry Papers No 41, Oxford. Forestry Institute, Oxford, UK. 281pp.

4. Spevacek , A.M. 2011. *Acacia (Faidherbia) albida*. KSC Research Series. US Agency for International Development, New York. 15pp.

5. Shitumbanuma, V. 2012. *Analyses of crop trials under* Faidherbia albida. Conservation Farming Unit, Zambia National Farmers Union. Lusaka.

6. Phombeya, H. 1999. Nutrient sourcing and recycling by *Faidherbia albida* trees in Malawi. PhD Dissertation, Wye College, University of London. 219pp.

7. Ajayi, C., Akinnifesi, F., Sileshi, G., Kanjipite, W. 2009. Labour inputs and financial profitability of conventional and agroforestry-based soil fertility management practices in Zambia. *Agrekon* 48:246–292.

8. Adesina, A., Coulibaly, O., Manyong, V., Sanginga, P.C., Mbila, D., Chianu, J. & Kamleu, D.G. 1999. *Policy shifts and adoption of alley farming in West and Central Africa.* International Institute of Tropical Agriculture, Ibadan, Nigeria. 21pp.

Farmers stop ploughing on Kazakhstani steppe

1. CIMMYT. 2013. Water-saving techniques salvage wheat in drought-stricken Kazakhstan. In: *Wheat research, Asia.* 21 March 2013 (available at http://www.cimmyt.org/en/what-we-do/wheat-research/item/water-saving-techniques-salvage-wheat-in-drought-stricken-kazakhstan).

2. FAO. 2015. FAOSTAT. Online statistical database: Production (available at http://faostat3.fao.org/download/Q/QC/E).

3. Nurbekov, A., Akramkhanov, A., Lamers, J., Kassam, A., Friedrich, T., Gupta, R., Muminjanov, H., Karabayev, M., Sydyk, D., Turok, J. & Malik Bekenov, M. 2014. Conservation agriculture in Central Asia. *In* R. Jat, K. Sahrawat & A. Kassam, eds. *Conservation agriculture: Global prospects and challenge.* CAB International.

4. Karabayev, M., Morgounov, A., Braun, H-J., Wall, P., Sayre, K., Zelenskiy, Y., Zhapayev, R., Akhmetova, A., Dvurechenskii, V., Iskandarova, V., Friedrich, T., Fileccia, T. Guadagni, M. 2014. Effective Approaches to Wheat Improvement in Kazakhstan: Breeding and Conservation Agriculture. *Journal of Bahri Dagdas Crop Research* (1–2):50–53, 2014.

5. FAO. 2012. *Conservation agriculture in Central Asia: Status, policy, institutional support, and strategic framework for its promotion.* FAO Sub-Regional Office for Central Asia. December 2012. Ankara.

6. FAO. 2015. FAOSTAT. Online statistical database: Trade (available at http://faostat3.fao.org/download/T/TP/E).

7. Karabayev, M. & Suleimenov, M. 2010. *Adoption of conservation agriculture in Kazakhstan*. In: Lead papers 4th World Congress on conservation agriculture: Innovations for improving efficiency, equity and environment. 4–7 February 2009. New Delhi.

8. Derpsch, R. & Friedrich, T. 2009. *Development and current status of no-till adoption in the world.* Rome, FAO.

9. FAO. 2009. *Importance of zero-tillage with high stubble to trap snow and increase wheat yields in Northern Kazakhstan.* FAO Investment Centre, June 2012. Rome.

10. FAO. 2012. *Advancement and impact of conservation agriculture/no-till technology adoption in Kazakhstan.* FAO Investment Centre information note. Rome.

11. Kienzler, K., Lamers, J., McDonald, A., Mirzabaev, A., Ibragimov, N., Egamberdiev, O., Ruzibaev, E. & Akramkhanov, A. 2012. Conservation agriculture in Central Asia – What do we know and where do we go from here? *Field Crops Research* 132 (2012) 95–105

12. Zhapayev, R., Iskandarova, K., Toderich, K., Paramonova, I., Al-Dakheel, A., Ismail, S., Pinnamaneni, S.R., Omarova, A., Nekrasova, N., Balpanov, D., Ten, O., Ramanculov, E., Zelenskiy, Y., Akhmetova, A. & Karabayev, M. 2015. Sweet sorghum genotypes testing in the high latitude rain-fed steppes of the northern Kazakhstan (for feed and biofuel). *Journal of Environmental Science and Engineering* B 4 (2015) 25–30. doi: 10.17265/2162-5263/2015.01.004.

13. Karabayev, M. 2012. *Conservation agriculture adoption in Kazakhstan.* A presentation made in WIPO Conference on Innovation and Climate Change, 11–12 July 2011. Geneva.

14. Lamers, J., Akramhanov, A., Egamberdiev, A., Mossadegh-Manschadi, A., Tursunov, M., Martius, C., Gupta, R., Sayre, K., Eshchanov, R. & Kienzler, S. 2010. *Rationale for conservation agriculture under irrigated production in Central Asia: Lessons learned.* In: Lead papers 4th World Congress on conservation agriculture: Innovations for improving efficiency, equity and environment. 4–7 February 2009. New Delhi.

15. FAO. 2014. Conservation agriculture for irrigated areas in Azerbaijan, Kazakhstan, Turkmenistan and Uzbekistan. Project GCP/RER/030/TUR Terminal report, Annex 4. Rome.

16. World Bank. *No-till: A climate smart agriculture solution for Kazakhstan. Agricultural Competitiveness Project.* 8 August 2013 (available at http://www.worldbank.org/en/results/2013/08/08/no-till-climate-smart-agriculture-solution-for-kazakhstan).

High yielding hybrids help adapt to climate change

1. Timsina, J., Buresh, R.J., Dobermann, A. & Dixon, J. 2011. *Rice-maize systems in Asia: current situation and potential.* pp.7–26 and 161–171. Los Baños (Philippines): International Rice Research Institute and International Maize and Wheat Improvement Center. 232pp.

2. FAO. 2015. FAOSTAT. Online statistical database: Production (available at http://faostat3.fao.org/download/Q/QC/E).

3. Ali, M.Y., Waddington, S.R., Hodson, D., Timsina, J. & Dixon, J. 2009. *Maize-rice cropping systems in Bangladesh: Status and research opportunities.* Working Paper, Mexico DF: CIMMYT.

4. Gathala, M.K., Timsina, J., Islam, Md. S., Rahman, Md. M., Hossain, Md. I., Harun-Ar-Rashid, Md., Ghosh, A.K., Krupnik, T. J., Tiwari, T.P. & McDonald, A. 2014. Conservation agriculture based tillage and crop establishment options can maintain farmers' yields and increase profits in South Asia's rice–maize systems: Evidence from Bangladesh. *Field Crops Research,* 172: 85–98.

5. Borlaug Institute for South Asia. 2015. Major Accomplishments 2012–2014. BISA Report Series 1. New Delhi, India. 38pp.

6. Hasan, M.M, Waddington, S.R., Haque, M.E., Khatun F. & Akteruzzaman, M. 2007. Contribution of whole family training to increased production of maize in Bangladesh. *Progressive Agriculture (Bangladesh)* 18(1): 267–281.

7. CIMMYT. 2009. *Maize motorizes the economy in Bangladesh.* CIMMYT E-News, Vol. 6 No. 5, August 2009 (available at http://www.cimmyt.org/en/what-we-do/socioeconomics/item/maize-motorizes-the-economy-in-bangladesh).

8. CIMMYT. 2009. *Don't put all your eggs in one basket: Bangladesh tries maize cropping for feed.* CIMMYT E-News, Vol. 6 No. 2, February 2009 (available at http://www.cimmyt.org/en/what-we-do/socioeconomics/item/dont-put-all-your-eggs-in-one-basket-bangladesh-tries-maize-cropping-for-feed).

Chapter 4. The way forward

1. FAO, IFAD & WFP. 2015. *The State of Food Insecurity in the World 2015. Meeting the 2015 international hunger targets: taking stock of uneven progress.* Rome.

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

3. FAO. 2011. *The state of the world's land and water resources for food and agriculture (SOLAW) – Managing systems at risk.* FAO, Rome and Earthscan, London.

4. Viala, E. 2008. Water for food, water for life a comprehensive assessment of water management in agriculture. *Irrigation and Drainage Systems,* 22(1), 127–129.

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

6. IFAD. 2010. *Rural Poverty Report 2011. New realities, new challenges: New opportunities for tomorrow's generation.* Rome.

7. FAO. 2012. *Towards the future we want. End hunger and make the transition to sustainable agricultural and food systems.* Rome.

8. FAO. 2014. *Building a common vision for sustainable food and agriculture: Principles and approaches.* Rome.

9. Arslan, A., McCarthy, N., Lipper, L., Asfaw, S. & Cattaneo, A. 2014. Adoption and intensity of adoption of conservation farming practices in Zambia. *Agriculture, Ecosystems & Environment,* Vol. 187, (2014) pp.72–86.

10. FAO. 2014. *Climate variability, adaptation strategies and food security in Malawi,* by Asfaw, S., McCarthy, N., Lipper, L. Arslan, A., Cattaneo, A. & Kachulu, M. ESA Working Paper No. 14–08. Rome.

11. UNEP (United Nations Environmental Programme). 2014. *A guidance manual for green economy policy assessment.* UNEP.

12. FAO. 2012. *Improving food systems for sustainable diets in a green economy.* FAO GEA Rio+20 Working Paper 4. Rome.

13. FAO. 2014. *Meeting farmers' aspirations in the context of green development.* Regional Conference for Asia and the Pacific, Thirty-second session. Ulaanbaatar, Mongolia, 10–14 March 2014. Rome

14. FAO. 2015. *Smallholder productivity under climatic variability: Adoption and impact of widely promoted agricultural practices in Tanzania,* by Arslan, A., Belotti, F. & Lipper, L. Rome.

15. FAO. 2011. *Climate-smart agriculture: smallholder adoption and implications for climate change adaptation and mitigation,* by McCarthy, N., Lipper, L. & Branca, G. FAO Working Paper, Mitigation of Climate Change in Agriculture (MICCA) Series 4, Rome.

16. HLPE (High Level Panel of Experts on Food Security and Nutrition). 2013. *Investing in smallholder agriculture for food security.* A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. FAO. Rome.

17. FAO. 2012. *The State of Food and Agriculture 2012: Investing in agriculture for a better future.* Rome.

18. FAO. 2014. *Institutional procurement of staples from smallholders. The case of purchase for progress in Kenya.* Rome.

19. HLPE. 2012. *Social protection for food security.* A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. FAO. Rome.

20. FAO. 2013. *State of food insecurity in the world: The multiple dimensions of food security.* Rome.

21. FAO. 2015. *An in-depth review of the evolution of integrated public policies to strengthen family farms in Brazil,* by Del Grossi, M.E. & Vicente, P.M. de Azevedo Marques. ESA Working Paper No. 15–01. Rome.

22. Committee on World Food Security. 2015. *Principles for responsible investment in agriculture and food systems.* FAO. Rome.

23. HLPE. 2011. *Land tenure and international investments in agriculture.* HLPE Report No. 2. FAO. Rome.

24. FAO. 2012. *Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security.* Rome.

25. FAO, IFAD, UNCTAD & World Bank. 2010. *Principles for responsible agricultural investment that respects rights, livelihoods and resources. Extended version.* Discussion note. (available at http://siteresources.worldbank.org/INTARD/214574-1111138388661/22453321/Principles_Extended.pdf).

26. FAO. 2014. *Developing sustainable food value chains – Guiding principles.* Rome.

27. FAO. 2015. *The rice value chain in Tanzania. A report from the Southern Highlands Food Systems Programme.* Rome.

28. Demont, M. & Ndour, M. 2015. Upgrading rice value chains: Experimental evidence from 11 African markets. *Global Food Security,* Vol. 5, June 2015, pp.70–76.

29. Pardey, P., Alston, J. & Chan-Kang, C. 2013. Public agricultural R&D over the past half century: an emerging new world order. *Agricultural Economics* 44(1): 103–113.

30. Marslen, T. 2014. *Declining Research and Development Investment: A Risk for Australian Agricultural Productivity. Strategic Analysis Paper.* Dalkeith (Australia), Future Directions International.

31. Pretty, J.N. & Bharucha, Z.P. 2015. Integrated Pest Management for Sustainable intensification of agriculture in Asia and Africa. *Insects* 2015, *6*(1), 152–182.

32. Casão Junior, R., de Araújo, A.G. & Fuentes-Llanillo, R. 2012. *No-till agriculture in southern Brazil: Factors that facilitated the evolution of the system and the development of the mechanization of conservation farming.* Londrina, Brazil. IAPAR and Rome, FAO.

33. Friedrich, T., Derpsch, R. & Kassam, A. 2012. Global overview of the spread of Conservation Agriculture. *Field Actions Science Reports Special Issue (Reconciling Poverty Alleviation and Protection of the Environment),* 6: 1–7.

34. Sims, B.G., Thierfelder, C., Kienzle, J., Friedrick, T. & Kassam, A. 2012. Development of the Conservation Agriculture Equipment Industry in Sub-Saharan Africa. *Applied Engineering in Agriculture* 28(6):1–11.

35. FAO. 2008. Mechanization for rural development: a review of patterns and progress from around the world. *Integrated crop management*, Vol. 20–2013. Rome.

36. Mrema G., Soni, P. & Rolle, R. 2014. *A regional strategy for sustainable agricultural mechanization.* FAO. Bangkok.

37. Ortiz, R. 2013. Marker-aided breeding revolutionizes 21st century crop improvement. *In* G.K. Agrawal & R. Rakwal, eds. *Seed development: OMICS technologies toward improvement of seed quality and crop yield.* Springer, New York. pp.435–452.

38. Tilman D., Cassman K.G., Matson P.A., Naylor R. & Polasky S. 2002. Agricultural sustainability and intensive production practices. *Nature,* 418: 671–677. doi:10.1038/nature01014.

39. Bindraban, P.S., Dimkpa, C., Nagarajan, L., Roy, A. & Rabbinge, R. 2015. Revisiting fertilizers and fertilization strategies for improved nutrient uptake by plants. *Biology and Fertility of Soils.* DOI: 10.1007/s00374-015-1039-7.

40. Tangtrakulwanich, K., Reddy, G., Wu, S., Miller, J.H., Ophus, V.L. & Prewett, J. 2014. Efficacy of entomopathogenic fungi and nematodes, and low risk insecticides against wheat stem sawfly. *Journal of Agricultural Science*, Vol. 6, No. 5, May 2014.

41. FAO & World Bank. 2010. *FAO/World Bank workshop on reducing post-harvest losses in grain supply chains in Africa, FAO Headquarters, 18–19 March 2010 - Lessons learned and practical guidelines.* Rome.

42. FAO. 2012. *Greening the economy with climate-smart agriculture.* Rome.

43. FAO. 2014. *Appropriate seed and grain storage systems for small-scale farmers: key practices for DRR implementers.* Rome.

44. Buresh, R.J., & Wopereis, M. 2014. *Save and Grow: Rice.* Paper prepared for the FAO Technical Consultation on Save and Grow: Maize, Rice and Wheat, Rome, 15–17 December 2014. FAO. (mimeo).

45. FAO. 2003. *World agriculture: towards 2015/2030. An FAO perspective.* J. Bruinsma, ed. London. Earthscan.

46. Pretty, J.N. 2003. Social capital and the collective management of resources. *Science* 302, 1912 (2003). DOI: 10.1126/science.1090847.

47. FAO. 2013. *Draft guide for national seed policy formulation.* Report to the Fourteenth Regular Session of the Commission on Genetic Resources for Food and Agriculture. Rome, 15–19 April 2013.

48. Solh, M., Braun, H-J. & Tadesse, W. 2014. *Save and Grow: Wheat.* Paper prepared for the FAO Technical Consultation on Save and Grow: Maize, Rice and Wheat, Rome, 15–17 December 2014. Rabat, ICARDA. (mimeo).

Abbreviations

BISA	Borlaug Institute for South Asia
CA	conservation agriculture
CGIAR	Consultative Group for International Agricultural Research
CIAT	International Center for Tropical Agriculture
CIMMYT	International Maize and Wheat Improvement Center
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSO	civil society organization
DMC	direct seeded, mulch-based cropping
EMBRAPA	Brazilian Agricultural Research Corporation
FAO	Food and Agriculture Organization of the United Nations
ha	hectare
GAEZ	Global Agroecological Zones
IAEA	International Atomic Energy Agency
ICAR	Indian Council of Agricultural Research
ICARDA	International Centre for Agricultural Research in the Dry Areas
ICIPE	International Centre of Insect Physiology and Ecology
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFAD	International Fund for Agricultural Development
IISA	International Institute of Administrative Sciences
IPM	Integrated pest management
IRRI	International Rice Research Institute
IWMI	International Water Management Institute
NERICA	New Rice for Africa
NGO	non-governmental organization
OECD	Organisation for Economic Cooperation and Development
QSMAS	Quezungual Slash-and-Mulch Agroforestry System
R&D	research and development
SOC	soil organic carbon
SSNM	site-specific nutrient management
SRI	System of Rice Intensification
t	tonne
UNCTAD	United Nations Conference on Trade and Development
USA	United States of America

Glossary

Abiotic stress. Negative effect of non-living factors (e.g. extreme temperatures)

Biological nitrogen fixation. Conversion of atmospheric nitrogen (e.g. by bacteria in legume root nodules) into plant-usable form

Biomass. Biological material derived from living organisms, usually not used for food or feed

Biotic stress. Negative effect of living factors (e.g. insects)

Conservation agriculture (CA). Farming approach that protects soil structure, composition and biodiversity through minimal soil disturbance, permanent surface cover and crop rotation

Cover crop. Crop grown during *fallow* periods to protect soil, recycle nutrients and control weeds

Crop residues. Plant parts remaining after a crop has been harvested

Crop rotation. Alternating species or families of crops in the same field

Direct-seeding. Sowing seed without prior ploughing or hoeing of the seedbed

Drill-seeding. Sowing seed in rows at optimal distance and depth, using a *seed drill*

Dry-seeding. Sowing seed into dry soil

Ecosystem services. Benefits from ecosystems that sustain life

Fallow (also **fallow rotation**). Stage in *crop rotation* in which the land is deliberately not used to grow a crop

Farmer field school. Group learning of ecosystem-based practices that reduce pesticide use and improve the sustainability of crop yields

Flooded (or **paddy) rice.** Rice grown on land that is flooded before *puddling*, then continuously flooded until crop maturity

Forage legume. Grassy or tree *legume* that provides leaves and stems for grazing or use in silage.

Grain legume. *Legume* (e.g. beans) that produces seeds used as food

Green manure. A crop (e.g. grass) that produces residues that serve as *mulch*

Intercropping. Growing two or more crops in the same field at the same time

Integrated pest management (IPM). Strategy that promotes pest control with minimal use of chemicals

Laser-assisted land levelling. Eliminating undulations on the soil surface using a laser transmitter and a receiver mounted on a tractor with a levelling blade

Legume. Plant of the Fabaceae (or Leguminosae) family

Mulch. Layer of organic material (e.g. *crop residues*) used to cover the soil in order to conserve moisture, suppress weeds and recycle soil nutrients

Mineral fertilizer. Fertilizer made through chemical and industrial processes

Monocropping (or **monoculture).** Cultivation of a single crop on the same land, year after year, using agrochemicals to control pests and fertilize soil

Nitrous oxide. Major greenhouse gas produced mainly in agricultural soils and linked to excessive use of *mineral fertilizer*

Permanent raised beds. *Raised beds* that are drill-seeded through a *mulch* of *crop residues*

Pulse. *Grain legume* (e.g. lentil) harvested for its dry seed

Puddling (rice). The tilling of flooded soil in order to create a muddy layer before seedlings are transplanted

Raised beds. Soil formed into beds approximately 50 cm to 2.5 m wide, of any length and from 15 cm in height

Relay cropping. Planting a second crop in a field before the first has been harvested

Save and Grow. FAO's model of *sustainable crop production intensification*

Soil organic matter. All organic materials found in soil

Soil structure. The arrangement of individual particles of sand, silt and clay in soil

Sustainable intensification. Maximization of primary production per unit of input without compromising the ability of the system to sustain its productive capacity

Sustainable crop production intensification. Ecosystem-based farming that produces more from the same area of land while conserving natural resources and enhancing *ecosystem services*

Seed-drill. Machine used in *conservation agriculture* to position seeds at equal distances and proper depth, and cover them with soil

Water productivity. The amount or value of product over volume or value of water depleted or diverted

Water-use efficiency. The ratio of water used by plant metabolism to water lost to the atmosphere

Zero-tillage. The *conservation agriculture* practice of *drill-seeding* with no prior tillage

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Sanjay Rajaram
World Food Prizewinner, 2014

"Timely and important. Provides excellent examples and makes principles very clear."

Jules Pretty
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