WORLD RESOURCES INSTITUTE

Working Paper

Installment 4 of "Creating a Sustainable Food Future"

IMPROVING LAND AND WATER MANAGEMENT

ROBERT WINTERBOTTOM, CHRIS REIJ, DENNIS GARRITY, JERRY GLOVER, DEBBIE HELLUMS, MIKE MCGAHUEY, AND SARA SCHERR

SUMMARY

The world's food production systems face enormous challenges. Millions of farmers in developing countries are struggling to feed their families as they contend with land degradation, land use pressures, and climate change. Many smallholder farmers must deal with low and unpredictable crop yields and incomes, as well as chronic food insecurity. These challenges are particularly acute in Sub-Saharan Africa's drylands, where land degradation, depleted soil fertility, water stress, and high costs for fertilizers contribute to low crop yields and associated poverty and hunger.

Farmers and scientists have identified a wide range of land and water management practices that can address land degradation and increase long-term agricultural productivity. The benefits of these improved land and water management practices to farmers and rural economies include higher crop yields, increased supplies of other valuable goods such as firewood and fodder, increased income and employment opportunities, and increased resilience to climate change. These benefits occur because these improved land and water management practices:

- Increase soil organic matter
- Improve soil structure
- Reduce soil erosion
- Increase water filtration
- Increase efficiency of water use
- Replenish soil nutrients
- Increase the efficiency of nutrient uptake.

CONTENTS

Summary 1
Land, Water, and Food 3
Land Degradation Challenges 6
Improved Land and Water Management Practices 11
Opportunities for Scaling Up 25
Recommended Approaches to Accelerate Scaling Up 27
A Call to Action 34
Endnotes 36
References 39

Suggested Citation: Winterbottom, R., et al. 2013. "Improving Land and Water Management." Working Paper, Installment 4 of *Creating a Sustainable Food Future*. Washington, DC: World Resources Institute. Accessible at: http://www.worldresourcesreport.org.

In this paper, we profile four of the most promising improved land and water management practices that are particularly relevant to the drylands of Sub-Saharan Africa:

1. *Agroforestry*—the deliberate integration of woody perennial plants—trees and shrubs—with crops or livestock on the same tract of land.
2. *Conservation agriculture*—a combination of reduced tillage, retention of crop residues or maintenance of cover crops, and crop rotation or diversification.
3. *Rainwater harvesting*—low-cost practices—such as planting pits, stone bunds, and earthen trenches along slopes—that capture and collect rainfall before it runs off farm fields.
4. *Integrated soil fertility management*—the combined use of judicious amounts of mineral fertilizers and soil amendments such as manure, crop residues, compost, leaf litter, lime, or phosphate rock.

This working paper examines each of these four practices in depth and describes their observed impacts on crop yields and other measurable benefits to farmers and rural communities. For example:

1. *Agroforestry*. In Malawi, maize yields increased by about 50 percent when nitrogen-fixing *Faidherbia albida* trees were planted in farms. In Senegal, the presence of *Piliostigma reticulatum* and *Guiera senegalensis* shrubs in fields has increased nutrient-use efficiency over sole crop systems, and has helped to create "islands of fertility" that have greater soil organic matter, nitrogen, and phosphorus concentrations under their canopies than in open areas.
2. *Conservation agriculture*. In Zambia, maize yields in conservation agriculture systems with crop rotation can be more than 50 percent higher than yields under conventionally tilled maize.
3. *Rainwater harvesting*. Farmers in Burkina Faso have doubled grain yields using multiple water harvesting techniques, including stone bunds and planting pits.
4. *Integrated soil fertility management*. In West Africa, adoption of integrated soil fertility management across more than 200,000 hectares resulted in yield increases of 33–58 percent over a four-year period, and revenue increases of 179 percent from maize and 50 percent from cassava and cowpea.

Farmers have realized even greater benefits when combining these practices, and have further enhanced yields when combining them with conventional agricultural technology solutions such as fertilizers and improved seed varieties. An example of a cost-effective, complementary practice is "micro-dosing," the targeted application of small quantities of fertilizer—often just a capful—directly to crop seeds or young shoots at planting time or when the rains fall. Nearly 500,000 smallholder farmers in Mali, Burkina Faso, and Niger have learned the micro-dosing technique and have experienced increases in sorghum and millet yields of 44–120 percent, along with an increase in family incomes of 50–130 percent.

These four improved land and water management practices can help smallholders boost crop yields and provide other benefits on individual farms. However, in many situations, sustaining or improving agricultural productivity will require coordination between resource users situated in different parts of the larger landscape, including in non-farmed lands, wetlands, forests, and rangelands. *Integrated landscape approaches* bring sectors and stakeholders together to jointly plan, design, and manage their landscapes for improved agricultural production, ecosystem conservation, and sustainable livelihoods.

Despite the multiple benefits of improved land and water management, adoption by smallholders remains limited in most regions. Some of the commonly cited barriers include a lack of awareness of the appropriate practices and their benefits, as well as low levels of investment in knowledge dissemination. In many cases, national policies and legislation do not provide sufficient incentives—such as secure land tenure and property rights—to stimulate farmers to invest in improved land and water management. Many smallholder farmers are not reached by extension agents at all. And where extension does exist, too often agroforestry, conservation agriculture, and other improved land and water management practices are insufficiently integrated.

Still, there is vast potential to scale up the improved management of land and water resources as an integral component of agricultural development strategies. In Sub-Saharan Africa, conditions are ripe for investing in agroforestry and other improved practices on croplands covering more than 300 million hectares. If improved land and water management practices were implemented on just 25 percent of this cropland to increase crop yields by an average of 50 percent, farmers would produce 22 million more tons of food per year. Such a scale-up could potentially provide 285 million people living in Africa's drylands with an additional 615 kilocalories (kcal) per person per day.

The productivity of degraded agricultural land can be restored and crop yields boosted if tens of millions of smallholder farmers were motivated to invest their labor and their limited financial resources in these proven land and water management practices. This working paper proposes seven pathways to accelerate scale-up of these improved practices:

1. Strengthen knowledge management systems and access to information.
2. Increase communication and outreach in ways that amplify the voices of champions and leverage direct engagement with farmers.
3. Support institutional and policy reforms, particularly for strengthening property rights.
4. Support capacity building, particularly in community-based management of natural resources.
5. Increase support for integrated landscape management.
6. Reinforce economic incentives and private sector engagement.
7. Mainstream investments in improved land and water management to catalyze adoption of these practices as a strategic component of food security and climate change adaptation programs.

While smallholder farmers are the key actors, many other entities and organizations have a role to play in implementing these strategies. National governments should create enabling agricultural development policies—as well as land tenure and forestry legislation—that secure farmers' rights to their land and recognize their ownership of on-farm trees. Governments also should create enabling conditions for the private sector to invest in market-based approaches to strengthening agroforestry value chains. The public and private sector—working with local communities, international partners and development assistance organizations—can take these improved practices to scale by investing in knowledge management, communication, and outreach, which will help restore agricultural productivity, enhance rural livelihoods, and contribute to a sustainable food future.

LAND, WATER, AND FOOD

In the first installment of the World Resources Report's *Creating a Sustainable Food Future* working paper series (Box 1), we show that the world faces a great balancing act of three needs. It needs to close a 6,500 trillion kilocalories (kcal) per year global gap between the food available in 2006 and that required in 2050—approximately a 69 percent increase in needed calories—to adequately feed the planet.[1] It needs agriculture to contribute to economic and social development. And it needs agriculture to reduce its impact on climate, water, and ecosystems.

Throughout the *Creating a Sustainable Food Future* series, we explore a menu of solutions that could combine to meet these needs. One menu item is to improve land and water management practices in order to boost yields on existing cropland. "Improved land and water management practices" refers to a suite of on-farm practices where farmers manage natural resources in order to maintain and increase soil organic matter content, recycle soil nutrients, reduce rainfall runoff, and generate other benefits. These practices include agroforestry (where perennial trees and shrubs are planted intermixed with crops), conservation agriculture, rainwater harvesting, and more. This menu item also includes the integration of practices that are particularly effective in managing soil fertility. Farmers can implement these practices as complements to other agriculture inputs such as fertilizers and improved seed varieties. Scaled up efforts to improve land and water management are particularly needed in Sub-Saharan Africa, the region of the planet experiencing a perfect storm of poor soils, highly variable water availability, low crop yields, and dramatically increasing demand for food.

Box 1 | The World Resources Report: *Creating a Sustainable Food Future*

How can the world adequately feed more than 9 billion people by 2050 in a manner that advances economic development and reduces pressure on the environment? This is one of the paramount questions the world faces over the next four decades.

Answering it requires a "great balancing act" of three needs–each of which must be simultaneously met. First, the world needs to close the gap between the food available today and that needed by 2050. Second, the world needs agriculture to contribute to inclusive economic and social development. Third, the world needs to reduce agriculture's negative impact on the environment.

The forthcoming 2013–14 World Resources Report, *Creating a Sustainable Food Future,* seeks to answer this question by proposing a menu of solutions that can achieve the great balancing act. "Improving land and water management" profiles one of these solutions or menu items, and is one installment in a series of working papers leading up to the World Resources Report.

Since the 1980s, the World Resources Report has provided decision makers from government, business, and civil society with analyses and insights on major issues at the nexus of development and the environment. For more information about the World Resources Report and to access previous installments and editions, visit www.worldresourcesreport.org.

How could scaling up improved land and water management practices contribute to a sustainable food future? How could such scaling up be realized? This working paper seeks to address these questions. It begins by summarizing the challenge to yield growth posed by land degradation and rainfall variability, highlighting the particular plight of Sub-Saharan Africa. It continues by introducing a range of improved land and water management practices and providing evidence of their positive impact on crop yields, as well as their cobenefits. It then examines the conditions that have encouraged farmers to invest in these improved practices, and the potential impact of improved land and water management practices on food production, particularly for Sub-Saharan Africa. It concludes by highlighting opportunities for scaling up improved land and water management, and recommending policies and approaches to accelerate the adoption of these practices.

Improving land and water management practices on existing croplands—particularly in regions facing food insecurity, rural poverty, and land degradation such as Sub-Saharan Africa—would meet the development and environmental criteria introduced in "The Great Balancing Act" (Table 1). By boosting crop yields and generating a range of additional benefits, improving land and water management practices would help to alleviate poverty and provide gender benefits while reducing pressures on ecosystems, climate, and water.

Table 1 | **How "Improving Land and Water Management Practices" Performs Against the Sustainable Food Future Criteria**

● = positive ○ = neutral/it depends ⊗ = negative

CRITERIA	DEFINITION	PERFORMANCE	COMMENT
Poverty alleviation	Reduces poverty and advances rural development, while still being cost effective	●	■ Improving land and water management practices can increase soil organic matter, soil moisture content, fertilizer-use efficiency, viability of improved seed varieties, and provide other benefits that boost yields and incomes directly for farmers. The challenge is to do so in such a way that smallholders will benefit. ■ Some improved land and water management practices—such as integrating perennial tree crops onto farms and expanding dry season gardens—can diversify and increase farmer income streams. Studies on the economic impact of such investments show significant benefits.
Gender	Generates benefits for women	●	■ Improving land and water management practices can diversify and increase women's income streams. Cobenefits such as improved access to fuelwood, fodder, and water can also reduce women's workload.
Ecosystems	Avoids agricultural expansion into remaining natural terrestrial ecosystems and relieves pressure on overstrained fisheries	●	■ Improving land and water management practices restores and boosts the productivity of existing agricultural land, thereby reducing the need to expand cropland area.
Climate	Helps reduce greenhouse gas emissions from agriculture to levels consistent with stabilizing the climate	●	■ Improving land and water management practices can sequester carbon on cropland by increasing levels of soil organic matter and density of trees and shrubs on farms. ■ Some improved land and water management practices reduce farmer vulnerability to increased climate variability by increasing soil moisture retention.
Water	Does not deplete or pollute aquifers or surface waters	●	■ Rainwater harvesting and other practices directly reduce rainfall runoff, increase infiltration of water into soils, recharge aquifers, and contribute to improved local water supplies.

LAND DEGRADATION CHALLENGES

The world's food production systems face enormous challenges. Although the area of land dedicated to crop production has never been greater, 870 million people are undernourished today.[2] A failure to successfully address the root causes of rural poverty, land degradation, and declining soil fertility is a significant factor in this ongoing challenge.[3] Seventy-five percent of the developing world's poor live in rural areas, and many depend on agriculture for their principal livelihood.[4] Yet many smallholder farmers must deal with low and unpredictable crop yields and incomes, as well as chronic food insecurity.[5] In South Asia and Sub-Saharan Africa in particular, smallholder farmers are caught in a web of rural poverty and hunger.[6] Of the 870 million people who were undernourished in 2010–12, 538 million were living in these regions.[7] For millions of smallholder farmers, increasing productivity is a critical stepping stone out of poverty. However, to boost productivity of their farms over the long term, farmers will need to change their practices that contribute to land degradation, and governments and development agencies will need to do more to facilitate these changes.

About 37 percent of the earth's land resources are used to grow food.[8] In addition, agriculture accounts for 70 percent of all freshwater withdrawals.[9] The Food and Agriculture Organization of the United Nations (FAO) estimates that 25 percent of all land is highly degraded from uncontrolled water and wind erosion, insufficient replenishment of soil organic matter and nutrients, overgrazing, land-clearing and loss of vegetative cover, salinization, and other consequences of unsustainable land use and poor management.[10] Land degradation, soil erosion, and desertification on this scale contribute to chronic poverty, hunger, and conflict.[11] Better land and water management and increased use of soil conservation practices could help to reverse soil degradation and boost crop yields, but in many regions of the world, these practices are not yet widely adopted.

The failure to maintain and improve soil fertility is a particularly important driver of land degradation. Globally only half of the nutrients removed from agricultural soils through cropping are replaced.[12] Nutrients in cropland soils are lost when the annual removal of nitrogen, phosphorus, and potassium by crops exceeds annual additions. Continuous cropping (without regular and lengthy fallows) is reducing soil fertility; without sufficient fallowing or other measures, both soil organic matter and soil nutrients drop over time. Global analysis shows a strong negative link between nutrient depletion and crop yields.[13]

As land and water resources are degraded, critically important ecosystem services—such as the regulation of water flows and flooding, soil formation, and nutrient and water cycling—are negatively impacted or lost.[14] The loss of these ecosystem services is undermining agricultural production,[15] and as cropland productivity stagnates or declines, the pressure to clear and convert new lands for crop and livestock production increases.

Land degradation is of particular concern in the world's drylands,[16] which cover 41 percent of the earth's surface. Globally, drylands are home to 36 percent of the world's population and account for 44 percent of global food production, including 50 percent of the world's livestock production.[17] The unchecked degradation of drylands is reducing the economic and biological productivity of these areas and undermining the well-being and resilience of the people who live in them.[18]

Land degradation and soil fertility challenges in Sub-Saharan Africa

Land degradation and the challenges related to soil fertility and agricultural production are particularly acute in Sub-Saharan Africa, where yield gains are greatly needed. Eighty percent of the chronically hungry in Africa are smallholder farmers.[19] Their hunger and poverty is related to low crop yields, linked to land degradation, loss of soil fertility, and periodic drought.[20] Other contributing factors include the poor state of rural infrastructure in many areas, the high costs for fertilizers and other inputs, high transport costs, and limited access to extension services and markets.[21] And, as noted later in this working paper, farmers have been reluctant to invest in fertilizers when economic returns are low and risks are high on highly weathered soils with low levels of soil organic matter. The Montpellier Panel—a group of international experts working to advise European development assistance efforts around agriculture and food security in Africa—has compiled data on food production challenges in Africa that reveal the need for a new paradigm for African agriculture (Box 2).[22]

Box 2 | Food Production Challenges in Sub-Saharan Africa

- More than 200 million people—or 27 percent of the population—in Sub-Saharan Africa are undernourished.[23]
- Forty percent of children under the age of five in Sub-Saharan Africa are stunted due to malnutrition.
- Although most regions of the world have achieved or are close to achieving replacement level fertility, Sub-Saharan Africa is the exception; its population is expected to more than double to 2.1 billion people by 2050.[24]
- Sub-Saharan Africa has the world's lowest crop yields, with cereal yields of 1.5 metric tons per hectare in 2011, or roughly half the world average.[25]
- Land degradation affects 65 percent of Africa's land; some 6 million hectares of productive land are lost each year.
- More than 95 million hectares—or 75 percent of the arable land in Sub-Saharan Africa—have degraded or highly degraded soil, and are so depleted of nutrients that major investments are needed to restore their productivity.[26]
- Climate change is likely to have a particularly negative impact on rainfed agriculture in Africa.

Moisture stress

More than 60 percent of Sub-Saharan Africa's population depends on rain-based rural economies.[27] In eastern and southern Africa, more than 95 percent of the food-producing sector is based on rainfed agriculture.[28] Rainfall frequently occurs in brief periods with high intensity and high rates of runoff.[29] Farmers also must contend with long intervals between rainfall, even periodic drought. The growing season is often short, and a relatively small percentage of rainfall is actually used by growing crops. Along with low nutrient status, soil moisture stress is one of the two most important constraints to food production in much of Sub-Saharan Africa.[30]

Moisture stress is not only a function of low and erratic precipitation but also of the ability of the soil to hold and release moisture. Such soil has a particularly negative impact on crop yields as farmers face climate change, with its associated increased incidence of drought, intense rainfall, and disruptions in rainfall patterns. Depending on the quantity and distribution of rainfall, crop yield losses can range widely from a small percent to almost total crop failure. These losses can greatly exacerbate food insecurity, especially in a region with a high rate of population growth.

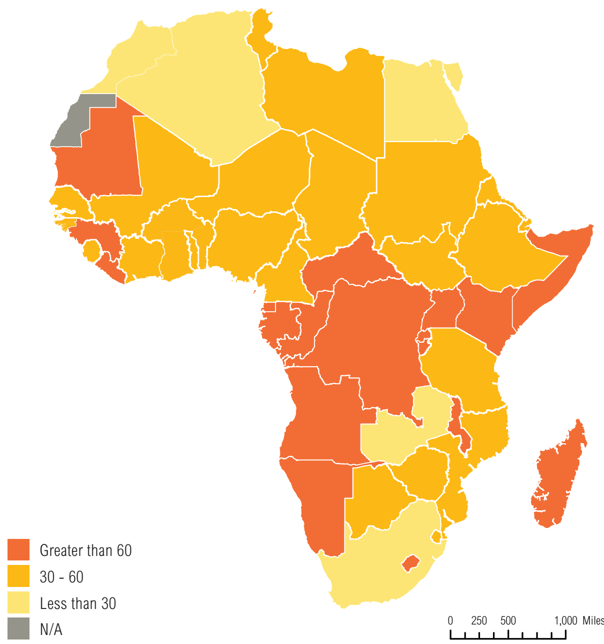
Weathered soils and nutrient depletion

Crop production in Sub-Saharan Africa also is constrained by the physical and chemical properties of soils that have been cultivated for long periods.[31] Only 10 percent of the soils in the region are geologically young and rich in nutrients.[32] Soil nutrient depletion is particularly serious in Sub-Saharan Africa, resulting from high rates of soil erosion, leaching of nitrogen and potassium, and continuous cropping.[33] During the period 2002–04, 85 percent of African farmland suffered a net annual loss of 30 kg of nutrients such as nitrogen, phosphorus, and potassium (NPK) per hectare, and 40 percent of African farmland had nutrient depletion rates greater than 60 kg NPK per hectare annually.[34] Nutrient depletion has been particularly severe in parts of the Congo Basin, the Horn of Africa, and Madagascar (Figure 1).

Low levels of soil organic matter

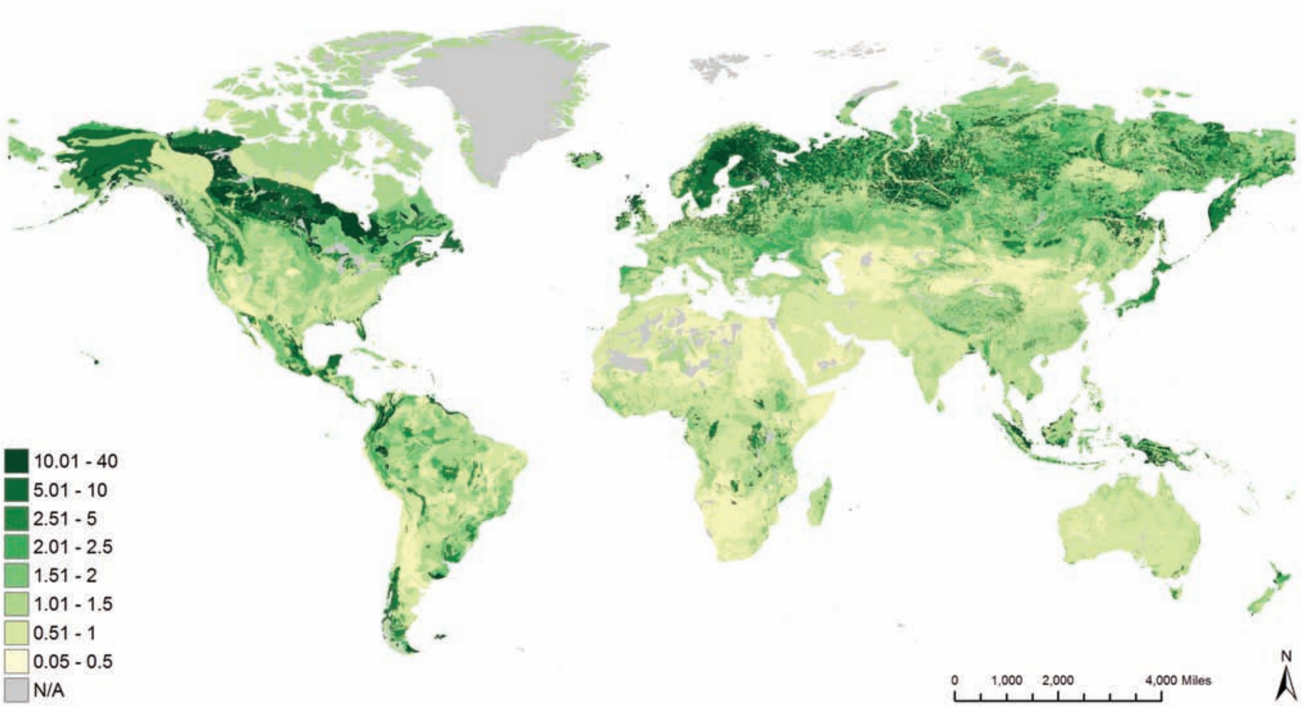
Soils in Africa are relatively low in organic carbon, which is related to the amount of organic matter in the soil released from crop residues, decomposing plants, tree leaf litter, and other sources (Figure 2). Soils that are low in soil organic matter are especially vulnerable to nutrient depletion when traditional fallows are shortened or eliminated. Research shows that soil organic matter contains practically all of the inherent nitrogen and 20–80 percent of the phosphorus in soils.[35]

Figure 1 | **Several regions in Africa have relatively high rates of nutrient depletion on agricultural lands (Annual nutrient depletion, kg NPK/ha/year)**



Source: Henao and Baanante, 2006.

Figure 2 | **Soils in Africa are relatively low in organic carbon (Topsoil organic carbon, percent mass fraction)**



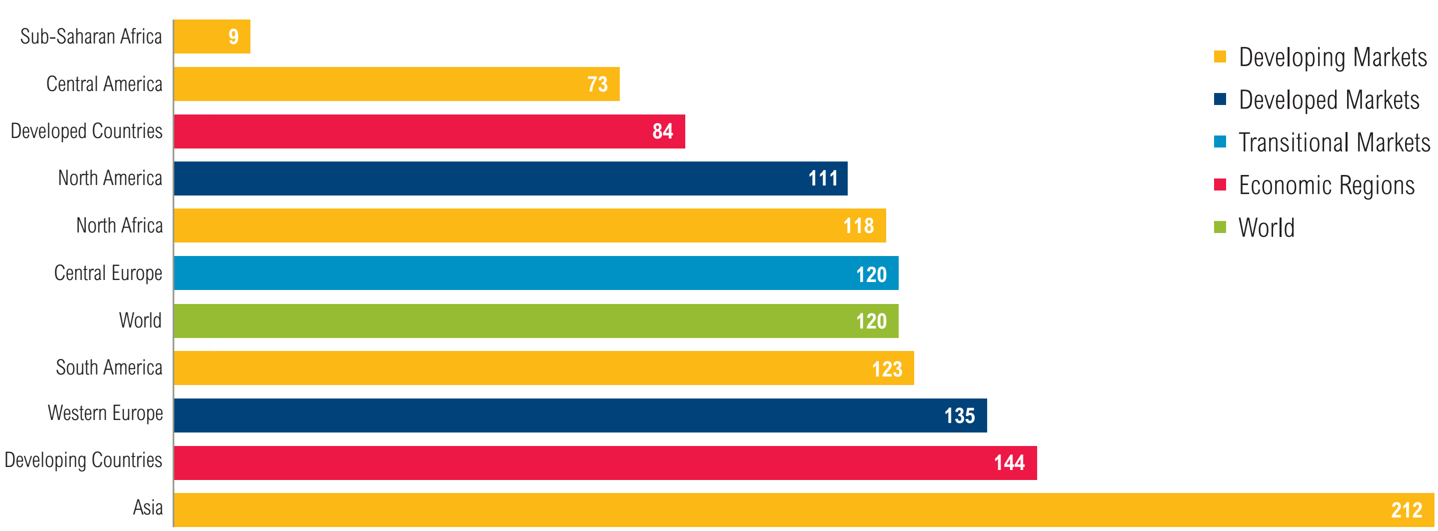
Source: Hengl and Reuter, 2009.

Sub-Saharan Africa's inherently low levels of soil carbon or organic matter, and high rates of nutrient depletion, are of particular concern because of their direct impact on crop production.[36] Soil organic matter plays a key role in retaining nutrients and moisture in the highly weathered soils that are prevalent in Africa. Low levels of soil organic matter, therefore, lead to less capacity for soils to hold nutrients and make them available to plants, and less capacity to retain water and sustain crop growth during dry periods. Applying fertilizers to soils with higher organic matter content produces greater results than applying fertilizers to soils with low levels of soil organic matter.[37] Some studies have suggested that the difference is enough to make nitrogen fertilizer application uneconomical for vast areas of farmland with very low levels of soil organic matter content. For example, research with smallholder farmers in western Kenya revealed that fertilizer-use efficiency was so low on soils with low organic matter that the yield response did not justify the added costs of fertilizer use.[38]

Low use of fertilizers

The low use of fertilizers, together with low fertilizer-use efficiency, contributes to Africa's lagging agricultural productivity growth.[39] Assuming that farmers can address the problems associated with highly weathered soils, moisture stress, and low levels of soil organic matter, significant increases in agricultural production will also require increased investment to replenish soil nutrients. Farmers in Sub-Saharan Africa use less than 10 kg/ha of fertilizer, compared to 90 kg/ha in Latin America and more than 170 kg/ha in Asia.[40] In Sub-Saharan Africa, low incomes in tandem with the high cost and inaccessibility of fertilizers have resulted in the lowest levels of fertilizer use in the world (Figure 3).[41]

Figure 3 | **Sub-Saharan Africa uses much less fertilizer per hectare than any other region (Kilograms per hectare)**

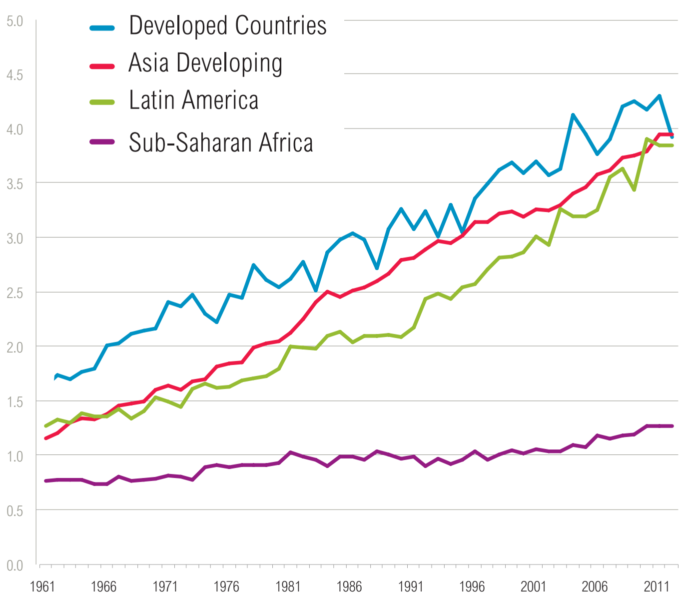


Source: IFDC, 2013.

Low crop yields

The significant impacts of land degradation combined with soil constraints and low use of fertilizers have contributed to low yields of cereals and other major crops, particularly in Sub-Saharan Africa (Figure 4). This is not to suggest that crop yields are uniformly high throughout Asia and Latin America; there are also extensive areas of degraded land and farms with significant yield gaps in other regions. However, the longer term trends in Sub-Saharan Africa warrant attention. With low crop yields and continued population growth, Sub-Saharan Africa is already forced to meet a significant portion of its food demands through imports. In 2010, Africa relied on imports for 14 percent of its animal products, 25 percent of its cereals, and 66 percent of its vegetable oil.[42]

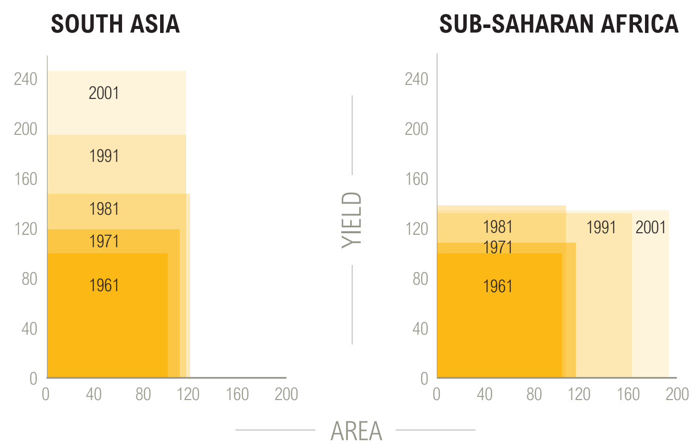
Figure 4 | **Cereal yields in Sub-Saharan Africa are much lower than other regions (Metric tons per hectare)**



Source: Derived from FAO data; graph by IFDC.

In several Asian countries, such as India and China, steady increases in crop yields have led to increased food production. In many areas, the limited amount of land suitable for agricultural expansion has driven intensified agricultural production. In some parts of Sub-Saharan Africa, agricultural intensification has fueled progress, as seen in Kenya's increased use of fertilizer and improved maize varieties.[43] But for the most part (and in contrast with Asia), increased food production in Sub-Saharan Africa is achieved by clearing more land and expanding the area of cropland—a process of "extensification" instead of intensification, which contributes to further land degradation (Figure 5).

Figure 5 | **From 1961–2001, food production increases in Sub-Saharan Africa were achieved mainly by expanding the area of cropland**



Note: Baseline data in 1961 is given the value of 100; subsequent data for yield, area and production are in units of percent change relative to 1961, with production = yield X area / 100).

Source: Henao and Baanante, 2006.

In the next section, we turn our attention to a number of improved land and water management techniques that can address the problems of soil moisture stress, nutrient depletion, low levels of soil organic matter, low utilization of mineral fertilizers, and, ultimately, low crop yields. Innovative farmers are already applying several of these improved practices, all of which could be further scaled up.

IMPROVED LAND AND WATER MANAGEMENT PRACTICES

A wide range of land and water management practices have evolved over the past several decades to address the negative impacts of land degradation and to increase long-term agricultural productivity.[44] Three recent reports—by the World Overview of Conservation Approaches and Technologies (WOCAT),[45] the World Bank,[46] and the U.S. National Research Council[47]—highlight these practices and include case studies where they are already being adopted across the globe. WOCAT, for example, identified seven major types of land and water management practices: conservation agriculture, manure and composting, vegetative strips, agroforestry, rainwater harvesting, gully rehabilitation, and terraces.[48]

Benefits of improved land and water management practices to farmers and rural economies include increased agricultural productivity (higher yields), increased income and employment opportunities from agriculture, and increased resilience to climate change and associated extreme weather events—such as water scarcity, intense rainfall, or droughts. These benefits occur because these management practices:

- Increase soil organic matter
- Improve soil structure
- Reduce soil erosion
- Increase water filtration
- Increase efficiency of water use
- Replenish soil nutrients
- Increase efficiency of nutrient uptake.

Smallholder farmers have themselves developed a number of these practices to increase their crop yields and simultaneously reap other important benefits (Box 3).[49, 50]

Investing in improved land and water management also enables more effective use of external inputs such as fertilizers and improved seed.[51] For example, farmers in the village of Dan Saga in Niger have begun integrating agroforestry and micro-dosing—the targeted application of small amounts of fertilizer. They believe that agroforestry alone leads to average cereal yields of about 500 kg/ha, but when they combine agroforestry with micro-dosing, they get yields close to 1,000 kg/ha. Many farmers in this village, both men and women, have become trainers in agroforestry and micro-dosing.[52]

Box 3 | Farmer innovation in Burkina Faso: The case of Yacouba Sawadogo

In the early 1980s, Yacouba Sawadogo, a farmer innovator in Burkina Faso's Yatenga region, improved a traditional water harvesting technique (*zai*) by increasing the diameter and the depth of planting pits and by adding organic matter to the pits at the end of the dry season. By doing so, he concentrated water and soil fertility in the same spot. The manure applied in the pits contained seeds of trees and bushes, which benefitted from favorable growing conditions. Many young trees emerged, which Yacouba protected by cutting millet stalks during harvest at a height of about 50 cm so the stalks would protect the young trees from browsing animals. In this way Yacouba created a forest of almost 25 ha with more than 60 different woody species. The planting pits helped raise crop yields, and the trees provided multiple benefits, including firewood, medicinal products, and honey. Yacouba's life, innovations, and impact are told in an award winning documentary "The Man Who Stopped the Desert" (http://www.1080films.co.uk/trailer-manwho-full.htm). Other farmers used the improved traditional planting pits to create agroforestry systems. The technique has restored tens of thousands of hectares of degraded land to productivity in Burkina Faso's Yatenga region and in Niger's Tahoua region.

The scientific literature as well as farmer experience point to a suite of promising land and water management practices (Appendix 1). In our perspective, four of the most promising are *agroforestry, conservation agriculture, rainwater harvesting, and integrated soil fertility management*. Particularly in the drylands of sub-Saharan Africa, agroforestry and rainwater harvesting are rapidly emerging as the key to increasing agricultural productivity while restoring other valuable ecosystem services in agricultural landscapes. Below we profile each of these promising practices.

Agroforestry

Agroforestry is a land use practice in which farmers deliberately integrate woody perennial plants—trees and shrubs—with crops or livestock on the same tract of land. The trees and shrubs in agroforestry systems can be selectively protected and regenerated, or planted and managed. Agroforestry systems can include native species as well as introduced non-native species. As farmers include woody species that produce wood, fodder, edible leaves, and other products, agroforestry systems evolve into more complex production systems that can provide a broader range of benefits and more resilient farming systems than those relying on simplified annual crop production.

A growing trend

Agroforestry is practiced in Africa, Latin America, and Asia, as well as in parts of Europe and North America. Farmers have implemented agroforestry for generations, but there are also numerous examples of new agroforestry systems.[53] For example, over the past decade, a particularly versatile and productive agroforestry species, *Grevillea robusta*, has become much more commonplace in the rural landscapes of Kenya. With support from government, nongovernmental organizations, and research institutes, rural communities are planting *Grevillea* along roadsides and field borders and intercropping it on farms. The tree produces wood, fodder, and other products, while conserving soil and water.[54] Since 1985, more than a million rural households in Niger have protected and managed the natural regeneration of native trees, growing in farm fields across 5 million hectares. Nigerien farmers have added approximately 200 million additional trees across agricultural landscapes, which have directly contributed to the increased production of about 500,000 tons of grain per year, an amount sufficient to feed an additional 2.5 million people.[55]

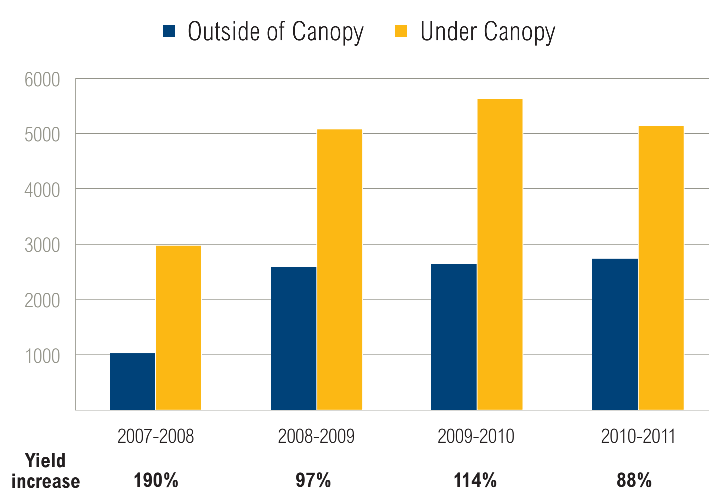
The U.S. Geological Survey recently mapped 450,000 hectares of newly created agroforestry parkland in the Seno Plains of Mali.[56] Farmers in Zambia and Malawi are also increasing the protection and management of trees on farms and increasing adoption of intercropping of nitrogen-fixing species, including the native tree *Faidherbia albida*.[57] It is estimated that currently about 500,000 Malawian farmers have *Faidherbia* trees on their farms.[58] The majority of these trees grew through assisted natural regeneration of seedlings that emerged in farmers' fields. Agroforestry is also playing a key role in dryland farming systems in India, Brazil, and other parts of the world.[59]

Impacts on crop yields

The woody perennial plants in agroforestry interact with the soils and crops to create an agro-ecological system that reinforces multiple ecosystem services to increase overall crop productivity. For example, a *Faidherbia albida* tree's roots fertilize the surrounding soil by fixing nitrogen, increasing the yields of crops grown in the vicinity of the tree. *Faidherbia* tree leaves drop during the crop growing season, meaning that the trees do not compete with crops for sunlight.

Scientists have long recognized the positive impact on crop yields of nitrogen-fixing species, like *Faidherbia albida*. In the 1970s, scientists noted that crop yields in Senegal's peanut basin increased from 500 kg/ha to 900 kg/ha when the peanuts grew under the canopy of *Faidherbia* trees in farms.[60] More recent studies provide further evidence of increased crop yields associated with agroforestry practices that include nitrogen-fixing species. For example, in Zambia, maize yields under the canopy of *Faidherbia* trees were 88 to 190 percent higher over four cropping seasons, from 2007 to 2011 (Figure 6).[61]

Figure 6 | **Maize yields in Zambia are higher under *Faidherbia* trees (Kilograms per hectare)**



Note: Average maize grain yields from trial sites under and outside canopies of mature *Faidherbia albida* trees across regions in Zambia.

Source: Shitumbanuma, 2012.

Of particular significance is the increase in yields associated with a combination of agroforestry practices and inorganic fertilizers. A study in Malawi showed that yields doubled from 1.5 t/ha to 3 t/ha when maize was grown under *Faidherbia* canopies, and with a fertilizer application of 30 kg/ha.[62] Other research in Malawi indicates that, in general, agroforestry practices increase yields from 1 t/ha to 2–3 t/ha, even if farmers cannot afford inorganic fertilizers. However, with an application of a quarter-dose of inorganic fertilizer to maize grown in an agroforestry system, yields can surpass 4 t/ha.[63]

A wide range of agroforestry systems can benefit farmers in diverse agro-ecological conditions and circumstances. For example, the most popular agroforestry system in southern Malawi, where average land holdings are very small (less than 1 hectare), is intercropping maize with nitrogen-fixing tree and shrub species, along with pigeon peas, which also fix nitrogen.[64] In this system, farmers plant the trees in rows between their crops. The farmers prune the trees back two or three times a year, and incorporate the nitrogen-rich leaves into the soil. A long-term study showed that continuous cultivation of maize with *Gliricidia* trees in small plots in Malawi yielded more than 5 t/ha in good years and 3.7 t/ha in average years, in the absence of fertilizers. In comparison, control plots without *Gliricidia* or fertilizers had average yields of 0.5–1.0 t/ha.[65]

Rotational fallows that incorporate nitrogen-fixing shrubs are suited to areas where landholdings are larger than 1 hectare. In this case, during the fallow period farmers grow short-lived shrubs such as *Sesbania sesban* and *Tephrosia candida* rather than the long-lived, intercropped trees. When it is time to plant, farmers cut down the shrubs and incorporate their leaves into the soil. Results from 152 farms in Malawi show that such rotational fallows increased the yield of maize by 54–76 percent compared to unfertilized maize grown alone.[66] When supplemented with inorganic fertilizer, the yield increase over the control was 73–76 percent across tree species.[67]

A number of other tree and shrubs that can be found in crop fields across the Sahel region of West Africa have been shown to increase crop yields. For example, *Piliostigma reticulatum* and *Guiera senegalensis* have been shown to increase yields of millet and peanut by more than 50 percent.[68] The presence of these shrubs in fields has increased nutrient-use efficiency over sole crop systems, and has helped to create "islands of fertility" that have greater soil organic matter, nitrogen, and phosphorus concentrations under their canopies than in open areas.[69] Intercropping by farmers in the Sahel with the shrub *Guiera senegalensis* has shown dramatic yield responses, even in the absence of fertilizer inputs.[70] Researchers are also finding that these shrubs increase nutrient availability, and even help to move subsoil water to the surface.[71] At night, when photosynthesis stops, water moves through the roots of these shrubs from the wetter subsoil and to drier surface soil through a process described by researchers as "hydraulic redistribution" (Box 4).[72]

Box 4 | New findings about the contribution of shrubs to cropland productivity

Over the past decade, agroforestry researchers have turned their attention to the role of shrub species that are prominent components of the vegetative cover in farm fields in the West African Sahel and other parts of Sub-Saharan Africa. Until recently, researchers, government agricultural extension agents, and policy makers have largely overlooked the role of shrubs in nutrient cycling and ecosystem function.[73] Although shrubs such as *Guiera senegalensis* and *Combretum* spp. are heavily cut for fuelwood and the aboveground biomass is often burned each spring when farmers prepare fields for the summer cropping season, these shrubs have a high potential to add soil organic matter that can contribute significantly to the soil microbial population and provide the largest source of carbon in cropped fields.[74] Shrubs can help to stimulate microbial activity in the soils that play an important role in nutrient cycling, even in the dry season after six months or more without rainfall.[75] This helps to drive biogeochemical processes year round in ways that were not previously recognized.[76]

Additional benefits of agroforestry

Well-managed agroforestry systems can generate a number of benefits in addition to enhanced crop yields.[77] For instance, depending on the species, trees might provide fruit, nuts, medicines, and fiber—all important for direct human use. Large branches can be cut to make poles for home construction or to sell in local markets for additional income. Trimmings of branches can be used for firewood. For example, *Leucaena leucocephala* trees, which grow at a rate of 3–5 m/year and supply wood at a rate of 20–60 m^3/ha/year, are efficient producers of firewood.[78] Seed pods and leaves can serve as fodder or forage for livestock; *Leucaena* hedgerows provide 2–6 tons of high-protein forage per hectare per year.[79] Leaves can be sold in markets; leaves of one mature baobab in Niger's Mirriah district vary in value from $28–$70, an amount sufficient to buy at least 70 kg of grain in the market.[80]

Among other things, the benefits and diversified sources of income associated with agroforestry systems help farmers in drylands build resilience to drought and climate change. When crops fail, trees continue to produce. In Niger, farmers with more trees on their farms were able to cope better with the impacts of the 2004–05 drought than farmers with fewer trees because they were able to sell tree products such as firewood, poles, and fodder that provided them with added income to buy grain.[81]

Conservation agriculture

In response to continued land degradation, a set of techniques designed to improve soil fertility and water use efficiency has become widespread, particularly on large commercial farms. These techniques, together referred to as "conservation agriculture," are based on three linked practices:

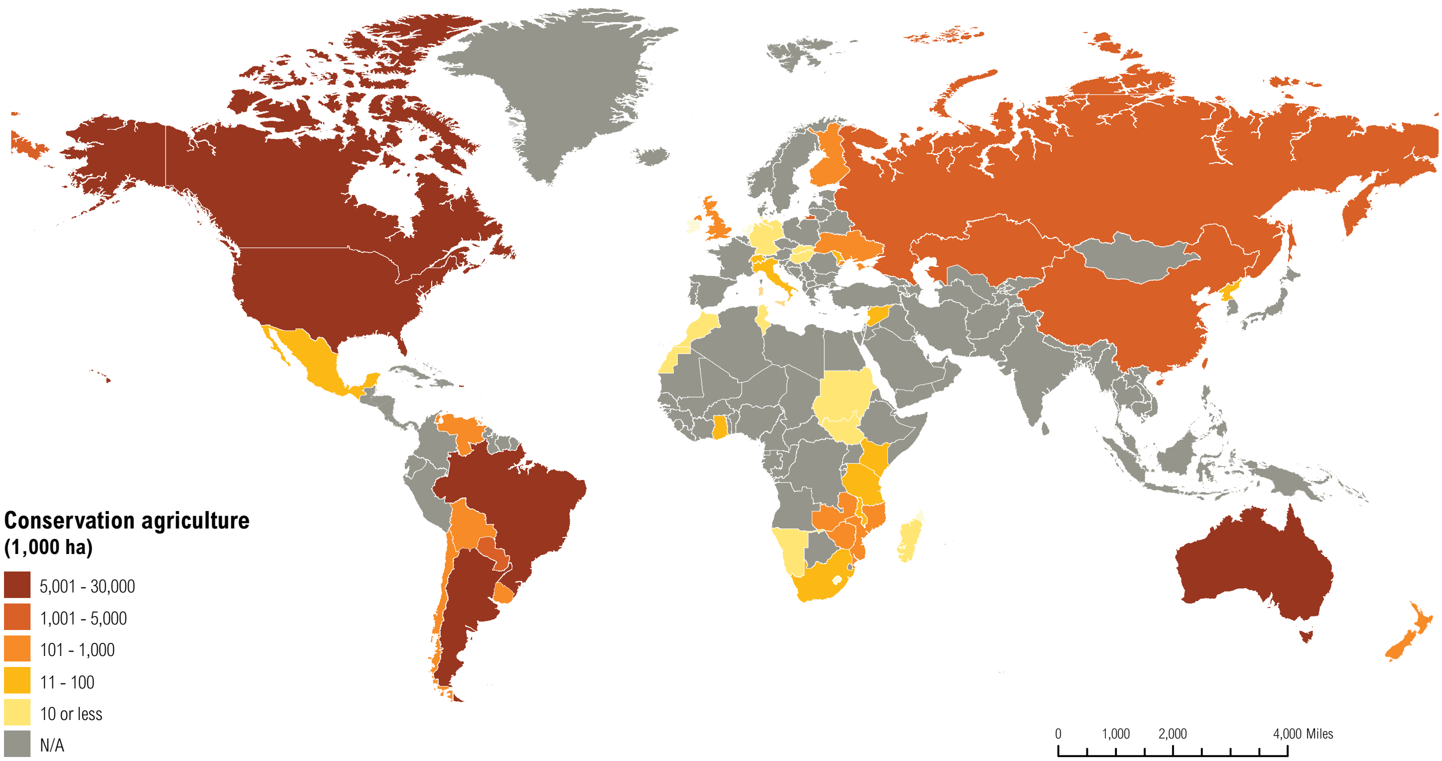
- Minimal soil disturbance by reducing the amount of tillage or adopting "no-tillage" techniques
- Retention of crop residues or maintenance of a cover crop
- Crop rotation or diversification of crop species grown in sequence and/or associations.[82]

These techniques combine to boost soil organic matter content, retain soil moisture, and protect cropland from erosion. Crop rotation also helps to control pests and diseases and, when nitrogen fixing legumes are used, contributes to nutrient management. Conservation agriculture is among a group of practices that provide a "triple win" of increased agricultural productivity, enhanced resilience to climate change, and sequestration of carbon.[83] Conservation agriculture, along with measures such as agroforestry and water harvesting techniques, are together referred to as "climate-smart agriculture" (Box 5).

Farmers in temperate regions have traditionally plowed to aerate and warm the soil, and to bury manure and crop residues and control weeds. However, conventional tillage's long-term effects have been a leading cause of accelerated erosion and land degradation, as well as pollution of waterways from sediment and chemicals in runoff from farmland.[84] Conservation agriculture practices emerged as a response to the drought, crop failures, and Dust Bowl of the 1930s in the United States. In recent decades, these practices have proven successful in reducing soil loss from erosion; no-till methods may decrease soil erosion by as much as 98 percent.[85] Other payoffs from the adoption of conservation agriculture include an increase in rainfall infiltration, a reduction in runoff and pollution, improvements in soil biota, and increased sequestration of soil carbon, along with savings in fuel and labor.[86]

Large-scale farmers cultivating wheat, maize, and soybeans in the United States, Canada, Brazil, Argentina, and Australia have led the way in adopting conservation agriculture and its associated reduced tillage techniques. By 2008, an estimated 88 percent of farmers in western Australia had adopted no-till on 12 million ha.[87] The observed benefits of conservation agriculture have led to growing support among farmers—as well as extension agents and scientists—in many countries. More than 105 million hectares worldwide are now farmed using conservation agriculture (Figure 7).[88] In the countries where conservation agriculture has taken root, many farmers have invested in specialized equipment adapted for reduced tillage and have access to herbicides to assist in weed control, as well as improved seed and fertilizers.

Figure 7 | **Conservation agriculture is widely used in many continents, but not in Africa**



Source: Data from FAO, 2013; map produced by WRI.

Box 5 | **What is Climate-Smart Agriculture?**

FAO defines climate-smart agriculture as "agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes greenhouse gases (mitigation) while enhancing the achievement of national food security and development goals." [89] According to the World Bank, climate-smart agriculture includes a number of proven practical techniques—such as mulching, intercropping, conservation agriculture, crop rotation, integrated crop-livestock management, agroforestry, improved grazing, and improved water management—and innovative practices such as better weather forecasting, more resilient food crops, and risk insurance.[90]

Impacts on crop yields and other reported benefits

In Brazil, the area of land farmed through conservation agriculture grew dramatically from 1972 to 2006, with a particularly rapid increase beginning in the early 1990s. Over 25 million hectares of cropland in Brazil are now under no-till.[91] From 1991 to 2004, grain production in Brazil more than doubled in association with the widespread adoption of conservation agriculture and the introduction of improved crop varieties, from 58 million tons to 125 million tons.[92] In Argentina, the total cultivated area increased by 53 percent while grain production increased by 150 percent from 1987/1988 to 2007/2008. The increased adoption of conservation agriculture was a key contributor to the increased productivity of major crops such as soybean.[93]

The adoption of conservation agriculture has enabled farmers to increase yields from 20–120 percent, while also reducing the threat of erosion.[94] Conservation agriculture has benefited farmers by increasing fertilizer-use efficiency by 10–15 percent and generating 15–50 percent savings in water use.[95] In addition, conservation agriculture has reduced the amount of time, labor, and fuel associated with plowing. For instance, farmers in India implementing conservation agriculture practices spent an average of $55 per hectare less in cultivation costs and saved 50–60 liters of fuel per hectare while raising yields by almost 250 kg/hectare.[96]

Experience in Sub-Saharan Africa

Despite the benefits that farmers in many countries have realized through conservation agriculture, the practice is uncommon among most smallholders in Sub-Saharan Africa.[97] In Zambia, retention of crop residues in fields conflicted with socio-cultural practices of farmers, and crop rotation was difficult because of the dominance of maize cultivation and the lack of markets for crop legumes.[98] Government policies were also unsupportive of conservation agriculture, and subsidies for fertilizer and hybrid seed promoted mono-cropping of maize.[99] And where free grazing by livestock after the harvest is the rule, farmers tend to quickly remove crop residues from their fields and stock them for their animals.

The main constraints to smallholders adopting conservation agriculture in Sub-Saharan Africa include:

- Competition for the use of crop residues (for fuel, livestock fodder, fencing)
- Short-term risks of lower yields during the transition period from conventional plowing to no-till
- High costs and limited access to specialized equipment
- Weed control and access to herbicides, particularly during the early transition
- Conflicting or ineffective extension messages
- Free-ranging livestock and customary grazing on crop residues, which make it more difficult for farmers to retain crop residues in fields.

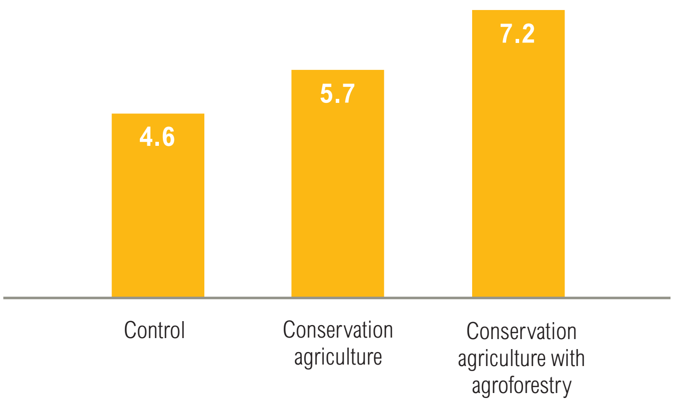
Despite these constraints, experiences in Malawi, Zambia, Zimbabwe, and Senegal have demonstrated effective approaches that enable smallholders in Africa to benefit from conservation agriculture practices.[100] Particularly promising results are being achieved by combining conservation agriculture with agroforestry, water harvesting, and adding small amounts of fertilizer. Combining these improved land and water management practices has helped to address some of the primary causes of land degradation, such as the burning and removal of crop residues, lack of soil protection, labor constraints, delayed planting due to untimely land preparation, and inefficient use of fertilizers.[101] Another feature of successful approaches to support the adoption of conservation agriculture is the provision of assistance to farmers to find alternatives to reliance on crop residues for livestock feed or household energy. Extension support for crop rotation and weed management and assistance with the judicious use of herbicides are also particularly helpful for farmers, especially when transitioning from conventional practices to conservation agriculture.

In Malawi, conservation agriculture has contributed to increased crop yields. In fields monitored by Total Land Care (a nongovernmental organization focused on smallholder livelihoods), yields of maize increased from 4.6 tons/ha to 5.7 tons/ha with the adoption of conservation agriculture.[102] And combining conservation agriculture with agroforestry improved yields even further to 7.2 tons/ha (Figure 8).

The latter increase in maize yields is a result of:

- Earlier planting with the first rains, which is possible due to increased rainfall infiltration
- Weed control with the use of herbicides provided with project assistance
- Increased soil fertility from nitrogen fixation by *Faidherbia albida* and added soil organic matter from the tree's leaf litter
- Improved capture of rainfall and reduced temperatures and evapotranspiration under the canopy of *Faidherbia albida*.[103]

Figure 8 | **Conservation agriculture increased maize yields in Malawi in 2011, and combining it with agroforestry (intercropping of *Faidherbia* trees) increased yields even further (Metric tons per hectare)**



Source: Bunderson, 2012.

Researchers in southern Africa have investigated the multiple impacts of conservation agriculture in comparison to conventionally plowed fields. There is growing evidence of improved water infiltration, decreased runoff and erosion, and decreased evaporation from the soil surface, along with increased soil biological activity and soil organic matter.[104] For example, in Zimbabwe, conservation agriculture systems show 65 percent greater water infiltration with direct seeding compared with plowed cropland. Soil carbon increased by 104 percent in direct-seeded conservation agriculture treatments in four cropping seasons from 2004 to 2008, while it remained at low levels on conventionally tilled control plots.[105] These impacts have in turn contributed to improved rainfall use efficiency and moisture retention during seasonal droughts, and to improved crop yields and reduced risk of crop failure.[106]

Rainwater harvesting

Without attention to soil and water conservation, the loss of rainfall due to runoff from denuded fields can be very significant. In Mali, for instance, 70–80 percent of rainwater falling early in the rainy season is lost to runoff, and rainfall runoff takes away about 40 percent of the nutrients applied to the soil through organic and mineral sources of fertilizer.[107] A variety of simple, low-cost water management practices have been developed over the past three decades that effectively capture and collect rainfall before it runs off farm fields.[108] These rainwater harvesting practices include:

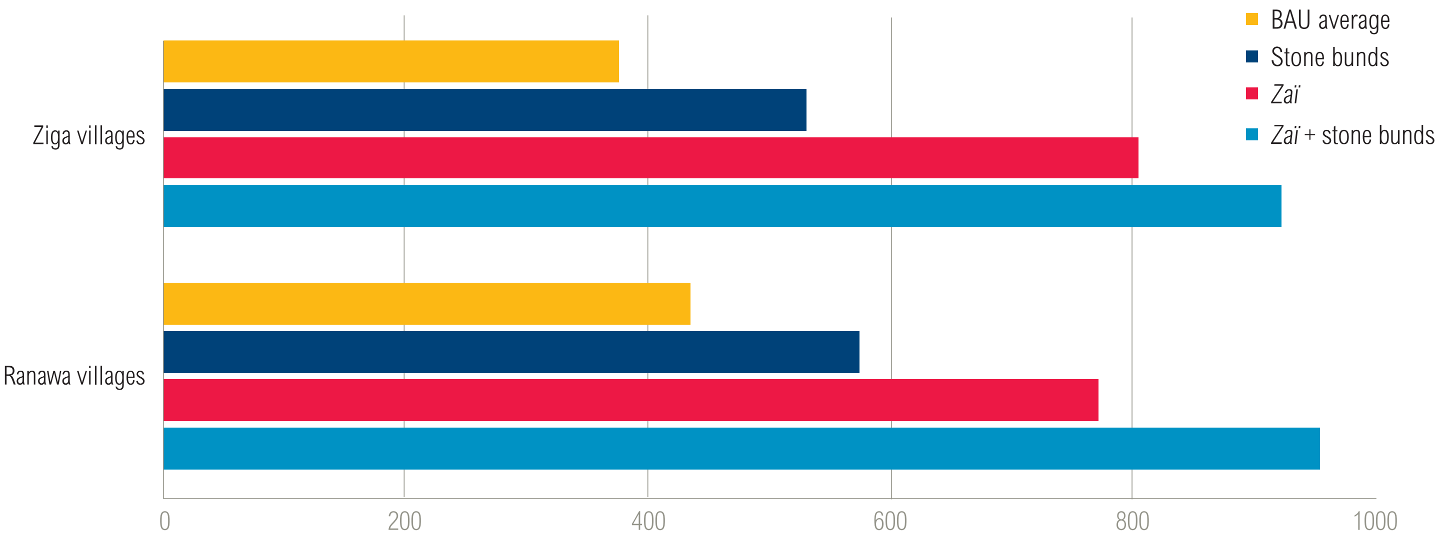
- Planting pits or *zaï*
- Demi-lunes, which are half-moon-shaped, raised earthen barriers
- Lines of stone placed along contours
- Ridge tillage, to produce earthen barriers or trenches along contours.

By slowing water runoff, water harvesting practices help farmers adjust to fluctuations in rainfall. Water harvesting is being used in dry regions such as the Tahoua region in Niger and the Central Plateau of Burkina Faso, where techniques of some form have been applied on about 500,000 hectares since the late 1980s.[109]

Impact on crop yields and other benefits

Yield improvements from water harvesting can vary from 500 to 1,000 kg/ha, depending on other factors such as soil fertility management.[110] Farmers in Burkina Faso using water harvesting techniques such as stone bunds and *zaï* to capture rainfall and reduce runoff have increased their yields from 400 kg to more than 900 kg per hectare.[111] Combining techniques on the same farm can increase yields more than one technique can on its own (Figure 9).[112] These findings from Burkina Faso have been documented by numerous studies.[113]

Figure 9 | **A combination of water harvesting practices increases grain yields more than one practice (Burkina Faso) (Kilograms per hectare)**



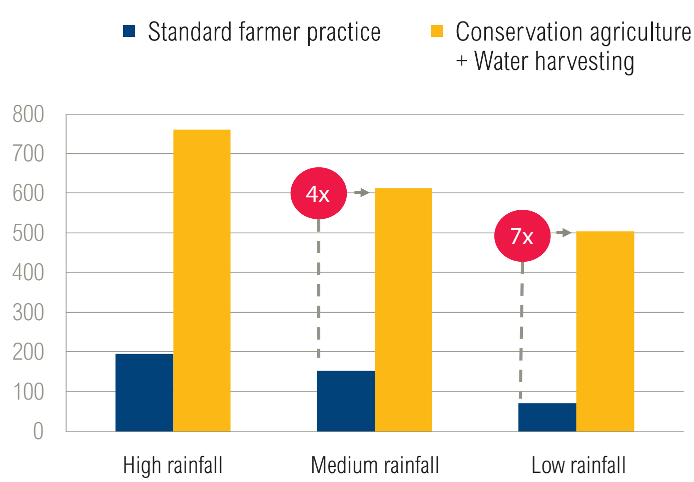
Note: These two groups of villages are located on the northern central plateau of Burkina Faso. "BAU" = business as usual

Source: Sawadogo, 2008.

Multiple studies indicate that water harvesting can help buffer farmers from the effects of erratic and reduced rainfall and thereby increase crop yields.[114] In Mali, for instance, the practice of ridge tillage has reduced rainfall runoff and helps to capture scarce rainfall in a dry year. The practice has resulted in soil moisture increases of 17–39 percent. Ridge tillage allows earlier sowing and prolongs vegetative growth by as much as 20 days per year, thereby increasing millet yields by 40–50 percent. Ridge tillage also has resulted in an increase of 12–26 percent in soil carbon, and an increase of 30 percent in fertilizer-use efficiency.[115]

Field observations and farmer testimonies indicate that water harvesting also has contributed to increased water levels in nearby wells and to an expansion of small-scale dry season irrigated vegetable gardens.[116] One study in Zimbabwe found that water harvesting, combined with conservation agriculture, increased farmer gross margins per hectare four-to-seven-fold and returns on labor two-to-three-fold compared to standard practices.[117] The greatest benefits from these practices have been observed in zones with lower rainfall (Figure 10).[118]

Figure 10 | **Water harvesting combined with conservation agriculture increases gross margins for farmers in Zimbabwe (Gross margins, US$ per hectare)**



Note: Data from nine districts in Zimbabwe, across rainfall zones.

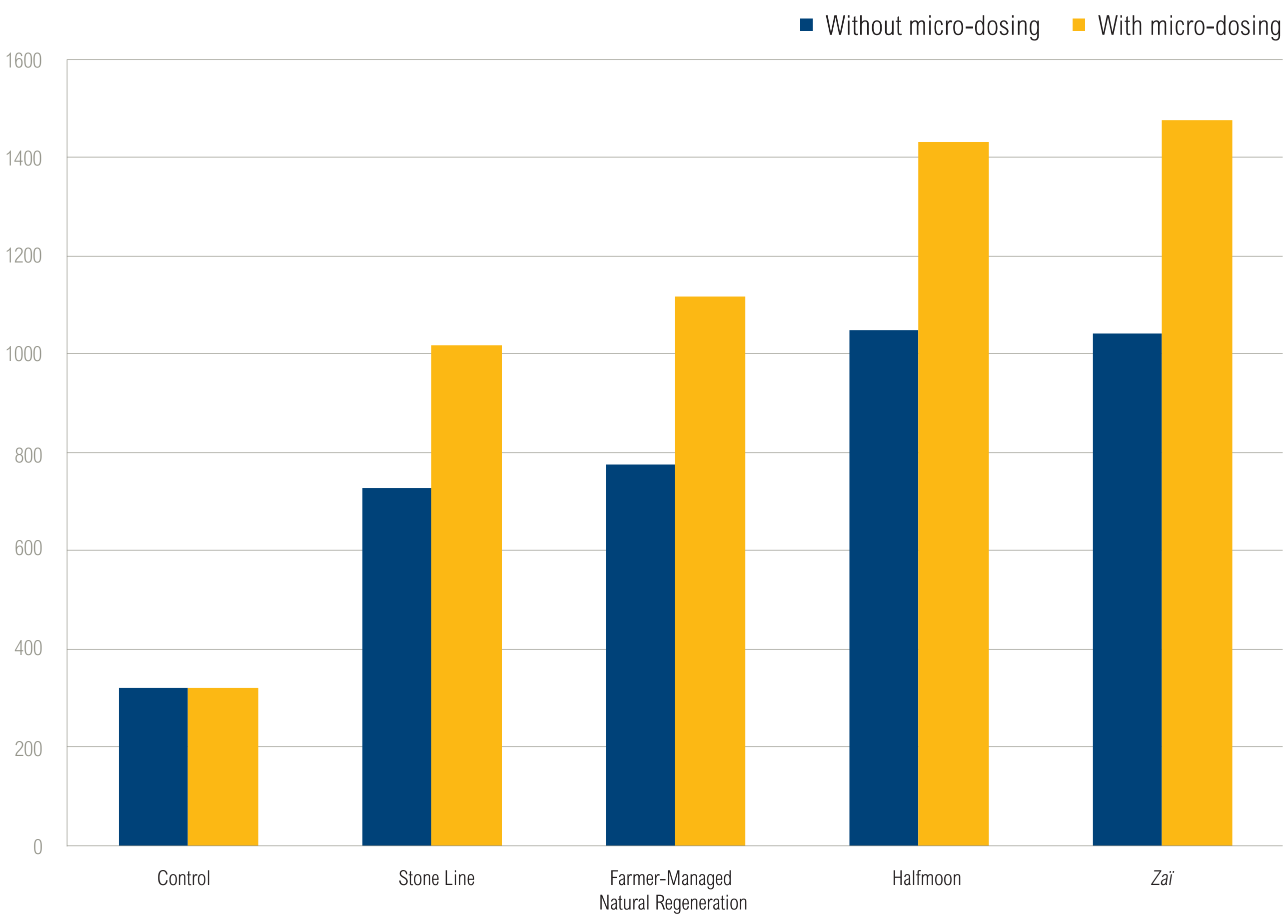
Source: Mazvimavi et al., 2008.

Complementing agroforestry and rainwater harvesting with micro-dosing

Land and water management practices can be conducted in isolation, together, or in conjunction with conventional technology solutions such as fertilizers and improved seed varieties. An example of a complementary practice is "micro-dosing," the targeted application of small quantities of fertilizer—often just a capful—directly to crop seeds or young shoots at planting time or when the rains fall.[119] Research in Sudan shows a 50 percent increase in yields when farmers mixed seed and fertilizers in equal quantities; this corresponds to 3 kg/ha of fertilizer—a relatively small application of fertilizer. Micro-dosing enables fertilizer, which is in many regions expensive or in limited supply, to go as far as possible with the least amount of waste.[120] This technique could benefit many low-income farmers in Sub-Saharan Africa. Currently, approximately 473,000 smallholder farmers in Mali, Burkina Faso, and Niger have learned the technique and have experienced increases in sorghum and millet yields of 44–120 percent, along with an increase in family incomes of 50–130 percent.[121]

Field results of sorghum in Burkina Faso indicate that combining micro-dosing with water harvesting techniques or agroforestry can increase crop yields significantly.[122] The average yield in 2009–11 for control plots was only 323 kg/hectare. The average yields for a range of land and water management techniques, including stone lines and agroforestry, were 100 to 200 percent higher than for the control plots. When micro-dosing was added to the different land and water management techniques, the yields jumped another 40 to 44 percent (Figure 11).

Figure 11 | **Micro-dosing further increases sorghum yields beyond other land and water management practices (Burkina Faso, 2009–11) (Kilograms per hectare)**



Source: Sawadogo, 2012.

Using averages and percentages in yield data, like Figure 11 does, can hide important information. The year 2010 was a good rainfall year and the combination of *zaï* and micro-dosing produced a sorghum yield of almost 1,900 kg/ha. This kind of yield compares to untreated fields with yields of 200–400 kg/ha, and enables smallholders not only to be food secure, but also to create a stock or to sell a surplus on the market. It is important to realize that these yields were obtained on land that produced 0 kg/ha before farmers reclaimed them and restored their productivity with simple water harvesting techniques, namely *zaï* and half-moons.

Farmers are especially concerned about their yields in dry years. For example, 2011 was a drought year and the yield on the control plot was only 118 kg/hectare. Farmers who had not used water harvesting techniques in 2011 did not fare well. Those who had invested in *zaï* or in half-moons fared much better in such years of below-average rainfall. The farmers investing in water harvesting realized yields in the order of 700 kg/ha and those who had added micro-dosing even achieved yields ranging from 1,000 to 1,100 kg/ha, underscoring how these practices contribute to resilience and food security.

Micro-dosing and other measures aimed at improved soil fertility management are important complements to the suite of improved land and water management practices. Agroforestry helps maintain or improve soil organic matter, increasing the amount of nitrogen in the soil. Water harvesting techniques not only help improve soil moisture, but also locally recharge groundwater. Fertilizer micro-dosing adds phosphorus and potassium where soils lack those elements. When conducted in sequence, agroforestry and water harvesting can prepare the cropland for micro-dosing and increase fertilizer-use efficiency.[123] The challenge and opportunity for farmers is to more consistently integrate these different land and water management practices, which have often been implemented in isolation. Micro-dosing can serve as a transition technology to introduce fertilizer use to farmers, and to build confidence in the use of fertilizers. It should, however, be followed up with additional steps to enable farmers to graduate to higher fertilizer application rates to ensure that soil nutrients are not depleted as crop production increases and as the farmers move up the ladder of agricultural intensification.[124]

Integrated Soil Fertility Management

Another land and water management practice that can boost yields is integrated soil fertility management (ISFM). In its broadest sense, ISFM refers to maximizing the best use of soil nutrient stocks, locally available resources, and fertilizers to increase land productivity while maintaining or enhancing soil fertility.[125] Basic ISFM practices center on the combined use of judicious but sufficient amounts of fertilizers and available soil amendments. The soil amendments are primarily from local sources of organic matter (livestock or green manure, crop residues, compost or mulch, leaf litter), but can also include lime and phosphate rock. With ISFM, the added fertilizer primarily targets the nutrient needs of the crop, while the organic inputs help maintain soil organic matter and overall soil fertility.

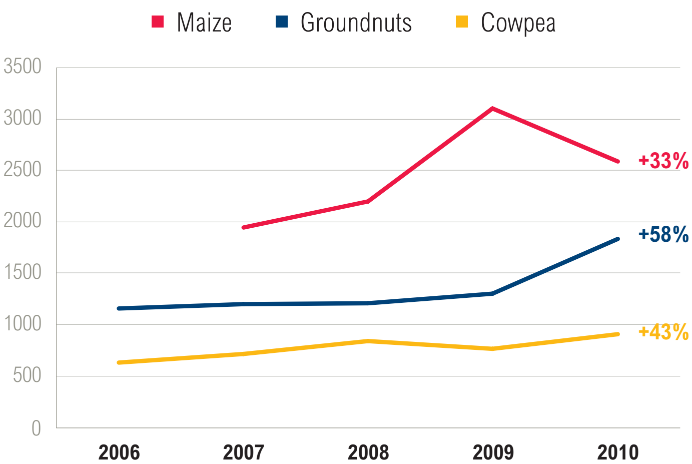
Improved yields require soil that is capable of supplying nutrients for cultivated crops, while simultaneously maintaining or improving its overall quality. The ISFM practices that incorporate the use of fertilizers and soil amendments address both of these requirements. Fertilizers provide the nutrients necessary to feed the crop, thereby increasing grain yields and biomass production. Soil amendments maintain or improve soil quality such as soil organic matter content, pH, and water infiltration. Because the nutrient delivery capacity of amendments is limited, additional fertilizers are necessary to adequately replenish soil nutrients that are removed annually through crop production. The use of fertilizers alone, however, can negatively influence soil quality through acidification and increased mineralization of soil organic matter. Soil amendments can help ameliorate these negative impacts by maintaining or improving soil properties.

Benefits of ISFM

Long-term soil fertility management trials in West Africa demonstrated that the highest yields were obtained where sufficient rates of fertilizers were used in combination with organic inputs.[126] On a research station in Saria, Burkina Faso, organic inputs of varying quality were applied annually at a rate of 10 tons per ha over a period of 20 years, with and without 60 kg of urea N per ha.[127] Additional treatments included a fallow treatment and a treatment using only fertilizers. While soil organic matter declined in all cropped plots compared to the fallow treatment, the largest significant decline occurred on the plots receiving only fertilizer.[128]

In West and Central Africa, farmers adopting ISFM practices are seeing increases in their crop yields and household income. In particular, these farmers have more than doubled their agricultural productivity and increased their farm incomes by 20 to 50 percent.[129] In West Africa, the adoption of ISFM practices by farmers on 236,200 ha between 2006 and 2010 resulted in significant increases in yields of four crops (using 2006 values as the baseline), including a 58 percent yield increase for groundnuts (Figure 12).

Figure 12 | **ISFM contributed to yield increases of three major crops for farmers in West Africa, 2006–10 (Kilograms per hectare)**

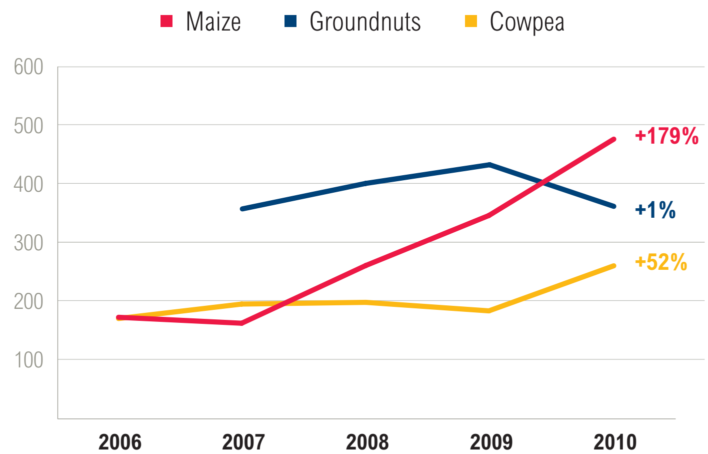


Note: No 2006 data was available for maize.

Source: IFDC, 2011.

Farmers using ISFM also benefitted through increases in their average annual income per hectare for these four crops (Figure 13). While groundnut accounted for the most significant yield increase, it had the lowest (yet significant) increase in average annual income per hectare of the four crops over the life of the project. Maize revenue increased 179 percent, while cassava and cowpea revenues increased by slightly more than 50 percent.

Figure 13 | **Revenues increased significantly for farmers adopting ISFM in West Africa, 2006–10 (US$ per hectare)**



Note: No 2006 data was available or groundnuts. Data converted from CFA francs using a conversion rate of 1 CFA franc = .0021 US Dollar.

Source: IFDC, 2011.

Experiences with adoption of ISFM in Central Africa

Drawing on the experiences and lessons learned in West Africa, farmers in Central Africa's Great Lakes region began scaling up ISFM in 2007.[130] IFDC used demonstrations and technology development that integrated farmer input and knowledge to initiate the scaling up of ISFM. The demonstrations highlighted the importance of organic soil amendments as well as fertilizers, along with improved seeds, and better soil and land management practices, including intensive agroforestry in combination with the appropriate use of fertilizers. Within two years, the ISFM practices were producing visibly positive results, due in part to organic inputs improving the efficiency of fertilizer use. On average, yields more than doubled and provided significant increases in net returns as a consequence (Table 2).[131]

Table 2 | **Farmers in Central Africa benefited greatly from increased crop yields and revenues following the adoption of ISFM practices (Annual benefits)**

COUNTRY	CROP	CONVENTIONAL FARMER PRACTICE	RECOMMENDED ISFM PRACTICE	ADDITIONAL YIELD FROM ISFM		INCREASE IN NET RETURNS FROM ISFM
		Kg/ha	Kg/ha	Kg/ha	% increase	US$/ha
Rwanda	Potato	8,000	19,500	11,500	144	1,600
	Maize	2,200	4,100	1,900	86	700
	Wheat	1,400	3,500	2,100	150	700
Burundi	Potato	3,200	15,900	12,700	397	2,200
	Rice	1,500	3,600	2,100	140	400
	Beans	400	1,600	1,200	300	300
	Wheat	300	2,200	1,900	633	500
DRC	Potato	6,600	19,100	12,500	189	2,200
	Rice	2,300	7,000	4,700	204	2,600
	Beans	200	800	600	300	100
	Maize	1,000	3,600	2,600	260	600

Source: IFDC, 2012.

Recent trends in the adoption of ISFM practices by farmers in the highlands of Rwanda, Burundi, and the Democratic Republic of Congo show what can be achieved through provision of appropriate support, once an improved practice has shown positive impacts. From an initial group of less than 4,000 farmer clusters, the number of participating farmer clusters over a period of three years has increased to more than 217,000, with 79 percent of the farmers adopting basic ISFM practices.[132]

In recent years, ISFM is proving to be a key to increasing agricultural productivity, protecting the environment, and maintaining or even enhancing the soil resource base. When combined with access to credit and markets and secure land tenure, it provides a means to increase crop yields and helps to transition subsistence smallholders to market-oriented production. Together with other improved land and water management practices, ISFM can help meet a strong increase in food demand while mitigating environmental impacts.

Integrated Landscape Approaches

The four improved land and water management practices described above can help smallholders boost crop yields, sustain resources, and provide other benefits on individual farms. However, in many situations, sustaining or improving agricultural productivity will require coordination between resource users and managers situated in different parts of the larger landscape, including non-farmed lands, wetlands, forests, and rangelands. As pressures increase on land, water, and biological resources—and as initiatives with multiple development objectives work in the same or adjacent and connected landscapes—a new set of approaches has also emerged to address and manage these pressures and sometimes conflicting objectives. *Integrated landscape approaches* bring sectors and stakeholders together to jointly plan, design, and manage their landscapes and institutional resources for improved agricultural production, biodiversity and ecosystem conservation, and sustainable livelihoods (Box 6).

Box 6 | Integrated Landscape Approaches

Society has begun to recognize that farmland is important for more than just the production of food calories. Society values and benefits from a range of goods and services provided by healthy ecosystems that support agricultural production systems across rural landscapes.[133] These include not only the production of grain, fodder, wood and other agricultural products, and ecosystem services that directly benefit farming (e.g., pollination, pest management, irrigation), but also other services such as source-water protection and the recharge of aquifers for diverse uses, nutrient cycling, regeneration of pastures and tree cover, conservation of wildlife habitat and biodiversity, and climate change mitigation and adaptation (Figure B6-1).

FIG B6-1 | INTEGRATED LANDSCAPE APPROACHES TAKE ACCOUNT OF THE IMPORTANCE OF ECOSYSTEM SERVICES IN MANAGING AGRICULTURAL LANDSCAPES

PROVISIONING	REGULATING	SUPPORTING	CULTURAL
▪ Crops and livestock ▪ Biomass Fuel ▪ Wild foods ▪ Genetic resources ▪ Natural medicines ▪ Freshwater ▪ Timber and other biological raw materials	▪ Erosion control ▪ Climate regulation ▪ Natural hazard mitigation (droughts, wildfire) ▪ Water flows and quality	▪ Soil formation ▪ Nutrient cycling ▪ Water cycling ▪ Habitat for biodiversity	▪ Local land races of agricultural crops ▪ Cultural landscapes ▪ Traditional agricultural practices ▪ Sacred groves

Source: Adapted from Millennium Ecosystem Assessment (2005); Wood, Sebastian and Scherr (2000).

Landscape-level coordination, therefore, is especially important in maintaining ecosystem services that operate at geographic scales larger than individual farms. Landscape management helps to manage the dynamics of land use change—mitigating impacts of agricultural development on forests and other native vegetation—while also ensuring that other uses of land—such as pasture lands or forests—complement agriculture.[134]

Integrated landscape management involves long-term collaboration and negotiation among different groups of land managers—farmers, pastoralists, forest and other resource user groups—and other stakeholders—local communities, government representatives, businesses—to achieve their multiple objectives within the landscape. Stakeholders seek complementary solutions to common problems and pursue new opportunities through technical, ecological, market, social, or policy means that reduce trade-offs and strengthen synergies among their varied objectives.

Agreed collaborative actions typically involve the farm-level improved land and water management practices described in the sections above, along with strategies that are spatially targeted, to ensure impacts in parts of the landscape that have the greatest aggregate effect. Landscape-level strategies can also mobilize investment from stakeholders who benefit from farmers' improved resource management, or are engaged in complementary activities in non-farmed areas. Strategies may be implemented through market mechanisms (such as payments for ecosystem services); strengthened social organization (such as community-based institutions); policy and institutional reforms (to empower landscape planning units); and other forms of capacity building, knowledge management, and technical support for integrated land use planning and collaborative management.

There are many different approaches to integrated landscape management, with different entry points, processes, and institutional arrangements. However, most share features of broad stakeholder participation, negotiation around common objectives and strategies, and adaptive management based on shared learning. Key features of integrated landscape approaches include:

1. Agreement among key stakeholders on landscape objectives
2. Management of ecological, social, and economic synergies and trade-offs among different land and resource uses in the landscape
3. Land-use practices that contribute to multiple landscape objectives
4. Development of supportive markets, policies, and investments
5. Establishment of collaborative processes for multi-stakeholder governance.

While documentation of impacts from landscape initiatives remains generally poor, data is beginning to emerge. Table 3 illustrates the kinds of benefits for agricultural production and incomes being generated from different types of collaborative landscape initiatives.

Table 3 | **Benefits of Integrated Landscape Management for Agricultural Production**

LANDSCAPE, COUNTRY	LANDSCAPE CHALLENGE	MAIN ACTIVITIES	DOCUMENTED BENEFITS FOR AGRICULTURAL PRODUCTION
Luangwa Valley, **Zambia**	Unsustainable production of cash crops had depleted soil nutrients and increased farmers' reliance on poaching of wild animals for subsistence.	Promoting food security through increased training on technology and land-use practices to promote agricultural production and reduce poaching; reduced-tillage training in exchange for traps and snares.	Crop production increased through use of reduced tillage, cover crops, crop rotation, and natural fertilizers. 15 percent increase in household food security.
Loess Plateau, **China**	High population growth rates and overgrazing and overuse had led to high levels of erosion, declining food supply and poverty.	Loess Plateau landscape restoration through reforesting slope areas and leveling land to produce high-yielding crops.	More efficient crop production on terraces, diversification of agriculture, and livestock production. Per capita grain output increased from 365 kg to 591 kg/year. Income increased from $70 to $200 per person per year.
Rajasthan, **India**	Environmental degradation and drought left dryland farming communities unable to meet water needs.	Collective community investments to reestablish and manage johads, traditional large-scale water harvesting structures.	Increased access to water for irrigation, enabling 23 communities to have an additional crop growing season and increased livestock production.
Wanggameti, Sumba Island, Nusa Tenggara province, **Indonesia**	Boundary and tenure disputes, livestock grazing conflicts, fire management, and illegal logging in and around protected forest and nature reserve; poverty of smallholder farm families.	Established more than 5,000 family forests (on-farm); promoted soil and water conservation; improved soil fertility through integrated farms (including livestock) under semi-arid conditions.	Increased agricultural and livestock productivity and improved soil and water retention for production on hillside farms for more than 3,400 rural households across 22 communities, reaching 17,400 beneficiaries. Established more than 5,000 family forests as sources of fuelwood, fodder, timber and non-timber products.

Source: EcoAgriculture Partners, 2013.[135]

Experience in applying integrated landscape approaches

Evidence is growing that integrated landscape approaches have the potential to transform degraded lands into productive lands that simultaneously contribute to increased food security and more resilient livelihoods.[136] For example, in the Tigray region of Ethiopia, with strong leadership and support from government, farmers and local communities have transformed significant parts of this region through community mobilization, local level participatory planning, and engagement in a wide range of activities, including reforestation, water harvesting, soil fertility management, terracing, and irrigation. These activities have reportedly reduced the levels of dependence on food aid during droughts in the past 5–10 years.[137]

As the experience with integrated landscape approaches has evolved and as interest has grown, initiatives have developed to take stock of lessons learned and to prioritize and support needed interventions. International partnerships supporting integrated landscape initiatives have emerged. One example is the Global Partnership on Forest Landscape Restoration, which aims to restore 150 million hectares of degraded forests by 2020, including 50 million to 100 million hectares of agroforestry.[138] The Landscapes for People, Food and Nature Initiative is working with a large number of institutions to strengthen the effectiveness of landscape initiatives and to support needed policies, finance, science, and business engagement.[139]

OPPORTUNITIES FOR SCALING UP

Although improved land and water management practices are taking root in some parts of the world, these practices will need to be scaled up if humanity is to feed a growing global population and improve the economic well-being of farmers without creating more pressure on the environment. A first step toward scaling up these practices is identifying some of the conditions under which farmers will invest in improved land and water management practices. A second step is identifying the opportunities for scaling up these practices in Sub-Saharan Africa.

Why Do Farmers Adopt Improved Land and Water Management Practices?

Fieldwork and research in the Sahel indicates that farmers are investing in improved land and water management practices under a set of common conditions:[140]

- When population pressure no longer allows farmers to restore soil fertility through conventional fallow systems or by clearing forests.
- Where land degradation and/or climate change reduces yields.
- When economic benefits of improved land and water management practices are evident to local communities.
- When policies and systems are in place to facilitate adoption of these practices—or at least remove barriers to adoption.

In the early 1980s, for example, with assistance from NGOs and development agencies, farmers in Burkina Faso's Yatenga region began investing in improved traditional water harvesting techniques, which supported the restoration of severely degraded land back into productivity. In 1985, farmers in Niger's Maradi and Zinder regions began building new agroforestry systems by protecting and managing natural regeneration of woody species. From the end of the 1980s, farmers in Niger's Illéla District began investing in water harvesting techniques to restore barren degraded land. In all three of these cases, higher population densities meant farmers could no longer restore soil fertility through conventional fallow systems. Farmers were forced to grow food on the same plots of land each year, and there were few opportunities to expand cultivated land by clearing forests. Average cereal yields had fallen to about 400 kg/hectare and many farm families were regularly facing major food shortages (six months to a year or more). Their only option was to intensify agriculture on existing cultivated land or to reclaim barren land.[141]

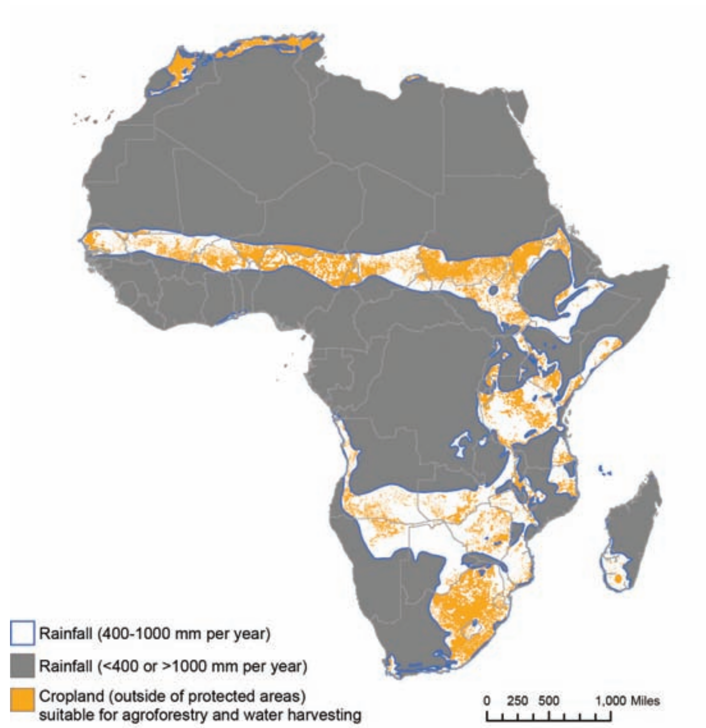
Although high population density was a catalyzing factor, in each case new knowledge (through indigenous innovation or from outside the community) was introduced into farming systems, which allowed for intensification to occur. Farmer-to-farmer exchanges helped others learn about simple, cost-effective improved land and water management practices, which could provide a means for farmers to intensify agricultural production without depending on major external investments. As described earlier in Box 3, in Burkina Faso's Yatenga region, a farmer improved traditional planting pits or *zaï* in 1980. These were subsequently used to reclaim tens of thousands of hectares of barren land. The same techniques were introduced after 1989 in Niger's Illéla District.[142] The spread of these techniques was facilitated by shifts in government policy and institutional reforms that favored increased security of land tenure and decentralized natural resource management.[143]

A similar picture is emerging in other parts of Africa. The mountain slopes and the valleys of the village of Abrha Weatsbha in Tigray (northern Ethiopia) were so degraded 15 years ago that the village was facing possible resettlement. With support from the regional government of Tigray, the villagers instead invested in a range of land and water management practices to capture rainfall runoff and reduce the threat of erosion, and to increase the density of trees on and off farms. The community has reclaimed over 224,000 hectares of land through reforestation and sustainable land management. This has improved soil quality, increased crop yields, and led to a significant recharge of groundwater. Hundreds of new wells have been dug to provide increased access to potable water. In 2008, rainfall was very low and the cereal crops failed, yet many families managed to cope because they were able to irrigate vegetable gardens and fruit trees planted near the wells.[144]

Potential for Scaling Up Improved Practices in Sub-Saharan Africa

The potential to expand improved land and water management practices—and in turn, produce more food to feed a growing population—is vast. In Sub-Saharan Africa, where population growth rates remain high, more than 300 million hectares are suitable for agroforestry, rainwater harvesting, and related practices. Figure 14 shows the approximate extent of cropland areas outside of protected areas with rainfall levels of 400 mm to 1,000 mm per year.[145] If improved land and water management practices were implemented on just 25 percent of this cropland and increased crop yields by an average of 50 percent, farmers would produce on the order of 22 million more tons of food, about 64 trillion kcal.[146] WRI estimates that scaling up these practices could potentially provide 285 million people living in Africa's drylands with an additional 615 kcal per person per day.[147]

Figure 14 | **Agroforestry and water harvesting could be scaled up on more than 300 million hectares in Sub-Saharan Africa**



Source: WRI, 2013.

Efforts to capitalize on the potential scope for scaling up these proven practices can also tap into many encouraging developments and emerging movements. For instance, in 2013 the government of the Netherlands approved a major project for the Sahel and the Horn of Africa that will integrate agroforestry, water harvesting, and micro-dosing. USAID will fund major resilience-building projects in the Sahel, which will have an agroforestry component. The World Agroforestry Center has developed political support for agroforestry in at least 17 African countries under its Evergreen Agriculture Initiative.[148] These developments indicate that interest in improved land and water management—as an integral part of mainstream agriculture—is growing.

RECOMMENDED APPROACHES TO ACCELERATE SCALING UP

Experiences in the Sahel and elsewhere underscore the importance of several strategies for scaling up improved land and water management practices. Seven strategies hold particular promise:

1. Strengthen knowledge management
2. Increase communication and outreach
3. Support institutional and policy reforms
4. Support capacity building
5. Increase support for integrated landscape management
6. Reinforce economic incentives and private sector engagement
7. Mainstream investing in improved land and water management.

It will be important to address the gender dimensions of each strategy, and to fully capitalize on the opportunities to ensure that investments in agricultural development and improved land and water management contribute to gender equality and women's empowerment (Box 7).

Box 7 | **Success in scaling up improved land and water management practices requires attention to gender**

In assessing, designing, implementing, and monitoring activities to address the opportunities to scale up improved land and water management practices, it is essential to take account of gender. Addressing gender is important because women have been marginalized in the past and inequities need to be corrected. And experience shows that making progress on gender equity and the empowerment of women leads to better development outcomes.

In rural areas of Sub-Saharan Africa, 95 percent of external resources and technical assistance (access to information and to inputs such as improved seeds and tools) are channeled to men, although women are responsible for 80 percent of agricultural work and their labor inputs into food production exceed those of men by 10–12 hours a week.[149] Studies in Sub-Saharan Africa indicate that agricultural productivity would increase by more than 20 percent if the gap in capital and inputs between men and women were reduced.[150] Women are also among those most affected by unchecked land degradation and associated shortages of fuelwood, fodder, food, and clean water.[151]

Women and men are both primary stakeholders in the adoption and scaling up of improved land and water management practices, yet they have different perspectives on the use of natural resources and the importance, feasibility, and cost-effectiveness of various practices. Women often do not have the same rights and management authority as men. Both customary and statutory provisions governing land tenure and resource rights need to be reviewed through a gender lens. Potential barriers to the adoption of improved land and water management practices that may be related to these differences in rights and security of tenure should be assessed and strategies developed to overcome these barriers.

Women and other marginalized stakeholders should be included in meetings and decision making, and should be represented in community-based institutions governing resource use. Women need to have direct access to information, training, and other assistance mobilized to scale up improved land and water management practices. Greater progress and success in mainstreaming these improved practices in agricultural development can be achieved by incorporating goals of gender equality and women's empowerment into agricultural program strategies and investments.[152]

1. Strengthen knowledge management

Expanding support for learning and applied research in ways that directly engage farmers is critical for catalyzing behavior change. It can also help to capitalize on the potential for further refinement of improved practices. Promising approaches include:

Facilitate peer-to-peer learning

Farmers can learn from other farmers working under similar agro-ecological conditions. Over the past two decades, farmer-to-farmer visits for knowledge sharing have become increasingly common. Farmers who are inexperienced with improved land and water management techniques should be supported to communicate with experienced farmers, visit farmer innovators, and share experiences. In Niger, an IFAD-funded project brought 13 farmers (10 men and 3 women) from the Illéla District to the Yatenga region in Burkina Faso, where farmers had restored the land with water harvesting techniques. Upon returning to Niger, some farmers experimented with *zaï* on a few hectares, with positive results. In 1990, *zaï* were used on about 70 hectares in the Illéla District. This was a drought year and only the farmers who had invested in *zaï* had a harvest. Its value demonstrated, the *zaï* technique thereafter began spreading rapidly. A market developed in degraded land, with farmers buying and selling degraded land to restore it to productivity.[153]

Strengthen knowledge management systems and access to information

The experience of innovative farmers and development projects are not always adequately documented. Where this is the case, it makes sense to invest in documenting relevant experience and making the information more easily accessible.

Even where knowledge and experience has been documented, the available information can show significant gaps. For instance, adequate data about costs and benefits of improved land and water management practices are often lacking. One reason is that the multiple impacts of these practices are not yet quantified. A clear example is the impact of water harvesting techniques on local groundwater recharge. The available impact data are usually anecdotal. Important knowledge gaps need to be identified and steps taken to fill those gaps. Such knowledge gaps can be addressed by better impact monitoring.

Expand monitoring and evaluation

Donor agencies may be reluctant to fund research on the impact of land and water management practices, but project budgets usually include a budget line for monitoring and evaluation. This budget line can be used to monitor socioeconomic impacts (poverty reduction, gender impacts, winners and losers), agronomic impacts (crop yields), and biophysical impacts (on soil fertility, groundwater, and carbon sequestration) of these practices. At an early stage, it is important to identify what role farmers and communities can play in monitoring and evaluation.

2. Increase communication and outreach

National and international policy makers—as well as most people living in the drylands—are often not informed about successes in improved land and water management. To encourage scaling up improved management practices, stakeholders need access to the information that can inspire them to act. Specific recommendations include:

Amplify the voice of champions for improved land and water management

Champions of improved land and water management practices should be identified at all levels of society and across a range of institutions, and helped to amplify their voices and expand their advocacy. In February 2013, for instance, the Executive Secretary of the United Nations Convention to Combat Desertification visited villages in Niger's Zinder region, where farmers were building new agroforestry systems. He discussed with villagers their experiences with improved practices, learned about the impacts, and used the information in keynote speeches to different groups of decision makers and in interviews with international news media.

Leverage technology to increase direct communication with farmers

Rural community radio stations, as well as regional and national stations, can air programs in which experienced farmers share their knowledge. Depending on the radio stations, the number of listeners will vary from several thousand to several million people. In southern Tunisia, a regional radio station had a special program on farmer innovation on a weekly basis in which farmer innovators shared their experiences and answered questions from researchers and specialists about their innovations. The radio station received numerous letters from listeners sharing their innovations or noting their intention to experiment with what they had heard on the radio.[154]

Journalists, too, can spread success stories in land and water management. In some countries, journalists have organized associations of environmental journalists. For instance, in Senegal journalists have organized themselves in a "research group on environment and press," which has published a special bulletin about Senegal's experience with developing agroforestry systems through farmer-managed natural regeneration.[155]

Mobile phones are also becoming a widespread tool for information sharing. The Web Alliance for Re-greening in Africa (www.W4RA.org) has developed a "Web of Voices" that links the use of mobile phones with radio stations and the internet. Information about market prices is often available in text format, but illiterate farmers cannot access SMS-based services. Using a text-to-speech system in local languages, farmers can access information about market prices. The farmers who wish to respond do so in their language and an automatic speech recognition system recognizes the information, stores it, and makes it accessible. This kind of technical innovation offers a huge potential for information sharing with and by land users.

Increase support for well-informed dialogue and national level consultations

Local organizations and stakeholder champions in Burkina Faso associated with the African Re-greening Initiative have been working to compile and disseminate information about the benefits of the adoption of improved land and water management practices. This is being done through the production of video documentaries and radio broadcasts, and by providing support for increased interaction between innovative farmers and the national media. These efforts have also included the organization of a national workshop in Burkina Faso to share knowledge about the spread and impact of agroforestry and related practices, and initiated actions for the preparation of a national strategy to mainstream agroforestry into food security and climate change adaptation programs.[156]

Improve quantitative understanding of the costs and benefits of improved land and water management practices

Relatively little attention has been given to the analysis of the costs and benefits of improved land and water management practices that farmers themselves are developing and adopting on a relatively large scale, including farmer-managed natural regeneration and improved planting pits such as *zaï*. Increased support for participatory research with farmers could fill important gaps in information about the costs and benefits of these improved practices. As it becomes available, this information could then be incorporated into knowledge products—such as policy briefs that can target national policy makers and other stakeholders—to share information and data on proven practices, costs, and multiple benefits. For example, the World Agroforestry Centre recently produced a technical report based on a pioneering study of the economic impact of agroforestry in the Sahel and its impact on crop yields, and it would be useful to summarize the report in a format that is accessible to busy policy makers.

3. Support institutional and policy reforms

Accelerating the spread of improved land and water management practices requires enabling policies and legislation, but also capacity building at the local, regional, and national levels. It is important to identify the policies and legislation needed to incentivize farmers to invest in improved land and water management practices.

Outdated forestry legislation should be reformed, and the rights of farmers to manage trees on their farms should be clarified and strengthened. Although much has been said about the importance of secure land tenure, still more attention is needed to support practical measures aimed at securing the full suite of property rights for smallholder farmers.

Specific recommendations include:

Reform outdated and counterproductive forestry legislation

Despite repeated attempts to enact reforms, the forest codes in Senegal, Mali, Burkina Faso, and other countries still contain many provisions that allow Forest Service agents to impose fines or to otherwise discourage farmers from investing in protecting, regenerating, and sustained-yield harvesting of trees in agroforestry systems. Reforming these laws is difficult when it involves changes to provisions related to the taxes, fines, and permitting requirements that forest agents exploit to supplement their meager incomes. And although these forestry laws and regulations are intended to conserve remaining areas of natural forests and woodlands, because they lack specific provisions governing the management of multipurpose trees in farming systems, they are liable to have a perverse effect that contributes to reducing tree cover in agricultural landscapes.

The negative effects of outdated forest laws are often reinforced by agricultural development policies and extension messages that emphasize agricultural "modernization" through the increased use of mechanization and subsidized inputs, without attention to measures needed to reduce land degradation and to facilitate the adoption of improved land and water management. For example, for many years, farmers in Senegal were encouraged by the Ministry of Agriculture to make use of tractors and animal traction to plow in straight rows, even if it meant removal of an overstory of *Faidherbia albida* trees or destruction of existing agroforestry parklands that had protected the soils from wind and water erosion and helped to replenish soil organic matter and nutrients. The Senegalese Forest Service was focused on expensive and relatively unsuccessful efforts to plant fast-growing exotics such as Eucalyptus along roadsides and in state-managed fuelwood plantations, and did little to facilitate adoption of "farmer managed natural regeneration" on farms. Clearly, there is ample scope and much need for further reforms of policies, laws, and regulations that can pose major impediments to the scaling up of agroforestry and other improved land and water management practices.

Establish more secure land tenure and management rights over trees and shrubs in agricultural landscapes

National governments should develop policies and legislation that incentivize smallholder farmers to adopt improved land and water management practices. But smallholder farmers will only adopt these practices when they feel secure on their land and when they are sure to reap the benefits of the improved practices. This means that land tenure and forestry legislation need to be integrated to eliminate inconsistencies, remove gaps and ambiguities, and ensure secure rights to land, water, and other resources. These resources should include trees on cropland that have been protected, regenerated, or planted by farmers. And farmers should be allowed to freely harvest and market the full suite of products from their farming systems, including wood and non-timber forest products from agroforestry parklands. In Senegal, a wide range of forest and "natural" products— including tree leaves, seeds, fruit, and wood—are subject to government taxes and permits for harvesting and transport, regardless of the origin (from woodlands or croplands).

Support the emergence and strengthening of local institutions to improve local natural resource governance

Experience underscores the critical importance of developing the capacity of local institutions—such as traditional or modern village development committees—to negotiate and locally enforce rules governing access and use of natural resources, particularly the protection and management of on-farm trees and of natural vegetation. This requires locally enforceable rules to sanction illegal cutting of trees, limit damage caused by livestock to on-farm trees, and to control bush fires.

For example, the International Fund for Agricultural Development has supported the building of village institutions in Niger's Aguié District for the protection and management of on-farm trees. The village organizations have 8–10 elected members, of mixed composition. The village committee in Dan Saga, for example, is composed of men and women. Representatives of sedentary herders are also consulted. At the village level, rules and regulations have been developed and accepted by all concerned stakeholders. Sanctions are imposed and enforced on those who violate the rules. Villages surrounding Dan Saga are now engaged through an inter-village platform. The community of Dan Saga perceived it as vital to communicate with surrounding villages about the new tree capital so they created an inter-village platform to address issues related to the protection, management, and exploitation of their on-farm trees.[157]

Reassess support of large subsidies for mineral fertilizers and increase support for balanced approaches combining outreach, research, and extension for improved land and water management practices

In Malawi, some rural development organizations are concerned that the current high level of subsidy of the cost of fertilizer could dissuade farmers from improving on-farm land and water management. The current extension messages encourage farmers to buy more mineral fertilizer to reverse declining crop yields. These messages could be revised, however, to give more attention to the opportunities and benefits for combining integrated soil fertility management with agroforestry and conservation agriculture.[158] Ongoing efforts to shift from the promotion of increased fertilizer use to a program that includes these land and water management practices need to be encouraged, highlighting the increased fertilizer-use efficiencies these practices bring.

Factors affecting the demand and supply of fertilizers should be reviewed along with the opportunities for promoting improved land and water management practices that could help to address the drivers of land degradation.[159] Government agricultural development policies and programs should be adjusted to improve incentives for both the appropriate use of fertilizers along with improved land and water management practices that boost crop yields while reducing environmental degradation and produce other benefits.

Accelerate and reinforce the mainstreaming of improved land and water management practices in agricultural development, food security, and climate change adaptation programs

Both governments and development assistance agencies could do more to mainstream the integration of improved land and water management practices into current agricultural development policies and programs. For example, the country-level investment programs identified and funded through USAID's Feed the Future initiative have focused on strengthening targeted value chains with a view toward increasing agricultural production and improving nutrition and food security. Increasingly, the programs are also taking account of needs and opportunities to reduce vulnerability to climate change and to enhance the resilience of rural communities. And research is under way to identify opportunities for sustainable intensification, including support for scaling up agroforestry, conservation agriculture, and improved land and water management.[160]

4. Support capacity building

The capacity of village communities to manage the productive capital they create through increased investments in land and water management should also be strengthened. Agroforestry systems cannot be protected, regenerated, and managed without support from community-based institutions empowered to adopt and enforce local measures to control over-grazing, tree cutting on cropland, and destructive bush fires. Where such local institutions have been established and strengthened to enforce "local conventions," farmers have more success in adopting improved land and water management practices.[161]

Specific recommendations include:

Organize training sessions to familiarize local communities with enabling legislation for local conventions

Over the past decade, as part of an effort to support decentralized natural resource management, national policies and legislation were adopted in Senegal, Mali and other Sahelian countries to enable local communities to debate and agree on critically important rules to be followed by resource users in local communities to help govern the access and use of natural resources. These locally adopted and locally enforced rules have proved to be especially important in reducing conflicts over the use of natural resources. For example, local conventions have helped to reduce damage from livestock to trees in crop fields, while also ensuring that corridors were maintained to facilitate the movement of livestock.

Facilitate the organization and empowerment of local resource management committees

In Niger and in other countries, the organization and empowerment of local committees to help govern the harvesting and sale of wood products have helped to increase the economic benefits that accrue to local communities from investing in farmer-managed natural regeneration.

5. Support integrated landscape management

In landscapes where restoration of degraded land and water resources requires action beyond the farm level, governments, civil society and other stakeholders need to provide the institutional support necessary for coordinated investment and management at the landscape scale. The partners of the Landscapes for People, Food and Nature Initiative have identified priority actions to address the major constraints to scaling up integrated landscape approaches. The priority is to strengthen integrated landscape initiatives on the ground, through capacity building of leaders and institutions, engaging farmer and community organizations more centrally, and more effective monitoring for adaptive management. The numerous communities of practice that are already promoting and supporting landscape initiatives need to share knowledge and experience more systematically.

Action also is needed to promote a more favorable enabling environment by incorporating landscape approaches into national and subnational policy frameworks, aligning sectoral policies, and empowering landscape partners to negotiate locally appropriate rules. The private sector needs to evaluate their own "business case" for engaging in landscape initiatives for long-term sustainable sourcing of agricultural products. Financing needs to be aligned across sectors and more public and private resources made available for integrated landscape investments. Finally, investment is needed to improve our understanding of the impacts, cost-effectiveness, and best practices related to integrated landscape approaches.[162]

6. Reinforce economic incentives and private sector engagement

It is critically important to develop input markets and increase economic incentives through private sector engagement. These strategies are needed to help farmers gain access to information and other inputs and services, and to increase economic incentives through the development of value chains associated with improved land and water management practices.

Ensure timely access by smallholder farmers to quality fertilizers and other inputs

National governments can facilitate the production and/or the importation of agricultural inputs by the private sector to ensure an adequate supply. This can be achieved, for instance, by reducing the import taxes on agricultural inputs and by reducing the barriers to local businesses that sell agricultural inputs. Due to poor road infrastructure, the costs of fertilizers sold to smallholders are often double the costs of fertilizers at the point of production or importation. These and other structural problems, as well as insufficient attention to resolve the drivers of land degradation and declining soil fertility, undermine the incentives for farmers to use fertilizer and for firms to supply fertilizer. The good practices for promoting fertilizer supply and demand that have been documented by the World Bank and others should be implemented.[163]

Support the development of agroforestry value chains

Governments should do more to remove unreasonable taxes and fines, illegal payments, and other barriers to the production, transportation, and marketing of products from agroforestry systems. As these barriers are removed or reduced, farmers and private sector partners will be encouraged to invest to a greater extent in developing agroforestry value chains. For example, a number of agroforestry species like *baobab, moringa, shea* and others have a track record in providing significant cash income to farmers through the sale of leaves, fruits, fiber, fodder, or other commercially valuable products. However, in some areas, these commercial activities are discouraged by inappropriate taxes or poorly administered requirements for harvesting and transportation permits. When the development of these value chains is promoted, there is significant potential for boosting the production of *moringa* and *shea* and other products that can be sold on the national market, as well as in international markets. A growing number of *moringa* and *shea* products are already for sale in high-end stores around the world.

7. Mainstream investing in improved land and water management

Significant funding will be required to catalyze the adoption of improved land and water management practices at the scale required to reverse at the landscape level current processes of land degradation. What order of investment is required? The costs per hectare are modest, but if applied on several hundred million hectares, it quickly adds up to billions of dollars. However, a significant part of this investment will be made by smallholder farmers themselves in the form of labor. And although there are periods when labor is in peak demand for cultivation, many of the labor investments in improved land and water management can be timed to take advantage of periods when rural households can mobilize the needed labor.

The costs of the same technique can vary significantly between regions. For instance, the labor investment for digging planting pits depends on the soil crust. The investment cost for contour stone bunds depends on the distance over which stones have to be transported and how they are transported. Agroforestry based on farmer-managed natural regeneration is low cost. No investment costs are required and farmers are responsible for protection and maintenance. The main costs are those related to supporting extension activities such as farmer study visits and radio programs.

Investment in improved land and water management practices will be money well-spent; the costs are much lower than the recurrent costs of emergency aid. The cost of providing nutrient-packed peanut paste to one child for one month is $25. This means that the costs of supporting this specific age class in the Sahel during one month only, is a staggering $125 million. In 2012, donors spent over $1 billion in humanitarian assistance in the Sahel.[164] The costs of developing five million hectares of new agroforestry parkland in Niger based on farmers protecting and managing natural regeneration cannot be calculated accurately because it reached this scale through a mix of project support for policy reform, institution strengthening, research and extension, and spontaneous adoption by farmers. But the investment costs to national government and funding agencies are most likely considerably lower than the amounts spent on drought relief and related humanitarian assistance.

There are indications that investments in improved land and water management affect the rural demographic dynamics. Young men decide to stay in the village because there are more income-earning opportunities and families do not leave the village to settle elsewhere.[165] This decreases the costs of expanding urban infrastructure to service additional millions of rural dwellers who decide to abandon their degraded land and settle in big, overcrowded cities.

Smallholders are responsible for the protection and management of trees on and off farm, which means that there are no recurrent costs for government. Nevertheless, situation-specific support to smallholders may be needed, which can include support in the form of food or cash during a transition period in which the investments do not yet generate benefits. It can also include the improvement of a rural road to improve access to the market during the entire year, or investing in study visits by farmers to expose them to new knowledge and experience.

A CALL TO ACTION

How can the world adequately feed more than 9 billion people by 2050 in a manner that advances economic development and reduces pressure on the environment? This working paper highlights that in many drylands, in particular Sub-Saharan Africa, the challenge is even bigger than in many other regions of the planet. Soil fertility is depleting, rainfall has become more erratic, and population is projected to more than double by 2050.

The good news is that during the past 30 years, a wide range of land and water management practices have been developed by innovative farmers, supporting NGOs and researchers. Many successes have already been achieved, both small and large.[166] The challenge now is to better integrate a number of proven land and water management practices—particularly agroforestry, water harvesting, conservation agriculture, and integrated soil fertility management—and to scale up successes, using a landscape approach whenever possible.

Experience shows that improving land and water management can enhance food security and reduce poverty while helping to adapt to and mitigate climate change. These practices can restore the productivity of degraded agricultural land and boost crop yields. But achieving gains at the necessary scale will only happen if tens of millions of smallholder farmers are motivated to invest their labor and limited financial resources in these practices.

While smallholder farmers are the key actors for implementing these practices, many other entities and organizations have a role to play. National governments should create enabling agricultural development policies as well as land tenure and forestry legislation that secures farmers' rights to their land and recognizes their ownership of on-farm trees. Governments should also create enabling conditions for the private sectors to invest in market-based approaches to strengthening agroforestry value chains. The public and private sectors, working with local communities, international partners, and development assistance organizations, can take these improved practices to scale by investing in knowledge management, communication, and outreach—helping to restore agricultural productivity, enhance rural livelihoods, and contribute to a sustainable food future.

APPENDIX 1: COMMONLY OBSERVED CONDITIONS AFFECTING CROP PRODUCTION AND WAYS TO ADDRESS THEM [167]

CONDITION	PROBLEMS	CONSEQUENCES	PRINCIPLE	PRACTICES
Intensive rainfall events (25–50% of rainfall runs-off)	High rainfall runoff rates	Reduced soil moisture Increased soil erosion	Capture rain where it falls and allow it to infiltrate into the soil	Water harvesting—planting pits, rock lines, vegetation strips, ridge tillage
Extended drought periods between rainfall events	Alternate wetting and drying of root zone	Poor germination Crop dieback Multiple sowings Shortened growing season and lower crop yields	Concentrate runoff in planting holes Amend soil organic matter to retain nutrients and soil moisture in the root zone of crops Apply partial shade	Water harvesting practices (above) Conservation agriculture to conserve soil moisture Apply crop residue, compost Agroforestry to add organic matter to soil and to shade crops
Nutrient-poor soils with little capacity to retain nutrients	Crops require fertilizer to get optimal response High percentage of applied fertilizer is lost through runoff, volatilization, leaching, and does not benefit crop growth	Yields limited by lack of nutrients Fertilizer-use efficiency is very low on degraded soils and may not be economically viable	Increase biophysical properties of the soil and maintain or improve soil organic matter (SOM) content in the root zone	Make use of available organic inputs, apply integrated soil fertility management Develop agroforestry systems as a source of organic inputs
Severe drought	Staple crop failure, despite mitigation efforts	Loss of main source of livelihood	Diversify household economy, particularly with crops that are less vulnerable to drought than annual rainfed staples	Develop tree crops, Livestock, Irrigation (if feasible)

ENDNOTES

Note: All dollars are U.S. dollars unless otherwise indicated.

1. These figures are modestly adjusted upward from those presented in the first installment of the World Resources Report working paper series (Searchinger et al. 2013) because UNDESA published in June 2013 (one month after the release of the first installment) increased population projections for 2050. Our adjusted figures in this working paper are based on FAO estimates of food consumption needs in 2050 in underlying data used for Alexandratos and Bruinsma (2012), adjusted by the recently released higher population estimates of UNDESA, which are higher than those used by the Alexandratos and Bruinsma (2012) study, and further adjusted to ensure a minimum food availability of 3,000 kcal per person per day in each region of the planet. The figures represent global annual crop production (measured in kcal), including all crops intended for direct human consumption, animal feed, industrial uses, seeds, and biofuels.
2. See Searchinger et al. (2013).
3. See National Research Council (2007).
4. See Pingali et al. (2006); World Bank (2008a); and National Research Council (2007).
5. See National Research Council (2007). A report prepared for WOCAT and edited by Hanspeter and Critchley (2007) noted that “over one billion people are engaged in agriculture and about 40% of the world’s population—over 2.5 billion women, men and children—live in agricultural households.”
6. See IFAD (2010).
7. FAO, WFP, and IFAD (2012).
8. See Searchinger et al. (2013). Using data from FAO (2011), WRI calculated that just under 50 percent of the planet’s landmass outside of Antartica is used to grow food, when deserts, permanent ice, and inland water bodies are excluded.
9. See Foley et al. (2005), cited in Searchinger et al. (2013).
10. See FAO (2011), pp. 112–113.
11. See National Research Council (2007).
12. See Place et al. (2013).
13. See Tan et al. (2005).
14. See Noble (2012).
15. See Eswaran et al. (2001), cited in Place et al. (2013).
16. See World Bank (2013). By drylands we are referring to the zones classified on the basis of an aridity index of 0.05 to 0.65, and encompassing the dry sub-humid, semi-arid, and arid zones. We are not referring to the hyper-arid zone with an aridity index of less than 0.05, which does not support crop and livestock production and is very sparsely populated. According to recent analysis by the World Bank, the drylands—including these three zones—cover some 1.3 billion hectares or nearly 55 percent of Sub-Saharan Africa, and are home to about 390 million people or roughly 48 percent of the region’s population. The dominant farming systems in the drylands of Sub Saharan Africa are “agro-pastoral” and “maize mixed.”
17. See Gnacadja (2013); UN News Service, 26 march 2012.
18. See Eswaran et al. (2001).
19. See The Montpellier Panel (2013).
20. See Bunch (2011).
21. See Haggblade, Hazell and Gabre-Madhin (2010).
22. Unless otherwise noted, the reference for listed bullet points is: The Montpellier Panel (2013).
23. FAO estimate cited in Searchinger et al. (2013b).
24. See Searchinger et al. (2013b).
25. See Searchinger et al. (2013b).
26. See National Research Council (2007).
27. See Rockstrom, Barron, and Fox (2003).
28. See Rockstrom (2000).
29. See Rockstrom, Barron, and Fox (2003).
30. See Bationo et al. (2006). As the authors note, “Soil moisture stress is perhaps the overriding constraint to food production in much of Africa. Moisture stress is not only a function of the low and erratic precipitation but also of the ability of the soil to hold and release moisture. About 10% of the soils in Africa have high to very high available water-holding capacities… Most African soils are inherently low in organic carbon (<20 to 30 mg/kg) and consequently have low capacity to retain soil moisture….The development of conservation agriculture technologies with permanent soil cover will be of importance for the conservation of soil moisture as shown in various FAO projects.”
31. See Bationo, Lompo, and Koala (1998). As noted by the authors, “African soils, and particularly those in West Africa, are much weathered and fragile and mostly of low to moderate inherent fertility. In the past, at low population pressure farmers shifted from a cultivated site to an uncultivated one before significant decline in crop yield could set in, thus leaving the fields to replenish soil fertility under natural regrowth. However, with rapid population growth, fallow periods have shortened. Continuous and intensive cropping without restoration of the soil fertility has depleted the nutrient base of most soils. For many cropping systems in the region, nutrient balances are negative indicating soil mining. To improve the food situation, West African agricultural growth must depend on improved soil productivity rather than on expansion of area under cultivation. The soil fertility in intensified farming can only be maintained through integrated plant nutrient management with efficient recycling of organic materials such as crop residue, compost or manure in combinations with mineral fertilizers and using rotations with legumes.”
32. See Breman et al. (2007).
33. See Noble (2012).
34. See Henao and Baanante (2006), cited in Noble (2012).
35. See Allison (1973).
36. See Bationo, Lompo, and Koala (1998).
37. See Marenya and Barrett (2009).
38. See Marenya and Barrett (2009).
39. See Morris et al. (2007).
40. See IFDC (2006).
41. See Kelly (2006).
42. See Searchinger et al. (2013b).
43. See Ariga and Jayne (2009).

44. See <www.wocat.net>.
45. See Liniger and Critchley (2007).
46. See World Bank (2008b) and Liniger et al. (2011). Sustainable land management (SLM) is defined as "a knowledge-based procedure that helps integrate land, water, biodiversity, and environmental management to meet rising food and fiber demands while sustaining ecosystem services and livelihoods. SLM seeks to avoid or reverse land degradation by targeting activities to preserve and enhance the productive capabilities of cropland, forests and grazing land, maintain the integrity of watersheds and the ability of aquifers to meet needs for water supply and other uses. Ecosystem services are the benefits people obtain from ecosystems, such as provisioning services (food, water, timber, fiber), regulating services (that affect climate, floods, disease, waste, water quality), and cultural and other support services (that provide recreation and other benefits, and support soil formation, nutrient cycling, photosynthesis). People fundamentally depend on the flow of ecosystem services."
47. See National Research Council (2007).
48. See Liniger and Critchley (2007).
49. See Reij (2012).
50. Sources for box on Yacouba Sawadogo: Sawadogo et al. (2001), Kaboré and Reij (2004).
51. See Haggblade, Tembo et al. (2010).
52. Personal communication: farmers Dan Saga during a workshop in Ouagadougou in October 2012.
53. See Critchley (2010).
54. See Critchley (2010).
55. See Reij, Tappan, and Smale (2009).
56. See Tappan (2012).
57. Personal comm. Trent Bunderson, Executive Director, Total Land Care, June 14–15 2012.
58. See Garrity et al. (2010).
59. The following link shows a documentary about a complex young agroforestry system in Brazil that was built from scratch: <http://www.youtube.com/watch?v=s1Tkqy_cUUg>.
60. See Felker (1978).
61. See Shitumbanuma (2012).
62. See Bunderson (2012).
63. See Akinnifesi et al. (2010); Sileshi et al. (2010).
64. See Snapp et al. (1998); Akinnifesi et al. (2008).
65. See Akinnifesi et al. (2007); Makumba et al. (2006).
66. See Akinnifesi et al. (2009).
67. See Akinnifesi et al. (2009).
68. See Dossa (2007), cited in National Research Council (2007).
69. See Dossa (2006).
70. See Dossa et al. (2012).
71. See Caldwell et al. (1998); Kizito et al. (2009).
72. See Diedhiou (2007); Dick (2008); Kizito et al. (2012).
73. See Dossa (2006); Diedhiou (2007).
74. See Dick (2008).
75. See Diedhiou-Sall et al. (2013).
76. See Diedhiou-Sall et al. (2013).
77. See Reij, Tappan, and Belemvire (2005); Botoni and Reij (2009); Reij, Tappan and Smale (2009).
78. See Tropical Forages (n.d.).
79. See Tropical Forages (n.d.).
80. See Yamba and Sambo (2012).
81. See Yamba (2006); Larwanou et al. (2008).
82. See FAO (2012).
83. See FAO (2013).
84. See Huggins and Reganold (2008).
85. See Huggins and Reganold (2008).
86. See Huggins and Reganold (2008).
87. See Derpsch and Friedrich (2009).
88. See Williams and Fritschel (2012).
89. See FAO (2013).
90. See World Bank (2012).
91. See Derpsch and Friedrich (2009).
92. See Derpsch and Friedrich (2009).
93. See Derpsch and Friedrich (2009).
94. See Williams and Fritschel (2012).
95. See Williams and Fritschel (2012).
96. See Williams and Fritschel (2012).
97. See Liniger and Critchley (2007) and Liniger et al. (2011) for a discussion of constraints to adoption of conservation agriculture by smallholders in Sub-Saharan Africa. See also Giller et al. (2009).
98. See Umar et al. (2011).
99. See Umar (2012).
100. See for example: <http://www.thewaterchannel.tv/en/videos/categories/viewvideo/1700/agriculture/conservation-agriculture>.
101. See Thierfelder (2012).
102. See Bunderson (2012).
103. See Bunderson (2012).
104. See for example, World Bank Institute (2012).
105. See Thierfelder and Wall (2012).
106. See Thierfelder (2012).
107. See Rockstöm, Barron, and Fox (2003).
108. See WOCAT and IFAD (2013), and Critchley and Gowing (2012).
109. See Botoni and Reij (2009).
110. See Hassane, Martin, and Reij (2000).
111. See Sawadogo (2006).
112. Hassane et al. (2000) show that yield improvements from water harvesting can vary from 500 to 1,000 kg/ha, depending on other factors such as soil fertility. Sawadogo (2013) found that farms in Burkina Faso using water harvesting techniques increased yields 50–100 percent when compared with adjacent cultivated land not using harvesting techniques. An increasing number of farmers in the Sahel have used water harvesting techniques to reclaim lands that had been out of production for generations. In areas close to Tahoua, Niger, they were able to convert very low potential lands into productive lands (as measured not only by yields but by land prices). Mazvimavi et al. (2008) found that water harvesting, combined with conservation agriculture, increased yields per hectare by 50 percent on average across nine districts in Zimbabwe.
113. See Sawadogo (2006) and Zougmoré et al (2004).
114. See Doumbia (2010).
115. See Doumbia et al. (2008); Kablan et al. (2008).
116. Reij, C. Personal communication. Senior Fellow, WRI. July 2012.
117. See Mazvimavi et al. (2008). Gross margins were measured in $/hectare and return on labor in $/day. Data comes from nine districts in Zimbabwe, representing high, medium, and low rainfall zones.
118. See Mazvimavi et al. (2008). Gross margins were measured in $/hectare and return on labor in $/day. Data comes from nine districts in Zimbabwe, representing high, medium, and low rainfall zones.

119. See Hayashi et al. (2008); Tabo et al. (2007); Bationo (2008); Sanginga and Woomer (2009a); Sanginga and Woomer (2009b).
120. It should also be noted that micro-dosing may not support the full development of agro-input markets and this can reduce its long-term contribution to reducing soil nutrient depletion. For example, unless fertilizer markets develop in response to increased demand from farmers, prices in SSA could remain high relative to other areas of the world.
121. See Aune and Bationo (2008); Vanlauwe et al. (2010).
122. See Sawadogo (2012).
123. See Sanders and Ouendeba (2012). John H. Sanders, Purdue University and Botorou Ouendeba, INTSORMIL, Niger
124. See Aune and Bationo (2008); Breman et al. (2001).
125. See IFDC (2005); Vanlauwe (2010).
126. See Sedogo (1993); Bationo et al. (1998).
127. The application of organic matter at this rate is not feasible for most smallholder farmers, who lack sufficient resources of livestock, fodder, and pasture land, and must manage competing demands for the use of crop residues. Furthermore, the collection and transport of such amounts of organic matter in the form of manure, compost, or crop residues presents additional challenges to most smallholders. However, the increased density of agroforestry species on farmland is one relatively low cost and feasible means for smallholders to increase the amount of organic matter that is directly available to replenish stocks of soil organic matter.
128. See Sedogo (1993); Mando et al. (2005).
129. See IFDC (2011).
130. See IFDC (2012).
131. Revenues are based on local market prices in 2012, when prices averaged \$0.37/kg. The price of maize in the local market in Central Africa can range from \$0.25 to \$0.45/kg, in part due to lower prices immediately following harvest, increasing as supplies dwindle and governments provide support for floor prices. Pers. Comm., 2013, Debbie Hellums, IFDC.
132. See IFDC (2012).
133. See Ranganathan et al. (2008).
134. See Bailey and Buck (2013); Sayer (2013); Scherr and McNeely (2008).
135. See EcoAgriculture Partners (2013).
136. See website for Landscapes for People, Food and Nature: <http://landscapes.ecoagriculture.org/>.
137. See Scherr et al. (2012).
138. See website for GPFLR: <http://www.forestlandscaperestoration.org/>.
139. See website for Landscapes for People, Food and Nature: <http://landscapes.ecoagriculture.org/>.
140. See Reij, Tappan, and Smale (2009); Reij, Tappan, and Belemviré (2005); Hassane, Martin, and Reij (2000); and Reij (1983).
141. See Hassane, Martin, and Reij (2000); and Reij (1983).
142. See Hassane, Martin, and Reij (2000); Hassane and Yamba (2013).
143. See World Resources Institute et al. (2008).
144. See UNDP (2013).
145. The range of 400–1,000 mm of rainfall corresponds to the rainfall regime for common agroforestry species such as *Faidherbia albida*, and to the rainfall range of observed successes in scaling up the improved land and water management practices described in this paper.
146. Based on a geographic information system analysis and calculation by the World Resources Institute. Total land area within rainfall range of 400–1,000 mm is 762 Mha. When protected areas, wetlands, rocky and non-arable land are excluded, available cropland is about 319 Mha. We assumed average cereal yields (of mainly millet, sorghum, and maize) of 600 kg/ha. Thus, a 50 percent increase equals 900 kg/ha, or an additional 300 kg/ha over 75 Mha (25 percent of 300 Mha), which is 22.5 million tons. We assume 2.9 million kcal/ton of cereal (e.g., maize, sorghum). Thus, 2.9 million kcal/ton X 22 million tons yields 64 trillion kcal of food. A 50 percent increase in production is conservative, when data shows increases of 100 to over 200 percent in yields from these practices.
147. As a conservative estimate, we assume that 25 percent of farmers in this area would adopt and apply these practices.
148. Government leaders in a number of countries have expressed keen interest in capitalizing on the potential EverGreen Agriculture, including Senegal, Mali, Burkina Faso, Ghana, Niger, Nigeria, Chad, South Sudan, Ethiopia, Uganda, Kenya, Rwanda, Burundi, Tanzania, Malawi, Zambia, and Zimbabwe. Pers comm. 2013, Dennis Garrity, ICRAF. For more information, see: <http://www.wri.org/event/2013/05/natural-resource-management-and-food-security-growing-population>.
149. See Reyes (2011).
150. See Quisumbing (2003).
151. See De Sarkar (2011).
152. See Kanesathasan (2012).
153. See Hassane, Martin, and Reij (2000); Hassane and Yamba (2013).
154. See Nasr et al. (2001).
155. Cahiers du GREP, Mai 2013
156. See: <http://insights.wri.org/news/2013/08/burkina-faso-farmers-lead-way-food-security-and-climate-change-resilience>.
157. See Pye-Smith (2013), and personal communication with villagers from Dan Saga, 2012.
158. See Marenya and Barrett (2009).
159. See Kelly (2006).
160. See African and Latin American Resilience to Climate Change (2013).
161. See Winterbottom (2013).
162. See LPFN (2013).
163. See Morris et al. (2007).
164. See USAID (2013).
165. See Reij, Tappan, and Belemvire (2005).
166. See Reij and Smaling (2007); Spielman and Pandya-Lorch (2010); Haggblade and Hazell (2010).
167. Compiled by Mike McGahuey, USAID Natural Resource Management Specialist, using information from a Compendium of Citations on African Soils, prepared for the Climate Smart Agriculture Group of USAID, Washington, DC (McGahuey 2013).

REFERENCES

African and Latin American Resilience to Climate Change. 2013. *Malawi Vulnerability Assessment: Final Report*. Draft report for USAID, Washington, D.C.

Akinnifesi, F.K., O.C. Ajyai, G. Sileshi, P.W. Chirwa, and J. Chianu. 2010. "Fertilizer trees for sustainable food security in the maize-based production systems of East and Southern Africa: a review." *Agronomy for Sustainable Development* 30 (3): 615–629.

Akinnifesi, F. K., W. Makumba, G.W. Sileshi, and O.C. Ajyai. 2009. "Farmer participatory assessment of two researcher-managed 'fertilizer tree systems' in Southern Malawi." *African Journal of Agricultural Research* 4 (4): 269–277.

Akinnifesi, F.K., G. Sileshi, O.C. Ajyai, P.W. Chirwa, F. Kwesiga, and R. Harawa. 2008. "Contributions of agroforestry research to livelihood of smallholder farmers in Southern Africa: 1. Taking stock of the adaptation, adoption, and impact of fertilizer tree options." *Agricultural Journal 3* (1) 58–75.

Akinnifesi, F.K., O.C. Ajayi, G. Sileshi, I. Kadzere, and A.I. Akinnifesi. 2007. "Domesticating and commercializing indigenous fruit and nut tree crops for food security and income generation in Sub-Saharan Africa." Paper presented at the New Crops International Symposium, 3-4 September, 2007, Southampton, United Kingdom.

Alexandratos, N. and J. Bruinsma. 2012. *World agriculture towards 2030/2050: the 2012 revision.* Rome: FAO.

Allison, F.E. 1973. *Soil Organic Matter and Its Role in Crop Production.* New York: Elsevier.

Ariga, J., and T.S. Jayne. 2009. "Unlocking the Market: Fertilizer and maize in Kenya." In D.J. Spielman and R. Pandya-Lorch. *Millions Fed: proven successes in agricultural development.* Washington, DC: International Food Policy Research Institute.

Aune, J,. and A. Bationo. 2008. "Agricultural intensification in the Sahel – The ladder approach." *Agricultural Systems* 98 (2): 119–125.

Bailey, I., and L.E. Buck. 2013. "Managing for Resilience: Exploring a landscape approach for improving food and livelihood security." Discussion Paper. Washington, DC: EcoAgriculture Partners.

Bationo, A., A. Hartemink, O. Lungu, M. Miami, P. Okoth, E. Smaling, et al. 2006. "African Soils: Their Productivity and Profitability of Fertilizer Use." Background Paper for the African Fertilizer Summit, Abuja, Nigeria, June 13, 2006.

Bationo, A., S.P. Wani, C. Bielders, P.L.G. Vlek and A.U. Mokwunye. 2000. "Crop Residue and Fertilizer Management to Improve Soil Organic Carbon Content, Soil Quality and Productivity in the Desert Margins of West Africa," IN *Global Climate Change and Tropical Econsystems,* pp.117-145, R.Lal, J.M. Kimble and B.A. Stewart (Eds.)

Bationo, A., F. Lompo, and S. Koala. 1998. "Research on nutrient Flows and balances in west Africa: state-of-the-art." *Agriculture, Ecosystems and Environment* 71 (1998) 19–35.

Beddington, J., et al. 2012. *Achieving food security in the face of climate change: Final report from the Commission on Sustainable Agriculture and Climate Change.* Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Accessible at: <ww.ccafs.cgiar.org/commission>.

Botoni, E., and C. Reij. 2009. "La transformation silencieuse de l'environnement et des systèmes de production au Sahel: Impacts des investissements publics et prives dans la gestion des ressources naturelles." Ouagadougou, Burkina Faso, and Amsterdam: Comite Permanent Inter-Etats pour la Lutte contre la Secheresse au Sahel and Vrije Universiteit Amsterdam.

Braimoh, A., and P. Vlek, eds. 2007. *Land use and soil resources.* Tokyo: Springer Media B.V.

Breman, H., et al. 2007. "The Lesson of Drente's 'Essen': Soil nutrient depletion in Sub-Saharan Africa and Management Strategies for Soil Replenishment." In A. Braimoh, et al., eds. *Land use and soil resources.* Tokyo: Springer Media B.V.

Breman, H., J. Rob Groot, and H. van Keulen. 2001. "Resource limitations in Sahelian agriculture. *Global Environmental Change* 11 (2001) 59–68.

Bridges, E. et al. 1999. "Responses to Land Degradation." Proc. 2nd International Conference on Land Degradation and Desertification, Khon Kaen, Thailand, January 25–29, 1999. New Delhi: Oxford Press.

Bunch, R. 2011. "Africa's soil fertility crisis and the coming famine." In State of the World 2011. *Innovations that nourish the planet.* New York: W.W. Norton & Company.

Bunderson, W.T., Z.D. Jere, I.M. Hayes and H.S.K. Phombeya. 2002. LandCare Practices in Malawi. Malawi Agroforestry Extension Project, Publication No. 41, Lilongwe, Malawi.

Bunderson, W. T. 2012. "*Faidherbia albida:* the Malawi experience." Lilongwe, Malawi: Total LandCare.

Bunderson, W.T., Z. Jere, J. Chisui, R. Museka, P. Wall, A. Ngwira and C. Mwale. 2012. "Integrating Agroforestry with Conservation Agriculture in Malawi: experiences of Total LandCare." Lilongwe, Malawi: Total LandCare.

Caldwell, M.M., T.E. Dawson, and J.H. Richards. 1998. "Hydraulic lift: water efflux from upper roots improves effectiveness of water uptake by deep roots." *Oecologia* 79: 1–5.

Craswell, E.T. and P.L.G. Vlek. 1982. "Nitrogen Management for Submerged Rice Soils." In *Symposium on Submerged Rice Soils and Their Management*, 12th International Congress of Soil Science, New Delhi, 3:158–181.

Critchley, William. 2010. *More people, more trees: environmental recovery in Africa.* Rugby, UK: Practical Action Publishing.

Critchley, W., and J. Gowing, eds. 2012. *Water Harvesting in Sub-Saharan Africa.* London: Routledge.

De Sarkar, S. 2011. "Gendering joint forest management." *IUCN* Arbor Vitae Issue 43: 10.

Derpsch, R., and T. Friedrich. 2009a. "Global Overview of Conservation Agriculture, No-till adoption." Presentation to 4th World Congress on Conservation Agriculture, New Delhi, India.

Derpsch, R., and T. Friedrich. 2009b. "Development and Current Status of No-till Adoption in the World." Proceedings on CD, 18th Triennial conference of the International Soil Tillage Research Organization (ISTRO), June 15–19, 2009, Izmir, Turkey.

Dick, Richard P. 2008. "Soil Microorganisms the final arbitrators: can they be managed to optimize carbon sequestration in semi-stable soil pools?" Presentation to International Symposium on Climate Change and Food Security in South Asia, July 25–29, 2008, Dhaka, Bangladesh.

Diedhiou-Sall, S., E. L. Dossa, I. Diedhiou, A. N. Badiane, K. B. Assigbetse, S.A.N. Samba, M. Khouma, M. Sene, and R.P. Dick. 2013. "Microbiology and macrofaunal activity in soil beneath shrub canopies during residue decomposition in agroecosystems of the Sahel." *Soil Science Society of America* 77 (2): 501–511.

Dossa, E.L., I. Diedhiou, M. Khouma, M. Sene, A. Lufafa, F. Kizito, S.A.N. Samba, A. N. Badiane, S. Diedhiou, and R.P. Dick. 2012. "Crop productivity and nutrient dynamics in a shrub (Guiera senegalensis)-based farming system of the Sahel." *Agronomy* 104 (5): 1255–1264.

Dossa, E. 2006. "An Abstract of the Dissertation of Ekwe L. Dossa." Accessible at: <http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/3806/Ekwe'sThesis.pdf?sequence=1>.

Dossa, E. 2007. "The Biogeochemistry of Nitrogen and Phosphorus Cycling in Native Shrub Ecosystems in Senegal." Ph.D. Dissertation. Corvallis, OR: Oregon State University.

Doumbia, M. 2010. "Conservation agriculture in the Sahelian region of West Africa." Bamako, Mali: Institut d'Economie Rurale. Accessible at: <http://www.fondation-farm.org/zoe/doc/conf2010_presentation05_mdoumbia.pdf>.

Doumbia, M., A. Jarju, M. Sene, K. Traore, R. Yost, R. Kablan, K. Brannan, A. Berthe, C. Yamoah, A. Querido, P. Traore and A. Ballo. 2008. "Sequestration of organic carbon in West African soils by *Aménagement en Courbes de Niveau.*" Agronomy for Sustainable Development.

EcoAgriculture Partners. 2013. *Reported Impacts of 23 Integrated Landscape Initiatives.* Washington, DC: EcoAgriculture Partners on behalf of the Landscapes for People, Food and Nature Initiative.

Eswaran, H., et al. 2001. "Land degradation: an overview." In E. Bridges, et al., eds. *Responses to Land Degradation.* Proc. 2nd International Conference on Land Degradation and Desertification, Khon Kaen, Thailand, January 25–29, 1999. New Delhi: Oxford Press.

FAO (Food and Agriculture Organization of the United Nations). 2011. *The state of the world's land and water resources for food and agriculture (SOLAW) – managing systems at risk.* Rome and London: FAO and Earthscan.

FAO (Food and Agriculture Organization of the United Nations). 2012. "Conservation Agriculture." Accessible at: <www.fao.org/ag/ca/index.html >.

FAO (Food and Agriculture Organization of the United Nations). 2013a. *Climate-Smart Agriculture Sourcebook.* Rome: FAO.

FAO (Food and Agriculture Organization of the United Nations). 2013b. FAOSTAT. Food and Agriculture Organization, Rome, Italy. Accessible at: <http://www.faostat.fao.org/site/575> and <http://faostat.fao.org.site/377>. (Accessed October 9, 2013.)

FAO, WFP, and IFAD (Food and Agriculture Organization of the United Nations, World Food Programme, and International Fund for Agicultural Development). 2012. *The State of Food Insecurity in the World 2012.* Rome: FAO.

Feed the Future. 2012. "Feed the Future Helps Scale-Up Ridge Tillage in Mali." Accessible at: <http://www.feedthefuture.gov/article/feed-future-helps-scale-ridge-tillage-mali>.

Felker, P. 1978. "State of the art: Acacia albida as a complementary intercrop with annual crops." USAID Information Services. Washington: USAID.

Foley, J., 2011. "Can We Feed the World and Sustain the Planet?" *Scientific American* Nov 2011: 60–65.

Foley, J. A., R. DeFries, G. P. Asner, C. Barford, G. Bonan, S. R. Carpenter, F. S. Chapin, M. T. Coe, G. C. Daily, H. K. Gibbs, J. H. Helkowski, T. Holloway, E. A. Howard, C. J. Kucharik, C. Monfreda, J. A. Patz, I. C. Prentice, N. Ramankutty, and P. K. Snyder. 2005. "Global Consequences of Land Use." Science 309: 570–574.

Garrity, D.P., F. Akinnifesi, O.C. Ajayi, S.G. Weldesemayat, J.G. Mowo, A. Kalinganire, M. Larwanou, and J. Bayala. 2010. "Evergreen Agriculture: a robust approach to sustainable food security in Africa." *Food Security* 2: 197–214.

Garrity, D.P., 2004. "Agroforestry and the achievement of the Millennium Development Goals." *Agroforestry Systems* 61: 5–17.

Giller, K. E., E. Witter, M. Corbeels, and P. Tittonell. 2009. "Conservation Agriculture and smallholder farming in Africa: the heretics' view." *Field Crops Research* 114 (2009) 23–34.

Gnacadja, L. 2013. "Excerpts from keynote speech by the UNCCD Executive Secretary at the World Forests Summit, Stockholm, Sweden." IDN-InDepthNews, March 20, 2013.

Haggblade,S., G.Tembo, D. Kaboré, C.Reij, O.C.Ajayi, S.Franzel, P. Mafongoya, and F.Place. 2010. "Sustainable Soil Fertility Management Systems." In S. Haggblade and P.B.R. Hazell, eds. *Successes in African Agriculture: lessons for the future.* Baltimore, MD: Johns Hopkins University Press.

Haggblade, S., and P.B.R. Hazell. 2010. *Successes in African Agriculture: lessons for the future.* International Food Policy Research Institute. Baltimore, MD: Johns Hopkins University Press.

Haggblade,S., P.B.R. Hazell, and E. Gabre-Madhin. 2010. "Challenges for African Agriculture." In S. Haggblade and P.B.R. Hazell, eds. *Sucesses in African Agriculture; lessons for the future.* Baltimore, MD: Johns Hopkins University Press.

Hassane, A., and B.Yamba. 2013. *Dynamique des exploitations agricoles en matière de collecte des eaux pluviales dans le Département d'Illéla, Région de Tahoua, République du Niger.* Report for the International fund for Agricultural Development.

Hassane, A., P.Martin, and C.Reij. 2000. *Water harvesting, land rehabilitation and household food security in Niger: IFAD's soil and water conservation project in illéla District.* Rome and Amsterdam: International Fund for Agricultural development and Vrije Universiteit.

Hayashi, K., T. Abdoulaye, B. Gerard, and A. Bationo. 2008. "Evaluation of application timing in fertilizer micro-dosing technology in millet production in Niger, West Africa." *Nutrient Cycling in Agroecosystems* 80: 257–265.

Henao, J., and C. A. Baanante. 2006. "Agricultural production and soil nutrient mining in Africa: implications for resource conservation and policy development." Technical Bulletin T-72. Muscle Shoals, Alabama: International Center for Soil Fertility and Agricultural Development. Cited in A. Noble. 2012. *The Slumbering Giant: land and water degradation.* Canberra, Australia: Crawford Fund Proceedings.

Hengl, T., and H. Reuter. 2009. "Topsoil organic carbon based on the HWSD [Data file]." ISRIC World Soil Information. Accessible at: <http://worldgrids.org/doku.php?id=wiki:tochws>. (Retrieved May 5, 2013).

Huggins, D.R., and J.P. Reganold. 2008. "No-till: the Quiet Revolution." *Scientific American* July 2008: 70–77.

IED Afrique and World Vision. 2013. « Régénération Naturelle Assistée pour reverdir les terres de cultures. » Cahiers du GREP no.7.

IFAD (International Fund for Agricultural Development). 2010. "Rural Poverty Report 2011: Overview." Rome and Washington, DC: International Fund for Agricultural Development and World Bank.

IFDC (International Fertilizer Development Center). 2005. "Development and Dissemination of Sustainable Integrated Soil Fertility Management Practices for Smallholder Farmers in Sub-Saharan Africa" Technical Bulletin T-71. Muscle Shoals, AL: International Fertilizer Development Center.

IFDC. 2011. "Strategic Alliance for Agricultural Development in Africa (SAADA) End of Project Report." Accessible at: <www.ifdc.org>.

IFDC. 2012. "Catalyze Accelerated Agricultural Intensification for Social and Environmental Stability." Project Summary. Accessible at: <www.ifdc.org>.

IFDC. 2013. "APPI Gross Margin Survey: FDP's Yield and Financial Benefits Proven," IN *IFDC* Report Vol. 38 No. 2. Accessible at: <www.ifdc.org>.

Kablan, R., R. Yost, K. Brannan, M. Doumbia, K. Traore, A. Yorote, Y. Toloba, S. Sissoo, O. Samake, M. Vaksman, L. Dioni and M. Sissoko. 2008. "*Aménagement en courbes de niveau* increasing rainfall capture, storage and drainage in soils of Mali." *Arid Land Res. Manag.* 22: 62–80.

Kaboré,D., and C. Reij. 2004. "The emergence and spreading of an improved traditional soil and water conservation practice in Burkina Faso." IFPRI EPTD Discussion Paper No. 114. Washington, DC: IFPRI.

Kanesathasan, A. 2012. "Cultivating Women's Participation: strategies for gender-responsive agricultural programming." Technical Brief. Washington, DC: International Center for Research on Women.

Kelly, V. 2006. "Factors Affecting Demand for Fertilizer in Sub-Saharan Africa." Agriculture and Rural Development Discussion Paper 23. Washington, DC: World Bank.

Kizito , F., M.I. Dragilam, M. Sene, J.R. Brooks, F.C. Meinzer, I. Diedhiou, M. Diouf, A. Lufafa, R.P. Dick, J. Selker, and R. Cuenca. 2012. "Hydraulic redistribution by two semi-arid shrub species: implications for Sahelian agro-ecosystems." *Journal of Arid Environments* 83: 69–77.

Lal, R. 2006. "Enhancing crop yields in developing countries through restoration of soil organic carbon pool in agricultural lands." *Land Degrad. and Dev.* 17: 197–209.

Lal, R. 2007. "Constraints to adopting no-till farming in developing countries." *Soil Tillage Res.* 94: 1–3.

Larwanou, M., and T. Adam. 2008. "Impacts de la régénération naturelle assistée au Niger: Etude de quelques cas dans les Régions de Maradi et Zinder." Synthèse de 11 mémoires d'étudiants de 3ème cycle de l'Université Abdou Moumouni de Niamey, Niger. Photocopy.

Liniger, H.P., R. Mekdaschi Studer, C. Hauert, and M. Gurtner. 2011. *Sustainable Land Management in Practice: guidelines and best practices for Sub-Saharan Africa.* TerrAfrica, World Overview of Conservation Approaches and Technologies (WOCAT), and Food and Agriculture Organization of the United Nations (FAO). Rome: FAO.

Liniger, H., and W. Critchley. 2007. *Where the Land is Greener.* Bern, Switzerland: CTA, FAO, UNEP, CDE on behalf of the World Overview of Conservation Approaches and Technologies (WOCAT).

LPFN. 2013. "A Call to Action. Landscapes for People, Food and Nature." Accessible at: <http://landscapes.ecoagriculture.org/action_and_advocacy/lpfn_action_call>.

Lufafa, A., I. Diedhiou, S. Samba, M. Sene, M. Khouma, F. Kizito, R.P. Dick, E. Dossa and J. Noller. 2008. "Carbon stocks and patterns in native shrub communities of Senegal's Peanut Basin." *Geoderma* 146 (2008) 75–82.

Makumba, W., B. Janssen, O. Oenema, and F.K. Akinnifesi. 2006. "Influence of time of application on the performance of gliricidia prunings as a source of N for maize." *Expl Agric* 42 : 51–63.

Mando, A., M. P. Sédogo, and L. Stroosnijder. 2005. "Long-Term Effect of the Application of Organic Resource of Contrasting Quality and Tillage on Soil Carbon and Nutrients Content Under Sudano-Sahelian Conditions." *Soil Tillage Res* 80:95–101.

Marenya, P., and C.B. Barrett. 2009. "Soil quality and fertilizer use rates among smallholder farmers in western Kenya." *Agricultural Economics* 40(5): 561–572.

Mazvimavi, D., Z. Hoko, L. Jonker, I. Nhapi, and A. Senzanje. 2008. "Integrated Water Resources Management: From Concept to Practice." Editorial. *Journal of the Physics and Chemistry of the Earth* 33: 609–613.

McGahuey, M. 2013. "Compendium of Citations on African Soils." Working paper prepared for the Climate Smart Agricultural Group of USAID, Washington, D.C.

Milder, J.C., A.K. Hart, P. Dobie, J. Minai, and C. Zaleski. 2012. "Integrated Landscape Initiatives: An Emerging Paradigm for African Agriculture, Development, and Conservation." Washington, DC: USAID, EcoAgriculture Partners, World Agroforestry Centre, and TerrAfrica.

The Montpellier Panel. 2013. *Sustainable Intensification: A New Paradigm for African Agriculture.* London: Agriculture for Impact, Imperial College.

Morris, M., et al. 2007. "Fertilizer Use in African Agriculture: lessons learned and good practice guidelines." Agriculture and Rural Development. Washington, DC: World Bank.

Nair, P.K.R. 1993. *An Introduction to Agroforestry.* Dordrecht, the Netherlands: Kluwer Academic Publishers, in cooperation with ICRAF.

Nasr, N., E.A. Hdaidi, and A. Ben Ayed. 2001. "A bridge between local innovation, development and research: the regional radio of Gafsa, Tunisia." In C. Reij and A. Waters-Bayer, eds. *Farmer Innovation in Africa: a source of inspiration for agricultural development.* London: Earthscan Publications.

National Research Council. 2007. *Emerging Technologies to Benefit Farmers in Sub-Saharan Africa and South Asia.* Washington, DC: National Academy of Sciences.

Noble, A. 2012. *The Slumbering Giant: land and water degradation.* Canberra, Australia: Crawford Fund Proceedings

Pingali, P., et al. 2006. *Eradicating extreme poverty and hunger: toward a coherent policy agenda.* Rome and Washington: FAO and World Bank.

Place, F., et al. 2013. "Food security and sustainable resource use – what are the resource challenges to food security?" Background paper for the conference on Food Security Futures: Research Priorities for the 21st Century, April 11–12, 2013, Dublin, Ireland.

Pye-Smith, C. 2013. "The Quiet Revolution: how Niger's farmers are re-greening the croplands of the Sahel." World Agroforestry Center (ICRAF), Trees for Change No.12. Nairobi: World Agroforestry Center.

Quisumbing, A.R. 2003. *Household decisions, gender and development: a synthesis of recent research.* Washington, DC: International Food Policy Research Institute.

Ranganathan, J., et al. 2008. *Ecosystem Services: A Guide for Decision Makers.* Washington, DC: World Resources Institute.

Reij, C. 1983. *L'évolution de la lutte anti-érosive en Haute Volta: vers une approche participative.* Amsterdam: Vrije Universiteit Amsterdam, Institute for Environmental Studies.

Reij, C. 2012. "Evidence of Success." *Farming Matters* December 2012: 14–17.

Reij, C., and E.M.A. Smaling. 2007. "Analyzing successes in agriculture and land management in Sub-Saharan Africa: is macro-level gloom obscuring positive micro-level change?" *Land Use Policy* 25 (3): 410–420.

Reij, C., F. Landsberg, and R. Winterbottom. 2013. "Burkina Faso Farmers Lead the Way on Food Security and Climate Change Resilience." *WRI Insights.* Accessible at: <http://insights.wri.org/news/2013/08/burkina-faso-farmers-lead-way-food-security-and-climate-change-resilience>.

Reij, C., G. Tappan, and M. Smale. 2009. "Agroenviromental Transformation in the Sahel: Another Kind of 'Green Revolution.'" Washington, DC: International Food Policy Research Institute.

Reij, C., G.Tappan, and A.Belemviré. 2005. "Changing land management practices and vegetation on the Central Plateau of Burkina Faso (1968–2002)." *Journal of Arid Environments* 63 (3): 642–659.

Reij, C., and A. Waters-Bayer. 2001. *Farmer Innovation in Africa: a source of inspiration for agricultural development.* London: Earthscan Publications.

Reyes, T. 2011. "Gender and farming in Tanzania." IUCN Arbor Vitae Issue 43: 7.

Rockstrom, J., and M. Falkenmark. 2000. "Semiarid crop production from a hydrological perspective: gap between potential and actual yields." *Crit. Rev. Plant Sci.* 19 (4): 319–346.

Rockström, J., J. Barron, and P. Fox. 2003. "Water Productivity in Rainfed Agriculture: Challenges and Opportunities for Smallholders in Drought-prone Tropical Agroecosystems." In J.W. Kijne, R. Barker, and D. Molden, eds. *Water productivity for agriculture: Limits and opportunities for improvements.* London: CAB International.

Sanders, J.H., and B. Ouendeba. 2012. "Intensive Production of Millet and Sorghum for Evolving Markets in the Sahel." Working paper produced for USAID-funded INTSORMIL CRSP.

Sanginga, N., and P.L. Woomer. 2009a. *Integrated soil fertility management in Africa: principles, practices and developmental process.* Nairobi, Kenya: Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture.

Sanginga, N., and P.L. Woomer. 2009b. "A manual on integrated soil fertility management in Africa." Paper presented at African Crop Science Society Conference, Cape Town, South Africa. September 28–October 1, 2009.

Sawadogo, H. 2006. "Fertilisation organique et phosphatée en système de culture zaï en milieu soudano-sahélien du Burkina Faso." (Thèse de doctorat). Gembloux, Faculté Universitaire des Sciences Agronomiques de Gembloux, Belgique.

Sawadogo, H. 2013. "Effects of microdosing and soil and water conservation techniques on securing crop yields in northwestern Burkina Faso." Working Paper prepared for the Institut de l'Environnement et de Recherches Agricoles (Burkina Faso).

Sawadogo, H., F. Hien, A. Sohoro, and F. Kambou. 2001. "Pits for trees: how farmers in semi-arid Burkina Faso increase and diversify plant biomass." In C. Reij and A. Waters-Bayer, eds. *Farmer Innovation in Africa: a source of inspiration for agricultural development.* London: Earthscan Publications.

Sayer, J., et al. 2013. "Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses." *Proceedings of the National Academy of Sciences* 110 (21): 8349–8356.

Scherr, S. J., S. Shames and R. Friedman. 2012. "From climate-smart agriculture to climate-smart landscapes." *Agriculture and Food Security* 2012 1:12

Scherr, S.J.,and J.A. McNeely. 2008. "Biodiversity conservation and agricultural sustainability: towards a new paradigm of 'ecoagriculture' landscapes." *Phil Trans Royal Soc Biol Sci* 363:477–494.

Searchinger, T., et al. 2013a. "The Great Balancing Act." Working Paper, Installment 1 of Creating a Sustainable Food Future. Washington, DC: World Resources Institute. Accessible at: <http://www.worldresourcesreport.org>.

Searchinger, T., et al., 2013b. "Achieving Replacement Level Fertility." Working Paper, Installment 3 of Creating a Sustainable Food Future. Washington, DC: World Resources Institute. Accessible at: < http://www.worldresourcesreport.org>.

Sedogo, M.P. 1993. "Evolution des sols ferrugineux lessivés sous culture: influence des modes de gestion sur la fertilité." Thèse de Doctorat Es-Sciences, Abidjan, Université Nationale de Côte d'Ivoire.

Selman, M., and S. Greenhalgh. 2009. "Eutrophication: Sources and Drivers of Nutrient Pollution." WRI Policy Note. Washington, DC: World Resources Institute

Shitumbanuma, V. 2012. "Analyses of Crop Trials Under *Faidherbia albida.*" Conservation Farming Unit, University of Zambia.

Sileshi, G., et al. 2009. "Evidence for Impact of Green Fertilizers on Maize Production in Sub-Saharan Africa: a meta-analysis." ICRAF Occasional Paper no. 10. Nairobi: World Agroforestry Center.

Smale, M., and T.S. Jayne. 2009. “Breeding an ‘Amazing’ Crop: improved maize in Kenya, Malawi, Zambia and Zimbabwe.” In D.J. Spielman and R. Pandya-Lorch, eds. *Millions Fed: proven successes in agricultural development.* Washington, DC: International Food Policy Research Institute.

Snapp, S.S., P.L. Mafongoya, and S. Waddington. 1998. ”Organic matter technologies for integrated nutrient management in smallholder cropping systems of southern Africa.” *Agric. Ecosys. Environ.* 71(1-3):185–200.

Spielman, D. J., and R. Pandya-Lorch. 2009. *Millions Fed: proven successes in agricultural development.* Washington, DC: International Food Policy Research Institute.

Tabo, R., A. Bationo, B. Gérard et al. 2007. “Improving cereal productivity and farmers’ income using a strategic application of fertilizers in West Africa.” IN Bationo et al. 2007. *Advances in integrated soil fertility management in sub-Saharan Africa: challenges and opportunities.* Springer: Dordrecht. p. 201-208.

Tan, Z., et al. 2005. “Global Soil Nutrient Depletion and Yield Reduction.” *Journal of Sustainable Agriculture* 26 (1): 123-146.

Thierfelder, C. 2012. *Building the CA evidence base in Southern Africa.* CIMMYT.

Thierfelder, C. and P.C. Wall. 2012. “Effects of conservation agriculture on soil quality and productivity in contrasting agro-ecological environments of Zimbabwe.” *Soil Use and Management* 28: 209–220.

Thierfelder, C. and P.C. Wall. 2009. “Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe.” *Soil and Tillage Research* 105 (2009): 217–227.

Total Land Care. 2012. “Conservation Agriculture in East and Southern Africa: evidence and guidelines for implementation.” TLC Booklet no. 4. Lilongwe, Malawi: Total Land Care.

Tropical Forages. n.d. “Leucaena Leucocephala.” Accessible at: <http://www.tropicalforages.info/key/Forages/Media/Html/Leucaena_leucocephala.htm>.

Umar, B. 2012. “Reversing agro-based land degradation through conservation agriculture: emerging experiences from Zambia’s smallholder farming sector.“ Sustainable Agriculture Research 1 (2): 72-87.

Umar, B., J. Aune, F. Johnsen and O. Lungu. 2011. “Options for improving smallholder conservation agriculture in Zambia.” Journal of Agricultural Science 3 (3): 50-62.

United Nations Development Programme. 2013. “Community-based sustainable land management: best practices in drylands from the Equator Initiative.” New York, NY: UNDP.

UN News Service. “UN Drylands Ambassador calls for greater efforts to fight desertification.” March 26, 2012.

USAID. 2013. *Sahel Resilience Learning project document.* Washington, DC: USAID.

Vanlauwe, Bernard. 2009. “Integrated Soil Fertility Management in Sub-Saharan Africa: Principles and Practice,” IN *Proc. of the International Plant Nutrition Colloquium XVI,* UC Davis, CA.

Williams, S.D., and H. Fritschel. 2012. “Farming Smarter.” *IFPRI Insights* Vol 2, Issue 2. Washington, DC: International Food Policy Research Institute.

Winterbottom, R. 2013. “USAID/Senegal Nature Wealth and Power Retrospective Study.” Contribution on “Nature” from the World Resources Institute. Working paper submitted to US Forest Service and USAID. Washington, DC: USAID.

WOCAT and IFAD. 2013. *Water Harvesting: Guidelines to Good Practice.* Bern and Rome: WOCAT and IFAD.

Wood, S., K. Sebastian, and S.J. Scherr. 2000. *Pilot Assessment of Global Ecosystems: Agroecosystems.* IFPRI and WRI: Washington, DC.

World Bank. 2008a. *World Development Report: Agriculture for Development.* Washington, DC: The World Bank.

World Bank. 2008b. *Sustainable Land Management Sourcebook.* Washington, DC: World Bank / International Bank for Reconstruction and Development.

World Bank. 2012. *Climate Smart Agriculture: A call to Action.* Washington, DC: World Bank. Accessible at:<http://www.worldbank.org/content/dam/Worldbank/document/CSA_Brochure_web_WB.pdf>.

World Bank. 2013. “What do we mean by drylands? Working definition for the African Drylands report. Washington, DC: World Bank.

World Bank Institute. 2012. *Conservation Agriculture- Zambia.* Washington, DC: World Bank.

World Resources Institute, with the United Nations Environment Programme, United Nations Development Programme, and the World Bank. 2008. *World Resources Report 2008; Roots of Resilience.* Case Study on Niger. Washington, DC: World Resources Institute.

Yamba, B. 2006. “Etude Sahélienne: Rapport d’étude sur le foncier, les institutions locales et l’évolution de la pauvreté.” Niamey, Niger: Centre Régional d’Enseignement Spécialise en Agriculture (CRESA).

Yamba, B. and M. Sambo. 2012. “La Régénération Naturelle Assistée et la sécurité alimentaire des ménages de 5 terroirs villageois des départements de Kantché et Mirriah (région de Zinder).” Rapport pour le Fonds International pour le Développement Agricole.

Zougmoré, R., A. Mando, L. Stroosnijder and E. Ouedraogo. 2004a. “Economic benefits of combining soil and water conservation measures with nutrient management in semiarid Burkina Faso.” *Nutrient Cycling in Agroecosystems* 70: 261–269.

Zougmoré, R., K. Ouattara, A. Mando, and B. Ouattara. 2004b. “Rôle des nutriments dans le succès des techniques de conservation des eaux et des sols (cordons pierreux, bandes enherbées, zaï et demi-lunes) au Burkina Faso.” *Sécheresse* 15 (1): 41–8.

ACKNOWLEDGMENTS

Many thanks to the following individuals for their valuable guidance and critical reviews: Jens Aune (Norwegian University of Life Sciences), William Critchley (Sustainable Land Management Associates, Ltd.), Craig Hanson (WRI), Norbert Henninger (WRI), Rattan Lal (Ohio State University), Tim Searchinger (WRI), Melinda Smale (Michigan State University), and Peter Veit (WRI).

We would also like to acknowledge the following individuals for their valuable assistance and contributions: Chris Barrett (Cornell University); Trent Bunderson (Total Land Care); Charles Governali (WRI); Erin Gray (WRI); Andrew Leach (WRI); Brian Lipinski (WRI); Abdoulaye Mando (IFDC); Tony Rinaudo (World Vision); Hamado Sawadogo (CNRST); Kathryn Solorzano Lowell (WRI); Gray Tappan (USGS); Richard Waite (WRI); Noemi Walzebuck (WRI); and Peter Weston (World Vision).

The publication was improved by the careful review by Dr. David Tomberlin and Emily Schabacker. We thank Richard Waite (WRI) and Bob Livernash for copy editing and proofreading. In addition, we thank Nick Price, Hyacinth Billings, and Jenna Park for publication layout and design.

For this working paper, WRI is indebted to the generous financial support of the Norwegian Ministry of Foreign Affairs, The Netherlands Ministry of Foreign Affairs, the United Nations Development Programme, the United Nations Environment Programme, and the Bill & Melinda Gates Foundation.

This paper represents the views of the authors alone. It does not necessarily represent the views of the World Resources Report's funders.

ABOUT THE AUTHORS

Robert Winterbottom, rwinterbottom@wri.org
(Director, Ecosystem Services, WRI)

Chris Reij, creij@wri.org (Senior Fellow, WRI)

Contributing authors:

Dennis Garrity (former Director General, World Agroforestry Center–ICRAF)

Jerry Glover (Soil Scientist, United States Agency for International Development–USAID)

Debbie Hellums (Program Leader, International Fertilizer Development Center–IFDC)

Mike McGahuey (Natural Resource Management Specialist, USAID)

Sara Scherr (President, EcoAgriculture Partners)

ABOUT WRI

WRI focuses on the intersection of the environment and socio-economic development. We go beyond research to put ideas into action, working globally with governments, business, and civil society to build transformative solutions that protect the earth and improve people's lives.

Solutions to Urgent Sustainability Challenges
WRI's transformative ideas protect the earth, promote development, and advance social equity because sustainability is essential to meeting human needs today, and fulfilling human aspirations tomorrow.

Practical Strategies for Change
WRI spurs progress by providing practical strategies for change and effective tools to implement them. We measure our success in the form of new policies, products, and practices that shift the ways governments work, businesses operate, and people act.

Global Action
We operate globally because today's problems know no boundaries. We are avid communicators because people everywhere are inspired by ideas, empowered by knowledge, and moved to change by greater understanding. We provide innovative paths to a sustainable planet through work that is accurate, fair, and independent.