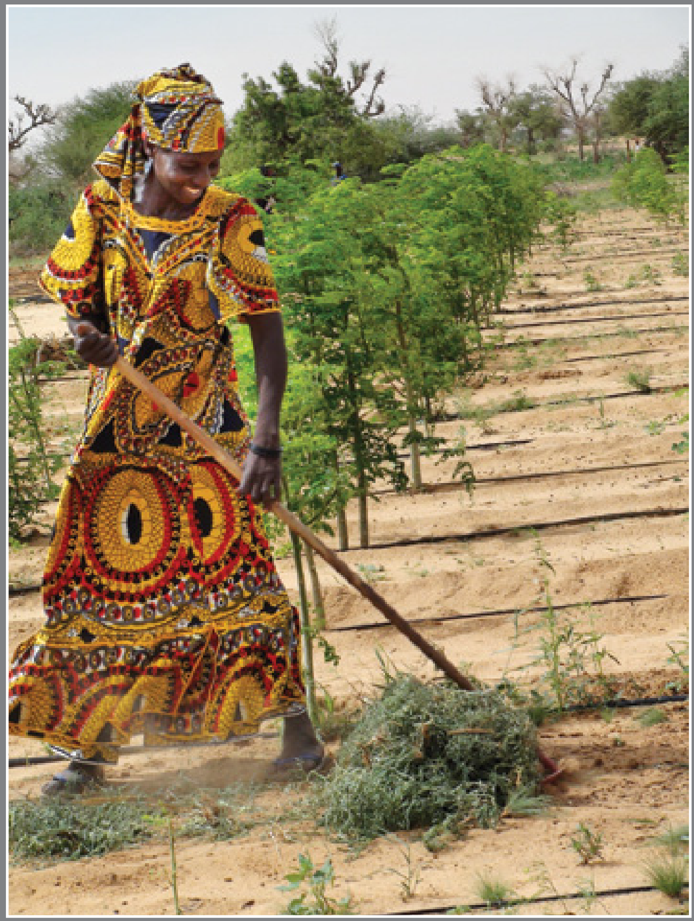
WORLDWATCH REPORT 188

Innovations in Sustainable Agriculture



Supporting Climate-Friendly Food Production

LAURA REYNOLDS AND DANIELLE NIERENBERG

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Innovations in Sustainable Agriculture:

Supporting Climate-Friendly Food Production

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On the cover: In Niger's Tanka village, women farmers with the Market Garden Project, developed by the International Center for Research in the Semi-Arid Tropics (ICRISAT), use solar-powered drip-irrigation systems to grow Pomme du Sahel trees, okra, tomatoes, eggplant, and other vegetables. The women work on their own crops but share tools, water, and skills. Their families can now eat better, and by selling their vegetables and trees at nearby markets, they have tripled their incomes and can afford to send their children to school.
Photograph by Bernard Pollack.

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Summary

From deadly drought in Kenya to heat waves in Russia and the United States, the world's climate is changing. Higher temperatures and unpredictable weather patterns are not only affecting people's daily routines, but they are disrupting life-sustaining agriculture in many parts of the world. These challenges are expected to grow only more pervasive in the future.

The Intergovernmental Panel on Climate Change (IPCC) predicts that the Earth's average surface air temperature could rise by 0.69 degrees Celsius by 2030, 1.8 degrees by 2065, and as much as 6.4 degrees by 2099. This warming, along with other climate-related shifts, including rising sea levels, drought, and ocean acidification, will make food production in the 21st century even more unpredictable, uncertain, and difficult.

Extreme weather events have always been a natural facet of life on Earth; however, as the IPCC states, human-caused climate change is likely the reason behind increased incidences of weather extremes such as drought, monsoons, and strong winds or hurricanes.

Because agriculture relies on healthy soil, adequate water, and a delicate balance of gases such as carbon dioxide and methane in the atmosphere, farming is the human endeavor most vulnerable to the effects of climate change. At the same time, agriculture is a major driver of human-caused climate change, contributing anywhere from 25 to 30 percent of global greenhouse gas emissions, depending on the analysis.

The good news is that agriculture, when done sustainably, holds an important key to mitigating climate change. The United Nations Food and Agriculture Organization (FAO) estimates that, through a variety of approaches, the global agricultural sector could potentially reduce and remove 80 to 88 percent of the carbon dioxide that it currently produces. Practices such as using animal manure rather than artificial fertilizer, planting trees on farms to reduce soil erosion, and growing food in cities all hold huge potential for reducing agriculture's environmental footprint and mitigating the damaging effects of climate change.

This report discusses six sustainable approaches to land and water use, in both rural and urban areas, that are helping farmers and other food producers mitigate or adapt to climate change—and often both. They are:

- **Building Soil Fertility:** Through a variety of techniques that organically rebuild dry or lifeless soils, farmers can improve soil fertility while reducing the need for chemical fertilizers and pesticides. Alternatives to heavy chemical use in agriculture—such as avoiding unnecessarily tilling and raising both crops and livestock on the same land—can help to drastically reduce the total amount of energy expended to produce a crop or animal, lowering overall emissions.
- **Agroforestry:** Growing trees on farmland can reduce erosion problems because the roots of trees and shrubs help hold the soil in place. Because trees remove carbon dioxide from the atmosphere, keeping them on farms whenever possible can help mitigate climate change. Agroforestry also keeps the soil healthier and more resilient by maximizing the amount of organic matter, microorganisms, and moisture held within it. But agroforestry doesn't just benefit the land on which it is practiced; it also provides shade for livestock and certain crops, and creates habitats for animals and insects, such as bees, that pollinate many crops.

Summary

- **Urban Farming:** Growing food in cities can mitigate the greenhouse gas emissions released from the transport, processing, and storage of food destined for urban populations. Urban agriculture also increases the total area of non-paved land in cities, making urban landscapes more resilient to flooding and other weather shocks, while improving the aesthetic value of these landscapes. Urban farming plays an important role in increasing food security, particularly in the poorest communities: the FAO estimates that, on average, poor urban households spend as much as 60 to 80 percent of their income on food.
- **Green Manure/Cover Cropping:** Planting cover crops improves soil fertility and moisture, making soil less vulnerable to drought or heat waves. Cover crops also serve as a critical deterrent against pests and diseases that affect crops or livestock, such as corn root worm or Rift Valley fever, particularly as warmer temperatures enable these organisms to survive in environments that were previously too cold for them. Like agroforestry, in addition to helping farmers adapt to climate change, cover crops can also help mitigate climate change; planting cover crops fixes elements like nitrogen into the soil, maintaining the delicate balance of gases within Earth's atmosphere.
- **Improving Water Conservation and Recycling:** Innovations in water conservation—such as recycling wastewater in cities, using precise watering techniques like drip irrigation rather than sprinklers, and catching and storing rainwater—all help to reduce the global strain on already-scarce water resources. These practices will be increasingly important in areas facing increasing drought, heat waves, and other weather conditions that threaten the availability of irrigation and safe drinking water. Conserving water also saves energy: by avoiding heavy energy expenditures from pumping water from deep within the Earth, as well as from transporting and distributing water from its sources, water conservation can mitigate the severity of climate change.
- **Preserving Biodiversity and Indigenous Breeds:** Growing diverse and locally adapted indigenous crops, such as yams, quinoa, and cassava, can provide a source of income and improve farmers' chances of withstanding the effects of climate change, such as heat stress, drought, and the expansion of disease and pest populations. Preserving plant and animal biodiversity also reduces farmers' overreliance on a small number of commodity crops that make them vulnerable to global markets.

These six agricultural practices all help to make farmland, farmers, and entire communities more resilient to the dramatic effects of climate change, while scaling back energy use and greenhouse gas emissions and thereby mitigating overall climate change. Many of these practices are inexpensive to adopt and do not require extensive infrastructure. But because they are relatively labor intensive, they are most appropriate for small-scale agricultural operations, rather than large-scale industrial agriculture. Smallholder farmers currently produce half of the world's food, including as much as 90 percent of the food grown in Africa and 41 percent of the food grains grown in India.

The FAO estimates that by adopting more-sustainable approaches, small-scale agriculture in developing countries has the potential to contribute 70 percent of agriculture's technical mitigation of climate change. But even large-scale industrial agriculture can learn crucial lessons from these practices. Many of these innovations have the potential to be replicated, adapted, and scaled up for application on larger farms, helping to improve water availability, increase diversity, and improve soil quality, as well as mitigate climate change.

By tapping into the multitude of climate-friendly farming practices that already exist, agriculture can continue to supply food for the world's population, as well as provide a source of livelihood for the 1.3 billion people who rely on farming for income and sustenance. Climate-friendly agriculture also can contribute to the reduction of greenhouse gas emissions and the mitigation of climate change. If agriculture is to play a positive role in the global fight against climate change, however, agricultural practices that mitigate or adapt to a changing climate will need to receive increased research, attention, and investment in the coming years.

Introduction

Fifteen or twenty years ago, it was easy for pastoralists in Samburu, Kenya, to find water for their Zebu cattle, a livestock breed that has adapted over centuries to the region's hot temperatures and arid landscape. But today things have changed. Water is increasingly scarce, and in 2010 and 2011 severe drought across eastern Africa killed thousands of animals, including 60 percent of herds in parts of Kenya and Ethiopia.[1]* The drought also fueled or intensified conflicts over grazing and water rights between many of the region's communities.

In Russia, meanwhile, wheat farmers experienced the worst drought in over a century in 2010: one-quarter of the country's wheat crop was lost, and forest fires raged across more than a million hectares. At the height of the drought, Russia's then-President Dmitri Medvedev, who previously had voiced skepticism about climate change, urged, "What's happening with the planet's climate right now needs to be a wake-up call to all of us."[2]

Farmers in the United States, too, are recognizing that they can no longer rely on historical weather patterns and predictions. The Mid-Atlantic and New England regions have historically been too far north to be seriously affected by the Atlantic Ocean's annual hurricane season. But in August 2011, Hurricane Irene swept across these regions, causing flooding from Virginia to Vermont and leaving more than $7.3 billion in damage.[3]† And in October 2012, Hurricane Sandy caused widespread destruction along the U.S. East Coast, with New York City particularly hard-hit. Economists estimate that the storm caused at least $50 billion in damage; however, losses to agriculture may have been less severe because most crops had already been harvested.[4]


Luca Esposti

Zebu cattle herd raises a dust cloud in Kenya.

In the summer of 2012, record heat and severe drought struck the U.S. Midwest, wreaking havoc on soybean and corn crops. As of August, due mainly to drought, the U.S. Department of Agriculture had designated more than half of the nation's counties as disaster areas—the largest area to fall under this drought classification in more than 50 years.[5] The U.S. corn crop was projected to decrease by an estimated 50.4 million tons, and the soybean crop by 2.6 million tons.[6]‡ Meanwhile, the decline in yields caused prices of staple crops to skyrocket: in June and July, as the total U.S. cropland under severe or greater drought increased from 17 to 60 percent, the dol-

* Endnotes are grouped by section and begin on page 33.

† All dollar amounts are expressed in U.S. dollars unless indicated otherwise.

‡ Units of measure throughout this report are metric unless common usage dictates otherwise.

lar value of crops in these areas increased accordingly, from 16 to 53 percent.[7]

All of these events, from Kenya to Russia to the United States, are a powerful reminder that the world's climate is changing. Higher temperatures and unpredictable weather patterns are already disrupting agricultural production in many regions, and these challenges are expected to grow only more pervasive in the future.

The Intergovernmental Panel on Climate Change (IPCC) predicts that Earth's average surface air temperature could rise by 0.69 degrees Celsius by 2030, 1.8 degrees by 2065, and as much as 6.4 degrees by 2099.[8] This warming, along with other climate-related shifts, including rising sea levels, drought, intensifying storm patterns and flooding, as well as coral reef depletion and ocean acidification, will make farming and fishing in the 21st century even more unpredictable, uncertain, and difficult. Extreme weather events have always been a natural facet of life on Earth; however, as the IPCC states, human-caused climate change is likely the reason behind increased incidences of weather extremes such as drought, monsoons, and strong winds or hurricanes.

Because agriculture relies on healthy soil, adequate water, and a delicate balance of gases such as carbon dioxide (CO_2) and methane in

Table 1. Summary of the Environmental Impacts of Agriculture

Land Area	Farming, livestock ranching, and related activities occupy 40–50 percent of Earth's surface.
Water Use	Agriculture accounts for 70 percent of global freshwater use; roughly 31 percent of this water goes to livestock.
Deforestation	Large-scale cattle ranching has been responsible for 65–80 percent of the deforestation of the Amazon. Each year between 1990 and 2000, 3.1 million hectares of forest worldwide were cleared, and between 2000 and 2010, 1.9 million hectares per year were cleared. Cattle ranching enterprises now occupy nearly 75 percent of this deforested area. Clearing forests releases more CO_2 into the atmosphere than does every car, truck, train, and bus in the world.
Greenhouse Gas Emissions	Agriculture accounts for between 25 and 30 percent of human-caused greenhouse emissions, depending on the analysis. Livestock alone directly contribute an estimated 18 percent of total emissions, including some 9 percent of global CO_2, 35 percent of global methane, and 65 percent of nitrous oxide emissions.
Chemical Use	Large-scale monoculture systems fueled by heavy water, fossil fuel, pesticide, and artificial fertilizer use often increase grain production at first. But production has declined in recent years as soil and water resources are strained beyond sustainable limits. Water tables in Gujarat, India, have dropped six meters per year. Chemical fertilizers have depleted the soil, making harvests more vulnerable to shocks such as extreme weather events.
Methane	Ruminant livestock alone produce some 80 million tons of methane each year, accounting for an estimated 28 percent of global methane emissions from human-related activities. Methane is 72 times more powerful than CO_2 in its ability to trap heat in the atmosphere over a 20-year period.

Source: See Endnote 11 for this section.

the atmosphere, farming is the human endeavor most vulnerable to the effects of climate change. At the same time, agriculture is a major driver of human-caused climate change, contributing anywhere from 25 to 30 percent of global greenhouse gas emissions, depending on the analysis.[9] This is due in part to agriculture's sheer scope: according to the IPCC, agricultural lands* occupy 40 to 50 percent of Earth's land surface.[10] Agriculture also accounts for 70 percent of human freshwater use, contributing to its significant environmental impact.[11] (See Table 1.)

But agriculture also holds an important key to mitigating climate change. The United Nations Food and Agriculture Organization (FAO) estimates that, through a variety of approaches, agriculture could potentially reduce or remove 80 to 88 percent of the CO_2 it currently produces.[12] Practices such as using animal manure rather than artificial fertilizer, planting trees on farms to reduce soil erosion, and growing food in cities all hold huge potential for reducing agriculture's environmental footprint and mitigating the damaging effects of climate change.

At the same time, agriculture can be sophisticated and varied enough to adapt to the effects of climate change. By tapping into the multitude of climate-friendly farming practices that already exist—such as planting indigenous and traditional crop varieties, using water-saving irrigation pumps, and growing cover crops on unused land—agriculture can continue to supply food for the world's population, as well as provide a source of livelihood for the estimated 1.3 billion people worldwide who rely on farming for income and sustenance.[13]

These climate-smart practices represent a major departure from the modern and mainstream farming practices that, since the second half of the 20th century, have come to be known collectively as industrial agriculture. Industrial agriculture, which often depends on the heavy use of chemicals and on a small number of highly productive crops, has boosted yields over the past half-century. But these increased yields have come at a high cost. Modern agricultural practices have depleted soil and water resources and used huge amounts of energy, greatly enlarging agriculture's global carbon footprint.[14] And industrial agriculture's focus on monocultures, or growing a single crop instead of many, has meant that thousands of nutritious and hardy species of crops (and livestock) have become very rare or even extinct.

Anna Lappé, environmental activist and co-founder of the Small Planet Fund, suggests that, "if we are to continue to feed the planet—and feed it well—in the face of global climate chaos, we should be radically rethinking the industrial food system."[15] Fortunately, a broad range of relatively simple yet effective innovations for transforming agriculture already exist.

* Defined as lands used for agricultural production, such as cropland, managed grassland, and permanent crops including agroforestry and bio-energy crops.

Agriculture's Contributions to Climate Change

To understand agriculture's potential to both mitigate and adapt to climate change, it is important to first understand how agriculture and food production affect the global climate.

When large quantities of greenhouse gases such as CO_2, methane, and nitrous oxide are released into Earth's atmosphere, they can trap solar radiation, raising global and regional temperatures and altering entire climate systems. The effects of these changes can be felt in a variety of ways—for example, as prolonged droughts, shifting rainfall patterns, and deadly heat waves. The weather anomalies seen around the world in recent years are just some examples of the disruption caused by Earth's changing climate.

The IPCC, in its most recent assessment published in 2007, concluded that global greenhouse gas emissions increased 24 percent between 1990 and 2004, and 70 percent between 1970 and 2004.[1] Not only has this dramatic increase in emissions resulted in rising global temperatures, but it has occurred during a period of rapid growth in global population, in world food production, and in the total land area used for cultivation and irrigation—highlighting the many interconnections between agriculture and climate change.[2]

Patty P

Soybean planting in Santa Rita, Paraguay.

According to scientists, the two main contributors to rising CO_2 concentrations in the atmosphere are the burning of fossil fuels such as coal, oil, and natural gas, and dramatic changes in land use, such as the clearing of forests to raise cattle and grow crops.[3] Between 2000 and 2005, 3.1 million hectares of forest were cleared annually worldwide, and pasture for beef cattle now occupies 75 percent of this deforested area.[4] Because trees are natural carbon sinks, clearing forests releases more CO_2 into the atmosphere than does every car, truck, train, and bus in the world.[5] To address these and other effects of deforestation, many countries are trying to stem their forest loss with help from the international community.[6] (See Sidebar 1.)

After deforestation, most of the remaining greenhouse gas emissions from agriculture result from energy-intensive and resource-depleting farming practices, such as applying artificial fertilizers and raising livestock industrially.[7]

Nitrogen-based chemical fertilizers require large amounts of energy to manufacture and distribute. In 2007, the production and application of fossil fuel-based nitrogen fertilizers released an estimated 750–1,080 million tons of CO_2-equivalent emissions, or roughly 1–2 percent of global greenhouse gas emissions.[8] In addition to contributing to climate change, prolonged use of

Sidebar 1. Agriculture, Land Use, and Climate Change: The Case of Paraguay

Around the world, the rising demand for agricultural products is contributing to dramatic changes in land use, and ultimately to a changing global climate. Paraguay, a landlocked country nestled in the heart of South America, is a primary example of the interconnections between agriculture, land use, and climate change.

Between 1990 and 2010, Paraguay lost 16.9 percent of its forest cover, or around 3.6 million hectares, as a result of clearing. In eastern Paraguay, forest cover was reduced from some 55 percent of the region's surface area in the 1940s to an estimated 8–18 percent in the 2000s, a loss of more than 5.9 million hectares. The conservation group WWF reports that only 13 percent of the country's original forest now remains, mostly in a highly fragmented and degraded state.

The primary driver of this loss is the conversion of land to agriculture, mainly for soybean production. Between 1990 and 2010, Paraguay's soybean production rose 315 percent, from 1.79 million tons to 7.46 million tons. The area of soybean harvested grew accordingly, by 308 percent, indicating that Paraguay's expansion in production was not due to improved agricultural productivity, but to sheer expansion in the area under cultivation.

The negative impacts of deforestation are wide ranging, from effects on indigenous populations to the loss of biological diversity. But deforestation has important implications for Earth's climate as well. Vast areas of forest, such as those in South America, serve as critical carbon sinks, absorbing CO_2 and preventing it from being released into the atmosphere. Removing these extensive tracts of vegetation can result in greatly increased greenhouse gas emissions.

To address this problem, the United Nations program on "Reducing Emissions from Deforestation and Forest Degradation" (UN-REDD) is working with Paraguay and 41 other countries to implement national forest-conservation policies. These range from imposing moratoria on new forest-clearing or logging concessions, to developing a financing mechanism that rewards businesses or communities for conserving forest cover.

In 2004, Paraguay signed a Forest Conversion Moratorium, known as the Zero Deforestation Law, which stipulates that landowners with forest on their property must retain 25 percent of their forest land, and that 100 meters on either side of waterways must be left forested to protect watersheds and reduce pollution and erosion. The law is set to expire in December 2013, and UN-REDD, along with organizations such as WWF, is working to develop a national program to ensure that deforestation rates do not return to their pre-2004 levels.

Unfortunately, the financial temptations to clear forests are strong, especially when the alternative to forest protection is growing lucrative agricultural commodities, such as soybeans. It will take intense collaboration among multilateral organizations, national governments, agribusinesses, and local communities to develop a sustainable land use system that encourages economic development while halting environmental degradation—not just in Paraguay, but around the world.

Source: See Endnote 6 for this section.

chemical fertilizers has reduced levels of beneficial micro-organisms in soils, degrading the integrity of soils and making them more vulnerable to extreme weather events.[9] (See Sidebar 2.)

Livestock are another major contributor to climate change, not just indirectly through the forest clearing that occurs to create land to raise them, but also as a result of the gases they produce within their guts. Ruminant livestock, including cows, sheep, and goats, alone produce some 80 million tons of methane each year, or a full 28 percent of human-caused global methane emissions, according to the U.S. Environmental Protection Agency.[10] Methane is an estimated 72 times more powerful than CO_2 in its ability to trap heat in the atmosphere over a 20-year period.[11] As worldwide demand for meat continues to rise, the contributions of livestock to the global climate and other environmental challenges will only intensify.[12] (See Sidebar 3.)

In total, agriculture contributes an estimated 25 to 30 percent of the greenhouse gas emissions

Sidebar 2. Soil Infertility in Africa and the Lure of Artificial Fertilizers

In his travels throughout sub-Saharan Africa, agroecologist Roland Bunch heard the same complaint in nearly every community he visited: infertile soils were keeping farmers from being able to grow enough food. "Our soils are tired out," said one Malawian farmer. "And it's getting worse every year." Another farmer agreed: "Last year, I harvested 35 bags of maize. But this year, I only harvested 27, even though it rained well." A third concluded, "Our soil has become so hard that even when it rains, the water just runs off." Villagers across the region were unanimous and adamant that the drop in fertility in their soils was one of the worst threats to long-term survival they had ever faced.

This same story has been told repeatedly across Africa in recent years. As the continent suffers from widespread soil infertility, the yields of many small-scale farmers—who account for the vast majority of the continent's farmers—have been shrinking, and new, un-fatigued cropland is in increasingly short supply. Some 265 million people in sub-Saharan Africa are already chronically hungry, and with the region's population growing by 2.5 percent per year, African soils will have to meet the rising need for food. As the continent's climate continues to change, already-weak soils will suffer, and the food system will face increasing stress.

To help African countries cope with soil infertility, the Consultative Group on International Agricultural Research (CGIAR) recommends that the international community subsidize chemical fertilizers, following the model of industrialized farming that has largely taken hold in the developed world. Malawi, for example, is already subsidizing fertilizer for poor farmers by up to 75 percent. But the fertilizer solution is a temporary one, and it ignores the root cause of the problem: lack of organic matter in the soil.

Africa cannot afford to repeat the failures of the Green Revolution. Lauded as a great success by the international community, this adoption of large-scale monoculture systems during the latter half of the 20th century, fueled by heavy inputs of water, fossil fuels, pesticides, and fertilizers, increased grain production exponentially. In northern India, chemical inputs helped boost grain production by 125 percent between 1960 and 1980.

Since then, however, food production in parts of India and elsewhere has suffered as soil and water resources are stretched beyond sustainable limits. In the state of Gujarat, water tables have dropped by as much as six meters per year. Prolonged use of chemical fertilizers has reduced beneficial micro-organisms in soils, degrading soil integrity and making it more vulnerable to shocks such as extreme weather events.

Moreover, nitrogen fertilizers require large amounts of energy to manufacture and distribute, and as nitrogen leaches from soil into waterways and into the atmosphere, it contributes significantly to greenhouse gas emissions in the Earth's atmosphere. With global trends pointing to increasingly higher energy prices, dependence on synthetic fertilizer is unsustainable financially as well as ecologically. Once fertilizer subsidies stop, poor farmers will be left with soils that lack the long-term resilience they will need to continue being productive.

Source: See Endnote 9 for this section.

from human activity, through activities such as deforestation, the production and application of artificial fertilizer and other agro-chemicals, irrigation, the burning of biomass, and the processing and transport of agricultural products.[13]

Sidebar 3. Meat and Climate Change

As the global population increases, rising meat consumption among the world's growing middle class is putting pressure on the global livestock sector. In low-income, food-deficit countries—which include Benin, Haiti, India, Iraq, and others—meat production increased more than 450 percent between 1980 and 2010, to 114 million tons. The global demand for meat is expected to rise more than 50 percent by 2030, with significant consequences for both livestock production and the global climate.

Worldwide, an estimated 80 percent of soybean production and 40 percent of corn production goes to feeding animals. The rapid growth of concentrated animal feeding operations, or CAFOs, is accelerating this trend in feed production. These industrialized agriculture systems, which source at least 90 percent of their feed externally, now account for 72 percent of poultry production, 43 percent of egg production, and 55 percent of pork production worldwide.

Due in part to CAFOs' high demand for livestock feed (predominantly soybeans and corn), the livestock sector is the world's largest consumer of Earth's land resources. Livestock grazing occupies 26 percent of the planet's ice-free land surface, and the production of livestock feed uses 33 percent of all agricultural cropland.

Livestock also contribute, both directly and indirectly, to climate change: directly because of enteric fermentation, a digestive process that emits large amounts of methane, and indirectly because of the 3.1 million hectares of forest cleared each year (75 percent of which becomes pasture for beef cattle). As a result of these direct and indirect forces combined, farm animals contribute anywhere between 18 and 51 percent of the world's greenhouse gas emissions.

But keeping livestock doesn't have to be destructive for people or the planet. Globally, the livestock sector generates 40 percent of the gross agricultural product and employs 1.3 billion people. Livestock can act as "living banks," providing farmers and livestock keepers with insurance for loans, investments for the future, or quick cash in times of emergency. Livestock raised in a sustainable production system can contribute to gender equality and opportunities for women, improve the structure and fertility of the soil, provide draught power, and control insects and weeds. Manure from livestock can be used for cooking and heating fuel for the estimated 1.3 billion poor or rural families who lack access to electricity.

Although consumers can easily help mitigate greenhouse gas emissions by lowering their meat consumption or sourcing their meat from environmentally sustainable producers, such a cultural change would benefit from greater political support. Policymakers need to find ways to encourage production of meat and other animal products in environmentally and socially sustainable ways. This can be done by establishing stricter regulations, such as waste management and zoning laws for CAFOs; by giving pastoralists land titles for their traditional grazing sites; by helping farmers gain access to critical financial services, including credit, insurance, and broader markets; and by funding research and education on the benefits of raising indigenous livestock breeds that are better adapted to harsh climates and lack of water.

Source: See Endnote 12 for this section.

Climate Change's Impacts on Agriculture

Globally, 2010 was one of the hottest years on record—tying with 1998 and 2005—and Arctic sea-ice cover was the lowest ever recorded.[1] The summer of 2012 was the third-hottest on record in the United States, and 2012 overall has the potential to break multiple world records in heat, Arctic sea-ice melt, and low precipitation.[2] From severe drought to unseasonal flooding, the weather anomalies and other predicted effects of climate change are already taking place in many parts of the world—and some of the biggest impacts have been on agriculture.[3] (See Table 2.)

After struggling through a decade of severe drought in Australia, which culminated in a record-breaking heat wave in 2009, farmers finally saw their chance to return to normalcy and salvage their businesses in 2010, when the rains returned. "After 10 years of not being able to turn a living, this was going to be the crop—all their problems were going to be solved," Australian journalist Richard Glover observed in an interview with National Public Radio in January 2011. "And then it kept on raining."[4] Eventually, the rain caused severe flooding, covering an area twice the size of France and dashing farmers' hopes of a good harvest—leading to a tragic and unprecedented increase in the number of suicides among Australian farmers. Climate scientists predict that extreme weather patterns in Australia will be increasingly severe and frequent in the coming decades.[5]

Farther north, Russia's 2010 summer season was the hottest ever recorded and the driest in 40 years. This unusual weather triggered hundreds of wildfires. The dry conditions damaged an estimated third of the country's wheat harvest, sending shock waves through the global food system and leading to high grain prices.[6] Around the same period, heavy monsoon rains brought the worst flooding ever recorded in Pakistan, destroying 2.4 million hectares of cultivated land and killing 450,000 livestock animals.[7] Meteorologists have suggested that extreme weather patterns in the two countries were linked through stationary patterns in the jet stream, an atmospheric current that heavily influences weather in Europe and Asia. Scientists suspect that higher overall global temperatures may be responsible for this lack of motion in the jet stream.[8]

The Amazon River basin also experienced severe drought during the second half of 2010, and the Rio Negro, a major tributary to the Amazon, fell to its lowest level ever recorded, affecting the yields of both farmers and fishermen.[9] The IPCC warns that the Amazon rain forest could shrink significantly in area as increasing regional temperatures and reduced rainfall trigger a shift in local ecosystems from tropical to savannah.[10]

Declining Productivity

But it isn't just one-off extreme weather events that put agriculture at risk. "The 2010 data confirm the Earth's significant long-term warming trend," said Michel Jarraud, Secretary-General of the World Meteorological Organization, in a January 2011 press release. "The ten warmest years on record have all occurred since 1998."[11] The increase in average global temperatures—along with other "slow-onset" impacts of climate change, such as sea-level rise—are expected to bring deep hardships to the food system between 2050 and 2100.[12]

Scientists had long predicted that, at least for the first few decades, the effects of climate change on global agricultural production would be positive. It was believed that the increased

Table 2. Destructive Weather Anomalies, Selected Examples, 2008–12

Year	Country or Region	Weather Anomaly	Estimated Damage (U.S. dollars)
2008	U.S. Midwest	An unseasonal deluge floods huge areas of farmland, disproportionately affecting farmers whose soil was more heavily depleted.	$15 billion
2009	Australia	A decade of severe drought culminates in a record-breaking heat wave that fuels devastating brushfires in Queensland.	Lowest agricultural income since 1995
2010	Russia	Severe drought leads to the loss of one-quarter of the country's wheat crop, and forest fires rage across over 1 million hectares.	$1.4 billion
2010	Pakistan	Heavy monsoon rains bring the country's worst flooding ever recorded, destroying 2.4 million hectares of cultivated land and killing 450,000 livestock animals.	$2.9 billion
2010	Amazon River Basin	Severe drought leads the Rio Negro, a major tributary to the Amazon River, to drop to its lowest level ever recorded.	Unaccounted for
2010–11	Kenya and Ethiopia	Severe drought kills thousands of farm animals and fuels conflicts over grazing and water rights.	$2.5 billion requested in aid
2011	U.S. Mid-Atlantic/ New England	Hurricane Irene sweeps across regions that are usually unaffected by hurricanes, causing unprecedented crop damage when rivers overflow their banks.	$7.4 billion
2012	U.S. Midwest	Severe drought wreaks havoc on soybean and corn crops. At the end of July, the U.S. Drought Monitor shows 88 percent of corn and 87 percent of soybean crops are in drought-stricken regions and 64 percent of the continental United States is under moderate to extreme drought—the largest area in over 50 years.	As yet unknown
2012	U.S. East Coast	Hurricane Sandy causes unprecedented flooding, damage, and loss of life in New York, New Jersey, and other regions. Because most crops had already been harvested, however, the impact on agriculture is less severe.	Estimated at more than $50 billion

Source: See Endnote 3 for this section.

CO_2 levels would act as a powerful plant fertilizer and actually boost crop yields, not reduce them.[13] But many climate scientists are now revising this prediction.

In 2011, a group of scientists from the University of Illinois published a 10-year study of the productivity of the world's four largest commodity crops—soybeans, rice, maize, and wheat—under conditions that mimicked the predicted effects of climate change, including higher average temperatures, increased incidence of drought and heat waves, and rising concentrations of CO_2 in the atmosphere.[14] They found that maize production declined by 3.8 percent and wheat production by 5.5 percent, compared to a scenario in which no climate changes occurred.[15] For soybeans and rice,

there was no significant drop in productivity, but there was also no bump in productivity resulting from CO_2's fertilizing effect, counter to what mainstream science had predicted.[16]

A related study on maize crops reveals that under otherwise normal conditions, every day that the temperature remains above 30°C reduces yields by at least 1 percent.[17] With each degree above that threshold, yields are stunted exponentially, and drought compounds the stunting even further.[18] The research predicts that a one-degree rise in average global temperature will reduce yields across two-thirds of the maize-growing areas of Africa.[19]

Already, shifting rain patterns are disrupting agricultural production in many regions, including many of the world's poorest communities that rely exclusively on rainfed (as opposed to irrigated) agriculture. The IPCC predicts that in southern Africa, yields from rainfed agriculture could be reduced by half between 2000 and 2020, and that in sub-Saharan Africa, the area of arid and semi-arid land could grow by 60–90 million hectares by around 2080.[20] Rainfed agriculture currently generates 60–70 percent of the world's staple food and is practiced on 80 percent of all agricultural land.[21]

USAID Africa Bureau

Young farmer with a drought-ravaged crop in Ethiopia.

When projections of reduced yields are considered alongside predictions of massive increases in both the human population and food consumption over the coming decades (by 2050, the global population is projected to reach 9 billion and annual cereal demand will rise to about 3 billion tons), it becomes clear that agriculture in its present form will struggle to continue to feed the world while under the stresses of climate change.[22]

Threats to Food Security

The coming climatic changes, both sudden and gradual, will have serious and far-reaching impacts on human health and development, beginning with declines in both food security and overall self-sufficiency in many communities. According to the United Nations Development Programme, 600 million additional people could be at risk of hunger by 2080 as a direct result of climate change.[23]

As the melting of polar ice caps and other land-based ice contributes to sea-level rise, human habitation (not to mention stable food production and income generation) on many low-lying islands, including the Maldive Islands in the Indian Ocean and the Carteret Islands of Papua New Guinea, soon might become impossible.[24] As island residents are forced to relocate, they will join the estimated 200 million "climate refugees" that the International Organization for Migration projects worldwide by 2050.[25] In addition to the socio-economic impacts of uprooting and disbanding entire communities, climate-caused relocation will increase the threats of population pressure, violent territorial clashes, and overexploitation of land elsewhere.

Sea-level rise is also causing the salinization of groundwater in some coastal areas. In Bangladesh, saltwater intrusion is making some aquifers and other groundwater sources unusable for irrigation because the salt water dries and destroys crops.[26]

Warmer temperatures may also facilitate expansion of the habitat range of certain crop pests and diseases, such as corn root worm and brown rust, as well as wind-borne livestock diseases, such as bluetongue and Rift Valley fever.[27] In addition, increases in daily temperatures and temperature variation could raise the frequency of food poisoning, further threatening public health and social stability.[28] According to the IPCC, warmer seas may lead to increased cases of shellfish and reef-fish poisoning, as well as increased diarrheal disease in both adults and children.[29]

Climate Change's Impacts on Agriculture

The UN Division for Sustainable Development reports that the acidification of oceans, a result of rising concentrations of CO_2 in the atmosphere, is destroying coral reefs that serve as important feeding and breeding grounds for many marine species, contributing to a decline in fish stocks. Fish are an essential source of nutrition for 3 billion people and provide at least 50 percent of animal protein and minerals to 400 million people in the world's poorest countries.[30]

Supplying the world's rapidly growing human population with enough food is essential if we wish to avoid widespread social turmoil, to say nothing of starvation and malnutrition. The close link between climate variation, food security, and social stability was painfully demonstrated when the food-price spikes of 2007–08 plunged an additional 150 million people into food insecurity and an additional 50 million into poverty.[31] The dramatic price increases resulted in food-related riots in more than 40 countries.[32] Major riots that resulted in social unrest and in some cases deaths took place in countries such as Burkina Faso, Cameroon, Indonesia, and Yemen.[33]

Although climatic patterns were not the only reason for the price spikes, droughts in grain-producing nations caused widespread crop failures that exacerbated global food shortages. In general, the urban poor spend 60–80 percent of their income on food and earn just $1–2 dollars per day; when food commodity prices rose by an average of 70 percent in dollar terms between September 2006 and February 2008, these populations had no safety net or emergency fund by which to feed themselves.[34]

In the past, food shortages in urban areas have helped to trigger bloody revolutions, such as in Paris in 1789, several European societies in 1848, and Russia in 1917. The food riots of 2008 were no exception; nor were the 2011 Arab Spring revolts. After the food-price spikes in 2007 and 2008, and the financial crisis in 2008 that halted investments in many Persian Gulf countries, residents of these countries experienced a huge loss in their food purchasing power and found little economic relief from their governments, helping to catalyze national uprisings throughout the region.[35]

Sidebar 4. Women and Climate Change

Making up the majority of the world's food producers, women are disproportionately affected by the impacts of climate change on agriculture. Women represent 50 percent of food producers in Asia and 80 percent in Africa. With so many women relying on the state of their crops to feed and nourish their families—as well as provide their economic livelihood—the increased risk of natural disaster, altered harvest seasons, and dwindling biodiversity severely affects women in developing countries.

Climate change not only harms the environment and food production, but also can be a roadblock to achieving gender equality and sustainable development by limiting economic opportunities, decreasing time available for education, and shortening life expectancy.

According to the United Nations, 3 billion people around the world rely on wood, coal, charcoal, or animal waste for cooking and heating their homes. Some women and girls spend about 16 hours a day producing food, doing household chores, and earning a livelihood. Due to climate change, women and girls have to spend more time collecting resources as they become scarce, contributing to deforestation and desertification. In addition to firewood, with increased drought caused by more extreme climatic conditions, women and girls have to spend more time finding and gathering water. This extensive time commitment jeopardizes the time available for women and girls to attend school and engage in economic and social activities.

Cooking with wood stoves can have a lethal effect on women and girls. Due to extended exposure to air pollution caused by wood stoves, respiratory illnesses disproportionately affect women, causing 2 million deaths each year from consequential pneumonia. Inefficient stoves also produce black carbon (a byproduct of charcoal, dung, wood, and other biomass fuels) that contributes to climate change. Providing women with renewable energy sources empowers them to be educators for others in their communities, serves as action against climate change, lifts a major burden on the time dedicated to collecting resources, and, most importantly, reduces the risk of fatal illnesses.

Another burden of climate change is the increased severity of disease in the developing world. Climate variability has increased malaria epidemics and cholera in Africa, Asia, and Latin America. The time dedicated to fulfilling the role of women as caretakers is often overlooked. When taking care of the ill, in addition to producing food, gathering resources, and maintaining a livelihood, women have even less time to make decisions about the most sustainable ways to carry out their activities.

Despite their intimate relationship with the consequences of climate change, women's voices are lacking in discussion, negotiation, and decision making on environmental and climate-based policy. According to the Center for Environment and Population, at past meetings discussing the global environment, women led only 10 percent of delegations. In 40 percent of delegations, the participants were 100-percent men.

—*Katie Spoden*

Source: See Endnote 36 for this section.

Climate Change's Impacts on Agriculture

Climate change will clearly have dramatic impacts on the agricultural sector and on global food production, and its effects will be felt far beyond agriculture. Because millions of the world's poorest people depend on farming for a living, disruptions in agricultural systems will most adversely affect those with the least capacity to withstand additional hardship. Women, who represent the majority of the world's food producers, are particularly vulnerable to the impacts of climate change on agriculture.[36] (See Sidebar 4.)

Magharebia

Youth rioters in Algiers protest high food prices and unemployment.

Any shocks to the global food supply will have far-reaching effects and deeply exacerbate poverty, hunger, and malnutrition, especially in developing countries. For this reason, agricultural techniques that can help food producers mitigate or adapt to climate change will enable farmers (and consumers) to better survive in an era of unpredictable weather patterns and a steadily warming climate.

Mitigating Climate Change Through Sustainable Agricultural Practices

Agriculture's heavy contribution to global greenhouse gas emissions means that the sector holds major potential to mitigate climate change in the coming decades, through practices that minimize fossil fuel use and retain more carbon in the soil and plants. According to the FAO, agriculture has the potential to sequester an estimated 5.5–6 billion tons of CO_2 per year, or 80–88 percent of its current emissions contribution.[1]

Given the significant impacts of livestock production on both global emissions and environmental health, consumers can play an important role in mitigating climate change by lowering their meat consumption and purchasing meat from environmentally sustainable producers. But climate change can be fought right on the farm as well. Three important pathways to mitigating climate change are: building soil health and fertility, practicing agroforestry, and growing crops in urban areas.

Building Soil Fertility

Rather than importing expensive, energy-intensive, and often toxic artificial fertilizers and pesticides, farmers can use fairly simple on-farm techniques to improve soil health and fertility, drastically reducing the total energy expended to produce a crop or raise animals. These climate-friendly techniques include rotating and diversifying crops, planting indigenous crop varieties, combining crop and livestock production, reducing soil tillage, using organic manure as fertilizer, and growing cover crops. In addition to shrinking the climate footprint of agriculture, many of these practices enhance biodiversity, reduce waste, and improve farmers' yields and incomes.

In an unseasonal deluge that flooded huge areas of the U.S. Midwest in 2008—causing $15 billion in damage to crops, livestock, and farm infrastructure—Mark Shepard of New Forest Farm in Kickapoo Valley, Wisconsin, says that he escaped devastation and bankruptcy simply by taking care of his soil.[2] By planting a wide range of crops and omitting chemical fertilizers, Shepard explains, his farm's soils were healthier, could absorb more water, and were resilient to erratic weather patterns.[3]

In the African Sahel, a semi-arid area that stretches from Senegal's Atlantic coast to the Ethiopian highlands, drought persisted from the late 1960s to the 1990s, causing large areas of cropland to become desert. Many have argued that population growth and expansion of agriculture and other land uses was responsible for the desertification. More recently, climate scientists have pointed out that unusually warm surface temperatures in the Indian Ocean caused drier weather patterns in the Sahel, leaving climate change to blame. In either case, a loss in vegetation has left much of the region's soil so dry and hard that it cannot retain what little rain falls.[4]

But some farming communities across the Sahel have been reviving traditional practices from this drought-prone region to reverse desertification. In the densely populated Central Plateau of Burkina Faso, farmers have been able to repair degraded cropland by digging a grid of small pits—known as *zai*—across hardened plots, and then adding organic matter and moisture to the bottom of the basin. The organic matter helps the soil retain water, and it attracts termites. Tunnels dug by the termites help water and nutrients cycle further into the soil.[5]

In Kenya, farmer Eddy Ouko has experimented to create a powerful (and organic) soil

fertilizer. He found that combining a certain flowering shrub, *Tithonia diversifolia*, with goat manure boosts crop productivity without depleting his soil's nutrients. "When I recently got dairy goats, I decided to experiment on my own," said Ouko. "I decided to mix *Tithonia* with goat manure and make compost and then apply it to my crops. I could not believe my eyes the very good harvest I got from my *shamba* [field]."[6]

Raising livestock on grass, instead of relying on external feed and other inputs, is helping to both replenish soil organic matter and sequester carbon in farming regions ranging from arid Africa to the eastern United States.[7] (See Sidebar 5.) Instead of using fossil fuels to produce and transport feed for livestock, grass farming relies on the natural environment to nourish the land, animals, and human consumers. It is also a cheaper, more efficient way of farming, resulting in higher profits and, in many cases, more-delicious and nutritious food.

These—and other—methods to rebuild soil health are relatively simple to implement, but they can have a dramatic effect on farms' resilience to both long-term and immediate climate and weather shocks.

ICRISAT

Women in Niger rehabilitate degraded land by planting okra in *zai* pits.

Agroforestry

Since 2002, on a 2,000-hectare plot of deforested land in the Indonesian state of East Kalimantan on the island of Borneo, an organization called Borneo Orangutan Survival (BOS) has been regenerating forest to create habitat for orangutans. By combining agriculture and forestry in a practice known as agroforestry, the Samboja Lestari project has planted more than a million trees, including 1,000 different species. This project has not only established a safe haven for orangutans, it has improved food security and incomes in the local community, stabilized the local microclimate, increased the availability of water, and helped establish a sustainable agricultural system managed by local people.

Combining trees and other non-crop species with crop production or animal husbandry can be a very effective way to mitigate climate change, while providing numerous benefits for farmland and pasture. (See Figure 1.) Agriculture is a significant driver of deforestation, but reforestation and agroforestry can build resilience on farms and reduce the need to destroy forests for cropland. The planet has lost roughly 20–50 percent of its forest cover since pre-agricultural times, and forests currently cover 31 percent of the global land surface.[8] With as much as 40 percent of terrestrial carbon stored in forest soils and vegetation, maximizing this vegetation is vital for mitigating climate change.[9]

When trees are incorporated into farms, the entire surrounding ecosystem reaps the benefits. Trees reduce wind and evaporation, helping to retain topsoil and moisture. Roots of non-crop vegetation help rain water filter into the ground, replenishing aquifers and allowing crops to access water even when it has not rained in days or, depending on the crop's root system, weeks.[10] Vegetative strips in and around fields, as well as larger adjacent natural areas, protect watersheds and support beneficial wildlife; insects and birds play a major role in pollination and pest control on farms.

In agroforestry systems, trees produce fodder for on-farm livestock, and the livestock's manure can be used as a powerful (and free) soil and crop fertilizer. Farmers can harvest the fruit and nuts from trees, as well as fuelwood, building materials, and other non-food necessities from non-crop vegetation. Meanwhile partial shade from trees helps protect crops and livestock from excessive exposure to sun and heat.[11] This last benefit will become increasingly critical amid the

prolonged heat waves credited to climate change, such as the record-breaking heat waves in 2011 and 2012 that forced cattle ranchers to auction off entire herds out of an inability to keep them fed and watered.[12]

Natural ecosystems such as grasslands or wetlands can provide numerous benefits to farmers, even if they do not produce a crop with a dollar value attached. Healthy ecosystems surrounding farms can provide ecosystem services including pollination, air and water purification, and pest control—all of which foster resilience to climate change.[13]

Indigenous farmers in the Tapajós region of the state of Pará in Brazil have established a successful mixed tree-crop zone on the periphery of their intensely cultivated fields. They have revived the traditional practice of growing rubber in the forest using low-input, low-impact methods, supplementing their incomes and further reducing the need to expand their farms. Their farms are bordered by protected forest areas, and they benefit from the non-monetary ecosystem services that the forest provides to their fields.

In Africa, hundreds of thousands of smallholder farms in Burkina Faso, Malawi, Niger, and Zambia have used agroforestry to dramatically increase their food crop yields. "In the past, I used to get about 10 bags of maize from my fields; now I get at least 25 bags," says Mary Sabuloni, whose farm is about an hour's drive southeast of Blantyre in Malawi. "In the past, we often went hungry, but now I can feed my family all year round." Dennis Garrity of the World Agroforestry Centre in Nairobi, Kenya, has called this revitalization of soils through agroforestry an "evergreen revolution"—an "affordable and sustainable way to increase smallholder food production."[14]

Agroforestry efforts in Niger have helped regenerate 5 million hectares and store climate-altering carbon in the soil, according to 14 scientists writing in the January 2012 issue of *Science.* The article claims that the practice "has benefited more than 1.25 million households, sequestered carbon, and produced an extra 500,000 tons of grain per year."[15] And Chris Reij of African Re-greening Initiatives writes that "trees have even radically reduced conflict between herders and farmers in the re-greened areas of Niger, as the 'resource cake' has expanded." Agroforestry is much more than planting trees; it is a gateway to increased gender equality, reduced conflict, and increased community self-sufficiency.

Sidebar 5. Farming Grass and Livestock

Grass farming, a term coined by Zimbabwean farmer Allan Savory, turns conventional livestock grazing on its head. Grazing livestock on a farm's grassland, instead of on externally sourced feed, is a natural way to replenish soil organic matter and sequester carbon. Livestock manure acts as a natural fertilizer, and rotating the areas on which the animals graze helps form an even layer of biomass throughout the farm that decomposes into healthy organic matter.

This method of raising livestock aims to "highlight the symbiotic relationship between large herds of grazing animals, their predators, and the grasslands." In other words, grass farming views livestock as an instrument to heal the land, rather than as a destructive force upon it.

Instead of treating farmland as a means of producing goods, grass farmers view their land as an entire ecosystem. They revolve their whole production chain around healthy, natural grass and believe that in addition to providing healthy and plentiful nourishment, a truly sustainable farm should support and enrich the local food system.

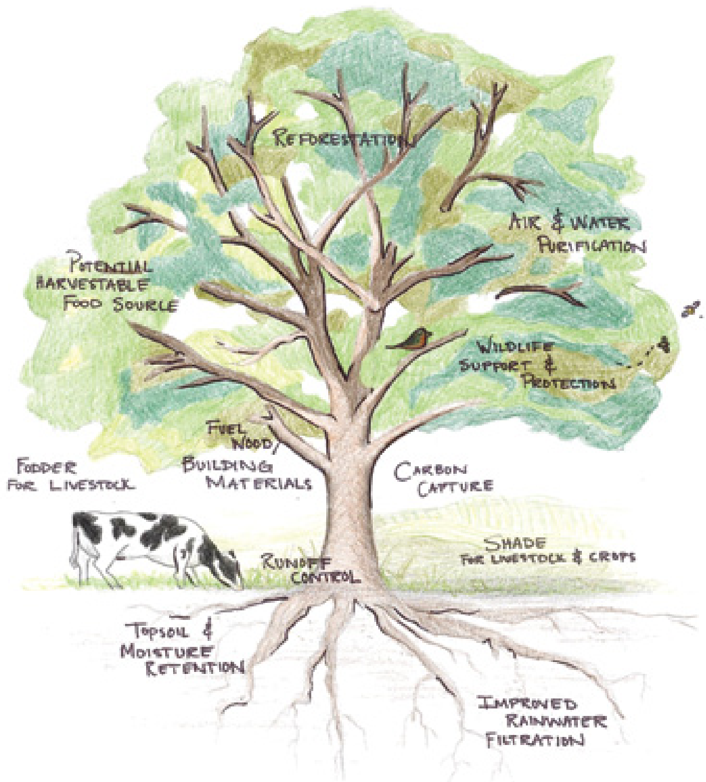
All of the livestock on Virginia's Polyface Farms, owned and run by U.S. agricultural activist Joel Salatin, continually mow, fertilize, and replenish the grass under their hooves—while in turn nourishing themselves. This natural process results in healthier animals and healthier land, both of which are critical tools to combat climate change.

Over the past 40 years, the United States has lost much of its topsoil, largely as a result of destructive, monocultural farming practices that deplete soil nutrients, require intensive application of chemical fertilizers and pesticides, and involve the running of heavy equipment over fragile soil—all to grow government-subsidized commodities such as corn, soybeans, rice, cotton, and sugar cane. Yet topsoil contains important organic matter that is essential for capturing CO_2 and nitrogen from the air and sequestering it in the ground. And strong topsoil retains more water for longer, helping plants survive during dry spells and also preventing floods, soil erosion, and harmful chemical runoff.

Overgrazing of livestock contributes to much of the world's land degradation and even desertification; as a result, many people believe that any form of raising livestock is environmentally destructive. But grass farmers such as Salatin and Osmond Mugweni, Director of the Njeremeto Biodiversity Institute in Zimbabwe, believe otherwise. According to Mugweni, "the *management* of animals is the problem, not the animals."

Source: See Endnote 7 for this section.

Figure 1. The Benefits of Agroforestry



Stephanie Buglione

Urban Farming

In Mexico City in 2007, three women working under the name Sembradores Urbanos, or Urban Cultivators, founded the city's first urban agriculture demonstration center. They wanted to teach residents how to safely and efficiently grow food in the city, while also reusing some of the 12,000 tons of waste generated by the city each day. Agricultural production in Mexico City, as in many cities, has developed within a chaotic and unofficial structure, often violating government regulations. Even with a population of around 8.9 million and climbing, Mexico City now boasts a vibrant urban agriculture system that ranges from keeping pigs, chickens, rabbits, and other livestock to managing Aztec-style *chinampas* or "floating gardens" of flowers, maize, beans, squash, and other plants.

Many of the resources produced in rural areas support urban lifestyles. Rural land and water resources produce vast amounts of food for the world's cities. But many cities are now producing their own food, and in some cases they are even providing seeds or plants for rural farmers, reversing the traditional city-country relationship.

By using urban space to farm, urban farmers are helping to mitigate greenhouse gas emissions from rural land clearing, as well as from transporting food long distances. Urban dwellers can increase their food security by producing food themselves, and greener urban landscapes help to temper the effects of extreme weather, for instance by absorbing excess rainfall or providing shade during heat waves.

"Urban agriculture has become a lifeline in a time of upheaval and profound change," write Nancy Karanja and Mary Njenga, researchers at Urban Harvest in Nairobi. "The appearance and staggering growth of Nairobi and other sprawling cities in sub-Saharan Africa—annual urban growth rates in the region are approaching 5 percent—are presenting new challenges to their inhabitants as well as to governments, [nongovernmental organizations], and the world at large."

Nairobi's Kibera slum is the largest in sub-Saharan Africa, with 700,000 to 1 million inhabitants living in an area about half the size of New York City's Central Park. With training from Urban Harvest, residents have been raising fast-growing vegetables such as amarynth and spider plant on vacant plots of about 50 square meters. A French organization called Soladarites trained women's groups to start sack gardens throughout the slum. Tall sacks are filled with dirt, and vegetables are grown on different levels by poking holes in the bags and planting seeds.

More than 1,000 small farmers are now growing food in Kibera. Urban farming kept residents from going hungry during the post-election violence in 2007 and 2008, when blockades prevented any food from entering into the slum. It could also insulate Kibera from climate change-related food shortages affecting Kenya, such as drought in rural areas.

Another important urban farming initiative is the international network known as Resource Centres on Urban Agriculture and Food Security (RUAF), which works to reduce urban poverty and improve food security and environmental management through agriculture. RUAF cooperates with local governments, nongovernmental

organizations, universities, farmers' organizations, and private enterprises in Africa, Asia, and Latin America. In Bangalore, India, RUAF trains urban residents to grow vegetables in the small spaces available to them—such as yards, terraces, and schools—and to recycle kitchen waste as compost and collect rainwater for their gardens. On the outskirts of Bangalore, residents are establishing farm plots, the produce from which is sold in inner-city farmers' markets.

And urban farming is certainly not limited to developing countries. Along the East River in Brooklyn, New York, Eagle Street Rooftop Farm is an organic vegetable farm on a 1,800-square-meter warehouse rooftop. Urban farmers run a farmers' market and deliver produce to area restaurants. Green roofs such as Eagle Street Rooftop Farm's reduce the total surface area in a city that absorbs heat from the sun in summer, and they insulate buildings from the cold in winter. This reduces energy consumption and, thus, greenhouse gas emissions.

With exponential population growth and urbanization, the expansion of both food production and cities is inevitable. A holistic approach that integrates agriculture with urban areas will reduce the contribution that urban development has on climate change, and will reduce the strain that a changing climate will place on limited resources.

Bernard Pollack

Author Danielle Nierenberg visits an urban gardening project in Kibera, Kenya—Africa's largest urban slum.

Adapting Agriculture to a Warming Planet

Many of the same approaches to agriculture that have the potential to mitigate climate change also create farming systems that adapt to, and are therefore more resilient to, the climate's projected shifts and volatility. Because they incorporate local climate and ecosystem characteristics into their growing practices, adaptive systems can adjust to regional climate variations and can respond better to resource limitations, such as water shortages.[1] Through the diversity of their plants and animals, these systems are more resistant to the pests and diseases that could become more common with warmer temperatures.[2] And they are generally more able to cope with the stress of uncertainty that comes with extreme weather events and shifting climates.

Over millions of years, ecosystems have adapted to be in balance with local resources and climate conditions. The more that human activity has altered a given ecosystem, the more vulnerable it generally is to shocks such as those brought on by climate change. By employing land-management practices that mimic the natural balance and adapt to changes in this balance, farmers can enhance the resilience of entire ecosystems and, in turn, promote resilience on their farms.[3] Three practices that can support climate adaptation are: green manure/cover cropping, improved water conservation and recycling, and preserving biodiversity and indigenous breeds.

Green Manure/Cover Cropping

One adaptive technique that has been practiced for centuries, but that is gaining new attention in the face of climate change, is growing green manure (cover crops) in fields where no other crop is being grown. Farmers often leave one or more fields fallow, or unused, to help rid it of crop-damaging pests or funguses and to rest its soil for the next crop. But leaving a field bare makes it vulnerable to wind and water erosion, as well as harmful weeds that deprive soil of nutrients, negating any benefits gained by not planting a crop. Farmers plant cover crops to avoid this erosion and replenish the soil with key nutrients such as nitrogen or potassium.[4] A cover crop's residues—the parts of the plant left over after harvesting—are known as green manures, and they act to return even more nutrient content to the soil.[5]

Green manure/cover crops include any plant (including trees, bushes, and vines) that can be used to improve soil fertility. Examples include leguminous plants such as cowpeas and scarlet runner and tropical trees that have large volumes of leaves that deteriorate quickly due to tropical conditions and therefore replenish organic material in the soil. Green manure/cover crops can help bring nutrients up to the soil surface, improve the soil's ability to retain water, increase nutrient content and diversity, and improve the soil's softness and permeability.

Green manure was used to replenish cropland for some 5,000 years before the invention of chemical fertilizers. This method of maintaining soil fertility can be continued today in the places where famine is most prevalent due to lack of soil fertility.

More than 1 million farmers, mostly in Central and South America, now rely on green manure/cover crops, and this approach is increasingly used in Africa and Asia.[6] (See Sidebar 6.) In Africa, many farmers use a three-tiered system of cover cropping to keep their soil fertile. The first tier is a layer of local leguminous plants such as cowpeas and scarlet runner. The second tier

Sidebar 6. The Use of Green Manure/Cover Crops Around the World

From Mali to Paraguay to North Korea, innovative farmers are using green manure/cover crops as a way to adapt to climate change and provide food in the hungriest parts of the world.

Mali

The Dogon people of Mali in western Africa are pioneers in green manure/cover crops. They have created their own simple three-tiered system: leguminous trees such as various forms of acacias; rotating millet crops with cowpeas, Bambara nuts, fonio, and peanuts; and allowing cattle herders to graze overnight for an extra source of manure.

This system has allowed Dogon farmers to harvest almost two tons of millet per hectare a year—nearly three times the average in the Sahel, despite the increased droughts and desertification of land in the region. The increased yields have been sustained over time, and in some cases have improved as soils get richer. Resorting to millennia-old farming practices has made the Dogon less reliant on environmentally harmful artificial fertilizers and has given them a sense of food security in one of Africa's most drought-prone areas.

Paraguay

In eastern Paraguay, the hot and humid climate turns the soil into hard, impermeable dirt and plagues farmers with weeds that compete with their crops for nutrients. During the summer months, Paraguay's soils can reach 60°C, but, according to the FAO, soil temperatures above 35°C significantly limit crops' ability to absorb water and nutrients. Planting cover crops amid food crops creates a microclimate at the plant level, providing much-needed shade for crops, reducing the evaporation of water from the soil, and allowing organic matter to decompose into the soil instead of drying out on the soil's surface.

Paraguay's humidity also creates huge weed problems, which cover cropping greatly alleviates. In the Department of Paraguarí, in southern Paraguay, soil scientists who planted *mucuna* or sunhemp as cover crops reduced weed infestations by 95 percent and 93 percent, respectively. Planting mucuna reduced the number of times farmers needed to hoe to get rid of weeds to just once per year; in plots without cover crops in the region, farmers typically need to hoe three times per year.

North Korea

In North Korea, farmers often combine their rice and potato crops to boost the productivity of each and preserve their soils. To break up soil for potatoes to grow, farmers normally need to intensely till their soils and disrupt their entire topsoil, where many critical nutrients are found. But in a potato-rice crop rotation, rice serves as the cover crop, keeping soil permeable, holding the topsoil in place, and reducing the need for intense mechanical tilling. Farmers can sow potato seeds into the soil under the mulch cover formed by the residues of the previous rice crop. The potatoes grow through the rice straw and are harvested within three months, and another crop of rice is planted immediately afterward. This system can produce 25 tons of potatoes and 7.5 tons of rice in a single hectare, and also reduce the need for chemical inputs, manual labor, and mechanical tilling.

—*Katie Spoden*

Source: See Endnote 6 for this section.

contains staple food crops such as cassava, maize, and sorghum. The third tier is dispersed trees, providing a light shade from the hot, midday sun to improve soil fertility and crop longevity. By incorporating edible, protein-rich crops into the cover cropping system instead of plowing all cover crops back into the ground, these farmers are able to boost their own nutritional intake as well as their soil's.

The cover crops' biomass, or leftover vegetation that decomposes into the soil, also increases carbon sequestration, contributing to climate mitigation as well as adaptation. And unlike commercial fertilizers and weed-reducing herbicides, there are no transportation costs, capital investment, or excess greenhouse gas emissions associated with green manure/cover crops. By adopting this technique, subsistence farmers can improve

income, reduce labor, boost their nutrition, and build up rather than deplete natural resources.[7]

Improving Water Conservation and Recycling

Because climate change will reduce the amount of water available to farmers (through shifts in both groundwater and rainwater availability), another way to adapt to climate change is to improve water conservation on farms. Not only will conserving water help farmers continue to produce food and generate income, but it will reduce the energy required to pump, transport, and distribute water to places where it is not readily or sufficiently available. Water conservation thus plays an equally important role in helping to reduce emissions and mitigate the onset and severity of climate change.

Bernard Pollack

Farmers in Bamako, Mali, learn to be better stewards of the environment through water conservation.

Globally, water scarcity as a result of increased flood damage, reduced water flow, and seasonal drought could lower world cereal production by an estimated 3 billion tons by 2050.[8] Significant amounts of water are needed to produce the world's food. For example, it takes an estimated 3,000 liters of water to meet a person's daily dietary needs of about 1 liter per calorie.[9] On average, agriculture uses 1,500 liters of water to produce one kilogram of wheat, and it takes 5,000 liters of water for one kilogram of rice.[10]

If current irrigation methods are used to meet the FAO's suggested 70 percent increase in food production by 2050, freshwater resources would need to increase by 11 percent.[11] But by using irrigation techniques that conserve water, coupled with agricultural practices that require less of it, farmers can produce more food in spite of resource and climate stresses.

The biggest potential to get more food from each drop of water is in rainfed fields, common to sub-Saharan Africa. Only 4 percent of the region's cropland is irrigated.[12] The IPCC projects that between 75 million and 250 million Africans will be exposed to increased water stress due to climate change.[13] Agriculture will have to cope with the drier conditions, and expansion of efficient irrigation is needed. Low-cost, low-tech innovations in getting moisture to the roots of crops are helping small-scale African farmers improve their yields.

Drip irrigation systems, for example, deliver precise doses of water directly to the roots of plants through perforated pipes or tubes. Affordable drip irrigation kits are now becoming available in rural African markets. Different systems can meet farmers' different water needs: $5 bucket kits, $25 drum kits, and $100 shiftable drip systems are available. An organization called Solar Electric Light Fund (SELF) is making solar-powered micro-irrigation drip systems available in Benin. Drip systems often double the productivity achieved per drop of water over conventional irrigation.

In Zambia, International Development Enterprises (IDE) is bringing treadle pumps to farmers. The foot-operated water pump is used by 2.3 million poor farmers in the developing world, including some 250,000 in sub-Saharan Africa. The pump makes it easier for impoverished small-scale farmers to irrigate larger pieces of land, diversify their crops, and improve crop yields.

Water conservation is not confined to rural farmland. With limited resources at hand, many poor urban farmers use wastewater to both irrigate and fertilize their crops. Although wastewater can carry health risks, including pathogens and contamination from heavy metals, it also provides a rich—and free—source of fertilizer. In Accra, Ghana, the International Water Man-

agement Institute has been working with urban farmers to improve management of wastewater irrigation. They have improved sanitation services and introduced simple filtering methods to make wastewater safe for farming.

Rainwater catchment systems help urban farmers make good use of the vast amounts of rain that fall onto city rooftops. This practice curbs consumption of valuable water resources. But it also reduces runoff, which is important for cities such as Dhaka, Bangladesh, which experiences regular flooding due in part to poor urban infrastructure. Bangladesh is expected to experience an increase in the frequency and intensity of storms from climate change. Urban farms increase the amount of permeable cover, allowing more rainwater to filter into aquifers instead of being funneled into storm drains.

Making the best use of rainwater, no matter how unpredictable, reduces the need for farmers to irrigate. Conservation tillage methods that leave the soil intact, timely weeding, mulching, and planting vegetative barriers all help to maximize rainwater stored in the soil and plants as moisture. Rainwater collected in small earthen dams and other rainwater harvesting systems can be stored and used for irrigation when it is needed.

Preserving Biodiversity and Indigenous Breeds

Preserving biodiversity, including crops, insects, microorganisms, domestic animals, and wildlife, is another way that farmers can prepare for and adapt to climate change. The planet's biological diversity, from insects to large mammals, is being lost at an alarming rate—between 1,000 and 10,000 times higher than the natural rate, according to the International Union for Conservation of Nature. This loss of biodiversity will reduce farmers' and communities' capacities to cope with climate-related stresses.

Genetically diverse farms function better as a system and make better use of ecosystem services from the surrounding environment. "[Like] a well-balanced stock portfolio, genetic diversity makes food production more resilient in the face of threats such as famine, drought, disease and the emerging challenge posed by climate change," says Irene Hoffmann of FAO's Agriculture and Consumer Protection Department. "Cataloguing and conserving this diversity will allow us to maintain and deploy the widest possible portfolio of genetic resources in order to increase the resilience of our food supply and develop improved breeds to help sustain food production."[14]

Like water conservation, preserving biodiversity is another practice that both adapts to and mitigates the effects of climate change. It reduces greenhouse gas emissions from cutting down and burning existing plants; it reduces energy use from transportation of foreign breeds around the world; and it reduces the need for the chemical- and energy-intense agricultural practices that are often necessary to sustain monocultural farms, such as pesticide use or heavy soil tillage.

An effective way to preserve biodiversity is to raise indigenous crop species and animal breeds. Indigenous varieties have greater genetic diversity, are often more resistant to pests, and through generations of evolution have assimilated to local climate patterns, such as when the last frost, rainy season, or pest invasions typically occur.[15] (See Table 3.) The Pomme du Sahel fruit tree, for instance, is one of the few hardy tree species that can survive and produce fruit on the windswept and heavily degraded soils of the African Sahel. Indigenous vegetables need fewer chemical and water inputs to grow, making them more affordable to the poorest farmers. They also boast adaptability to harsh environments and have a high nutritional value.

Indigenous crops are often thought of as weeds, and have been largely neglected by agricultural research and investment. But they are regaining attention, and the seeds of indigenous vegetable crops are being made more widely available, with improvements in quality. Traditional culinary traditions are being revived that include indigenous vegetables, and more diverse diets are improving nutrition. Indigenous varieties of livestock, which can withstand local climate stresses, are also gaining focus. Gene banks have been created to conserve crop diversity and to act as a resource to plant breeders and farmers looking for ways to adapt farms to climate changes.

Researchers from two leading agricultural research organizations, the International Center

Table 3. Using Indigenous Crops and Livestock to Adapt to Climate Change

Indigenous Vegetable	Native Region	Climate Change Advantages
Soursop	Central and South America	• Nearly continuous growing season
Pomme du Sahel	Western Sahel desert	• Can survive degraded, windswept soils • Helps restore health of damaged soil • Easy income for farmers
Shea tree	Sudan and Guinean savannas; The Sahel	• Drought resistant • Fireproof bark • Fodder for sheep and goats • Intercropping helps prevent wind erosion
Imbe	Africa	• Hardy • Drought and salt tolerant
Safou "Butterfruit"	West and Central Africa	Good for intercropping and agroforestry
Red Maasai sheep	East Africa	• High natural disease and parasite resistance • Adapted to semi-arid environments • Adapt well to climate change • Drought tolerant
N'Dama cattle	West Africa	• High natural disease and parasite resistance, especially to trypanosomiasis (African cattle disease) • Heat tolerant • Adapted to the harsh environment

Source: See Endnote 15 for this section.

for Tropical Agriculture and the Consultative Group on International Agricultural Research (CGIAR), reported in early 2012 that the cassava plant will fare particularly well under the predicted impacts of climate change. They found that cassava, a perennial shrub native to South America but grown extensively throughout Africa, will be able to cope with temperature increases of up to 2°C, as well as changes in rainfall patterns, in sub-Saharan Africa through 2030.

Cassava is consumed by about 500 people each day and is the second most important source of carbohydrates in sub-Saharan Africa. The research found that cassava could even be more well-suited to the region's environment than it is now (by as much as 17 percent) and will outperform many other staple crops. In the study, the suitability of beans to the future sub-Saharan climate dropped by as much as 16 percent, that of potatoes by as much as 14 percent, and that of bananas by 2.5 percent.[16]

For millennia, pastoralists throughout the world have been breeding livestock that are well adapted to local conditions. The animal gene pool that exists within the multitude of less well-known livestock breeds throughout the world contains valuable resources that could be vital for food security with the advance of climate change. Understanding and preserving these breeds could be useful in helping communities adapt to changing environments and climates

in the coming decades. But the global diversity of livestock breeds is rapidly narrowing: according to the FAO, 21 percent of the world's livestock breeds—1,710 breeds—are in danger of extinction.[17]

After missionaries introduced large, mixed-breed cattle to Samburu, Kenya, 15 years ago, livestock keepers there began replacing their indigenous Zebu cattle with these mixed breeds. These breeds produced more, but they were not as hardy as the natives. The Zebu breeds have evolved in Kenya's dry conditions, and can walk 40 kilometers and back for food and water. Anikole cattle are another breed indigenous to East Africa that are known for their ability to survive in extremely harsh, dry conditions. Introduced breeds cannot tolerate the long distances or the heat without much water.

Kenya is expected to experience increasing drought from climate change, and the loss of indigenous herds of cattle has left pastoralists more vulnerable. The newer breeds are more susceptible to African pests and diseases. When pastoralists adopt these breeds, they must then spend money on pesticides and antibiotics to keep cattle healthy. But governments and agribusiness continue to promote cross-breeding of native livestock breeds with commercial breeds that were designed to gain more weight and produce more milk.


TREEAID

A woman in Burkina Faso processes collected Shea tree nuts into Shea butter.

It is important for farmers to maintain a diversity of indigenous crops and animals that will perform well in the predicted climate changes; but it is just as important to promote and invest in research on indigenous and exotic crops and animals, which will help farmers decide what to grow and how to reduce uncertainty regarding their incomes and yields.

Scaling Up Climate-Friendly Agriculture

The six sustainable agriculture practices presented in this report all help to make farmland, farmers, and entire communities more resilient to the dramatic effects of climate change. Many of these practices are inexpensive to adopt and do not require extensive infrastructure. But because they are relatively labor intensive to implement, they are most appropriate for small-scale agricultural operations, rather than industrial agriculture. Smallholder farmers currently produce half of the world's food, including as much as 90 percent of the food grown in Africa, and 41 percent of the food grains grown in India.[1]

The FAO estimates that, by adopting more-sustainable approaches, agriculture in developing countries has the potential to contribute 70 percent of agriculture's technical mitigation of climate change.[2] But even large-scale industrial agriculture can learn crucial lessons from these practices. Many of these innovations have the potential to be replicated, adapted, and scaled up for application on larger farms, helping to improve water availability, increase diversity, and improve soil quality, as well as mitigate climate change.

Agriculture provides income for at least 1.3 billion people worldwide and is the main source of livelihood for an estimated 86 percent of the 3 billion rural people living in developing countries.[3] Meanwhile, climate change has already begun to affect nearly every place on Earth, mostly in negative ways, and will have a disproportionately large impact on some of the world's most impoverished and vulnerable communities, such as island nations or villages bordering Africa's rapidly expanding Sahara Desert. Applying agricultural solutions to mitigate and adapt to the impacts of climate change is therefore a global, and monumental, task.

But while the challenge is global in scale, it requires participation, collaboration, and innovation from all levels of society, from the backyard fish farmer in Indonesia to the Director-General of the FAO. "We must create an enabling environment for all stakeholders, from small farmers to national governments, to invest in the economic and environmental resiliency of their land resources," argues Professor Tekalign Mamo of the Ethiopian Ministry of Agriculture.[4]

At the grassroots level, farmer-led re-greening projects in southern Niger demonstrate the power of individual action to combat environmental degradation. Farmers began planting trees on their land in the late 1980s after decades of recurring droughts and food crises, in an effort to rebuild the health of their dried and hardened soils. By 2005, U.S. Geological Survey satellite images showed that farmers had independently planted 200 million new trees, producing $270 million of value that could feed an extra 2.5 million people in times of emergency or food shortage.[5] By using traditional farming practices such as sowing crops in pits to maximize soil fertility, these farmers made a bigger impact on their local ecosystem than did some of the largest aid organizations working in the region.

This is not to say that governments or multilateral organizations do not also contribute to local resilience. In January 2012, the European Commission and the FAO announced a three-year, $7 million project to promote "climate-smart" approaches to agriculture in Malawi, Vietnam, and Zambia.[6] These three countries are expected to be affected significantly by climate change, and they all have relatively narrow eco-

Table 4. Selected Initiatives to Achieve Food Security in the Face of Climate Change

Australia	Real-time information and forecasting for rainfall, temperature, humidity, and drought are helping farmers prepare for the increased volatility of farming amid climate change. The Bureau of Meteorology provides Seasonal Climate Outlooks with forecasts and risk assessments, three-month weather predictions, and six-month El Niño Southern Oscillation predictions.
Bangladesh	Investing $7.8 billion, the Bangladesh Country Investment Plan sets out 12 priority investment programs to improve food security and nutrition, with an emphasis on improving land tenure and water rights, access to credit and other financial resources, and empowering women in household food production.
Brazil	To meet its target of reducing the deforestation rate in the Amazon 80 percent by 2015, Brazil has established ecological and economic zoning plans to balance the production of major agricultural commodities, such as sugar cane and palm oil, against needs for local food security and environmental conservation. Brazil's Development Bank has also restructured its lending guidelines to be conditional on environmental protection measures.
China	Increased research and development spending by 10 percent annually since 2001 has shifted an estimated 7 billion people out of poverty for every $1,500 of investment. The country's Plan for the Construction of Protective Cultivation Projects will rebuild soils and grasslands covering 2.7 million hectares between 2009 and 2015, enhancing soil resistance to drought and saving 1.7–2.5 billion cubic meters of irrigation water.
Ethiopia	The Productive Safety Net Program broadens food security by giving chronically food-insecure households cash and food in exchange for participation in labor-intensive public works projects that improve soil quality, water supply, ecological condition, infrastructure, and social services. The program has graduated approximately 1.3 million individuals from food security and rehabilitated 9 million hectares of land.
India	The Mahatma Gandhi National Rural Employment Guarantee Act provided jobs for over 50 million rural households in 2010–11, and requires that one-third of these jobs be provided to women. Over 80 percent of the projects providing employment under the act have contributed to rebuilding India's natural resource base in some way.
Kenya	The East Africa Dairy Development Project is a regional industry development program in Kenya, Uganda, and Rwanda, implemented by Heifer International, the International Livestock Research Institute, Nestlé, and other international partners. The project increases access to markets and training, and emphasizes reducing post-harvest losses by developing 27 collection hubs to store and chill milk.
United Kingdom	The Waste Resources and Action Programme (WRAP) works with businesses, individuals, and communities to reduce food waste, diverting 670,000 tons of food waste since its establishment in 2001, and saving about $950 million per year.
Vietnam	In response to the predicted 12–14 percent decline in global rice production by 2050 due to climate change, Vietnam implemented an Integrated Crop Management (ICM) program in 2002. By 2004, 103,000 farmers in 13 provinces were using ICM to produce higher grains yields with significantly reduced use of nitrogen fertilizer, seeds, water, and pesticides, leading to higher profits. Farmers are now using ICM on more than 1 million hectares.

Source: See Endnote 11 for this section.

nomic bases, meaning that a large part of their populations and economies center around agriculture. According to the FAO, "climate-smart agriculture sustainably increases productivity, resilience, and reduces greenhouse gas emissions, while enhancing the achievement of national food security and development goals."[7]

This type of project fits with the FAO's goal of positioning agriculture as a key solution to climate change.[8] Agriculture has historically been left out of climate policy, in part because of the sheer area that agriculture covers, the variety of farming systems operated, and the number of farmers involved in the sector—as well as the expense or labor required to measure, report, and verify agricultural techniques that might combat climate change.[9]

Aridité Prospère

An Aizen (*Boscia senegalensis*) tree, planted 10 years ago, continues to thrive in Zinder, Niger.

To encourage policymakers to include agriculture in their climate policies and programs, the CGIAR Research Program on Climate Change, Agriculture and Food Security published a report in March 2012 titled *Achieving Food Security in the Face of Climate Change.*[10] The report highlights seven priority actions for government and institutional leaders to consider when planning agricultural solutions to climate change in the coming decades. These include developing programs that target populations and regions that are most vulnerable to climate change, fostering healthy and sustainable eating habits among the public, and reducing loss and waste in food systems by improving both national infrastructure systems and household habits. These and other programs are being implemented in places as diverse as Australia, Brazil, the United Kingdom, and Vietnam.[11] (See Table 4.)

The CGIAR report also urges policymakers to significantly raise the level of global investment in sustainable agriculture and food systems over the next decade, noting that the tangible benefits of investments in agricultural development often take many years to materialize, while the predicted effects of climate change are already being seen.

Agriculture plays an undisputed role in human-caused climate change, contributing an estimated 25 to 30 percent of all greenhouse gas emissions.[12] But local farmers around the world are utilizing relatively simple innovations—including soil fertility improvements, agroforestry, and urban farming—that help mitigate farming's impacts on planetary warming. At the same time, agriculture can be sophisticated and varied enough to adapt to the effects of climate change. By tapping into the multitude of climate-friendly farming practices that already exist—such as growing cover crops on unused land, using water-saving irrigation pumps, and planting indigenous and traditional crop varieties—agriculture can continue to provide food for the world's growing population.

Although the innovations presented here have tremendous potential for small-scale farmers, they also need to be at the center of both climate change and sustainable development discussions. If agriculture is to play an effective role in the global fight against climate change, agricultural practices that mitigate or adapt to climate change—including the diverse approaches discussed here—will need to receive increased research, attention, and investment in the coming years.

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The good news is that agriculture, when done sustainably, holds an important key to mitigating climate change. The United Nations estimates that the global agricultural sector could potentially reduce and remove 80 to 88 percent of the carbon dioxide that it currently produces. Practices such as using animal manure rather than artificial fertilizer, planting trees on farms to reduce soil erosion, and growing food in cities all hold huge potential for shrinking agriculture's environmental footprint and mitigating the damaging effects of climate change.

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