WORLDWATCH REPORT 179

Mitigating Climate Change

Through Food and Land Use

SARA J. SCHERR AND SAJAL STHAPIT

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On the cover: A farmstead in Nepal framed by ripening rice.
Photograph by Sajal Sthapit

The report is also available at www.ecoagriculture.org/publications.php.

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Acknowledgments

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Ecoagriculture Partners (www.ecoagriculture.org) is an international non-profit organization dedicated to supporting people in agricultural landscapes to produce food and enhance their livelihoods while protecting biological diversity and ecosystem services. Through collaboration with ecoagriculture innovators all over the world, Ecoagriculture Partners works to better understand the principles, practice, and tools for ecoagriculture; link people and organizations who are practicing ecoagriculture; and promote markets and policy action that encourage and sustain ecoagriculture landscapes.

Summary

Land makes up a quarter of Earth's surface, and its soil and plants hold three times as much carbon as the atmosphere. More than 30 percent of all greenhouse gas emissions arise from the land use sector. Thus, no strategy for mitigating global climate change can be complete or successful without reducing emissions from agriculture, forestry, and other land uses. Moreover, only land-based or "terrestrial" carbon sequestration offers the possibility today of large-scale removal of greenhouse gases from the atmosphere, through plant photosynthesis.

Five major strategies for reducing and sequestering terrestrial greenhouse gas emissions are:

- **Enriching soil carbon.** Soil is the third largest carbon pool on Earth's surface. Agricultural soils can be managed to reduce emissions by minimizing tillage, reducing use of nitrogen fertilizers, and preventing erosion. Soils can store the carbon captured by plants from the atmosphere by building up soil organic matter, which also has benefits for crop production. Adding biochar (biomass burned in a low-oxygen environment) can further enhance carbon storage in soil.
- **Farming with perennials.** Perennial crops, grasses, palms, and trees constantly maintain and develop their root and woody biomass and associated carbon, while providing vegetative cover for soils. There is large potential to substitute annual tilled crops with perennials, particularly for animal feed and vegetable oils, as well as to incorporate woody perennials into annual cropping systems in agroforestry systems.
- **Climate-friendly livestock production.** Rapid growth in demand for livestock products has triggered a huge rise in the number of animals, the concentration of wastes in feedlots and dairies, and the clearing of natural grasslands and forests for grazing. Livestock-related emissions of carbon and methane now account for 14.5 percent of total greenhouse gas emissions—more than the transport sector. A reduction in livestock numbers may be needed but production innovations can help, including rotational grazing systems, manure management, methane capture for biogas production, and improved feeds and feed additives.
- **Protecting natural habitat.** The planet's 4 billion hectares of forests and 5 billion hectares of natural grasslands are a massive reservoir of carbon—both in vegetation above ground and in root systems below ground. As forests and grasslands grow, they remove carbon from the atmosphere. Deforestation, land clearing, and forest and grassland fires are major sources of greenhouse gas emissions. Incentives are needed to encourage farmers and land users to maintain natural vegetation through product certification, payments for climate services, securing tenure rights, and community fire control. The conservation of natural habitat will benefit biodiversity in the face of climate change.
- **Restoring degraded watersheds and rangelands.** Extensive areas of the world have been denuded of vegetation through land clearing for crops or grazing and from overuse and poor management. Degradation has not only generated a huge amount of greenhouse gas emissions, but local people have lost a valuable livelihood asset as well as essential watershed functions. Restoring vegetative cover on

degraded lands can be a win-win-win strategy for addressing climate change, rural poverty, and water scarcity.

Agricultural communities can play a central role in fighting climate change. Even at a relatively low price for mitigating carbon emissions, improved land management could offset a quarter of global emissions from fossil fuel use in a year. In contrast, solutions for reducing emissions by carbon capture in the energy sector are unlikely to be widely utilized for decades and do not remove the greenhouse gases already in the atmosphere. To tackle the climate challenge, we need to pursue land use solutions in addition to efforts to improve energy efficiency and speed the transition to renewable energy.

Yet so far, the international science and policy communities have been slow to embrace terrestrial climate action. Some fear that investments in land use will not produce "real" climate benefits, or that land use action would distract attention from investment in energy alternatives. There is also a concern that land management changes cannot be implemented quickly enough and at a scale that would make a difference to the climate.

But most of these concerns are misplaced or can be addressed effectively now. While many land-use activities are not strictly "permanent," there are numerous ways to ensure that commitments to reduce or offset emissions are strictly met, such as by using large-area programs and investing in reserve areas for insurance. Carbon sequestration through interventions such as agroforestry do not present any "leakage" problems, and the risks of leakage from avoided deforestation can be addressed through large-scale monitoring and project screening.

Investments to overcome major barriers to farmer adoption of climate-friendly land use systems (such as lack of technical assistance, credit, or planting materials) are clearly "additional," even when the interventions are themselves profitable to land users, and land uses with long-term profitability are far more permanent. Great strides have been made in devising methods for monitoring land-use carbon at field scales for many diverse practices and components of the landscape (soils, grasses, trees, animal wastes, etc.), and methods for integrated landscape-wide carbon assessment will soon be available.

While there are institutional challenges to rapidly scaling up climate-friendly practices in diverse rural areas of the world, expertise can be tapped to overcome them—in rural development agencies, farmers' organizations, nongovernmental organizations, and private agricultural businesses. Institutional platforms exist in many countries to promote sustainable land management on a large scale. Community land use planning and action models are widely implemented and can be strngthened and adapted to address climate change mitigation as well as adaptation.

The food industry is beginning to mobilize investments for climate action in its agricultural supply chains, in response to anticipated consumer demand and regulation. National policies can re-shape public investments and subsidies to support climate-friendly agriculture and land use. Indeed, the benefits for food security, rural livelihoods, and watershed and biodiversity protection that accompany wise, locally appropriate investments in land use will expand political support and new coalitions for climate action generally. They will be an attraction, not a distraction.

To tap the full potential of land use mitigation, six principles for action are recommended:

1. Include the full range of terrestrial emission reduction, storage, and sequestration options in climate policy and investment;
2. Incorporate farming and land use investments in cap-and-trade systems;
3. Link terrestrial climate mitigation with adaptation, rural development, and conservation strategies;
4. Encourage large, area-based programs;
5. Encourage voluntary markets for greenhouse gas emission offsets from agriculture and land use;
6. Mobilize a worldwide, networked movement for climate-friendly food, forest, and other land-based production.

Appreciating Terrestrial Carbon

Few people realize that Indonesia is the third largest emitter of greenhouse gases on the planet, after the United States and China. This is because the bulk of Indonesia's emissions—as much as 85 percent—do not come from widely publicized sources such as polluting factories or gas-guzzling vehicles.[1*] Instead, they are related to land use: the clearing of land for agriculture and infrastructure, and the burning of forests and peatlands.

Indonesia emits 3 billion tons of carbon dioxide equivalent annually, or about half the yearly emissions of the United States.[2†] Although the country covers only about one-fifth the U.S. land area, its rich tropical vegetation and peatlands store enormous volumes of carbon in branches, roots, leaves, and soil.[3] When this carbon is released into the atmosphere, it heats the planet just as surely as coal-fired power plants or combustion engines do.

Forest fires are the main driver of deforestation in Indonesia, followed by illegal logging and rising worldwide demand for palm oil, an ingredient used in food, cosmetics, and biofuel.[4] Elsewhere in Southeast Asia, as well as in the Amazon and Africa, the main driver of forest loss is the conversion of new land on which to grow commodity crops and graze livestock. These agricultural activities have a significant impact on the global climate. New Zealand's millions of sheep and cattle, for example, are responsible for nearly a third of the country's greenhouse gas emissions.[5] In the U.S. Midwest, intensive soil tillage, erosion, and fertilization are a major source of these releases.[6]

It is increasingly clear that no strategy for mitigating global climate change can be complete or successful without addressing the widespread emissions from agriculture and forestry, also known as the land use sector. Yet so far, land-based, or "terrestrial," carbon has been largely ignored in climate mitigation initiatives, including at the highest levels. This has grave implications not only for the success of global efforts to head off dangerous climate change, but also for the future of the planet as we know it.

Sajal Sthapit

Monsoon rains have led to landslides and soil erosion in these deforested hills of Nepal.

Land makes up a quarter of Earth's surface, and its soil and plants hold three times as much carbon as the atmosphere does. About 1,600 billion tons (5,872 billion tons of carbon dioxide equivalent) of this terrestrial carbon is in the soil as organic matter, and some 540–610

* Endnotes are grouped by section and begin on page 40.

† All measurements are expressed in metric units unless indicated otherwise.

billion tons is in living vegetation, such as long-living forests, grasses, and palms.[7] Although the volume of carbon on Earth's surface and in the atmosphere pales in comparison to the many trillions of tons stored deep under the surface in sediments, sedimentary rocks, and fossil fuels, terrestrial carbon is crucial to climate change and life due to its inherent mobility.[8]

Carbon, it appears, moves around a lot. Terrestrial carbon moves from the atmosphere to the land and back, and in this process it drives life on the planet. Plants use carbon dioxide from the atmosphere to grow and produce food that sustains the rest of life. When these organisms breathe, grow, die, and eventually decompose, carbon is released to the atmosphere and the soil. Carbon from this past life provides the fuel for new life. Indeed, life depends on this harmonized movement of carbon from one "sink" to another.[9] (See Sidebar 1.)

Large-scale disruption or changes on land alter this harmonious movement of carbon drastically. Deforestation, agriculture, and livestock grazing are the major land use changes that increase the release of carbon into the atmosphere. Globally, land use and land use changes account for around 31 percent of total human-induced greenhouse gas emissions into the atmosphere.[10] (See Sidebar 2.) Together, land use changes and the burning of fossil fuels such as oil and coal are the two dominant sources of the increased carbon dioxide in the atmosphere that is changing the global climate.

Burning fossil fuel releases carbon that has been buried for millions of years. In contrast, deforestation, intensive tillage of soil for crops, and overgrazing release carbon from living or recently living plants and soil organic matter. Some land use changes further affect climate by altering regional precipitation patterns (for example, removing forest cover reduces transpiration from plants, affecting the hydrological cycle), as is occurring now in the Amazon Basin in South America.[11]

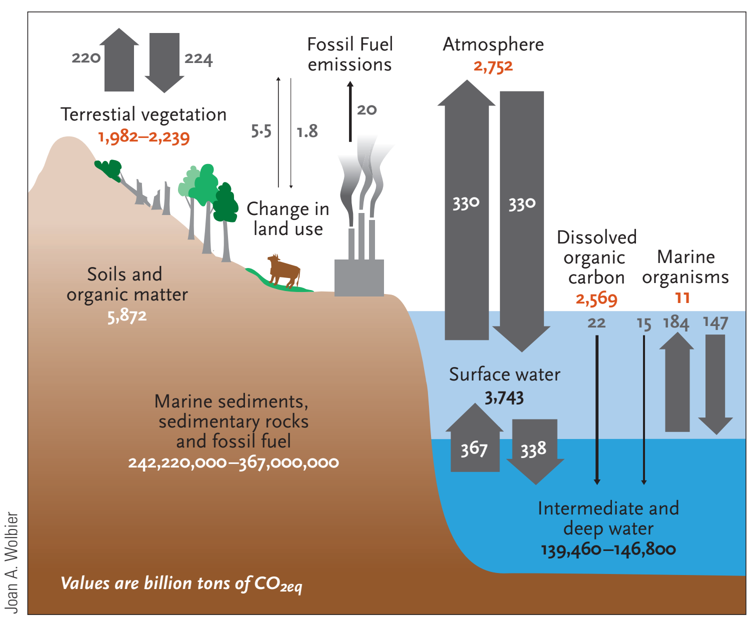
On the up side, other kinds of land uses can play an opposite, positive role in the climate cycle. Plants that are growing, whether as natural habitat or for productive uses, can remove huge amounts of heat-trapping carbon from the atmosphere, breaking it down into its constituent parts and storing the carbon in vegeta-

Sidebar 1. The Carbon Cycle

The carbon cycle is the movement of the element carbon (C), sometimes in altered chemical forms, through different reservoirs or carbon sinks on the planet. Over a relatively short timescale of less than thousands of years, the carbon cycle is a biological and physical process whereby carbon moves among the vegetation, soil, and animals on land; the atmosphere; and the organisms and water in the oceans. (See Figure.) Over a longer time span of millions of years, the carbon cycle is a geological process, during which carbon also moves to and from the deeper parts of Earth's surface as sediments.

Carbon dioxide (CO_2) and methane (CH_4) are two greenhouse gases in the atmosphere that contain carbon; a third major greenhouse gas, nitrous oxide (N_2O), does not. Green plants use the energy of sunlight to facilitate a chemical reaction (photosynthesis) between atmospheric CO_2 and water to produce complex sugars that are the ultimate food source for almost all life on the planet. In the process, plants remove carbon from the atmosphere and add it into soils, vegetation, and the bodies of animals that feed on that vegetation. Meanwhile, plants, animals, and organic matter continue to release carbon dioxide and methane into the atmosphere through respiration and decay.

Increasing the amount of carbon in a sink or reservoir other than the atmosphere is called "carbon sequestration. "Carbon storage" refers to the net carbon that stays in living biomass and in soils.



Source: See Endnote 9 for this section.

Sidebar 2. Greenhouse Gas Emissions from Land Use

Carbon dioxide (77 percent), nitrous oxide (8 percent), and methane (14 percent) are the three main greenhouse gases that trap infrared radiation and contribute to climate change. Land use changes contribute to the release of all three of these greenhouse gases. (See Table.) Of the total annual human-induced GHG emissions in 2004 (49 billion tons of carbon dioxide equivalent), roughly 31 percent—15 billion tons—was from land use. By comparison, fossil fuel burning accounts for 27.7 billion tons of CO_2-equivalent emissions annually.

Deforestation and devegetation release carbon in two ways. First, the decay of the plant matter itself releases carbon dioxide. Second, soil exposed to wind and rain is more prone to erosion. Subsequent land uses such as agriculture and grazing exacerbate soil erosion and exposure. The atmosphere oxidizes the soil carbon, releasing more carbon dioxide into the atmosphere. Application of nitrogenous fertilizers leads to soils releasing nitrous oxide. Methane is released from the rumens of livestock such as cattle, goats, and sheep when they eat and from manure and water-logged rice plantations.

Naturally occurring forest and grassland fires also contribute significantly to greenhouse gas emissions. In the El Niño year of 1997–98, fires accounted for 2.1 billion tons of carbon emissions. Due to the unpredictability of these events, annual emissions from this source vary from year to year.

Land Use	Annual Emissions (million tons CO_2 equivalent)	Greenhouse Gas Emitted
Agriculture	**6,500**	
Soil fertilization (inorganic fertilizers and applied manure)	2,100	Nitrous oxide*
Gases from food digestion in cattle (enteric fermentation in rumens)	1,800	Methane*
Biomass burning	700	Methane, nitrous oxide*
Paddy (flooded) rice production (anaerobic decomposition)	600	Methane*
Livestock manure	400	Methane, nitrous oxide*
Other (e.g., delivery of irrigation water)	900	Carbon dioxide, nitrous oxide*
Deforestation (including peat)	**8,500**	
For agriculture or livestock	5,900	Carbon dioxide
Total	**15,000**	

** The greenhouse gas impact of 1 unit of nitrous oxide is equivalent to 298 units of carbon dioxide; 1 unit of methane is equivalent to 25 units of carbon dioxide.*

Source: See Endnote 10 for this section.

tion and soils. This can not only stabilize the climate but also benefit food and fiber production and the environment. Thus, to be successful, it is imperative that any climate change mitigation strategy embrace solutions based on terrestrial carbon, including emission reduction, sequestration, and storage.

So why has terrestrial carbon largely been ignored as a climate change mitigation strategy in intergovernmental initiatives, including those under the United Nations Framework Convention on Climate Change? Many policymakers are aware of the dramatic impacts of tropical forest burning and large-scale deforestation, and the international negotiations currently under way to frame a successor climate change agreement to the Kyoto Protocol are likely to result in some strategy to increase international public funding for "avoided deforestation" (referred to as "reduced emissions from deforestation and degradation," or REDD). But this is being done reluctantly, through mechanisms that are isolated from those focused on energy and that receive far less (and less-secure) funding. There is considerable resistance to expanding the scope of land use-related climate mitigation activities beyond certain types of forest conservation.

Several factors have contributed to the widespread reluctance of climate policy actors to use terrestrial carbon as a solution for climate change. For one, most climate leaders

Appreciating Terrestrial Carbon

come out of the atmospheric science or energy sectors and are little aware of proven and promising land use mitigation options. While so-called "Annex 1" countries (those countries obligated to meet emission-reduction goals under the Kyoto Protocol) must report on emissions from a broad range of land uses, regulatory schemes in signatory countries have generally not included sources of land use emissions. And while land use issues have been analyzed in-depth scientifically by the Intergovernmental Panel on Climate Change (IPCC), particularly in its *Fourth Assessment Report* released in 2007, land use action has not been championed in negotiations either internationally or in Europe.

In the United States, by contrast, agricultural interests have raised the profile of soil carbon potentials. A 2006 study for the Pew Center on Global Climate Change estimated that between 257 and 807 million tons of carbon dioxide equivalent, or up to 11 percent of U.S. 2007 emissions, can be sequestered annually in the country's agricultural soils.[12] This could be done through widespread adoption of better management practices, such as the retention of crop residues for increased moisture and organic matter, zero tillage, and the efficient application of manures, fertilizers, and water.

The diversity of land uses and emission sources from land use, the differences in their emission patterns across ecosystems, and the diversity and variation of practices to reduce emissions or sequester carbon in different farming systems and ecosystems is daunting for non-specialists to consider. The level of complexity is actually quite comparable to energy systems, but because energy issues are much more familiar to most of the specialists involved in climate negotiations, tackling energy-based solutions may seem more manageable than dealing with land use issues.

Another reason climate policy actors may be reluctant to use terrestrial carbon as a climate solution, even if they recognize the potential and necessity of land use mitigation, is that they lack confidence that actions will produce real, measurable, and permanent net benefits. Plants sequester carbon only when they are growing, and the benefits can be reversed quickly through deforestation, fires, and poor soil management. As long as the economy sends price signals that make land-clearing lucrative, avoiding deforestation in one region may simply contribute to forest clearing elsewhere, causing "leakage" of the sequestered carbon.

As a result, some climate experts consider it unwise to trust our climate future to carbon sinks, such as tropical forests or other carbon-rich lands that could be ephemeral.[13] They also see great challenges in measuring and monitoring terrestrial carbon emissions in heterogeneous and dynamic land use systems well enough to inform a global emissions tracking or trading system.[14]

Moreover, many of those who do accept the scientific evidence of the potential climate benefits of land use action—and who are persuaded by recent advances that there are practical solutions to the challenges of permanence and measurement—remain skeptical that agricultural and land use investments can be scaled up quickly enough to make a difference to the climate. One of the most compelling arguments for terrestrial carbon investment is that technologies are immediately available and can thus be implemented right away, without long delays for further research and development. Renewable energies such as wind and solar are also ready for scaling, but even these promise only to reduce emissions, not to capture and store them.

But the largest gains globally from land use are in developing countries, many of whose land use sectors have poor reputations. Agriculture and forestry are perceived as stagnant sectors with weak institutions, and existing terrestrial carbon projects are very small scale. Small-scale farmers, who dominate agriculture worldwide, are assumed capable of only small-scale climate action. Meanwhile, the diversity of agricultural systems implies few economies of scale.

Finally, even among those who recognize the scale of land use impacts on the climate, and the potential scale of mitigation, there is a concern that action in the land use sector will distract critical attention and resources from efforts to transform the energy economy. Champions of terrestrial carbon-based mitigation often highlight the many "co-benefits," such as increased food security, restoration of degraded resources, and protection of ecosystem services and biodiversity. But some in the climate sector are skeptical of this win-win proposition. They agree that these are important goals, but fear that embracing them within climate action strategies will undermine commitment to achieving rigorous climate outcomes. Or they fear that the lower cost of emission reductions and sequestration in the land use sector—seemingly a major advantage—would undermine political will to take ambitious action in the energy sector or would let industrial-country emitters "off the hook."[15]

All of these concerns must be addressed before terrestrial carbon is fully incorporated into our climate management strategies. Terrestrial carbon-based mitigation is a viable as well as a necessary course to take to secure our climate future. Concerns about permanence, additionality, leakage, and measurement of land use climate solutions are being rigorously addressed, and scaling up can be achieved rapidly by building on existing institutional models. The co-benefits of land use investments are more likely to attract allies to ambitious climate action, rather than distract. And there are many positive opportunities for engaging farmers and other land managers and for mobilizing terrestrial carbon-based mitigation as a major strategy to slow and ultimately stop climate change.

USDA NRCS/Tim McCabe

Liquid manure from a hog farm being spread on cropland in Iowa.

Carbon-Rich Farming

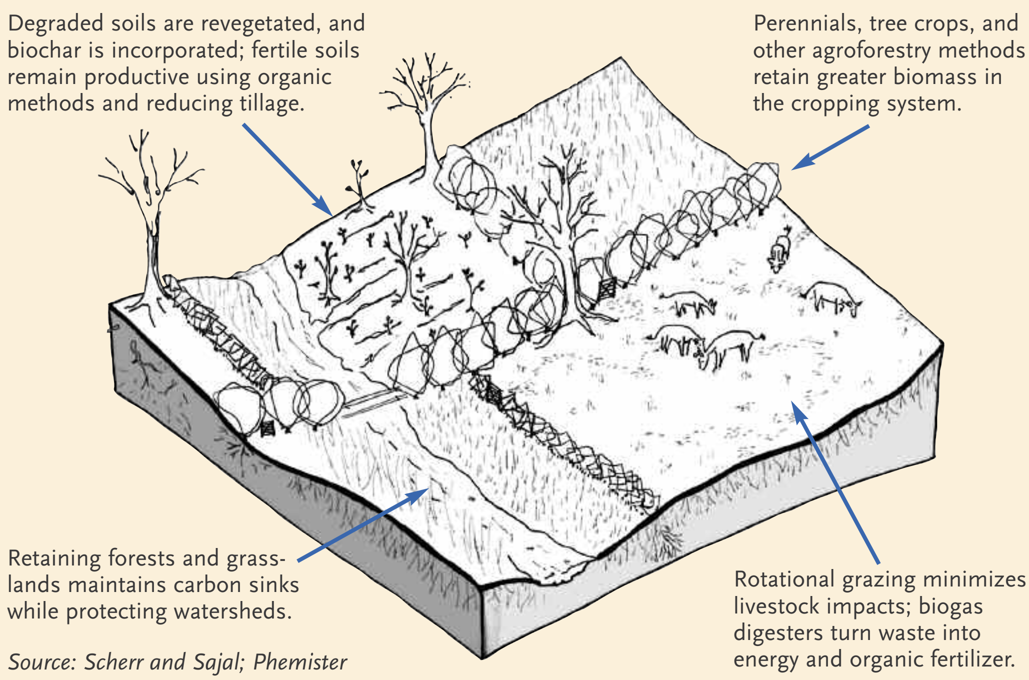
Today, we face a unique opportunity to achieve "climate-friendly" landscapes. These include, for example, large expanses of agricultural land, interconnected with natural habitats, that are managed to minimize greenhouse gas emissions and maximize the sequestration of carbon in soils and vegetation. Many options are already at hand to achieve such landscapes.[1] (See Figure 1.) None is a silver bullet, but in combinations that make sense locally they can help us move forward decisively.

Three strategies are especially promising to convert today's high-emissions food production systems to "carbon-rich" farming systems. They are: enriching soil carbon, incorporating perennials in cropping systems, and promoting climate-friendly livestock production systems.

Strategy 1: Enriching Soil Carbon

Soil has four components: minerals, water, air, and organic materials (both nonliving and living). The nonliving material comes from dead plant, animal, and microbial matter, whereas the living organic material is from plants and other organisms in the soil, including living

Figure 1. Multiple Strategies to Productively Absorb and Store Carbon in Agricultural Landscapes



Source: Scherr and Sajal; Phemister

Carbon-Rich Farming

roots and microbes. Together, living and non-living organic materials account for only 1–6 percent of the soil's volume, but they contribute much more to its productivity.[2] The organic materials retain air and water in the soil and provide nutrients that the plants and the soil fauna depend on for life. They are also reservoirs of carbon in the soil.

In fact, soil is the third largest carbon pool on Earth's surface. New mapping tools, such as the 2008 *Global Carbon Gap Map* produced by the United Nations Food and Agriculture Organization, can identify areas where soil carbon storage is greatest, as well as areas with the physical potential for billions of tons of additional carbon to be stored in degraded soils.[3] In the long term, agricultural practices that build and conserve soil carbon from year to year through organic matter management, rather than depleting it, will provide productive soils that are rich in carbon and require fewer chemical fertilizers.

Current use of inorganic (chemical) fertilizers is estimated at a staggering 102 million tons worldwide, with use concentrated in industrial countries and in irrigated regions of developing nations.[4] Soils with nitrogen fertilizers release nitrous oxide, a greenhouse gas that has about 300 times the warming capacity of carbon dioxide. Fertilized soils release more than 2 billion tons (in terms of carbon dioxide equivalent) of greenhouse gases every year.[5] It is possible to reduce these emissions, however, by adopting soil fertility management practices that increase soil organic matter and siphon carbon from the atmosphere.

Numerous technologies can be used to substitute or minimize the need for inorganic fertilizers. Examples include composting (the decomposition of food and plant waste in the presence of air to produce dark organic matter), green manures (crops grown during fallows to be plowed into the soil to add nutrients and organic matter), nitrogen-fixing cover crops (such as velvetbean), intercropping, and the use of livestock manure. Even improved fertilizer application methods can reduce emissions.

In one example of organic farming, a 23-year experiment by the Rodale Institute compared organic and conventional cropping systems in the United States and found that organic farming increased soil carbon by 15–28 percent and nitrogen content by 8–15 percent.[6] The researchers concluded that if the 65 million hectares of corn and soybean grown in the United States were switched to organic farming, a quarter billion tons of carbon dioxide (or about 4 percent of annual U.S. emissions) could be sequestered.[7]

The economics and productivity of these methods vary widely. In some very intensive, high-yield cropping systems, replacing some or all inorganic fertilizer may require methods that use more labor or require costlier inputs, but there is commonly scope for much more efficient use of fertilizer through better targeting and timing. The field of precision agriculture recognizes that variations exist on-farm and tries to improve efficiency of inputs, including fertilizers, through targeted use aided by remote-sensing techniques. In less-intensive systems, the use of organic nutrient sources with small amounts of supplemental inorganic fertilizer can be quite competitive and attractive to farmers seeking to reduce cash costs.[8]

Improvements in organic technologies over the past few decades have led to comparable levels of productivity across a wide range of crops and farming systems. The question of whether organic farming can feed the world, as many argue, remains controversial.[9] And more research is needed to understand both the potentials and limitations of agro-ecological systems across the broad range of soil types and climatic conditions globally. But there is little question that farmers in many production systems can already profitably maintain yields while using much less artificial fertilizer—with major benefits to the environment and the climate.

Soil used to grow crops is commonly tilled, or turned over, to improve the conditions of the seed bed and to uproot weeds. But tilling turns the soil upside down, exposing anaerobic microbes to oxygen and suffocating aerobic microbes by working them under. This disturbance exposes nonliving organic matter to oxygen, leading to a chemical reaction that releases carbon dioxide. Keeping crop residues or mulch on the surface helps soil retain moisture, prevents erosion, and returns carbon to the soil through decomposition. Hence, many practices that reduce tillage also reduce carbon emissions in certain types of soils and ecosystems.[10]

A variety of conservation tillage practices accomplish this goal. In non-mechanized systems, farmers might use digging sticks to plant seeds and can manage weeds through mulch and hand-weeding. Special mechanized systems have been developed that drill the seed through the vegetative layer and use herbicides to manage weeds. Many farmers combine no-till methods with crop rotations and green manure crops. In Paraná, Brazil, farmers have developed organic management systems combined with no-till. No-till plots yielded a third more wheat and soybean than conventionally ploughed plots and reduced soil erosion by up to 90 percent.[11] The latter has the additional benefit of reducing labor and fossil fuel use and enhancing soil biodiversity—all while cycling nutrients and storing carbon.


Sajal Sthapit

In Nepal, terraces for rice cultivation help prevent erosion.

Worldwide, approximately 95 million hectares or about 7 percent of the world's arable land is under no-till management—a figure that is growing rapidly, particularly as rising fossil fuel prices increase the cost of tillage.[12] The actual net impacts on greenhouse gases of reduced emissions and increased carbon storage from reduced tillage depend significantly on associated practices, such as the level of vegetative soil cover and the impact of tillage on crop root development, which depends on the specific crop and soil type. It is projected that the carbon storage benefits of no-till may plateau over the next 50 years, but this can be a cost-effective option to buy time while alternative energy systems develop.[13]

Decomposition of plant matter is another way of enriching soil carbon if it takes place securely within the soil; decomposition on the surface, on the other hand, releases carbon dioxide into the atmosphere. In the humid tropics, for example, organic matter breaks down rapidly, limiting the carbon storage benefits of organic systems.

Another option, recently discovered, is biochar—the burning of biomass in a low-oxygen environment.[14] This keeps carbon in soil longer and releases the nutrients slowly over a long period of time. While the burning does release some carbon dioxide, the remaining carbon-rich dark aromatic matter is highly stable in soil. Hence, planting fast-growing trees in previously barren or degraded areas, converting them to biochar, and adding them to soil is a quick way of taking carbon from the atmosphere and turning it into an organic slow-release fertilizer that benefits both the plant and the soil fauna.

Interestingly, between 500 and 2,500 years ago Amerindian populations added incompletely burnt biomass to the soil. Today, Amazonian "dark earth" soils created in this way still retain high amounts of organic carbon and fertility in stark contrast to the low fertility of adjacent soils.[15] There is a global production potential of 594 million tons of carbon dioxide equivalent in biochar per year, simply by using waste materials such as forest and milling residues, rice husks, groundnut shells, and urban waste.[16] Far more could be generated by planting and converting trees. Initial analyses suggest that planting vegetation for biochar on idle and degraded lands could be quite economical, though not in more highly productive lands, and is thus a promising option for carbon emission offset payments.[17]

Most crops respond with improved yields for biochar additions of up to 183 tons of carbon dioxide equivalent.[18] If biochar additions were applied at this rate on just 10 percent of the world's cropland (160 million hectares), this method could store 29 billion tons of carbon dioxide equivalent, offsetting nearly all the emissions from fossil fuel burning.[19]

Strategy 2: Farming with Perennials

Plants harness the energy of the sun and accumulate carbon from the atmosphere to produce biomass on which the rest of the biota depend. The great innovation of agriculture 10,000 years ago was to manage the photosynthesis of plants and ecosystems so as to dependably increase yields. With 5 billion hectares of Earth's surface now used for agriculture (69 percent under pasture and 28 percent in crops) in 2002, and with half a billion more hectares projected by 2020, agricultural production systems and landscapes have to not only deliver food and fiber but also support biodiversity and important ecosystem services, including climate change mitigation.[20]

A major strategy for achieving this is to increase the role of perennial crops, shrubs, trees, and palms, so that carbon is stored while crops are being produced. Perennials constantly keep root biomass, while tree crops and agroforestry maintain significantly higher biomass than clear-weeded, annually tilled crops.

Although more than 3,000 edible plant species have been identified, 80 percent of world cropland is dominated by just 10 annual cereal grains, legumes, and oilseeds.[21] Currently, two-thirds of all arable land is used to grow annual grains.[22] Wheat, rice, and maize cover half of the world's cropland.[23] Since annual crops need to be replanted every year and since the major grains are sensitive to shade, farmers in much of the world have gradually removed other vegetation from their fields. Production of annuals depends on tilling, preparing seed beds, and applying chemical inputs. Every year, the process starts over again from scratch. This makes production more dependent on chemical inputs, which also require a lot of fossil fuels to produce. Furthermore, excessive application of nitrogen fertilizers, which is the norm, is a major source of nitrous oxide emissions.[24]

Achieving a carbon-rich cropping system, as well as the year-round vegetative cover required to sustain soils, watersheds, and habitats, will require farmers to plant a variety of crops and to incorporate a far greater share of perennial plants. In contrast to annual grains, perennial grasses retain a strong root network between growing seasons. Hence, a good amount of the living biomass remains in the soil instead of being released as greenhouse gases. Furthermore, these grasses help hold soil organic matter and water together, reducing soil erosion and emissions. Finally, their perennial nature does away with the need for annual tilling that releases greenhouse gases and causes soil erosion, and also makes the grasses more conservative in the use of nutrients. In one U.S. case, harvested native hay meadows retained 179 tons of carbon and 12.5 tons of nitrogen in a hectare of soil, while annual wheat fields retained only 127 tons of carbon and 9.6 tons of nitrogen.[25] This is despite the fact that the annual wheat fields had received 70 kilograms of nitrogen fertilizer per hectare annually for years.[26]

Researchers have already developed perennial relatives of cereals (rice, sorghum, and wheat), forages (intermediate wheatgrass, rye), and oilseeds (sunflower) that provide nutritious and good-tasting alternatives to conventional annual crops. In the U.S. state of Washington, some perennial wheat varieties have already been bred that yield more than 70 percent as much as commercial wheat.[27] Domestication work is under way for a number of lesser known perennial native grasses, and many more perennials offer unique and exciting opportunities.[28]

Shifting production systems from annual to perennial grains should be an important research priority for agricultural researchers and crop breeders, but significant research challenges remain. Breeding perennial crops takes longer than annuals due to longer generation times. Perennials also have lower seed yields than annuals, though this could be improved through breeding. Since annuals live for one season only, they give priority to seeds over vegetative growth, making yield improvement in annuals. Perennials have to allocate more resources to vegetative parts like roots in order to ensure survival through the winter. But in the quest for high-carbon agricultural systems, plants that produce more biomass are a plus. Through breeding, it may also be possible to redirect increased biomass content to seed production.

Another method of increasing carbon in agriculture is agroforestry, in which productive trees are planted in and around crop fields and pastures. The tree species may provide products (fruits, nuts, medicines, fuel, timber, and so on), farm production benefits (such as nitrogen fixation from leguminous tree species for crop fertility, wind protection for crops or animals, and fodder for animals), and ecosystem services (habitat for wild pollinators of crops, for example, or micro-climate improvement). The trees or other perennials in agroforestry systems sequester and store carbon, boosting the carbon content of the agricultural landscape.

Agroforestry was common traditionally in agricultural systems in forest and woodland ecosystems and is being newly introduced into present-day subsistence and commercial systems. The highest carbon storage results are found in multistory agroforestry systems that have many diverse species using ecological "niches," from the high canopy to bottom-story shade-tolerant crops.[29] Examples are shade-grown coffee and cocoa plantations, where cash crops are grown under a canopy of trees that sequester carbon and provide habitats for wildlife. Simple intercrops are used where tree-crop competition is minimal or where the value of tree crops is greater than the value of the intercropped annuals or grazing areas, or as a means to reduce market risks. Where crops are adversely affected by competition for light or water, trees may be grown in small plots in mosaics with crops. Research is also under way to develop low-light tolerant crop varieties.[30] And in the Sahel, some native trees and crops have complementary growth patterns, so that the trees shed their leaves during the crops' growing season, avoiding light competition all together.[31]

While agroforestry systems have a lower carbon storage potential per hectare than standing forests do, they can potentially be adopted on hundreds of millions of hectares. And because of the diverse benefits they offer, it is often more economical for farmers to establish and retain them. A "Billion Tree Campaign" to promote agroforestry was launched at the United Nations climate convention meeting in Nairobi, Kenya, in 2006. Within a year and a half, the program had shattered initial expectations and mobilized the planting of 2 billion trees in more than 150 countries.[32] Half the plantings occurred in Africa, with 700 million in Ethiopia alone. By taking the lead from farmers and communities on the choice of species, planting location, and management, and by providing adequate technical support to ensure high-quality planting materials and methods, these initiatives can ensure that the trees will thrive and grow long enough and large enough to actually store a significant amount of carbon.

In a prescient book in 1929, Joseph Russell Smith observed the ecological vulnerabilities of annual crops and called for "A Permanent Agriculture."[33] This work highlighted the diversity of tree crops in the United States that could substitute for annual crops in producing starch, protein, edible and industrial oils, animal feed, and other goods as well as edible fruits and nuts—if only concerted efforts were made to develop genetic selection, management, and processing technologies. Worldwide, hundreds of indigenous species of perennial trees, shrubs, and palms are already producing useful products for regional markets but have never been subject to systematic efforts of tree domestication and improvement or to market development. Since one-third of the world's annual cereal production is used to feed livestock, finding perennial substitutes for livestock feed is especially promising.[34]

Exciting initiatives are under way with dozens of perennial species, mainly tapping intra-species diversity to identify higher-yielding, higher-quality products and developing rapid propagation and processing methods to use in value-added products. For example, more than 30 species of trees, shrubs, and liane in West Africa have been identified as promising for domestication and commercial development. Commercial-scale initiatives are under way to improve productivity of the Allanblackia and muiri (*Prunus africanus)* trees, which can be incorporated into multistrata agroforestry systems to "mimic" the natural rainforest habitat.[35] Growing trees at high densities is not, however, recommended in dry areas that are not naturally forested, as this may cause water shortages, as has happened with eucalyptus in some dry areas of Ethiopia.[36]

Around the world, farmers and energy producers are converting large areas of land to biofuels. Shifting biofuel production from annual crops (which often have a net negative impact on greenhouse gas emission due to cultivation, fertilization, and fossil fuel use) to perennial alternatives like switchgrass offers a major new opportunity to use degraded or low-productivity areas for economically valuable crops with positive ecosystem impacts.[37] But this will require an approach that strategically integrates biofuels into landscapes in ways that use resources sustainably, enhance overall carbon intensity in the landscape, and complement other key land uses and ecosystem services.[38]

Strategy 3: Climate-Friendly Livestock Systems

Domestic livestock—cattle, pigs, sheep, goats, poultry, donkeys, and so on—account for most of the total living animal biomass worldwide. A revolution in livestock product consumption has been under way since the 1970s. Meat consumption in China, for example, more than doubled in the past 20 years and is projected to double again by 2030.[39] This trend has triggered the rise of huge feedlots and confined dairies—or factory farms—around many cities, and the clearing of huge areas of land for grazing.[40]

Livestock generate prodigious quantities of greenhouse gases. Methane is produced from the fermentation of plant matter in the animal's stomach, while manure releases methane and nitrous oxide, both of which are more potent greenhouses gases than carbon dioxide. Carbon dioxide and nitrous oxide are also released as a result of land clearing for pastures and feed crops, during soil degradation, and through the consumption of fossil fuels in various stages of the livestock supply chain.[41]

Remarkably, annual greenhouse gas emissions from livestock total some 7.1 billion tons (including 2.5 billion tons of carbon dioxide equivalent from clearing land for the animals), accounting for about 14.5 percent of climate-altering emissions from human activities, or nearly half of all emissions from agriculture and land use change.[42] Indeed, a single cow/calf pair on a beef (or even dairy) farm in the eastern United States is responsible for more greenhouse gas emissions in a year than a person driving nearly 13,000 kilometers in a mid-sized car.[43]

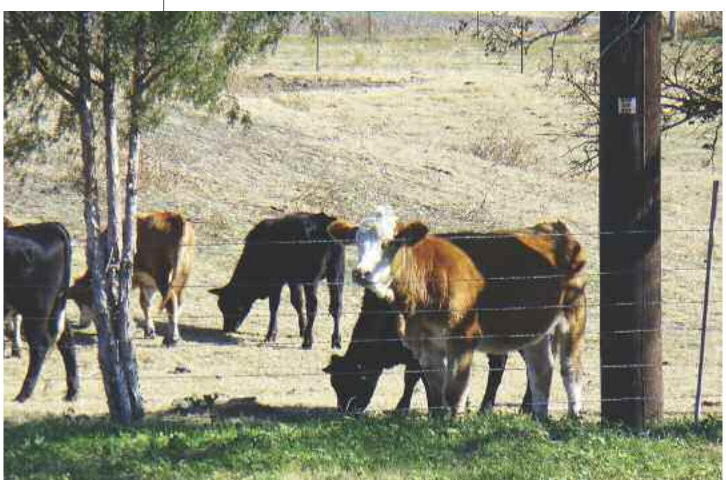
Sajal Sthapit

Agroforestry: mango trees interspersed in rice paddies in Nepal.

Serious action on climate change will almost certainly require reductions in the global consumption of meat and dairy by today's major consumers in industrial countries, as well as slowing the growth of demand in developing countries. As with other sources of agricultural emissions, no such major shift seems likely without putting a price on livestock-related greenhouse gases, so that producers treat them as a business cost and thus have a direct incentive to reduce them.

Carbon-Rich Farming

Meanwhile, a variety of solutions are at hand to reduce current livestock-related emissions. Innovative grazing systems, for example, offer alternatives to both extensive grazing systems and confined feedlots and dairies, greatly reducing net greenhouse gas emissions while increasing productivity. Conventional thinking says that the current number of livestock in many grazing areas of the world far exceeds the carrying capacity of the ecosystem. But in many circumstances, this reflects poor grazing management practices rather than having too many animals in one place.



Raymond Gilford

In need of rotation: cattle on over-grazed pasture near Elgin, Texas.

Research shows that grasslands can support large livestock herds more sustainably through better management of herd rotations, which allows the vegetation to regenerate after grazing. Letting plants recover protects the soil organic matter and carbon from erosion while maintaining or even increasing livestock productivity in some places. For example, a 4,800-hectare U.S. ranch that uses rotational grazing practices was able to triple the perennial species in the rangelands while also nearly tripling beef production, from 66 kilograms to 171 kilograms per hectare.[44] Various types of rotational grazing are being practiced successfully in the United States, Australia, New Zealand, parts of Europe, and southern and eastern Africa.[45] Large areas of degraded rangeland and pastures around the world could be brought under rotational grazing to enable sustainable livestock production.

Rotational grazing also offers a viable alternative to confined animal operations. A major study by the U.S. Department of Agriculture compared four temperate dairy production systems: a full-year confinement dairy, confinement with supplemental grazing, an outdoor all-year and all-perennial grassland dairy, and an outdoor cow-calf operation on perennial grassland.[46] The study found that the *net* carbon emissions were much higher for the confinement dairy than for the grazing systems, mainly because high carbon sequestration in the latter more than offsets somewhat higher overall carbon emissions. The researchers concluded that the best ways to improve the greenhouse gas footprint of intensive dairy and meat operations are to: improve carbon storage in grass systems, feed more grain and less forage in confined operations, use higher-quality forage overall, eliminate the storage of manure or cover the stores and flare the gas, increase production per animal, and use well-managed rotational grazing.

Methane produced in the animal's rumen—the first stomach of cattle, sheep, goats, and other species that chew the cud—accounts for the annual release of some 1.8 billion tons of carbon dioxide equivalent.[47] Nutrient supplements and innovative feed mixes, such as those with increased starch content, have been developed to make feed easier for animals to digest, thereby reducing methane production. Other advanced techniques for methane reduction include removing specific microbial organisms from the rumen (a process known as defaunation) and adding other bacteria that actually reduce gas production in the rumen. Defaunation can reduce methane emissions by 20 percent, although this practice is not yet commercially viable for most farmers.[48] Research is also under way to develop vaccines against the organisms in the stomach that produce methane.[49]

These approaches require fairly sophisticated management, so they are useful mainly in larger-scale, intensive livestock operations (which also tend to be a significant source of livestock-related methane emissions).[50]

They will not benefit the millions of pastoralists who depend on livestock for their daily survival. As a result, other solutions that rely on rotational grazing, managing herds, and restoring grasslands must be further developed and implemented.

Manure is a major source of methane, responsible for some 400 million tons of carbon dioxide equivalent.[51] And poor manure management is a leading source of water pollution.[52] Large manure lagoons, or pits, can leak into groundwater and also contaminate surface water when they overflow during storms or hurricanes.

But manure is also an opportunity for an alternative fuel that can reduce a farm's reliance on fossil fuels. By using appropriate technologies such as an anaerobic biogas digester, farmers can profit from their farm waste while helping the climate. A biogas digester is basically a temperature-controlled air-tight vessel. Manure (or food waste) is fed into the vessel, where microbial action breaks it down into methane or biogas and a low-odor, nutrient-rich sludge. The biogas can be burned for heat or electricity and the sludge can be used as fertilizer in locations where it makes economic sense. Methane has 25 times the global warming potential of carbon dioxide, so collecting the methane and burning it to convert it to carbon dioxide will have a lesser overall impact on the climate.[53]

By thinking creatively, previously undervalued and dangerous wastes can be converted into new sources of energy, cost savings, and even income. In 2005, the Penn England dairy farm in Pennsylvania invested $141,370 in a digester to process manure and $135,000 in a combined heat and power unit, with a total project cost of $1.14 million to process the manure from 800 cows.[54]* Today, the farm generates 120 kilowatts of electricity, which in some months is more that it can use.[55] In addition, the generator produces sufficient heat to warm the digester, make hot water, and heat the barns and farm buildings.

Many large dairies and confined pig operations in the United States are already receiving large government subsidies to invest in anaerobic digesters. In the developing world, some communities are using manure to produce biogas cooking fuel. Biogas digesters involve an initial cash investment that often needs to be advanced for low-income producers, but lifetime benefits far outweigh the costs.[56] This technology could be extended to millions of farmers, with benefits for the climate as well as for human well-being by providing greater access to energy.

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

Conserving and Restoring Natural Habitats

Most farming landscapes around the world still retain, or have the potential to restore, large areas of forests and natural grasslands under private, community, or public management. These areas are often important for local livelihoods, whether for gathering food, fuel, raw materials, or medicines, or for grazing, and they provide critical habitat for biodiversity. Conserving and restoring these resources on a large scale would contribute powerfully to slowing climate change. Thus, two additional strategies for sequestering terrestrial carbon are protecting natural habitat and restoring degraded watersheds and rangelands.

Strategy 4: Protecting Natural Habitat

The planet's 4 billion hectares of forests and 5 billion hectares of natural grasslands are a massive reservoir of carbon—both in vegetation above ground and in root systems below ground.[1] As forests and grasslands continue to grow, they remove carbon from the atmosphere and contribute to climate change mitigation. Natural and undisturbed forests are particularly important. Intact natural forests in Southeast Australia, for example, hold 2,349 tons of carbon dioxide equivalent per hectare, compared with 796 tons on average for temperate forests.[2] Thus, in terms of total emissions reduction from land use interventions, protecting Earth's existing carbon in forests and grasslands could have the largest impact, if achieved.

Massive deforestation is releasing stored carbon back into the atmosphere. Between 2000 and 2005, the world lost forest area at a rate of 7.3 million hectares per year.[3] For every hectare of forest cleared, hundreds of tons of carbon are added to the atmosphere, depending on the type of tree removed.[4] Deforestation and land clearing have many causes, from large-scale, organized clearing for crop and grazing land and infrastructure, to the small-scale movement of marginalized people into forests in search of farming or employment opportunities. Trees are also cleared for the commercial sale of timber, pulp, and fuelwood. In many cases, the key drivers of deforestation are outside the productive land use sectors and are instead the result of public policies in other sectors, such as the construction of roads and other infrastructure, human settlements, or border control.

Unlike many of the other climate-mitigating land use strategies described in the previous section, protecting large areas of standing natural vegetation typically provides fewer short-term financial or livelihood benefits for landowners and managers. It may even reduce their incomes or livelihood security. In places where there is strong enforcement capacity, the solution may lie in regulation: in Australia, for example, comprehensive laws restrict the clearing of natural vegetation.[5] In many areas, however, the challenge is to develop incentives for conservation for the key stakeholders.

Several approaches are being used. One is to raise the economic value of standing forests or grasslands by improving markets for sustainably harvested, high-value products from those areas or by paying land managers directly for their conservation value. Current international negotiations are exploring the possibility of compensating developing countries for leaving their forests intact or improving forest management. At the United Nations climate convention in Bali, Indonesia, in December 2007, governments agreed to a two-year negotiation process that would lead to the adoption of a mechanism for "reduced emissions from deforestation and degradation" (REDD) after 2012.[6] Implementation of any eventual REDD mechanism will pose major methodological, institutional, and governance challenges, but numerous initiatives are already under way to begin addressing these problems.

A second incentive for conservation is product certification, whereby agricultural and forest products are labeled as having been produced without clearing natural habitats or in "mosaic" landscapes that conserve a minimum area of natural patches. For example, the International Finance Corporation's Biodiversity and Agricultural Commodities Program seeks to increase the production of sustainably produced and verified commodities (for example, palm oil, soy, sugarcane, and cocoa), working closely with commodity roundtables and their members, regulatory institutions, and policymakers. While the priority focus is on conservation of biodiversity, this initiative will have significant climate impacts as well, due to its focus on protecting existing carbon vegetative sinks from conversion, developing standards for sustainable biofuels, and establishing certification systems.[7]

A third approach is to secure local tenure rights for communal forests and grasslands so that local people have an incentive to manage these resources sustainably and protect them from outside threats such as illegal commercial logging or land grabs for agriculture. Many women in particular are not allowed to own land, even in places where they comprise a majority of the farmers and livestock keepers. A study in 2006 of 49 community forest management cases worldwide (admittedly a small number) found that all the initiatives that included tenure security were successful, but that only 38 percent of those without it succeeded.[8] Diverse approaches and legal arrangements are being used to strengthen tenure security and local governance capacity.

The burning of biomass—forests, grasslands, and agricultural fields—is a significant source of carbon emissions, especially in developing countries. Controlled biomass burning in the agricultural sector, on a limited scale, can have positive functions as a means of clearing and rotating individual plots for crop production; in some ecosystems, it is a healthy means of weed control and soil fertility improvement. In several natural ecosystems, such as savanna and scrub forests, wild fires can help maintain biotic functions, as in Australia.[9] But in many forest ecosystems, fires are set mostly by

Tatiana Gerus

Waterfall in the forested wilderness of New South Wales, Australia.

humans and are environmentally harmful—killing wildlife, reducing habitat, and setting the stage for more fires by reducing moisture content and increasing combustible materials. Even where they can be beneficial from an agricultural perspective, fires can inadvertently spread to natural ecosystems, opening them up for further agricultural colonization.

Systems are already being put in place to track fires in "real time" so that governments and third-party monitors can identify the people responsible. In the case of large-scale ranchers and commercial crop producers, better regulatory enforcement is needed, along with alternatives to fire for management purposes. For small-scale, community producers, the most successful approaches have been to link fire control with investments in sustainable intensification of production, in order to develop incentives within the community to protect investments from fire damage. These "social controls" have been used effectively to generate local rules and norms around the use of fire in Honduras and The Gambia.[10]

Protected conservation areas provide a wide range of benefits, including climate regulation. Just letting these areas stand not only helps the biodiversity within, it also stores the carbon, avoiding major releases in greenhouse gas emissions. Moreover, due to some early effects of climate change, important habitats for wildlife are shifting out of protected areas. Plants are growing in higher altitudes as they seek cooler temperatures, while birds have started altering their breeding times.[11] Larger and geographically well distributed areas thus need to be put under some form of protection.

This need not always be through public protected areas. At least 370 million hectares of forest and forest-agriculture landscapes outside official protected areas are already under local conservation management, while half of the world's 102,000 protected areas are in ancestral lands of indigenous and other communities that do not want to see them developed.[12] Conservation agencies and communities are finding diverse incentives for protecting these areas, from the sustainable harvesting of foods, medicines, and raw materials to the protection of locally important ecosystem services and religious and cultural values as well as opportunities for nature tourism income. Supporting these efforts to develop and sustain protected area networks, including public, community, and private conservation areas, can be a highly effective way to reduce and store greenhouse gases.

Strategy 5: Restoring Degraded Watersheds and Rangelands

Extensive areas of the world have been denuded of vegetation from large-scale land clearing for annual crops or grazing and from overuse and poor management in community and public lands with weak governance. This is a tragic loss, from multiple perspectives. People living in these areas have lost a potentially valuable asset for the production of animal fodder, fuel, medicines, and raw materials. Gathering such materials is an especially important source of income and subsistence for low-income rural people. For example, researchers found in Zimbabwe that 24 percent of the average total income of poor farmers came from gathering woodland products.[13] At the same time, the loss of vegetation seriously threatens ecosystem services, particularly watershed functions and wildlife habitat.

Efforts to restore degraded areas can thus be "win-win-win" investments. Although there may be fewer tons of carbon dioxide sequestered per hectare from restoration activities, millions of hectares can be restored with low opportunity costs and strong local incentives for participation and maintenance.

Hydrologists have learned that "green water"—the water stored in vegetation and filtrating into soils—is as important as the "blue water" in streams and lakes.[14] When rain falls on bare soils, most is lost as runoff. Landscapes that retain year-round vegetative cover in strategically selected areas and natural habitat cover in critical riparian areas can maintain most, if not all, of various watershed functions, even if much of the watershed is under productive uses. In many of the world's major watersheds, most of the land is in productive use. Poor vegetative cover limits the capacity to retain rainfall in the system or to filter water flowing into streams and lakes—therefore accelerating soil loss. From a climate perspective, lands stripped of vegetation have lost the potential to store carbon.

With rapid worldwide growth in the demand for water and with water scarcity looming in many countries (probably in part due to climate change), watershed revegetation is now getting serious policy attention. Both India and China have launched large national programs targeting millions of hectares of forests and grasslands for revegetating, and they see these as investments to reduce rural poverty and protect critical watersheds.[15] In most cases, very low-cost methods are used for revegetation—mainly temporary protection to enable natural vegetation to reestablish itself without the threat of overgrazing or fire. In Morocco, 34 pastoral cooperatives with more than 8,000 members rehabilitated and manage

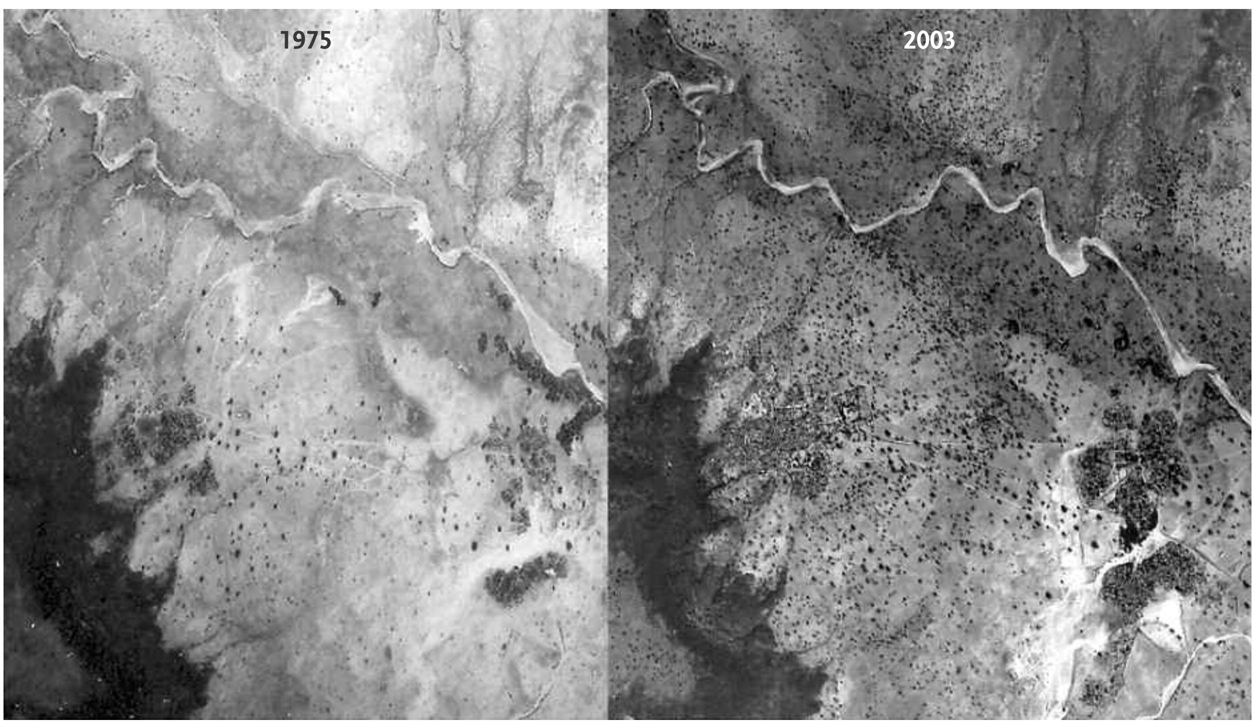
450,000 hectares of grazing reserves.[16]

On highly degraded soils, some cultivation or reseeding may be needed. Two keys to success in these approaches are to engage local communities in planning, developing, and maintaining watershed areas, and to include rehabilitation of areas of high local importance. These areas can include productive grazing lands, local woodfuel sources, and features such as gullies that can be used for productive cropping. In Rajasthan, India, community-led watershed restoration programs have reinstated more than 5,000 traditional *johads* (rainwater storage tanks) in over 1,000 villages, increasing water supplies for irrigation, wildlife, livestock, and domestic use and recharging groundwater.[17] As a result, natural vegetative cover has been re-established and crop biomass has increased, sequestering carbon in soils.

In Niger, a "regreening" movement using farmer-managed natural regeneration and simple soil and water conservation practices reversed desertification, increased tree and shrub cover 10- to 20-fold, and reclaimed at least 250,000 hectares of degraded land for crops.[18] (See Figure 2.) Over 25 years, at least a quarter of the country's farmers were involved in restoring about 5 million hectares of land, benefiting at least 4.5 million people through increased crop production, income, and food security.[19] Extending the scale of such efforts could have major climate benefits, with huge advantages as well for water security, biodiversity, and rural livelihoods.

Loss and fragmentation of natural habitat

Figure 2. Managing Natural Regeneration in the Drylands of Niger



Difference in vegetation levels between 1975 (left) and 2003 (right) in Niger. This increase can be attributed to the farmer-managed natural regeneration of vegetation. The 15–20 times increase in on-farm tree numbers is absent across the border in Nigeria despite similarities in landscape, soils, vegetation type, and even greater average rainfall.

Source: See Endnote 18 for this section.

Conserving and Restoring Natural Habitats

T Chu

A sample of Brazil's Atlantic Forest, on the island of Ilhabela.

are leading threats to biodiversity worldwide. Conservation biologists have concluded that in many areas, conservation of biodiversity will require the establishment of "biological corridors" through production landscapes to connect fragments of natural habitat and protected areas and to give species access to adequate territory and sources of food and water. One key strategy is to reestablish forest or natural grassland cover (depending on the ecosystem) to play this ecological role, taking advantage of uncultivated areas in and around farmers, culturally important protected areas, and lands around public and private infrastructure and settlements. Such reforestation efforts would also have major climate benefits.

In Brazil's highly threatened Atlantic Forest, conservation organizations working in the Desengano State Park struck a deal with dairy farmers to provide technical assistance to improve dairy-farm productivity in exchange for the farmers reforesting part of their land and maintaining it as a conservation easement. Milk yields tripled and farmers' incomes doubled, while a strategic buffer zone was established for the park.[20]

In northwestern Ecuador, two-thirds of coastal rainforests have been lost due to logging and agricultural expansion, risking the survival of 2,000 plant and 450 bird species. The Chocó-Manabí corridor reforestation project is attempting to improve wild species' access to refuge habitats by restoring connectivity between native forest patches through reforestation efforts. This project is restoring 265 hectares of degraded pastures with 15 native trees species and as a result is sequestering 80,000 tons of carbon dioxide.[21] The opportunity for such investments is mobilizing new partnerships among wildlife conservation organizations, the climate action community, farmers, and ranchers.

A Real Climate Solution?

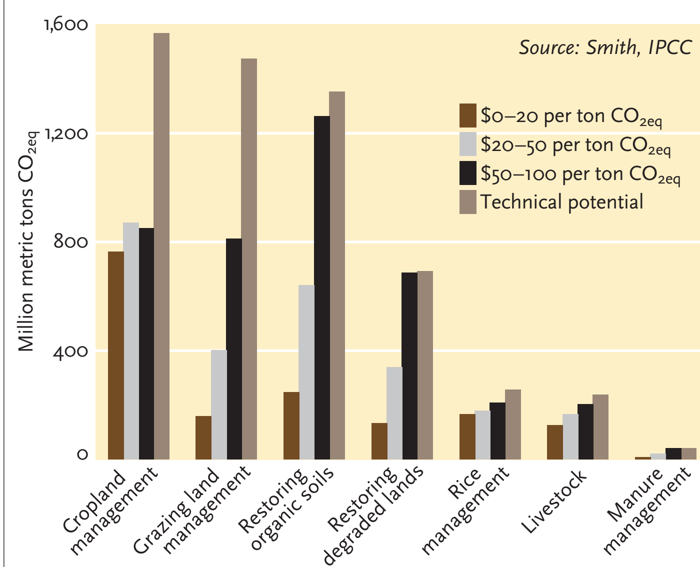
If we add up all the ways in which farming and land use can help store carbon, it is clear that farmers and the agricultural community can play a central role in fighting climate change. The IPCC estimates that at $100 per ton of greenhouse gas mitigation, agriculture has a sequestration potential of 4.0–4.3 billion tons of carbon dioxide equivalent a year by 2030.[1] (See Figure 3.) Afforestation, reduced deforestation, and better forest management have the potential of sequestering 13.8 billion tons a year by 2030.[2] Even at prices at or below $20 per ton of carbon dioxide equivalent, 1.5–1.6 billion tons can be sequestered annually from better agronomic, grazing, and soil management practices, and 5.8 billion tons can be sequestered by the forestry sector.[3]

Even at the lower mitigation prices, these actions would be sufficient to offset a quarter of global emissions from fossil fuel use in a year. In contrast, many of the most promising solutions for reducing emissions in the energy sector are still in the technology development and testing phase, and they are unlikely to be widely utilized for decades. Alternative energy systems play the important role of lowering total greenhouse gas emissions by replacing fossil fuels. But the land use and agriculture sector have the crucial role of sequestering the carbon already in the atmosphere. To really tackle the climate challenge, we need to be pursuing both energy and land use solutions.

Meanwhile, the current concentration of greenhouse gases in the atmosphere is above 382 parts per million of carbon dioxide, up from 278 ppm in pre-industrial times.[4] The IPCC *Fourth Assessment Report* set 450 ppm as the lowest "safe" concentration of carbon dioxide in the atmosphere.[5] However, recent scientific evidence and analyses have induced many scientists to argue that concentrations must actually drop to at least 350 ppm if we are to avoid the risk of catastrophic consequences for food production, ecosystem stability, and human health.[6] This implies not simply reducing emissions, but actually achieving net sequestration of greenhouse gases.

Potential solutions for large-scale greenhouse gas sequestration, such as geological carbon capture and storage, are not ready to be deployed on a large scale for at least another

Figure 3. Greenhouse Gas Sequestration Potentials from Farming and Land Use, by Level of Mitigation Spending



Note: Figure illustrates how different strategies can achieve varying degrees of emission reduction by the year 2030 for a given amount of money spent. In the case of cropland management, nearly half of the technical potential can be achieved at a carbon price lower than $20 per ton, but spending additional money (up to $100 per ton) gives little further benefit. On the other hand, spending more on grazing land management, restoring organic soils, and restoring degraded lands can achieve significantly higher emission reduction.

10–15 years.[7] More crucially, these technologies are designed primarily to capture emissions produced at coal-burning power stations and not to sequester greenhouse gases already present in the atmosphere, which urgently needs to happen.

Only terrestrial carbon sequestration offers that possibility today. Most of the solutions described in this report already exist and are widely known and deployed by farmers, agribusinesses, agricultural and environmental organizations, and public agencies. Scaling up could begin immediately, building on existing efforts in those sectors. Many options can be implemented at relatively modest cost and in some cases by sharing costs with groups interested in the collateral benefits, such as product supply or watershed protection.

USDA/NRCS

How long sequestered? A pine plantation in the United States.

But would such actions result in a real, lasting, and measurable impact on greenhouse gas concentrations in the atmosphere? And is it really feasible to scale up climate-friendly agricultural, livestock, restoration, and habitat conservation efforts by hundreds of millions of hectares in the next few decades? Will the mainstream food industry help or hamper these efforts? And can national policy make a difference?

Fortunately, land use interventions for climate change can be designed to produce real results for the climate. Experts are developing ways to measure those benefits well enough to satisfy buyers of carbon offset credits and regulatory entities, as well as mechanisms that can be used to scale up climate-friendly land-use practices.

Producing Real Results

The single most important criterion for investing in farming and land use for carbon emissions reduction, sequestration, and storage must be that net emissions actually decline as expected. Thus, the three big questions raised about farming and land use carbon investments are:

- Will the emissions be reduced, only to be emitted back into the atmosphere later for no net benefit—that is, will the impact be *permanent*?
- Will climate benefits actually be greater than those expected in the baseline conditions—that is, will they be *additional*?
- Will emission reductions in one place simply be offset by increases in emissions elsewhere—that is, will there be *leakage*?

The issue of "permanence" arises because the carbon stored in soils and vegetation can easily be released, either intentionally through cultivation and harvest or unintentionally through accidental burning or natural disaster. Land use is inherently dynamic in response to both ecological processes and economic incentives, so any system that incorporates farming and land use action must allow for site-level changes.

One approach commonly used in forestry projects is to calculate tree growth and harvest regimes, and to recognize only the *net* carbon sequestration. Insurance systems are essential. Producers typically self-insure by implementing climate-friendly management over much larger areas than are committed for sequestration, by adjusting the latter for defined risks, and by developing and implementing risk management plans. Experience has shown that forestry and agroforestry projects that are managed by or with local communities typically have lower risk profiles than those on large plantations.[8] Where investments lead to a transformation of production and land use systems to incorporate far greater perennial components in profitable practices, these can be very long-lived.

Even land use practices that sequester and store carbon for long periods and then ultimately release most or all of the carbon have a positive impact on climate by delaying emissions that increase concentrations of greenhouse gases in the atmosphere. Although such systems should not be rewarded at the same rate as more permanent stores, they play a valuable role. Moreover, by devising climate action strategies over large geographic areas (watersheds, landscapes, and territories), large-scale changes in land use, land management and institutions, permanence of emission reductions, and sequestration/storage in aggregate can be tracked and rewarded.

Freezing land use patterns is not a viable goal. Rather, we should be seeking transitions to new dynamic equilibriums in which overall sequestration is vastly greater than overall emissions. This will occur only with shifts in underlying incentives for conserving carbon in soils and perennial vegetation and for low-emissions farm and land management. While absolute permanence cannot be guaranteed, "long-lasting" changes are highly feasible and are worth striving for. Moreover, because of the cumulative impacts of carbon in the atmosphere, there are huge climate benefits from sequestration in the near-term, even if that carbon is ultimately released in several decades. Land use sequestration, even if not fully permanent, is thus highly complementary with energy strategies whose impacts are projected in future decades.

There is a common concern about "additionality"—the concept that land managers should not be rewarded with financing or payments for climate-protective land uses and management practices that they are doing already (or that they would be likely to do in response to demographic, economic, or ecological changes under way) without "additional" resources. The concern is expressed particularly in relation to land uses and management practices that are inherently profitable to the manager. If no-till systems or rotational grazing save the farmers money, why should special efforts or resources be put into helping them or rewarding them for making this change? One stance on additionality is that farmers should be paid only for activities that are highly unprofitable—such as taking land out of production or using expensive mitigation technologies—to compensate them for giving up these profits.

But this type of thinking will not facilitate large-scale land use change. There are now robust methodologies for establishing conservative baselines for land use and associated emissions change in many types of agroecosystems and landscapes. (See next section). It is also now fairly well established that additionality criteria are met when investments enable farmers and land users to overcome significant barriers to adopting profitable climate-friendly practices. These include, for example, lack of technical assistance, lack of regionally available planting materials, lack of investment credit, or lack of essential infrastructure. In such cases, investments to overcome those barriers are acknowledged to create "real" additional benefits for the climate.

Inherently profitable and sustainable interventions are precisely those with the greatest potential for large-scale adoption, impact, and permanence, as continuous external payments and investments are not needed to ensure their continued use. Financial resources for continuous payments can then be used to compensate farmers and land users to maintain strictly conserved, undisturbed areas in selected high-priority wildlife nesting sites or critical watersheds that generate few financial flows to farmers.

Furthermore, failing to reward sustainable producers creates perverse incentives whereby historically good land managers are bypassed by programs that favor producers who have contributed most to climate problems. In Nicaragua, for example, farmers who were bypassed for carbon and biodiversity payments, despite a history of excellent land husbandry, wondered if they would be eligible if they uprooted their trees.[9] Most cap-and-trade systems to address carbon emissions are currently set up this way, but there are alternative mechanisms to ensure that good actors are rewarded. Options include premiums for climate-friendly certification or preferred procurement, taxes on high emitters, and incorporating the value of positive climate impacts into land valuation and payments.

The third issue of concern in making sure that land use projects are effective is potential "leakage," a situation where achieving climate benefits in one place simply displaces land use pressures elsewhere, resulting in no net reduction in emissions. Stopping deforestation for logging and land-clearing in one forest, for example, may simply induce loggers to move to another forest and increase clearing there. This problem arises mainly for interventions of "avoided emissions," where the intervention that reduces production and demand can easily shift to other sources of supply of land or products. Thus, if low-emissions cropping systems result in lower overall supply or induce price increases for the product, then other non-climate-friendly or lower-cost producers may step into the market.

For the subset of farming and land-use interventions where this is an issue, several solutions have been devised. The first is implementation at a large scale, spatially. Here, monitoring and financial support take into account the net change in emissions across the entire area or market. This is the motivation behind the requirement that countries develop national baselines to become eligible for large payments for REDD activities. Another solution is to limit the market only to producers that can be certified as "climate-friendly" by regulators or third-party certification systems.

But leakage is simply not a problem for most types of climate-friendly farming and land use that involve carbon sequestration, or where emission reduction practices do not significantly increase farmers' costs of production. Investing in agroforestry practices in settled farming systems is far more likely to take land-clearing and harvest pressure *off* of any nearby natural forests. Enhancing soil carbon in agricultural fields will typically increase crop yields and farm income, enabling farmers to use less land for the same production and to avoid land-clearing. Reducing methane emissions from dairy operations through biogas digesters that supply farm energy needs will sometimes make those farms more profitable than their high-emitting competitors. Relatively modest initial investments in helping farmers overcome adoption barriers can lead to long-lasting benefits from climate-friendly, sustainable farming systems.

Measuring Climate Impacts

For terrestrial carbon offsets to work, sellers of the offsets must satisfy buyers and regulatory agencies that the offsets produce measurable reductions of greenhouse gases over time. Negotiations for a successor international climate agreement to the Kyoto Protocol will likely include "avoided deforestation" (REDD) mechanisms, facilitated by the development of national forest carbon accounting methods.

A major constraint to the inclusion of agricultural emissions and offsets in international, European, and national greenhouse gas trading, market, and offset schemes is the absence of rigorous, validated methodologies for assessing agriculture-related emissions, sequestration, and storage. Yet scientists are rapidly developing methodologies for assessing carbon balances for specific components of agricultural land use—for example, soil organic matter enrichment, conservation tillage, grassland management, and tree crop plantations and agroforestry systems.[10]

The scientific capacity to measure soil carbon is quite developed, and significant advances have been made in just the last few years. Soil sampling equipment and protocols have been around for decades. New lab protocols and modern dry-combustion auto-analyzers can now measure the carbon content of a soil sample within the range of 1–2 percent error. Field experiments have documented the impact of environment and management changes on soil carbon content.

Since carbon content in soils from an individual field can vary widely, sampling approaches are being developed that link remote sensing with representative samples of soil. Instead of measuring directly, a lower-cost alternative is to measure adoption of specific management practices whose average impact has been validated for a particular agroecosystem. An integrated approach that combines the best elements of each is probably the most practical way forward.

Diverse measurement and monitoring approaches have been developed for farm forestry and agroforestry, and for restoring degraded lands. These include remote sensing of above-ground (and in some cases below-ground) biomass, oblique ground-based photography, field sampling, and participatory monitoring by farmers.

This piecemeal approach, however, generates skepticism that climate investment benefits in one component of the landscape will be undermined by increased emissions elsewhere in the landscape. Absent is an integrated approach to landscape-level carbon accounting that would reflect diverse land uses and practices and thus enable rigorous but more cost-effective monitoring of large-area carbon sequestration or offset investment programs in heterogeneous, dynamic landscapes.

Several groups, such as the Terrestrial Carbon Group, the World Agroforestry Centre, and the Cornell University Ecoagriculture Working Group, have begun to mobilize research on affordable methodologies for landscape-scale assessment. It is quite feasible now to develop a step-by-step timeline for developing rigorous measurement methods, while enabling investments in specific components to move ahead with their own measurement systems. A checklist-based process can certify that investments are not associated with increased emissions from other land use components in the landscape.

Scaling Up Investment

Most of the climate-friendly farming and land use approaches described in this report have been successful in pilot or individual landscape cases. But these initiatives must be mobilized at a large-enough scale to make a difference to the world's climate. Prevailing perceptions held by the climate change science and policy communities are that agriculture, forestry, and conservation are lagging sectors with weak institutions, unlikely to provide solutions at scale, while the energy sector is considered cutting-edge and thus more promising.

This skepticism has a variety of sources. The diversity of site-specific practices makes it hard to envision that significant economies of scale will develop in terrestrial carbon-based mitigation. Working with small-scale farmers is assumed to imply working only at a limited scale, even if millions of participants are involved. Drylands and other areas where plant growth is slow and biomass per hectare is low are assumed to have low potential for sequestration, despite the fact that huge areas could be involved. Pilot projects are being done at a small scale, allowing for rigorous work and an objective assessment of progress against a good baseline. But sustaining funding for such rigorous work on a larger scale is presently a big hurdle.

High-quality climate projects with farmers and rural communities require community-scale planning—both technical and organizational—and this is seen as too slow a process to satisfy carbon investors or to scale up adequately. In developing strategies for carbon payments and trading, there is a concern that poorly developed and integrated market institutions (not just sellers' and buyers' groups but also regulators, verifiers, certifiers, brokers, bankers, and registers) and poor negotiating power on the part of rural communities means that most of the value of carbon credits will be taken by intermediaries, with little left over to provide meaningful financial incentives to land managers.

But these are the "barriers" that justify the "additionality" of climate finance investment. And there are institutional models and experiences already available to overcome most of these hurdles; they just require institutional investment, capacity-building, and finance for scaling up. This expertise is held largely in rural development agencies, farmers' organizations, nongovernmental organizations, and private agricultural input and service providers. In fact, sustainable land management and rural development are pretty much bread-and-butter issues for many of these groups. But that expertise has not been fully tapped by the climate expert and advocacy communities, which will be crucial if the hard-won lessons of the last 50 years are not to be expensively reinvented.

A Real Climate Solution?

For example, small local projects can be coordinated, and critical services provided, in the context of overall regional development efforts that can provide sustained funding and a common vision. A larger platform can provide a forum for drawing general patterns from pilot experiences that reduces the need for re-inventing the wheel by spreading knowledge from past efforts. National platforms for coordinating actions on sustainable land management offer a forum for partnerships that foster common vision and goals and consolidation of resources.

One example is TerrAfrica, a multi-stakeholder platform to upscale and align investments related to sustainable land management in sub-Saharan Africa.[11] The platform supports implementation of countries' National Action Programs for the U.N. Convention to Combat Desertification and the New Partnership for Africa's Development's (NEPAD's) Comprehensive Africa Agriculture Development Program to improve food security and productivity. It provides knowledge-sharing, coalition-building, and coordination of country-based investments across sectors, which is already being tapped for climate adaptation and mitigation activities.

Territorial management initiatives, including programs implemented by indigenous peoples' authorities, are also under way in the Andes and Mesoamerica. Very large-scale government programs for restoring degraded lands and forests are being implemented in India and China and can be enhanced as a platform for climate-focused action. India's Integrated Wasteland Development Project, for example, has set a long-term goal of restoring over 30 million hectares of non-forest wastelands. And China's Sloping Lands Program has set a soft target of converting 14.7 million hectares of wasteland into forests, although the top-down planning approach with little community input has come under criticism.[12]

Community-led initiatives for managed natural regeneration in Africa, with modest external support, have restored 250,000 hectares of degraded lands in Niger and 350,000 hectares in Tanzania.[13] Conservation International now has at least 33 agreements with indigenous families, fishers, farmers, and communities in six countries to sequester and store carbon, enhance biodiversity, and improve rural livelihoods on more than 600,000 hectares of land.[14] And the International Fund for Agricultural Development has long experience with rural land restoration projects for very low-income farmers and pastoralists.[15] South Asian and East African dairy farmer cooperatives, which are numerous and well-organized, with tens or hundreds of thousands of smallholders, could be a platform for climate-friendly production systems.

Meanwhile, community planning and stakeholder participation for climate action—time spent in meetings and negotiations—should not be seen as time wasted. Instead, it is time invested to reduce future risks. As stakeholders develop trust and relationships by working together, and as more groups are involved, there is less risk that an action will fail or be abandoned. Project designs are more effective and sustainable, and the benefits are enjoyed more widely.

Action can be initiated with organized and tenure-secure communities, and then expanded to build the capacity of farmer and local organizations working on the landscape scale. As local groups take leadership roles, the climate sector can focus on developing small-grant facilities for local analysis, planning, facilitation, and mapping. Communities should also be represented at the negotiation table. Through the Community Knowledge Service, for example, the Equator Initiative and Ecoagriculture Partners have helped farmer and community representatives participate in previous international negotiations. There should be a strong presence at the Copenhagen meetings in December 2009, as well as at future meetings both internationally and nationally where the "rules of the game" are established.

New and improved institutional models are needed to implement terrestrial emission reduction and sequestration initiatives at scale and in a way that will enable financial incentives to be delivered efficiently to land users. This will require facilitating collaboration among large numbers of land managers in selling climate benefits, developing investment vehicles for buyers, and organizing efficient intermediation to achieve economies of scale.

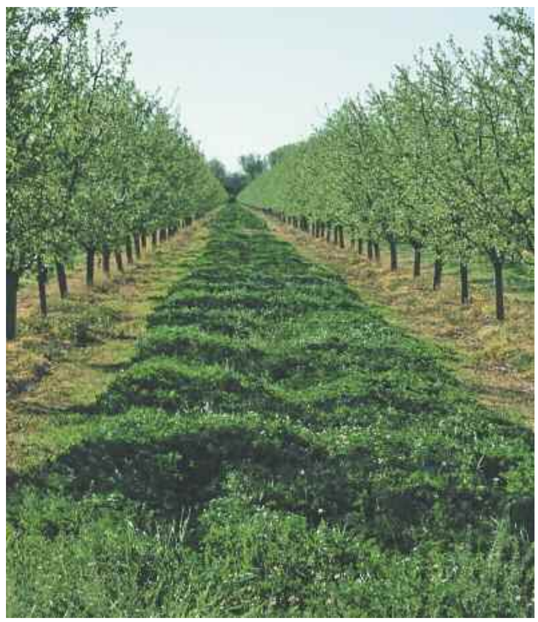
Innovation in the Food Industry

A core opportunity for mobilizing climate action is shifting policy and investment priorities and supporting institutions to create incentives for farmers, pastoralists, forest owners, agribusiness, and all other stakeholders within the agriculture and forestry supply chains to scale up best practices and innovate new ones. This will require concerted action by consumers, farmers' organizations, the food industry, civil society, and governments, which is already beginning to happen.

The central players in any response to climate change are the producers—those who actually manage land—and the food industry, which shapes the incentives for the choice of crops, quality standards, and profitability. Some innovators are already showing the way. For example, the Sustainable Food Lab, a collaborative of 70 businesses and social organizations from around the world, has assembled a team of member companies, university researchers, and technical experts to develop and test ways to measure and provide incentives for low-carbon agricultural practices through the food supply chain, mainly by increasing soil organic matter, improving fertilizer application, and enhancing the capacity of crops and soil to store carbon.[16]

A key driver is consumer and buyer awareness. Consumers will take the needed steps once they realize that their choice of grain, meat, and dairy products, and their support for natural forests and grassland protection, can have a greater impact on the climate than how far they drive their cars. One immediate action is for consumers, processors, and distributors to support labeling of the climate impacts of food and fiber products. This can be based on greenhouse gas "footprint analysis" that evaluates the products' full lifecycle impacts—including the resources used in production, transport, refrigeration, and packaging—to identify strategic intervention points.

Greenhouse gas impact is a key metric that can be used for evaluating new food and forest production technologies and for allocating resources and investments. Policymakers can then include incentives for reducing carbon emissions in cost structures throughout the food and land use systems, using various market and policy mechanisms. In 2007, for instance, the Dole Corporation committed to establishing by 2021 a carbon-neutral product supply chain for its bananas and pineapples in Costa Rica.[17] The first step in this process was to purchase forest carbon offsets from the Costa Rican government equal to the emissions of the company's inland transport of these fruits.



USDA NRCS/Gary Kramer

Cover crops between rows of a California orchard.

Product markets are also beginning to recognize climate values. The last two decades have seen the rise of a variety of "green" certified products beyond organic, such as "bird-friendly" and "shade-grown," that have clear biodiversity benefits. Various certification options already exist for cocoa and coffee (through the Rainforest Alliance and Starbucks, for example).[18] The Forest Stewardship Council's certification principles "prohibit conversion of forests or any other natural habitat" and maintain that "plantations must contribute to reduce the pressures on and promote the restoration and conservation of natural forests," supporting the use of forests as carbon sinks.[19] New certification standards are starting to include impacts on climate, which will for the first time send clear signals to both producers and consumers.

The rise of carbon emission offset trading could potentially provide a major new source of funding for the transition to climate-friendly agriculture and land use. A great deal can be done in the short term through the voluntary carbon market, but in the long run it will be essential for the international framework for action on climate change to fully incorporate agriculture and land use.

National Policy

Governments can take specific steps immediately to support the needed transition by integrating agriculture, land use, and climate action programs at the national and local landscape levels. Costa Rica is a leader in these efforts. The country increased its forest cover from 21 percent in 1986 to 51 percent in 2006, and the government has committed to achieving "climate neutrality" by 2021, with an ambitious agenda including greenhouse gas mitigation through land use change.[20] The country is also taking advantage of ecotourism and markets that make payments for ecosystem services to support these efforts. Costa Rica is a participant in the Coalition for Rainforest Nations, a group that is encouraging avoided-deforestation programs.[21]

Currently, governments spend billions of dollars each year on agricultural subsidy payments to farmers for production and inputs. The greatest expenditures occur in the United States ($2 trillion, or 16 percent of the value of agricultural production) and Europe ($77 billion, or 40 percent of the value of agricultural production), but high subsidies also exist in Japan, India, China, and elsewhere.[22] Most of these payments exacerbate chemical use, the expansion of cropland to sensitive areas, and overexploitation of water and other resources, while distorting trade and reinforcing unsustainable agricultural practices. Some countries are beginning to redirect subsidy payments to agri-environmental payments for all kinds of ecosystem services, and these can explicitly include carbon storage or emissions reduction.

The growth in commercial demand for agricultural and forest products from increased populations and incomes in developing countries, and rising demand for biofuels in industrial nations, is stimulating investments by both the private and public sectors. In 2003, African governments committed to increasing public investment in agriculture to at least 10 percent a year, although only Rwanda and Zambia have done this so far.[23] The World Bank and the Bill & Melinda Gates Foundation have committed to large increases in funding in the developing world. There is a major window of opportunity right now to put climate change mitigation (and adaptation) at the core of these strategies.

This is beginning to happen in small steps. Brazil is crafting a diverse set of investment programs to support rural land users to invest in land use change for climate change mitigation and adaptation.[24] The United Nations Environment Programme is initiating dialogues on "greening" the international response to the food crisis, linking goals of international environmental conventions with the Millennium Development Goals.[25]

But much more comprehensive action is needed to ensure that ecologically sustainable, climate-friendly practices are the focus of increased agricultural investments. If not, this otherwise positive trend could seriously undermine climate action programs. A new vision is needed to respond to this food crisis that not only provides a short-term Band-Aid to refill next year's grain bins, but also puts the planet on a trajectory toward sustainable, climate-friendly food systems. New pricing schemes are needed that incorporate greenhouse gas emissions into the cost of producing and processing food.

National policy, however, is not enough to scale climate action. It is essential to invest in building capacity at local levels to manage ecoagricultural landscapes—to enable multistakeholder platforms to plan, implement, and track progress in achieving climate-friendly land use systems that benefit local people, agricultural production, and ecosystems.

Co-Benefits: Distraction or Opportunity?

Land use-based climate solutions can create co-benefits that meet several of the important United Nations' Millennium Development Goals in developing countries. These goals include eradicating extreme poverty and hunger (Goal 1), promoting gender equality and empowering women (Goal 3), and ensuring environmental sustainability, including access to safe drinking water and conservation of biodiversity (Goal 7). Indeed, a key pillar for achieving the hunger eradication goal is to restore and protect natural resources, including soils and vegetative cover, upon which poor people rely for food production and gathering.[1]

Globally, land-based climate solutions can help the transformation of agricultural and forestry production systems and ecosystem services to a sustainable and climate-friendly trajectory. They can also help finance land management that produces ecosystem services. Potential co-benefits are extensive and diverse. (See Figure 4, next page.)

Although climate leaders are sensitive to these ideals, they are not yet convinced that it is their place to promote development and conservation activities. Rather, these activities are seen as a potential distraction of attention and resources from the immediate need for emission reduction in the energy sector.

This concern is misplaced. The core rationale for aggressive and comprehensive climate action on farming and land use is, of course, that these sectors account for nearly a third of all global emissions and are on a trajectory of emissions increase. Moreover, there is a moral imperative for action to mitigate the impacts of climate change on the world's poorest and most vulnerable people. Rather than being a distraction, linking sustainable land management with climate action will attract a broad group of actors with a stake to become political allies in promoting overall stricter climate regulation and greater investment in mitigation.

Farming and Land Use Mitigation Can Help the Poor More

To get to the heart of the matter, we should ask: Why is humanity concerned about climate change? After all, climate change and its impacts are not new phenomena. In the last half million years, four ice ages and four warm periods have passed. Glaciers have covered continents and then retreated, and sea levels have risen and fallen. The asteroid impact in the Yucatan peninsula put the final nail in the dinosaurs' coffin, cloaked the planet in darkness, and led to the rise of mammals to fill in the vacated ecological niches.

Our principal concerns in addressing climate change are to avoid human suffering and ecosystem damage. Impending human losses are unacceptable for the 6.7 billion people inhabiting the planet and particularly for the more than 1 billion who are already desperately poor and vulnerable. Fires will be more frequent and rampant, as will hurricanes. Sea-level rise will displace coastal populations, and crops will fail. These impacts do not distinguish between rich and poor, but we know from global experience with disasters that the poor suffer disproportionately due to greater vulnerability, fewer services, lack of insurance, and other factors.[2] For them, climate change will cause an unprecedented number of displacements, diseases, crop failures, property

Figure 4. Sustainable Development Benefits Motivating Climate Action

Climate action in and around farms and grazing lands tends to create platforms for improved biodiversity and provision of ecosystem services that improve farming livelihoods. Access to wild plants, game, and sources of micro-nutrients improves nutrition, while also providing "safety nets" during lean seasons. Access to medicinal plants, fuel, and construction materials provides options for additional income, while fodder, fertilizer trees, pollination services, improved soil health, nutrient cycling, and improved water quality and supply make farming more sustainable and productive.

Seth Shames

Meike Andersson

Above: Windbreaks and other planted trees create habitat and corridors for biodiversity of neighboring forest and protect the soil and crops from erosion. Kijabe, Kenya.

Above right: Intercropping citrus trees with vegetable crops such as cabbage increases the carbon sequestered on the farm and diversifies food production. Diversified production is crucial for resilience necessary to adapt to climate change. Bali, Indonesia.

Right: Agroforestry can be used to grow valuable fodder trees among crops to create complex habitat for biodiversity on the farm and to provide a reliable, nutritious, and cheap source of feed for livestock—all while sequestering carbon. Pokhara, Nepal.

Sajal Sthapit

damages, and deaths. Most of the severe and unacceptable human impacts will first affect the rural poor, and many are feeling the impacts already—from lost homes due to Hurricane Katrina in New Orleans, to flooding in Bangladesh, to crop losses in Africa.

In particular, climate change is going to undermine the stability of our food supply and heighten the risk of food insecurity for billions. Agricultural systems have developed during a time of relatively predictable local weather patterns. The choice of crops and varieties, the timing of input applications, vulnerability to pests and diseases, the timing of management practices—all these are closely linked to temperature and rainfall. With climate changing, production conditions will change—and quite radically in some places—which will lead to major shifts in farming systems. An increasingly open trade system may be needed to get food to those who need it. But the failure of the Doha Round of international trade negotiations raises doubts about our ability to use trade flows to improve the world's food security.[3]

Models of climate impact in the 1990s and early 2000s predicted that rising agricultural yields in high-latitude regions would offset the yield losses elsewhere.[4] These models assumed that the increase in atmospheric carbon dioxide will also improve crop growth, but recent field studies do not justify this assumption.[5] The impact of higher temperatures and frequency of extreme events are likely to easily overturn the theoretical benefits of carbon dioxide fertilization.[6]

In addition, the massive shifts in weather patterns will threaten critical ecosystems, endangering the ecosystem services on which human well-being depends—such as water flow and quality, pollination, soil formation, and waste decomposition. Due to the already-extensive human-induced habitat loss and fragmentation across the globe, Earth's remaining biodiversity is also threatened by climate change where territorial movement is blocked or new pest and disease complexes arise. Climate scenarios predict, for example, that more winter rains in the Sahel can create favorable breeding conditions for the desert locust (*Schistocerca gregaria*), a migratory plant pest that was responsible for consuming 100 percent of crops in some areas of Niger in 2004.[7]

Although obviously critical to slowing climate change, investments aimed at reducing energy-based emissions will not help the rural poor, who already use pitifully little of the world's energy. In Africa, for example, only 19 percent of the rural population has access to electricity, and the per capita fossil fuel emission is about a quarter of the global average of 4.4 tons of carbon dioxide equivalent per year.[8] But investment in terrestrial carbon based solutions can provide short and long-term relief to the most vulnerable and innocent victims of climate change (provided that pro-poor approaches and safeguards are used) and can help protect ecosystem services and biodiversity.

The global strategy for reducing greenhouse gas concentrations must recognize the need for major increases in food and fiber production in developing countries to adequately feed the 850 million people currently at risk of hunger, as well as continually growing populations with higher incomes.[9] Investments must be channeled so that increased production comes from climate-friendly, carbon-rich production systems rather than from systems that clear large areas of natural forest and grasslands, mine organic matter from the soil, strip vegetative cover from riparian areas, or leave soils bare for many months of the year. Moreover, making existing and anticipated investments in agriculture and land management climate-friendly further augment and leverages investment flows for mitigating climate change.


USDA ARS/Scott Bauer

A researcher notes excellent corn growth on manured soil treated with alum residue, which cuts ammonia emissions to the air and phosphorus losses in runoff water.

New Champions for Climate Action

Many of the actions most needed in land use systems to adapt to climate change and mitigate greenhouse gas emissions will bring positive benefits for water quality, air pollution, smoke-related health risks, soil health, energy efficiency, and wildlife habitat. These tangible benefits can generate much broader political support for climate action than simply a fear of future problems.

The prospect of such benefits can generate many new groups of people with a self-interest in promoting ambitious climate action goals. Farmers and conservationists who are in a position to sell soil-carbon offsets will become vocal advocates of tighter emission caps and public investment in alternative energy. Politi-

Co-Benefits: Distraction or Opportunity?

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A farmer plows his field to plant rice, Pokhara, Nepal.

cians with rural constituencies likely to benefit from restored watersheds and a more resilient food supply will be more inclined to join political coalitions for climate action. Agribusinesses and food industries can gain reputational benefits with their clients and consumers as "climate-friendly" companies, as consumers shift their buying habitats to reduce climate impacts.

We therefore encourage climate leaders to turn their thinking around. Investing in climate-friendly farming and land use, with their myriad related benefits, is not a distraction from developing alternative energy systems; rather, it is part of a comprehensive solution. Why should we not take every opportunity to find synergies between action to reduce climate change and action to advance other social goals? So long as the carbon benefits are real, we should seek to prioritize those efforts that maximize co-benefits.

Realizing the Potential

Human well-being is wrapped up with how food is produced. Over the past century, ingenious systems were developed to supply food, with remarkable reliability, to most of the world's 6.7 billion people. But these systems need a fundamental restructuring in the coming decades to establish sustainable food systems that do not contribute to climate change and that are also more resilient to it. Private-sector action will determine the response, but public policy and civil society will play a crucial role in providing the incentives and framework for markets to respond effectively.

Food production and other land uses are currently among the highest greenhouse gas emitters on the planet—but that can be reversed. Although recent food price riots have discouraged actions that could raise costs, if action is not taken costs will rise anyway as local food systems are disrupted and as higher energy costs ripple through a system that has not been prepared with alternatives.

As described in this report, many technologies and management practices are already available that could lighten the climate footprint of agriculture and other land uses and protect the existing carbon sinks in natural vegetation. Many more could become operational fairly quickly with proper policy support or adaptive research and with a more systematic effort to analyze the costs and benefits of different strategies in different land use systems. Additional innovative ideas will emerge if leading scientists and entrepreneurs can be inspired to tackle this challenge.

It is heartening that there are already so many initiatives to address climate change in the food and land use sectors, and these efforts have established a rich foundation of practical, implementable models. But the scale of action so far is dishearteningly small. With the exception of the recent REDD initiatives to save standing forests through intergovernmental action, which are still at an early stage, there are no major international initiatives to address the interlinked challenge of climate, agriculture, and land use.

As we move toward international climate negotiations in Copenhagen in December 2009, and the years after that when international and national climate action rules and guidelines are crystallized, we recommend the following six principles for tapping the full potential of land use based mitigation:

1. **Include the full range of terrestrial emission reduction, storage, and sequestration options in climate policy and investment.** The most important action is to ensure that the full range of terrestrial emission reduction, storage, and sequestration options is included in international framework agreements, national legislation, and investment programs to address climate change. This approach will not only ensure that terrestrial emissions receive the critical attention they need and that terrestrial sequestration opportunities are fully realized, but it will also broaden the potential set of citizens, businesses, and other interested parties with a stake in effective climate protection.
2. **Incorporate farming and land use investments in cap-and-trade systems.** We will need maximum effort from all sectors to meet the 450 parts per million goal set by the IPCC in 2007, much less the 350 ppm

goal now considered by many scientists to be necessary to prevent risk of catastrophic impacts.[1] Emphasis should be on limiting overall greenhouse gas emissions with a schedule of gradually lowered caps that will meet the goal. Caps should be extended to the land use sectors and eventually the full value chain of food, fiber, and biofuel industries. Within those caps, we should seek the lowest-cost options to achieve both emission reduction and sequestration.

Cap-and-trade systems will generate dramatically greater resources for shifting to a low-carbon economy than can be done with government tax revenues. It may take a few years to sort out implementation and measurement issues, but there should be a clear timeline and roadmap for doing so. The way to handle risks and uncertainties is through various insurance mechanisms and through strict, context-adapted monitoring protocols.

http://earthobservatory.nasa.gov/, courtesy Compton Tucker, NASA GSFC

Formerly tropical dry forest, in 2000 this area of Bolivia became an agricultural settlement for farmers relocated from the Altiplano.

3. **Link terrestrial climate mitigation with adaptation, rural development, and conservation strategies.** Greenhouse gases that are sequestered and stored anywhere on the planet have the same beneficial impact in slowing climate change. Thus, decisions on how, where, and with whom to invest in terrestrial emission reduction and sequestration can and should be made to maximize anticipated co-benefits for sustainable rural development, poverty reduction, and ecosystem conservation. Climate action plans should help shift economies to a low-carbon/low greenhouse gas trajectory.

   Hence, climate funding should help to accelerate the transformation of agricultural systems to long-term profitable alternatives, helping to overcome early transition costs and barriers to adoption and to invest in improved technologies. This means refining the definition of "additionality" to ensure that climate investments result in production and land use approaches that are both profitable and sustainable over the long term. Wherever possible, mitigation efforts should be linked to adaptation goals and planned and implemented jointly. Agriculture, rural development, and conservation strategies should incorporate mitigation and adaptation centrally in their plans.

4. **Encourage large, area-based programs.** The synergies arising from such coordinated and integrated approaches are likely to be greatest in large, area-based programs. Using landscape, watershed, or territorial frameworks for planning can maximize links to development, agricultural, ecosystem management, and energy strategies. Landscape-wide monitoring of emissions and sequestration can be done at lower cost, and setting caps or targets at this scale enables maximum flexibility for land use and management to reflect a dynamic economy. Large reserves within the landscape can be maintained as self-insurance, and leakage will be minimized. Carbon payments, whether made by governments or markets, can be used to pay for coordinated, large-scale investments.

5. **Encourage voluntary markets for greenhouse gas emission offsets from agriculture and land use.** It is likely to take some time for fully inclusive cap-and-trade systems to be in place. Meanwhile, policymakers, businesses, nongovernmental organizations, and farmer organizations should make extensive use of emerging voluntary carbon markets. Climate action advocates should raise aware-

ness and social pressure to engage in such markets on the part of emitters not yet required to act by regulation. This sector can be used intentionally and creatively to test diverse types of institutional rules and arrangements, monitoring methods, and farmer engagement processes, for later incorporation into regulated markets.

6. **Mobilize a worldwide, networked movement for climate-friendly food, forest, and other land-based production.** It is time to forge unusual political coalitions that link consumers, producers, industry, investors, environmentalists, and communicators to mobilize action to slow climate change. Food is something that the public understands. By focusing on food systems, climate action will become more real to people.

No climate change mitigation strategy can be complete or successful without addressing greenhouse gas emissions and sequestration in agriculture, forestry, and conservation land uses. Engaging rural land users in mitigation as well as adaptation, and linking them effectively with urban consumers and industrial emitters, will broaden societal understanding of the issues and deepen commitment to an ambitious climate response. Such action will also stimulate higher standards of planning, management, and implementation in rural production and conservation sectors, and can contribute to sustainable rural economic development. Indeed, the status of farmers and land managers in societies will be enhanced as their responsibility as stewards for a stable climate is recognized and rewarded. And society will reconnect in a new way with its ancient roots in the cultivation of land for food.

Sidebar 3. Six Principles for Tapping the Full Potential of Land Use Mitigation

1. Include the full range of terrestrial emission reduction, storage, and sequestration options in climate policy and investment.
2. Incorporate farming and land use investments in cap-and-trade systems.
3. Link terrestrial climate mitigation with adaptation, rural development, and conservation strategies.
4. Encourage large, area-based programs.
5. Encourage voluntary markets for greenhouse gas emission offsets from agriculture and land use.
6. Mobilize a worldwide, networked movement for climate-friendly food, forest, and other land-based production.

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WORLDWATCH REPORT 179

Mitigating Climate Change Through Food and Land Use

Agriculture, forestry, and other changes in land use are responsible for more than 30 percent of human-caused greenhouse gas emissions. Despite advances in the energy sector, the only method currently available for removing large amounts of carbon from the atmosphere is plant photosynthesis. Thus, no strategy for mitigating global climate change can be complete or successful without engaging the land use sector.

Changing how we grow crops, raise livestock, and use land can reduce greenhouse gas emissions and increase carbon sequestration and storage. Key strategies to cut land-based or "terrestrial" emissions are: enriching soil carbon, farming with trees and other perennials, using climate-friendly livestock practices, protecting natural habitat, and re-vegetating degraded watersheds and rangelands.

Yet so far, terrestrial carbon has been largely ignored in climate change mitigation efforts. Some scientists and policymakers worry that investments in land use will not produce "real" climate benefits, that land use action will distract attention from investment in energy alternatives, and that land management changes cannot be scaled up enough to make a difference.

But in fact, knowledge, tools, and institutions are already available to enable scaling up of effective agriculture and land use mitigation strategies. Wise and locally appropriate investments in land use can bring diverse benefits for food security, rural livelihoods, and ecosystem protection—expanding political support and generating new coalitions for broad climate action.

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