AGRICULTURE & RURAL DEVELOPMENT
NOTES

ISSUE 60
MARCH 2012

Productivity and Climate Benefits of Improved Land Management Technologies

Ensuring food security under changing climate conditions is one of the major challenges of our era. Agriculture must not only become increasingly productive, but must also adapt to climate change while reducing greenhouse gas emissions. Carbon sequestration, the process by which atmospheric carbon dioxide is taken up by plants through photosynthesis and stored as carbon in biomass and soils can be instrumental in supporting these goals. First, increased soil carbon raises agricultural productivity, which is essential for reducing rural poverty. Second, it limits greenhouse gas concentrations in the atmosphere. Third, it mitigates the impacts of climate change on agricultural ecosystems. This note describes the potential benefits of selected land management technologies that purposefully sequester carbon.

BACKGROUND

Agriculture is the economic foundation of many developing countries, employing up to two-thirds of the workforce and contributing between 10 and 30 percent of gross domestic product (GDP). For the poorest people, GDP growth originating in agriculture is about three times more effective in raising incomes than GDP growth originating from other sectors (World Bank, 2010). Yet agricultural growth rates have declined significantly over the last decade and food insecurity remains pervasive. Food production must increase by 70 percent by 2050 to meet the demands of a world with 9 billion people and changing diets. In some African countries it must increase by more than 100 percent.

Agriculture is highly vulnerable to climate change. Its direct relationship with the environment has always been one of agriculture's distinguishing characteristics, and more than any other major economic sector, it will need to adapt to the changing climate. Under optimistic lower-end projections of temperature rise, climate change may reduce crop yields by between 10 and 20 percent. Increased incidence of droughts and floods may lead to a sharp increase in prices of some of the major grain crops by the 2050s.

While agriculture is exceptionally susceptible to climate change, it is also a major contributing cause, accounting for about 14 percent of global greenhouse gas emissions. This proportion rises to about 30 percent when considering land-use change, including deforestation driven by agricultural expansion for food, fiber and fuel. The net increase in agricultural land during the 1980s and 1990s was more than 100 million hectares across the tropics. About 55 percent of this new agricultural land came at the expense of intact forests, while another 28 percent came from the conversion of degraded forests (Gibbs et al. 2010). The triple imperatives of increasing productivity, enhancing resilience to climate change, and reducing emissions call for alternative practices which are collectively referred to as *climate-smart agriculture* (CSA).

Historically, agricultural soils have lost more than 50 billion tons of carbon. A proportion of this carbon can however be recaptured through sustainable land management (SLM) practices. While there is a growing global consensus on the need to rapidly scale-up CSA, doing so successfully will rely on an improved knowledge base on what kinds of investment in land management technologies most effectively increase the storage of organic soil carbon. A World Bank study titled *Carbon Sequestration in Agricultural Soils* documents important lessons learned in the area which are summarized in this note.

FARMS CAN BECOME MORE PROFITABLE THROUGH SUSTAINABLE LAND MANAGEMENT

SLM technologies can benefit farmers by increasing yields and reducing production costs. These technologies include integrated nutrient and water management, mulching and residue management, no-tillage,

Maize growing under Faidherbia albida trees. Photo: World Agroforestry Centre.

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CLIMATE-SMART AGRICULTURE, SUSTAINABLE LAND MANAGEMENT, AND CONSERVATION AGRICULTURE

Climate-smart agriculture seeks to increase productivity in an environmentally and socially sustainable way, strengthening farmers' resilience to climate change, and reducing agriculture's contribution to climate change by reducing greenhouse gas emissions and sequestering carbon on farmland. It includes a variety of proven techniques such as mulching, integrated nutrient management, intercropping, conservation agriculture, crop rotations, integrated crop-livestock management, agroforestry, improved grazing, and improved water management. It also includes a number of innovative practices such as better weather forecasting, early warning systems, and risk management.

A key element of CSA is *sustainable land management* (SLM), which is defined as a knowledge-based procedure that helps integrate land, water, biodiversity, and environmental management to meet rising food and fiber demands while sustaining ecosystem services and livelihoods. It entails the implementation of land use systems and management practices that enable humans to maximize the economic and social benefits from land while maintaining or enhancing the ecosystem services that accrue from land resources.

Among the most important practices associated with SLM is *conservation agriculture,* which aims to achieve sustainable and profitable agriculture and subsequently aims at improved livelihoods of farmers through the application of the three principles: minimal soil disturbance, permanent soil cover, and crop rotations.

crop rotation, cover crops, and agroforestry. The integrated land use systems combine trees and shrubs with crops, and in many settings with both crops and livestock. Profits increase for a variety of reasons that vary by system and by crop. Profit gains achieved in no-tillage systems for instance primarily result from the reduction in labor required for seedbed preparation and related operations compared to conventional tillage systems. In Zambia, no-tillage led maize yields to double and cotton yields to increase by 60 percent. While maize, sorghum, millet, cotton and groundnut yields often increase significantly in agroforestry systems, the relatively high labor intensity required to manage competition between trees and crops tends to offset part of the profits gained. Inorganic fertilizers also result in relatively high profits by providing nutrients that are readily absorbed by plants. They are however less environmentally-friendly owing to nitrous oxide emissions associated with high application rates of nitrogen fertilizers and to the fossil fuel-based emissions associated with fertilizer production and transportation.

MAXIMIZING SYNERGIES AND MANAGING TRADE-OFFS

Trade-offs occur when activities that increase carbon storage reduce productivity and profitability. Synergies on the other hand imply a positive correlation between carbon sequestration and profitability. Increasing food security with CSA will require land management technologies that maximize synergies and minimize tradeoffs. Two agroforestry systems in particular achieve important synergies: intercropping and alley farming (top right quadrant of figure 1). Intercropping is growing crops near existing trees, whereas alley farming is growing crops simultaneously in alleys of perennial, preferably leguminous trees or shrubs. Both are important strategies for increased productivity and resilience of the farming system.

Land management technologies in the lower right quadrant of figure 1 have high mitigation potential, but are only modestly profitable. Afforestation using fast-growing trees to accelerate soil rehabilitation and establish barriers against erosion across sloping areas tends to remove land from production for significant periods of time. This reduces the amount of land available for cultivation in the short run, but can lead to overall increases in productivity and stability in the long run. The time-averaged, above-ground biomass of crop residues and other technologies in the lower left quadrant of figure 1 is relatively small compared to that of agroforestry systems. Because crop residues do not accumulate biomass easily, mitigation benefits are also limited.

Fertilizers counter soil nutrient depletion and increase crop yields, enabling intensified production that can reduce pressure for agriculture to expand into marginal and forested areas. Applied judiciously, the negative environmental impacts associated with fertilizer use can be effectively minimized. Inorganic fertilizer tends to be more economical than manures owing to the labor costs entailed by collecting and processing manures. Manures also have lower nutrient contents, requiring the application of large amounts on any given parcel of land, and are associated with high methane emissions.

PRIVATE BENEFITS AND PUBLIC GOODS

Soil carbon sequestration can provide farmers with substantial *private benefits* through its positive effects on soil fertility and crop yields. Other benefits such as improved water and air quality and biodiversity are *public goods,* the benefits of which accrue to whole communities and societies. In the case of technologies that contribute to climate change mitigation, the benefits are global in scope. Government intervention is often required to encourage land management practices and the adoption of technologies that generate these public goods. A number of technologies such as afforestation, improved fallows, terracing, and cross-slope barriers incur high costs and generate few if any profits in the short term – and sometimes longer. This leaves farmers with little incentive to invest in these areas, particularly if their rights to the land are insecure. The relatively high mitigation potential of these technologies warrants the investment of public resources. Less profitable technologies with lower mitigation potential—such as those located in the lower left quadrant of figure 2—require substantially less if any public support. Public support which focuses on research, investments

FIGURE 1: TRADEOFFS BETWEEN PROFITABILITY AND CARBON SEQUESTRATION OF SUSTAINABLE LAND MANAGEMENT TECHNOLOGIES

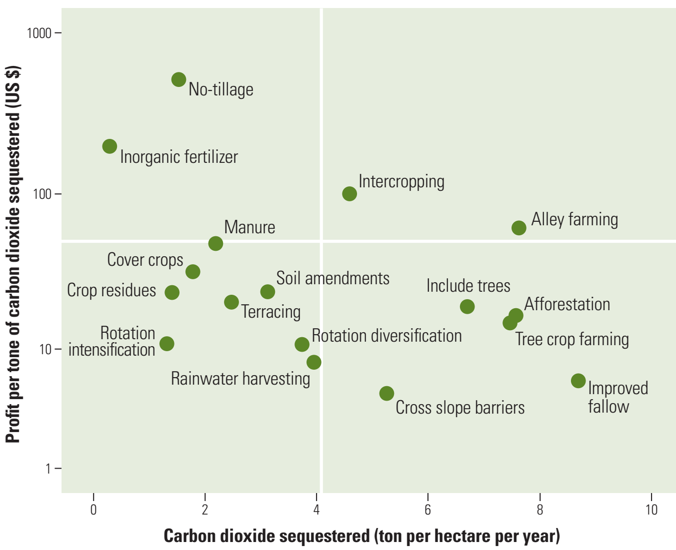
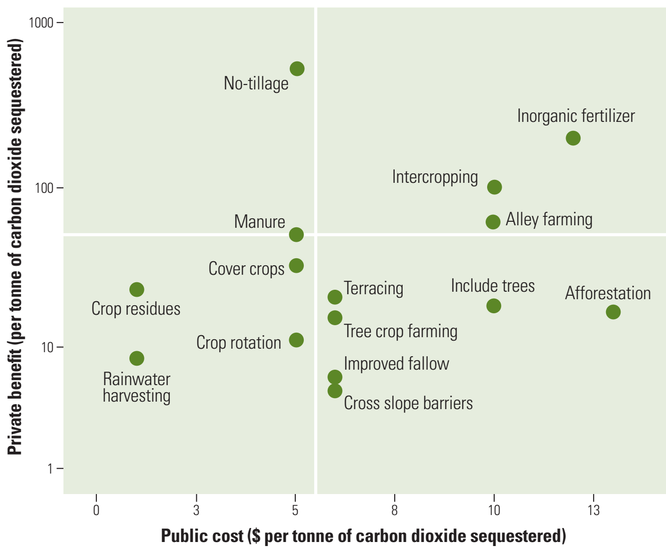


FIGURE 2: RELATIONSHIP BETWEEN PRIVATE BENEFITS AND PUBLIC COSTS



in improved land management and land tenure rather than on input support are generally more effective, benefit more farmers, and are more sustainable in the long run.

While the distinction between private benefits and public goods is a useful reference for targeting the investment of finite public resources, determining which forms of funding are the most appropriate for any given technology requires an understanding of the barriers and constraints that prevent farmers from adopting that technology.

OVERCOMING BARRIERS TO ADOPTION

Although improved land management technologies and practices can generate substantial public and private benefits, their adoption often faces a variety of socioeconomic and institutional barriers. These include the significant upfront investments and expenditures that are often required to adopt a new technology. Necessary inputs may not be available in local markets. Farmers may lack information about the potential gains of adopting a new technology. Some new technologies are incompatible with traditional practices. Capacity to implement new techniques is often limited, and many farmers have little if any experience with the kinds of collective action that are needed for the diffusion of certain technologies. While the factors that determine adoption rates vary, a number of them appear to be particularly prominent. Table 1 suggests that lack of credit and inputs and land tenure problems are by far the most important factors limiting adoption. Improved availability of inputs appears to be a necessary but not sufficient condition, and better market prices for crops and other agricultural produce are crucial. Secure land rights is a precondition for CSA because it provides incentives for local communities to manage land more sustainably.

TABLE 1: RELATIVE IMPORTANCE OF DIFFERENT FACTORS FOR ADOPTING IMPROVED LAND MANAGEMENT PRACTICES

Land management technology	Inputs/ Credits	Market access	Training/ Education	Land tenure	Research	Infrastructure
Inorganic fertilizer	***	**	**	**	*	**
Manure	**	**	*	**	*	**
Conservation agriculture	**	**	***	**	**	*
Rainwater harvesting	**	**	**	***	**	**
Cross-slope barriers	**	*	**	**	**	*
Improved fallows	**	*	*	***	**	*
Grazing management	***	***	**	***	**	*

*Key * = Low importance, ** = Moderate importance; *** = High importance.*

For technologies that generate significant private returns, grant funding or loans may be more suitable to overcoming adoption barriers. For technologies such as conservation agriculture that require substantial up-front investment in machinery and other inputs, other schemes such as those involving payment for ecosystem services may be more effective in overcoming the adoption barrier. Technologies such as agroforestry systems, which entail tree planting and extended waiting periods before the trees mature and generate economic returns, helping farmers bridge these periods can be decisive - and potentially a highly strategic purpose toward which to channel resources from carbon finance. Public sector costs are also limited by the proportion of overall investment that is assumed by the private sector. Private investment for instance is instrumental in establishing tree plantations and in developing improved seeds and seedlings.

A number of improved land management technologies are knowledge-intensive, and promoting their adoption is likely to require training and extension. Conservation agriculture for instance entails sophisticated combinations of no-tillage, residue management, use of cover crops, and other activities and practices that many farmers have limited experience with. The knowledge base of local land management practices can also be improved through careful targeting of capacity development programs.

POLICY IMPLICATIONS

Because the private benefits that drive land use decisions often fall short of social costs, carbon sequestration may not reach optimal levels from a social point of view unless mechanisms are in place to encourage farmers. Some public policies that can potentially incentivize carbon sequestration include:

Strengthen the capacity of governments and agencies to implement climate-smart agriculture. Countries must be prepared to access new and additional finance, and to systematically build the technical and institutional capacity of the government ministries that play a necessary role in implementing CSA programs. Capacity building is also vitally necessary to prepare extension and training services, with agents who are both well-informed about land management technologies and well-aware of local conditions and the needs and concerns of farmers. Existing national policies, strategies, and investment plans are being examined, and where necessary, will be strengthened to become effective instruments in scaling-up investments for CSA.

Place agriculture in a Global Cooperative Agreement. Given the tremendous significance that agriculture has for the global climate, progress in incorporating it into the UN Framework Convention on Climate Change (UNFCCC) has been slower than many people hoped for. While the negative impacts of agricultural production in terms of land-use change and greenhouse gas emissions were reasonably well covered by the Convention, the real and potential contributions the sector can and does make in terms of sequestering carbon in agricultural biomass and soils was for the most part omitted. Redressing this omission promises to foster a more balanced perspective in which food security is not necessarily at odds with climate change adaptation and mitigation (an unworkable conflict in which longer term environmental concerns are virtually guaranteed to universally lose out politically to the more immediate concern of food supply). A more practical and thorough picture makes it possible for agriculture to be rewarded for its positive environmental impacts, and to be an integral part of "the solution" as well as part of "the problem." This is vitally important, because agriculture needs to be fully incorporated into adaptation and mitigation strategies. As a result, the international community has recognized the importance of integrating agriculture into the ongoing negotiations on the international climate change regime. At the 17th Conference of Parties to the UNFCCC in Durban, South Africa in 2011, the Parties asked the UNFCCC Subsidiary Body for Scientific and Technological Advice to explore the possibility of a formal work program on agriculture.

Raise the level of national investment in agriculture. Finite public resources can be selectively targeted by:

a) identifying sustainable land management technologies that generate no short term returns and therefore would benefit from services and resources that help adopters to bridge the interim period between the initial investment and when returns begin to be realized; and
b) purposefully tailoring interventions to address the specific needs and concerns of farmers.

Introducing policies that provide for an enabling environment for private sector investment can increase overall investment, and this private investment can be targeted to some degree as well by providing incentives for financial service providers to tailor lending instruments to meet the needs of agricultural clients. Bundling agricultural credit and insurance together, and providing different forms of risk management such as index-based weather insurance or weather derivatives are areas of private investment that can be encouraged through public policy and public-private partnerships.

This ARD Note was written by Dr. Ademola Braimoh, and edited by Gunnar Larson of the World Bank's Agriculture and Rural Development Department.