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Creating Incentives for the Adoption of Sustainable Agricultural Practices in Developing Countries: The Role of Soil Carbon Sequestration*

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Sustainable agricultural development is widely acknowledged as a critical component in a strategy to combat both poverty and environmental degradation. Yet sustainable agricultural development remains an elusive goal, particularly in many of the poorest regions of the world. Soil degradation continues to be a key factor in unsustainable production systems, despite decades of research on soil conservation and other sustainable practices (Hudson; Scherr; Barrett, Place, and Aboud; Sanchez). Various studies stress the role played by resource-poor farmers in human-induced natural resource degradation (Bruntland Commission; Reardon and Vosti; Barbier).

The prevailing economic explanation for the continuing trend towards resource degradation in many parts of the world is that economic incentives often encourage degradation and discourage conservation. These incentive problems have been attributed to poor farmers' high discount rates, lack of capital markets, high transport costs and other market imperfections, adverse government policies, insecure property rights, and

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limited availability of fodder for grazing or fuel for cooking and heating (e.g., Lutz, Pagiola, and Reiche; Heath and Binswanger).

From this perspective, the challenge facing researchers and policy analysts is to understand the factors and processes causing the use of unsustainable practices, and how to design mechanisms that will provide farmers in developing countries with the economic incentives needed to adopt more sustainable land use and management practices. A key component of many unsustainable agricultural systems is degradation of soils through loss of soil organic matter. We know that when soil is put into cultivation, the associated biological and physical processes result in a release of soil organic carbon (SOC) over time, often 50% or more, depending on soil conditions and agricultural practices. Consequently, there is a potential to increase SOC in most cultivated soils. Agricultural science has established that many management practices can increase SOC, including conversion of cropland to permanent grasses or trees, incorporation of crop residues, increases in cropping intensity and fertilization, and reductions in tillage (Lal et al.). Due to the fact that farm households in degraded environments are some of the world's poorest people, incentive mechanisms for carbon sequestration in agricultural soils could simultaneously contribute to the goals of alleviating rural poverty, enhancing agricultural sustainability, and mitigating greenhouse gas (GHG) emissions (Soil Management CRSP).

As of the present time, the use of agricultural soil carbon sequestration has been limited under the Marrakesh Accords of the Kyoto Protocol (UNFCCC). The decision of the United States not to sign the Kyoto Protocol further limits its role in policies to

mitigate GHG emissions. The purpose of this paper is not to speculate about the role that soil carbon sequestration might play under the Kyoto Protocol or any other policy regime. Rather, our goal in this paper is to assess the role that soil carbon sequestration could play in helping developing countries deal with soil degradation problems, if and when governmental or non-governmental entities take actions to reduce GHG emissions.

Factors Affecting Incentives for Soil Conservation

A variety of factors affect the incentives that influence farmers' land use and management decisions that ultimately result in soil conservation or degradation. On the one hand, when property rights to land are well-established, and farmers understand how to maintain productivity (prevent erosion, maintain SOC, etc.), farmers clearly have an incentive to manage their land so as to maintain it as a valuable form of capital. It is worth noting that farmers may rationally choose to depreciate their soil resources, e.g., when short-term survival is at stake, or when resources extracted from soils can be more profitably invested elsewhere (McConnell). On the other hand, farmers with insecure rights, operating small plots of marginal land, lacking education and knowledge of how their management degrades productivity, may take actions that degrade soil resources unintentionally. In addition, in many countries resource degradation is associated with market failures caused by a lack of well-functioning political, legal and economic institutions (World Bank).

The general policy environment also contributes to the incentives perceived by farmers to maintain or degrade soils. An adverse economic environment for agriculture in many parts of the world is caused, in part, by the well-known policy bias in many

countries against agriculture and rural areas. These domestic policy biases are aggravated by low commodity prices caused in part by continued subsidization of agriculture in much of the developed world. These low prices weaken the incentive to invest in agriculture. Inward-looking trade policies based on import substitution strategies, and widespread use of tariff and nontariff barriers to reduce external competition result in high domestic input prices. Particularly in Sub-Saharan Africa, policy reforms and currency devaluation have increased real costs of fertilizers (Kherallah et al.), but have not always resulted in increased output prices (Reardon et al.).

Farmers appear to have responded to this adverse policy environment in some parts of the world by “mining” soil fertility, either as a rational response to economic conditions they faced, or because they did not know the long-term consequences of their decisions. In either case, the result appears to have been a net loss of soil fertility in many areas (Stoorvogel, Smaling, and Jansen).

One explanation for this mining of soil fertility is that organic matter often has a relatively high value when used for animal feed, fuel, and other non-agricultural uses, whereas returns to investments in soil fertility are often relatively low. For example, in Senegal, the growth in population and the demand for animal protein, especially in urban areas, has contributed to the increase in the demand for crop residues used for animal feed (Tiffen). Incentives to increase and maintain high SOC levels for purposes of carbon sequestration will have to compete with the demand for animal feed and other uses. This situation is aggravated by policies that generally discriminate against small-scale semi-subsistence agriculture in rural areas.

Productivity Dynamics, Adoption Thresholds and Incentives

We now consider the farmer's decision to adopt soil conservation practices that could sequester C in soil. In order to increase the stock of C in the soil on a land unit, the farmer must make a change from production system i (e.g., a specified crop rotation) that had been followed over some previous period (the historical land-use baseline), to some alternative system s . We assume that utilization of management practice i up to time 0 results in a soil C level of $C(i)$, and adoption of practice s at time 0 causes the level to increase to $C(s)$ at time T. At time T, the soil reaches a new level (referred to as the "attainable maximum" by Ingram and Fernandes) at which the level of soil C stabilizes until further changes in management occur.

Changes in management practices that maintain or enhance soil resources may also increase productivity, for example by increasing topsoil depth and water holding capacity, and by improving soil structure. However, these productivity benefits typically come after some time lag. The magnitude of the productivity effect of conservation investments plays a critical role in determining their profitability, and interacts strongly with factors such as farmers' rates of time preference and financial positions (Valdivia).

Government programs or private contracts to sequester soil C also could provide a financial incentive for participation. Many conservation programs pay farmers for each hectare of land on which they adopt specified practices (a per-hectare contract). However, it can be shown that it is more efficient to pay farmers per unit of environmental benefit produced, in this case per ton of carbon sequestered (a per-ton contract) rather than per hectare (Antle et al.). Under per-ton contracts, the farmer receives a payment of $\$P_t$ per

tonne of C sequestered each time period, so if the farmer changes from practice i to practice s and soil C increases by $\Delta c_t(i,s)$ tonnes per hectare per period, the farmer receives a payment of $P_t \Delta c_t(i,s)$ per hectare per period. The net present value (NPV) of changing from system i to system s for T periods is given by:

$$(1) \quad NPV(i,s) = \sum_{t=1}^T D_t [NR(p_t, \mathbf{w}_t, z_t, s) + g_t(i,s) - M_t(i,s)] - I(i,s)$$

where $D_t = (1/(1+r))^t$ and r is the annual interest rate, $NR(p_t, \mathbf{w}_t, z_t, s)$ is net returns per hectare for system s in period t , given product price p_t , input prices \mathbf{w}_t and capital services z_t ; $g_t(i,s) = g_t$ if a per-hectare contract, or $g_t(i,s) = P_t \Delta c_t(i,s)$ if a per-ton contract; $M_t(i,s)$ is the maintenance cost per period for changing from system i to s ; and $I(i,s)$ is the fixed cost for changing from system i to system s . If the farmer does not participate in the contract and continues producing with system i , then $g_t(i,s) = M_t(i,s) = I(i,s) = 0$ and the farmer earns $NPV(i)$. The farmer enters the contract if and only if $NPV(i,s) > NPV(i)$, and does not enter the contract otherwise.

For purposes of our discussion, it is useful to consider the special case where $NR(p, \mathbf{w}, z, s)$, P , $\Delta c(i,s)$, and $M(i,s)$ are constant over time. If we also let the fixed investment be converted into an equivalent annuity of $fc(i,s)$ dollars per period, with these assumptions the expression $NPV(i,s) > NPV(i)$ is equivalent to

$$(2) \quad NR(p, \mathbf{w}, z, s) + g(i,s) - M(i,s) - fc(i,s) > NR(p, \mathbf{w}, z, i).$$

This expression has several implications for analysis of adoption of soil carbon sequestration practices.

First, suppose there are no payments for carbon sequestration, so $g = 0$. In this case, a farmer adopts the conservation practice only if it provides higher net returns than the conventional practice. If the productivity benefits of the conservation practice are realized with a time lag, what expression (2) shows is that a farmer who is uncertain about future productivity benefits, or who highly discounts future benefits, would bear the costs of adopting the practice but would not be aware of or attach value to the benefits. Therefore, a lag between adoption and the realization of productivity benefits may create an adoption threshold. Note further that if farmers don't have access to well-functioning capital markets, then they cannot finance the fixed component of the investment cost, and so the annualized investment cost term $fc(i,s)$ would be replaced with the full investment cost $I(i,s)$ in equation (2), thus exacerbating the threshold effect.

Second, if there is a payment for adoption of practices that sequester carbon, we can rearrange equation (2) to:

$$(3) \quad g(i,s) > NR(p, \mathbf{w}, z, i) - NR(p, \mathbf{w}, z, s) + M(i,s) + fc(i,s).$$

The expression on the right-hand side is the farm opportunity cost for switching to system s from system i . The farmer will switch practices when the farm opportunity cost is less than the payment per period. In the case of a per-tonne contract, $g(i,s) = P\Delta c(i,s)$ and therefore the condition for participation in the contract can be expressed as $P > (NR(p, \mathbf{w}, z, i) - NR(p, \mathbf{w}, z, s) + M(i,s) + fc(i,s))/\Delta c(i,s)$. The term on the right-hand side is now the farm opportunity cost per tonne C , and thus the farmer will participate when the price per tonne C is greater than the farm opportunity cost per tonne. This last expression shows that when farmers are being paid per ton of carbon sequestered, as would be the case

when they participate in a market for carbon emissions reductions credits, the market price per ton of carbon plays a key role in determining which farmers would participate.

Equation (3) shows that when incentive payments are made, it is no longer necessary for the conservation practice to be more profitable than the conventional practice for adoption to take place. Indeed, in cases where farmers are informed about the benefits and costs of conservation investments, and they choose not to adopt them, we can safely assume that the conservation practices are less profitable. A positive financial incentive will be required to induce and maintain adoption.

Carbon Permanence as an Emergent Property of Conservation Technologies

In public debates about soil carbon sequestration, much has been made of the fact that biological forms of carbon sequestration, including soil carbon, are not necessarily stored permanently in soils. Forests can be harvested and used for fuel; dis-adoption of the soil carbon-sequestering practices could likewise cause carbon to be released back into the atmosphere.

Given that there is an attainable maximum stock of carbon in soil, carbon can be said to accumulate only for a certain number of years, at which time the soil becomes “saturated.” In addition, soil research has shown that sequestered carbon can be released back in to the atmosphere in a short period of time if farmers revert back to conventional practices. A simple way to address this permanence issue is to view farmers who enter into soil C contracts as providing a service in the form of accumulating and storing soil C. In effect, buyers of carbon contracts are paying for the service, and when the service is discontinued the buyer would be responsible for a corresponding liability (Marland, Fruit,

and Sedjo). Once the soil C level reaches the saturation point, the farmer is providing only storage services. The key point, however, is that both accumulation and storage services depend on the farmer continuing to maintain the land use or management practices that make the accumulation possible. Therefore, if the practices that store carbon are not more profitable than the conventional practices that release carbon for the duration of the contract, farmers will have to be provided an incentive for the full duration of the time that the carbon sequestering and storing practices are to be maintained.

The discussion in the previous section noted that practices that store carbon may also yield higher returns, although these higher returns may come with a lag. When this is true, the model presented in the previous section (equation 1) can be used to show that during the initial phase of adoption, farmers may require a positive financial incentive to be encouraged to bear the fixed and variable costs of adopting and maintaining the conservation practice. However, this model also shows that once productivity increases and the conservation practices become more more profitable, farmers are likely to maintain the conservation practice indefinitely without additional financial incentives for carbon sequestration. Therefore, we can conclude that if a carbon sequestration practice becomes profitable at some point before the contract expires, the carbon sequestered through adoption and maintenance of these practices is likely to be permanent as long as the practices remain profitable. Thus, when conservation practices enhance the productivity of the production system so as to eventually make the practices profitable, carbon permanence may be an emergent property of the system.

The model outlined above also shows that the incentives for farmers to maintain a practice depend on all of the economic factors that affect profitability. Therefore, it is possible that changes in economic conditions could cause farmers to dis-adopt formerly profitable practices. However, this seems unlikely to occur when the carbon-increasing practice is a fixed conservation investment such as a terrace or hedgerow, except under extreme circumstances.

Designing Soil Carbon Contracts for Farmers in Developing Countries

There has been some discussion in the literature of how contracts for soil sequestration might be designed in the context of the United States (Antle et al., Antle and McCarl), and some of the factors that would affect how carbon sequestration incentives could be created for farmers in developing countries (Antle). In a country with well-defined property rights and corresponding financial institutions, farmers could plausibly participate in a domestic or international market for tradable emissions reductions credits. Farmers would enter contracts, either with private or public entities, to adopt specified practices for a specified period of time. They would earn per hectare payments or would be paid per ton of carbon sequestered. To verify compliance with contracts, it would be necessary to monitor farmers' practices, and to measure the quantities of carbon being sequestered over time. Third-party intermediaries would likely act as consolidators of contracts with farmers, thus aggregating enough land units to make a commercially tradable contract.

In developing countries, several factors would be likely to inhibit the participation of small-scale farmers in this kind of carbon credit market. First, the transactions costs

associated with aggregating land units to create a marketable contract would be larger because of the smaller scale of production. In addition, verifying compliance with contracts (i.e., monitoring land use and management practices) could be more costly for a number of small farms. Second, significant issues would arise where land property rights are not formalized. It is not clear how contracts would work if farmers did not hold legal title to the land they manage. For example, in many parts of the developing world, farmers have use rights given by village authorities, and these use rights can change over time. Third, many parts of the developing world lack well-functioning legal and financial institutions. If contracts are not enforceable, buyers of carbon contracts will have little recourse if farmers are found not to be complying with the terms of the contract.

Likewise, in countries that lack financial markets, farmers may not be able to borrow to make investments needed to adopt practices that sequester carbon. The carbon market could function as a form of financing of these investments, by paying in advance all or part of the capitalized value of the carbon expected to be sequestered. For example, a “carbon loan” program could provide financing for conservation investments, to be paid back through generation of carbon credits.

Co-Benefits

Many practices that increase SOC have other valuable benefits, such as reducing soil erosion and protecting water quality (Lal et al.). Practices that contribute to carbon sequestration also will likely have important impacts on the level and stability of farm production and food consumption. These impacts translate into improvements in health and nutrition of rural households and ultimately to improvements in rural economic

development. However, the impacts of carbon payments and other payments for environmental services on income distribution are not clear. On the one hand, relatively poor farmers tend to manage degraded lands; on the other hand, carbon payments based on land ownership might benefit relatively wealthy landowners, and would not benefit the landless, except possibly indirectly.

Measuring possible co-benefits of carbon sequestration requires analysis that goes beyond models of agricultural production. Antle presents an integrated assessment framework that could be used to address the on-farm and immediate off-farm environmental consequences of adoption of management practices that sequester soil C. To account for regional economic impacts, additional data would be needed to characterize farm and non-farm rural households, and to analyze market and non-market effects of improvements in agricultural production. Partial or general equilibrium economic models would be needed to assess rural development impacts.

Reducing atmospheric concentrations of GHGs produces a global benefit by reducing the risk of climate change, whereas most other environmental and social impacts are local. A market for GHG emissions reductions would not take into account the local co-benefits produced by farmers. This fact means that the incentives provided to farmers through a GHG emissions trading system will not be as large as they would be if they incorporated the social value of other environmental and social co-benefits. An important topic for further research is to assess how appropriate incentives can be created that account for the value of local co-benefits.

Conclusions

There is a scientific consensus that soil degradation is a significant problem in the developing world and that this problem is often linked to poverty. There is also a long history of attempts to solve this problem through development of improved agricultural practices and related conservation technologies. These technologies have been successful in some parts of the world and not others. There is clearly a need for a better understanding of the causes of chronic land degradation in the places where existing technologies have not been adopted, and ways in which incentive mechanisms could help address the problem. It appears that emerging policies to mitigate GHG emissions, such as the Kyoto Protocol and other international and national policies, could provide a way to create incentives for farmers to adopt and maintain practices that would have long-term benefits to them individually while also contributing to the global goal of reducing net GHG emissions.

As we have discussed in this paper, a number of significant challenges would have to be overcome before poor farmers on marginal lands in the developing world be able to participate in a global carbon market or a policy mechanism such as the Kyoto Protocol's Clean Development Mechanism. The conceptual issues surrounding this question can be assessed using basic economic concepts as discussed in this paper. Detailed case studies are needed to assess the economic feasibility of soil carbon sequestration under conditions representing different parts of the world. These studies should quantify the on-farm opportunity costs of available technology options for soil carbon sequestration, and should also assess the feasibility and costs of institutional

mechanisms needed to coordinate the creation of carbon sequestration contracts. A “carbon loan” program is one example of an institutional innovation that could help farmers overcome adoption thresholds caused by imperfect capital markets.

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