

Economic potential for soil carbon sequestration in the Nioro region of Senegal's Peanut Basin

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Abstract

This paper presents results from an analysis of the economic potential for soil carbon sequestration in the Nioro region of Senegal's Peanut Basin. This analysis was based on the linkage of site-specific biophysical models and economic simulation models using the Tradeoff Analysis System to simulate farmers' participation in contracts to sequester soil carbon. Available soils and climate data were used to implement the DSSAT/Century models to estimate crop yields and changes in soil carbon stocks under nine scenarios of increased fertilizer use and increased incorporation of crop residues in a peanut-millet rotation. Data from the 2001 farm survey conducted by the Ecole Nationale d'Economie Appliquée were used to parameterize a spatially explicit econometric-process simulation model for the peanut-millet production system. The economic simulation model was used to simulate a carbon-payment scheme that requires farmers to apply higher fertilizer rates and incorporate some crop residues into the soil. The results show that the combination of increased fertilizer use and crop residue incorporation could result in the supply of marketable quantities of carbon that could be sequestered in the soils of the Nioro region. However, the sensitivity of results to the levels of labor costs of incorporating crop residues, the value of crop residues, and the transaction costs of implementing carbon payment schemes, suggests the need for better data on these variables and for an accurate assessment of the capabilities of local institutions to implement carbon contracts.

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1. Introduction

Soil degradation through loss of soil organic matter continues to be a key factor in unsustainable agricultural production systems, despite decades of research on soil conservation and other sustainable practices (Scherr, 1999; Barrett et al., 2002; Sanchez, 2002). We know that agricultural practices accelerate the mineralization of soil organic matter. Without sufficient incorporation of organic matter (e.g., crop residues), the associated biological and physical processes may reduce soil organic carbon (SOC) contents over time, by 50% or more, depending on soil con-

ditions and agricultural practices. With proper agricultural management (including e.g., minimum tillage, residue incorporation, and fertilization) SOC contents can be increased (Lal et al., 1998; Batjes, 2001). Due to the fact that farm households in degraded environments comprise some of the world's poorest, 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 emissions.

Several important factors must be considered in assessing the potential for soil carbon sequestration to address the problem of soil degradation and poverty. First, because greenhouse gases cause a global externality in the form of an enhanced greenhouse effect, policies are needed to create

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incentives for carbon sequestration in soils and in other forms like biomass (Young, 2003). Second, poor farmers in developing countries often are working highly degraded soils that have a high technical potential to sequester carbon, but these soils may also be very costly to rehabilitate. Therefore, we must determine both the technical potential to store SOC and the economic returns to farmers who adopt practices that sequester carbon in soils. Third, practices that sequester carbon may generate additional social benefits, sometimes referred to as “co-benefits”, e.g., reduced off-farm damages caused by soil erosion and leaching of agricultural chemicals, as well as reductions in poverty and improvements in nutrition. Thus, to determine socially efficient incentives for farmers, the full array of economic benefits and costs of soil carbon sequestration, both public and private, must be assessed. To conduct this assessment, accurate information and data on costs and benefits are necessary. Unfortunately, there is a dearth of good quality data on these variables, which seriously constrains the analysis of farm technology or practice adoption, as we shall see in this paper. Finally, appropriate and efficient incentive mechanisms for soil carbon sequestration need to be designed for developing countries. These incentive mechanisms must work with large numbers of poor farmers managing small land parcels, and must be compatible with the legal and financial institutions in these countries (Antle and Diagana, 2003).

Few studies have assessed the economic feasibility of agricultural soil carbon sequestration outside of the United States (Antle et al., 2003). Previous research in Senegal has estimated carbon rates (Batjes, 2001) and evaluated the economic returns to alternative practices (Tschakert, 2001, 2004; Tschakert et al., 2003), but no study to date has combined site-specific biophysical and economic data and models to predict the economic feasibility of carbon sequestration at alternative carbon prices. In this paper we utilize a spatially explicit econometric-process simulation model that accounts for the spatial variability in biophysical and economic conditions in the region. We use this model to simulate Senegalese farmers’ participation in contracts to sequester carbon, and use these results to derive carbon supply curves that show the economic potential to sequester carbon in the peanut-millet production system in the Southern Peanut Basin of Senegal.

2. Conceptual framework

In this section we present the conceptual framework we use to analyze a farmer’s decision to participate in carbon contracts by adopting soil carbon sequestering technologies or practices. The decision-making process is a sequence of site-specific decisions about land use (or crop choice), and associated management decisions (e.g., land preparation, tillage, fertilization, pest management, harvest, residue incorporation). In order to increase the stock of SOC on a land unit, a farmer must make a change from production

system i (conventional) that had been followed over some previous period (the historical land-use baseline) to some alternative (conservation) system s . We assume that utilization of management practice i up to time 0 results in a SOC level of $C(i)$, and adoption of practice s at time 0 causes the level to increase to an equilibrium $C(s)$ at time T . At time T , the soil reaches a new level (referred to as the “attainable maximum” by Ingram and Fernandes, 2001) 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 and their magnitude plays a critical role in determining their profitability, and interacts strongly with factors such as farmers’ rates of time preference and financial positions (Valdivia, 2002).

Contracts, either governmental or private, to sequester soil C 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., 2003). Under per-ton contracts, the farmer receives a payment of $\$P_t$ per ton of C sequestered each time period, so if the farmer changes from practice i to practice s and soil C increases by $\Delta c_t(i, s)$ tons 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

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

where $D_t = (1/(1+r))^t$ and r is the interest rate per time period, $\text{NR}(p_t, \mathbf{w}_t, z_t, s)$ 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 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 $\text{NPV}(i)$. The farmer enters the contract if and only if $\text{NPV}(i, s) > \text{NPV}(i)$.

For purposes of our discussion, it is useful to consider the special case where $\text{NR}(p, \mathbf{w}, z, s)$, 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 $\text{NPV}(i, s) > \text{NPV}(i)$ is equivalent to

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