From the Perspective of Global Warming: Alternative Farming Systems and Sustainability

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According to Article 3.4 of the Kyoto Protocol, agricultural soil could be used as a sink for carbon sequestration. Soil sequestration of carbon provides dual benefits: an increase in soil productivity and a reduction in atmospheric carbon concentration. The gain in soil productivity is a slow process and attaining a steady-state level of carbon in soil takes several years. A frequently encountered difficulty in this situation is how to discount the future benefit of carbon sequestration into a current term. We compared the net benefit of four alternative management systems using discount rates based on the sliding gamma distribution, market rate of investment, and the social rate of time preference. We also calculated the sustainability of these alternate management systems based on the profitability and productivity index and their capacity to maintain the natural capital in soil. The result indicated that a management system that combines no-till and an organic source of nutrients is the most attractive system based on carbon sequestration, total discounted net present value, and sustainability perspectives.

Key words: carbon sequestration, conservation practices, strong and weak sustainability, discounting method

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Article 3.4 of the Kyoto Protocol on climate change states that agricultural soil could be used as a sink for carbon sequestration. In an effort to actively involve the U.S. and convince the government to accept the Kyoto Protocol, the Conference of Party-6 (COP-6) recently indicated that it would apply the carbon sequestered in soil as part of the goal mentioned in the Protocol (COP-6 report, April 2001). U.S. soil has the potential to sequester as much as 3 billion metric tons of carbon (Bruce and Langdale, 1997). The objective of this study is to use cotton production in Georgia as an example in showing how management systems can help to sequester carbon and provide an alternative, profitable cropping system over the long run. This example represents a potentially significant contribution to carbon management, since Southern soils tend to be low in organic carbon, a condition exacerbated by traditional cotton production systems, and cotton is grown in 3.7 million acres of land in the Southeast (USDA 2001). We analyzed adoption of conservation practices from two perspectives: meeting the Kyoto Protocol carbon emission goal and evaluating a farming system based on soil productivity, sustainability, and profitability.

In comparing alternative management systems, one faces the problem of how to measure the long-term benefit of these systems, since change in organic matter is a slow process. It is also a dynamic process, and converting the benefit of organic matter into yield and then net returns must be carefully assessed. When evaluating the long-term benefits, selection of an appropriate discount rate is central to the analysis. The working group in economics and social science of the International Protocol on Climate Change (IPCC) suggests using either a social rate of time preference (0.5 - 3%) or a market rate of return on investment (ranging from 3 - 6 % in real terms for the long-term) to calculate the net return from the project associated with the global climate change. However, there is no consensus on what discount rate to use among economists, who are frequently divided on such issues when evaluating the benefits of a project whose effects are spread over a long period of time (Mohr, 1995; Heal, 1997; Weitzman, 1998;

Cropper and Laibson, 1999; Portney and Weyant, 1999; Weitzman, 2001). In the most recent of these studies, Weitzman (2001) conducted a two-stage survey asking 2,160 economists in the first phase and 50 "expert" economists in the second phase to find the best discount rate to use for a project whose effect extends for centuries. His conclusion is that a sliding gamma discounting is the most appropriate to evaluate the benefit from this kind of project.

The difficulty of choosing an appropriate discount rate is further exacerbated by the fact that we can have little or no knowledge about the preference or utility function of future generations. Therefore, one of the alternatives has been to use the sensitivity of a discount rate in choosing whether or not a certain mitigation strategy is appropriate. We use the recent literature in this area to evaluate the effects of long-term benefits from farming systems from the perspective of organic matter buildup in soil. We simulate the long-term organic matter gain in soil, and found the net return in each system over a long time period by connecting a soil organic matter development function to crop yield using a suitable production function. We calculate the profitability and productivity indices of alternative systems to find whether these systems are sustainable in the long run. The total benefit of soil organic matter buildup under four different management systems is calculated from the direct benefit from crop yield increase and the indirect benefit from carbon sequestration in soil.

Soil organic matter as natural capital

Organic carbon is the most frequently reported attribute of soil from long-term agricultural experiments. We chose it as the most important indicator of soil quality and agronomic sustainability because of its impact on other physical, chemical, and biological indicators of soil quality. Soil organic matter, composed of soil organic carbon, is the foundation of productive soils. Understanding the role of organic matter in maintaining a healthy soil is essential to developing sustainable agricultural practices. As organic matter decreases, plant growth and yield decline in the absence of substitutes because of lower fertility, less available water, and increased soil compaction and erosion. Higher levels of inputs such as fertilizers, pesticides, and machinery are required to maintain yields in the face of organic matter depletion. The sustainable management of soil resources includes increasing soil organic matter.

Long-term conservation tillage studies demonstrate that within climatic limits, increases in soil organic carbon help to maintain agronomic productivity and economic sustainability. Soil organic matter can be managed by using no-till in conjunction with an organic source of plant nutrients. Intensive tillage reduces soil organic matter through the oxidation of organic matter.

Soil organic matter is affected by agricultural management practices such as frequency of fallow, fertilization, and residue management. The addition of organic amendments such as broiler litter constitutes direct management control of soil organic matter supply to soil (Paustian *et al.*, 1992).

Tillage and other mechanical disturbances of soil have been found to decrease aggregate stability, which may result in increased susceptibility to decomposition of organic matter. While tillage influences a number of other factors affecting decomposition rates including soil moisture, temperature, and aeration, the degradation of soil structure and loss of physical protection have been postulated as major causes of soil organic matter loss when conventional tillage using primary tillage equipment is used (Camberdella and Elliott, 1993).

The quantity of organic matter in the soil from crop residue may be increased by adding more crop residue or applying an organic source of plant nutrients such as broiler litter. The nutrient content of dry broiler litter varies, but averages about 3.9, 3.7 and 2.5 percentage of nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O), respectively (Mitchell *et al.*, 1990). Of these amounts, only 75 percent of total phosphorus and potash and 50 percent of nitrogen are available to plants for consumption. It is common to apply broiler litter in cotton production as a source of nitrogen (Mitchell *et al.*, 1995). Generally, broiler litter is applied at the rate of three tons per acre to replace ammonium nitrate. However, litter rates as high as four tons per acre had no negative effects on cotton yields and cotton did not show excessive vegetative growth. Experimental results show that the addition of broiler litter with winter cover crop residue increases organic matter in soil (Cabrera *et al.*, 1993).

Sustainability and discount rate

The Bruntland Commission definition of sustainability (World Commission on Environmental Development, 1986) implies that sustainability requires preservation of agricultural productivity capacity for the foreseeable future. The ability of a cropping system to maintain a consistent flow of marketable output over time without degradation of the natural capital stock is an indicator of its economic and environmental sustainability. Van den Bergh (1996, p. 108) commented that "sustainable development is unconditionally related to a long-term perspective." This requires consideration of long-term dynamic models of change that make explicit the path of gains or losses in both the environmental and economic system goals. In addition, van den Bergh (1996) argued that in integrated models, the interactions of the environmental and economic submodels must be made explicit by linking the short-term processes, such as year-to-year production decisions, with the long-term processes, such as carbon sequestration. This approach is taken here.

For operational purposes, increasing total factor productivity (TFP) with a nonnegative trend in organic matter should be sustainable. This is true if the initial soil organic matter is above the threshold level considered by ecologists and agronomists. TFP is a ratio of an index of aggregate output to aggregate input. By constructing an index of TFP, it is possible to assess objectively the productivity performance of the system over time (Diewart, 1992). The ratio of TFP between a pair of years denoted by r and s is defined by

$$\frac{\mathrm{TFP}_s}{\mathrm{TFP}_r} = \frac{\mathrm{Y}_s / \mathrm{I}_s}{\mathrm{Y}_r / \mathrm{I}_r} \qquad (1)$$

Here, Y_s is an index of aggregate output in year s, Y_r is an index of aggregate output in year r, I_s is an index of aggregate input in year s, and I_r is an index of aggregate input in year r. Construction of the aggregate output (input) index requires choice of the weights and specific functional form for the aggregator function. Relevant prices are employed to define the weights in the economic approach to productivity measurement since monetary value is a common unit of output and input measurement for the purpose of aggregation. Using monetary value as the measuring rod is natural since the ratio of any two input prices represents relative marginal costs of the inputs in a competitive economy. Thus prices should provide information about the relative worth of cotton output and inputs. Cotton is the only output in each system, the by-product of which is cotton seed. The output index here consists of both cotton lint and cotton seed.

The value Y_s/Y_r denotes the output growth rate and I_s/I_r denotes the input growth rate. If output remains the same, there is no growth in output over the entire planning horizon. Since prices are assumed constant, input cost changes depending on the management system. If it is easier to maintain organic matter in a given system, input growth and cost will be lower.

Calculation of the output and input indices followed the concept of Laspeyres index. The base period prices are used as weights, but the values of aggregate input and output are calculated based on the specified production function. Assuming r is the base period and r < s, then the Laspeyres index uses prices in period r as weights. The index can be represented as

$$\frac{Y_s}{Y_r} = \frac{\sum_{i=1}^{m} P_{ir} Y_{is}}{\sum_{j=1}^{m} P_{jr} Y_{jr}}, \qquad \frac{I_s}{I_r} = \frac{\sum_{i=1}^{n} W_{ir} I_{is}}{\sum_{j=1}^{n} W_{jr} I_{jr}} \quad . \tag{2}$$

Here, P is the price of output, Y is the amount of output produced, W is the price of input, and I is the amount of input applied in producing Y, the subscript i denotes the number of output produced or input applied, the subscript r denotes base time period, and the subscript s denotes any other time period.

The choice of a particular index is often justified with respect to statistical and economic properties. Over a short time period, a simple index such as the Laspeyres can often provide an acceptable approximation to a flexible aggregator function (Diewart, 1992; Rayner and Welham, 1995). For agronomic trials where inputs are frequently used in roughly fixed proportions at least for relatively short periods of time, the Laspeyres index may be a satisfactory representation of the underlying production function. Further, if we assume that technology does not change in a given planning horizon, the Laspeyres index should work even in the long- run comparison of cropping system from one time period to another time period.

A profitability index measured with TFP gives more details about the economic sustainability of a system. An agricultural system must at least meet its costs, in both the short run and over the long run, in order to survive. The profitability of a system is defined as the ratio of aggregated output values (R_t) to input costs (C_t) in time t, and is shown as

$$\pi_t = \frac{\sum Y_t P_t}{\sum I_t W_t} = \frac{R_t}{C_t} \tag{3}$$

Constructing an index of TFP for long-term simulation data permits the evaluation of the ability of the cropping system to maintain productivity over time. In conjunction with a measure of profitability, the system is sustainable if it can maintain productivity over time with a nonnegative trend in the TFP index, and if the value of outputs generally exceeds the value of variable and fixed inputs over both the long and the short run.

In analyzing a long-term project such as the effect of global warming and long-term productivity change due to improved management practices, it is difficult to decide on the appropriate discount rate to value the future benefits. For example, discounting everything using one rate would not be appropriate because it puts unnecessarily low weight to the benefits possible to obtain in a far distant period. The role of a discount rate is to express the benefit incurred in the future period in terms of present value, to make comparing alternative systems easier. Therefore, the use of an appropriate discount rate is important.

There are several suggestions on what to kind of discount rates to use for this kind of project. According to Weitzman (2001), the following approximate sliding discount rates may be ideal combinations of discount rates to value the benefits in a long-term productivity change study.

Time period	Name	Marginal discount rate
within years 1 to 5	immediate future	4
within years 6 to 25	near future	3
within years 26 to 75	medium future	2
within years 76 to 300	distant future	1
beyond 300 years	far-distant future	0

There are a few others who believe that discounting future values should be done at a declining rate of interest (Cropper *et al.*, 1994). They propose that a hyperbolic discount rate may be useful when evaluating a project with effects spread over many years. Cline (1999) believes that a social rate of time preference should be used to find the economic impact of the long-term project. He suggests using a hybrid approach where a policy maker may use a market rate of preference for 30 years and then use a social rate of time preference after 30 years. Weitzman (1998) argues that the far distant future should be weighted less than the near future because we have less idea of what is going to happen. Uncertainty about the future provides a strong rationale for using certainty equivalent discount rates that decline over time, with the smallest value for the most distant time period.

Relationship between organic matter and productivity

Knowledge regarding the relationships among management systems, organic matter buildup and crop yields is central to the formulation of a sound cropping system. Most research on soil conservation has focused on the relationship of soil loss and crop yield to no-till or conservation tillage practices (Burt, 1983; Walker, 1982; McConnell, 1983; Miranowski, 1984; Krause and Roy, 1995; and Goetz, 1997). However, none have explored the linkage between a farmer's incentive to adopt alternative farming systems, organic matter-induced productivity change, and the economics of future farm land productivity from the global warming point of view. We highlight the effect of productivity benefits on the choice of system using a dynamic organic development model, in accordance with the recommendations for modeling sustainable development set out by van den Bergh (1996).

Suppose cotton production, Y_t, is a function of inputs for which usage level depends on organic matter and inputs for which usage does not depend on organic matter. Organic matter may substitute for some inputs and complement others. Fertilizer is an example of a substitutable input, since organic matter provides plant nutrients. Complementary relationships due to enhancement of ecosystem function, such as improved nutrient-cycling capacity and water-holding capacity, increase input efficiency. Both substitution and complementarity effects are continuous functions, but the substitution effect is negative (more organic matter means a decrease in use of the input) and the complementary effect is positive (more organic matter means an increase in efficiency). The same input may have both characteristics. For example, organic matter may substitute for some portion of fertilizer use, and may enhance the productivity of the remaining fertilizer applied. Both effects should be accounted for in an economic-environmental production model.

If we represent organic matter in time t by M(t), then we can describe inputs in terms of their relationship to M(t). Let $Z_t(M(t))$ be a vector of inputs for which organic matter may substitute, and let $K_t(M(t))$ be an efficiency term for inputs whose functional value increases as organic matter increases. The inputs that are not related to organic matter are given by Q_t. The production function is

$$Y_t = f(Z_t(M(t)), K_t(M(t)), Q_t). \tag{4}$$

Input requirements change over time as soil productivity is altered by organic matter content. Organic matter change depends on the initial level of organic matter in soil and residue treatment over time. For convenience, we assume the substitution and complementary effects are additive and that technology, once chosen, is constant. This is a reasonable assumption if technology is selected to simultaneously maximize both yield and organic matter build up. Then the change in yield over time is

$$\frac{dY}{dt} = \frac{\partial f}{\partial z}\frac{\partial z}{\partial M}\frac{dM}{dt} + \frac{\partial f}{\partial k}\frac{\partial k}{\partial M}\frac{dM}{dt} + \frac{dQ}{dt} \tag{5}$$

If technology is constant, as assumed, the last term in equation (5) equals zero. If farmers do not change the level of Z_t over time, change in yield over time is described solely by the change in the organic matter. The substitution effect is MZ/MM < 0 and the efficiency effect is MK/MM >0, which does not differ by cropping system. If the improvement is slow, the effects may not be observable to the farmer in the relevant planning horizon. If the maximum obtained organic matter for a system is below the threshold needed to observe the positive effects, the farmer will not choose the system. We tested and compared observable changes (yield, net return, productivity index and profitability index) due to organic matter for four different management systems recommended by agronomists.

The rate of organic matter gain or loss depends on the rate at which biomass is added to the soil, the rate of conversion of residue to organic matter and the rate at which erosion and biological oxidation deplete organic matter in soil. Depletion effects are accelerated by tillage because it speeds physical and biological degradation. This is true even with heavy manure treatment as long as conventional management, defined as conventional tillage, chemical fertilizer, and no winter cover crop, is practiced. In a residue management system (RMS), characterized by no-till cultivation, manure application, and winter cover crop, the microenvironment is favorable for the generation and decomposition of crop residue and its conversion into organic matter earlier and more rapidly than for a conventional management system. A residue management system also prevents loss of topsoil by surface residue deposition and minimal soil disturbance.

Compared to a conventional system, a residue management system offers cotton farmers both lower cost and higher yield. The cost-saving advantage of an alternate management system can be explained in term of the technical change component. Once enough organic matter accumulates, the farmer can produce the same output at lower cost due to the substitution effect of organic matter. With increased productivity, explained by the complementarity effect, application of other inputs to the soil can be reduced as the system becomes more efficient in their use. Once enough organic matter accumulates in the soil to trigger the substitution and complementarity effects, the benefits of a residue management system can be observed in both profit and yield.

Productivity and profitability of cropping systems

Soil productivity is affected by the amount of organic matter, which can be increased with the proper residue management practices. Soil productivity gains occur in small increments and have cumulative effects on soil quality and yield. Models that examine the relationships among productivity and economic variables must be dynamic to account for changes over time. We focus on the role of organic matter in the cotton production function. The following model is used to find the net present value of the organic matter additions if system i is adopted until M is reached at the steady state level, defined as time period T, so that M(T) is the dynamic equilibrium level of organic matter for cropping system i.

$$NPV_i = \sum_{t=1}^{T} (1+d)^t [p \, .Y_i(M_i(t)) - c_i(M_i(t)) - FC_i]. \qquad (6)$$

Here, Y_i (M(t)) is per acre cotton lint and cotton seed yield in time t when average soil organic matter during the growing season is M_{it}, c_i (.) is the cost function associated with building up organic matter, p is the price of cotton in dollars per bale, FC_i is an operating cost other than the cost of crop residue. Profit is summed over a time period until the organic matter reaches a steady-state level. The net return is then discounted using a social rate or a market rate of preference or a sliding discounting rate to find the best management system.

If the benefit is calculated in the short run (a farmer’s planning horizon), the higher organic matter content in soil may be capitalized into land value. Farmers would be willing to pay more rent for land that has higher organic matter since it provides higher yield. Land value increases with organic matter so that $MS/MM > 0$, where S is land value. Depending on the sign of MM/Mt, economic returns may be higher or lower at any time $t_1 > t_{0,}$ but should always be higher for a system with a high residue amount compared to a low residue amount.

Study description

Four management systems were compared as an alternative to the currently practiced management system (conventional tillage, chemical fertilizer, no cover crop). These four management systems were compared in experimental plots over a three-year time period and found to have the most promise in the region (Paudel, 1999). The management practices adopted in the experimental plots were followed exactly to find the long-term impact of farming systems on organic matter development and discounted net return associated with residue management.

For each management system, the winter wheat cover crop was planted in October by overseeding into standing cotton stalks. The cover crop was killed in April with the spray application of Roundup^{TM} or Paraquat^{TM}. The plot was mowed with a rotary mower after the cover crops were killed.

In ***System 1***, the plot was plowed with a chisel plow and then disked. Nitrogen was applied in the form of ammonium nitrate at a rate of 60 pounds per acre, 40 pounds during planting and the remainder as a top dressing before squaring. The plot was lightly disked after herbicide or pesticide application to incorporate fertilizer and pesticides. This is considered a ***conventional tillage chemical nitrogen*** system.

In ***System 2***, a primary tillage operation was done using a chisel plow followed by disking. Cotton was planted by using row planters, and broiler litter was applied at planting at the rate of two tons per acre to supply 60 pounds of available nitrogen per acre, then spread using a broiler litter spreader. This is considered a ***conventional tillage broiler litter*** system. In both Systems 1 and 2, chisel and disk plows were used. After three weeks of germination, both systems were cultivated using a rototiller, and cultivated again a month later to control weeds.

In ***System 3***, cotton was planted using a no-till planter at a row spacing of 30 inches. Nitrogen in the form of ammonium nitrate was applied at the rate of 60 pounds per acre, 40 pounds at planting and the remainder as top dressing. *Amaranthus* and crab grass were controlled using Select^{TM} and Paraquat^{TM} herbicides, respectively. This system is considered a ***no-till chemical fertilizer*** system.

In ***System 4***, cotton was planted using a no-till planter at a row spacing of 30 inches. Nitrogen was applied in the form of broiler litter at a rate of two tons per acre, which supplies nitrogen at 60 pounds per acre. Broiler litter was spread in the field using a broiler litter spreader. To control *Amaranthus* and crabgrass, Select^{TM} and Paraquat^{TM} were applied during the cotton-growing season as postemergent and postemergent-directed herbicides, respectively. This system is considered a ***no-till broiler litter*** system.

Each system was planted with a cover crop, and two weeks before cotton planting, the cover crop was killed using Roundup^{TM} or Grammaxone^{TM}. The cover crop supplied the source of residue needed for land cover during the growing season. Cotton variety Stoneville 474 was planted in May. In each system during the time of planting, Temik^{TM} was used to control thrips and nematodes at the rate of four pounds per acre. Cotoran^{TM} was applied as a broadleaf herbicide at the rate of two pints per acre. Prowl^{TM} was applied at the rate of 1.5 pints per acre to control annual grass and broadleaf weeds. Pix^{TM} was applied as a growth regulator soon after the bloom, and Harvade^{TM} and Prep^{TM} were applied as defoliant and boll opener. Cotton was hand-harvested in November to find the yield in each system.

Organic matter simulation

We analyzed the four systems with different tillage and nutrient sources. Since cotton residue must be removed from the field after cotton harvesting, a winter cover crop provides a source of crop residue in all systems considered in this study. Two systems include broiler litter, which follows a path of decomposition similar to crop residue in transforming into soil organic matter. Theoretically, the change in organic matter in any system over a particular time is represented by the following equation of motion

$$\frac{dM(t)}{dt} = g(R_{t-i}) - kM(t-1) \tag{7}$$

Here, M is organic matter at time t measured as soil carbon as a percentage of soil weight to a depth of 20 cm, g(.) is a function that describes the conversion of crop residue into organic matter, $R_{t\text{-}i}$ is residue added in year t-i, and k is the loss of organic matter in the form of carbon dioxide. It is assumed that complete decomposition of residue takes three years from the time of its incorporation into the ground; therefore, i = 0,1,2 with 0 representing the current year t. The transformation function g(.) and k differ according to the tillage method and nitrogen source. It is assumed that k is higher for a system with greater soil disturbance. Residue sources include a cover crop residue in all systems and broiler litter in two systems, both measured in pounds of carbon per acre of application.

Because residue transformation is different across systems, inputs are utilized differently based on management practices. Consistent with the model presented in equation (5), we assumed that organic matter increases the efficiency of certain applied inputs, making it possible to produce the same output with less input use.

Organic matter transformation functions in these four systems were simulated to find the steady-state level of organic matter in soil under the assumption that the management practices used in this study are continuously followed to time T, when the steady state is reached. We found that organic matter reached the steady-state equilibrium level after 500 years in each of these systems (Fig. 1). The steady state levels of organic matter for Systems 1, 2, 3 and 4 are 1.3, 2.0, 1.4 and 2.4%, respectively, compared with a starting value of 1% under a conventional system.

Since a farmer's planning horizon is usually limited to 30 years at most, choice of cropping system will only depend on organic matter additions if the economic effects are detectable within this planning horizon. In Figure 2, organic matter development in all four systems is plotted together to see the change in the level of organic matter during 30 years. This figure shows that organic matter declines dramatically and remains less than the starting value of 1% at the end of 30 years in both Systems 1 and 3, the systems relying on chemical fertilizer as a nitrogen source. For Systems 2 and 4, where broiler litter is added, show that organic matter first decreases and then increases to levels above the starting value. In System 4, positive changes in organic matter are observed after the fifth year, whereas it takes 11 years for organic matter accumulation to begin in System 2. The organic matter percentages at the end of a 30-year planning horizon in Systems 1, 2, 3 and 4 are 0.92, 1.15, 0.96 and 1.2%, respectively.

System 1 accumulates 70% of its 500-year equilibrium organic matter level by the end of 30 years. The other systems accumulate 57% (System 2), 68% (System 3), and 50% (System 4) of the long run dynamic equilibrium by the end of the planning horizon. This result indicates that the systems using broiler litter, and thus receiving additional material from which to form organic matter, achieve greater land capitalization for the farmer’s planning horizon and continue to transfer economic value to the land beyond this time period, making these systems more attractive investments.

Soil organic matter and production function

Organic matter simulation was conducted based on the same amount of input application during the entire simulation period. Since the same input combination is used during the entire period of simulation, we regressed organic matter content on soil and cotton yield to find the economic effect of building up organic matter in soil. To find a relationship between cotton yield and organic matter in soil, we needed long-term data on these two variables, but found it did not exist for the experiment location. However, cotton production in Alabama is very similar to the study area, and experiments with cotton management practices to find the effect of crop rotation and winter cover crop have been conducted since 1896. Because of the management similarity and long-term data availability, we used the results from this experiment to find the relationship between cotton yield and soil organic matter.

We used 1984 to 1992 soil organic matter and cotton yield data from the long-term plots to determine the best-fitting production function. This period was selected because it best reflects the current technology used in cotton production. Seven different production functions commonly used in crop yield/input relationships were tested to find the best-fitting model. The production functions fitted for the data obtained from the long-term rotation were linear, log linear, square root, quadratic, quadratic with plateau, Mischerlich-Baule and von Liebig. The coefficients of the parameters in the model were estimated using the SAS statistical package version 8 (SAS Institute, 2001).[1]

Except for the linear and log linear models, the maximum possible yield was found to be around 1,100 pounds of cotton lint per acre. This yield is almost double the current average cotton lint yield in the region but comparable to the yield result obtained on the experimental plots in the region. It may be possible to increase the yield even more if soil organic matter is increased beyond the level used in our estimation of the production function. Since the maximum yield would be constrained by the amount of soil organic matter, and since soil organic matter can be increased higher than the level currently observed

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[1] The corresponding author can furnish the details of the estimated results. Space constraints would not allow us to report all the results here.

in the long-term experimental plots, we used the log linear model to estimate the impact of the discount rate in long-term adaptation of these management practices in a farmer's field. This production function should be justifiable at least in the cotton-growing area of the southeastern United States, where the maximum amount of soil organic matter content may not increase beyond half of the natural level of soil organic matter present before cultivation started (Cole, 1995).

The estimated parameters of the model showing the relationship between yield and organic matter are as follows:

$$\ln Y = \underset{(-0.89)}{-162.6} + \underset{(5.84)}{498.66} * \ln(M) \qquad \text{Adj. } R^2 = 0.34 \tag{9}$$

Here, Y is cotton lint yield in pounds per acre, and OM is the grams of organic matter per kilogram of soil obtained in the top 20-cm layer of the soil. The values in the parentheses are t-statistics. The coefficient associated with the intercept in the model is insignificant whereas the coefficient associated with organic matter is significant at the $\alpha = 0.01$ level. The model in equation (9) indicates that a one percent increase in organic matter will result in 499 pounds more lint per acre. The adjusted R^2 of the model is 0.34. The negative sign of the coefficients is valid because in the Georgia Piedmont, without a certain buildup of organic matter, cotton yield is zero. Mitchell and Entry (1998) estimated the relationship between soil organic matter and cotton yield using a quadratic model. The result of this study also showed a negative intercept term in the regression value, which supports the intercept value obtained in our model.

Results

Cost-return analysis

Enterprise budgets were developed based on the following assumptions: the average farm size is 1,200 acres and the size of each plot is 40 acres. The farmer owns two tractors — a heavy tractor with 125 horsepower, and a light tractor with 60 horsepower. The farmer also has other machinery and equipment needed for cotton farming. The prices of inputs and outputs reflect 1998 prices and were obtained from different sources such as the National Agricultural Statistics Service and enterprise budgets developed by the University of Georgia Cooperative Extension Service (Givan and Shurley, 1998).

All management systems tested use chemicals to control insects and weeds. The chemicals selected represent the most common chemicals used in cotton production in the Piedmont region. In a conventional tilled plot, herbicides such as Cotoran™ and Prowl™ are applied during planting. In the case of no-till plots, Fusillade™ and Roundup™ are applied as over the top and postemergent herbicides, respectively. Cover crops are killed in both conventional and no-till plots using Roundup™. It costs 49% more for herbicides and their application in the no-till systems.

We have shown the major cost differences in alternative systems in Table 1. Since insecticides are applied at the same rate in all systems, the cost is the same for all systems. The other major difference between no-till and conventional tillage arises due to machinery use. Conventional plots are plowed and cultivated. No-till plots are chemically sprayed so the cost difference of 18% more in conventional tilled system is due to the difference in tillage equipment. Associated with the machinery is the cost of fuel, which is shown together with the machinery cost.

Machine-use costs reflect both fixed and variable costs. Variable costs associated with machinery use include the costs of repair, maintenance and fuel. In the conventional tillage treatments, the total cost of machine use is 18.8% higher than in no-till treatments. The labor costs are 7.9% higher in the conventional tillage systems than in the no-till treatment due to the more extensive machinery use.

Fixed costs include the cost of machinery, interest on operating capital, cost to management and overhead. Interest on operating capital is calculated based on 5% of the total variable cost incurred during the production period. Cost to management is also charged 5% of the total variable cost and reflects the opportunity cost of the farm manager. General overhead includes costs such as office expenses, sanitation service, soil analysis, and property taxes. Generally, data on this cost are not available so the amount is also assumed to be the 5% of the total variable costs incurred in the production process.

To illustrate how much the net return differs between these alternative managements systems, we compared the net return values from these four management systems based on the data obtained from the experiment field in Watkinsville, GA (Paudel, 1999). Paudel found that three year average of net return from the system with no-till and poultry litter is 3.5 times higher than the system with conventional tillage and chemical fertilizer use. This provide example on the benefit of using no-till method in crop production. However, the production function in any system depends upon the organic matter content of the system at that time. If one system is better at maintaining organic matter, that system should produce a higher profit and provide a greater annual return to the cotton producer. It is the annual return over the productive life of the farm, or annuity, that is of most importance to the farmer.

Sustainability of alternative management systems

All four systems were compared against each other by their capacity to maintain natural capital in soil, and their potential to increase productivity and profitability indexes. We also calculate the net benefit of these alternative systems using the IPCC-recommended discount rate and Weitzman's recommended sliding gamma discounting rule. The discount rates used in the social rate of time preferences were between 0.5 - 3% and the market rates of discount rate used are from 3 to 6%. Analysis was carried out for both the farmer's planning horizon and the long-run time horizon. We used 300 years for the long-run analysis as the gamma rate of discounting proposed by Weitzman suggests using zero discount rate after 300 years. Since the steady state of carbon accumulation was obtained at different times in different management systems, we did not use this basis for comparison.

As shown on Table 2, when the planning horizon used was 300 years, all four management systems were found to be sustainable using average productivity and average profitability indices. We define strong sustainability as a criteria where average value of the total factor productivity and natural capital (soil organic matter) do not decrease over time. Similarly weak sustainability is defined as the situation where total factor productivity shows a positive change but the place of natural capital in this case is likely to be taken by manufactured capital. In a sense, the increase total factor productivity comes at the cost of natural resources. If a strong criterion of sustainability is to be chosen, which would suggest that the amount of natural capital not be reduced from the current status, then only System 4 would be a sustainable farming system. If the criterion is to be modified, so that the average soil organic matter fall no lower than the present amount, then all four farming systems would be sustainable using both strong and weak sustainability criteria. The highest net present value is obtained in System 4 followed by Systems 2, 3, and 1. The highest net present value was obtained when the discount rate was 0.05, consistent with the social rate of discount. The sliding gamma rule produced total net present value between 1 and 1.5%. The same held true for Systems 2, 3 and 4.

The highest net present values are obtained in System 4 and the lowest in System 1; both are obtained when the discount rate is assumed to be 0.5%. System 2 has 11% less net present value than System 4 and ranks next to it. System 3 has 34% less net present value than System 4. System 1 generated the lowest net present value. The sliding gamma discounting rule produced similar results. The difference between the highest value obtained by using the social rate of time preference and the one obtained by using the gamma sliding discount rate is double in all four systems.

When the annuity value is calculated with 300 years as the total planning horizon, we found that the highest annuity value of $493 per acre per year was paid in System 4 with the assumption that the discount rate is 0.5%. The lowest annuity value of 257 per acre pre year was obtained in System 1 with a 6% discount rate.

We also conducted the analysis based on the assumption that the farmer's planning horizon is only 30 years. The logic behind a 30-year planning horizon is that the effects of alternative management systems should be observable if farmers are to adopt these management systems. Our analysis, shown on Table 3, indicated that total nondiscounted value for 30 years is highest in System 4, followed by Systems 2, 3 and 1. The net present value obtained using the gamma sliding rule falls in between the net return calculated with 2.5 and 3% discount rate. This shows that the net present value obtained by using the sliding gamma rule depends on the planning horizon. If the planning horizon is long, the net present value would be approximately equal to the lower value of discount rate as suggested in the social rate of discount rate proposed by the Intergovernmental Panel on Climate Change (1995).

The average productivity index is below 1 in Systems 1, 2 and 3 but is exactly 1 in System 4. Having an average productivity index of 1 means that the net return to cost ratio did not change from the base time period to the current time period. The average profitability index is the highest in System 4 with a value of 1.56. The average profitability index is above 1 in all four systems. Based on the weak sustainability criteria, only System 4 is sustainable. When examined from the perspective of strong sustainability (whereby we require maintenance of natural capital at the current level), System 4 also qualifies as strongly sustainable, as the percentage of organic matter never falls below the 1% level.

The highest net present value is obtained when the discount rate is 6%. If the rate is changed to an annuity value, System 4 should generate $292 net return per acre per year during the entire planning horizon. The lowest annuity value of $239 per acre per year is obtained in System 1, when the discount rate used was 0.5%.

These annuity values are consistent with the present value of the net return obtained from the experiment results. Even if we were to use strong sustainability index, the management system with no-till and an organic source of nutrients comes out to be the sustainable system. Using weak sustainability as the criterion for comparing management systems within a 30-year time horizon did not give different results as far as the superiority of a management system is concerned. The lack of maintaining the initial level of organic matter, and a low productivity index, made three management systems unsustainable.

Using both strong and weak sustainability criteria in 30-year and 300-year planning horizons, we found that the management system containing no-till and an organic source of nutrients could be viable over the long run. For example, if this system is to be implemented on a large scale in Georgia’s cotton-producing region, it would be able to sequester as much as 21,434 tons of carbon over 30 years. Even using a conservative estimate, the market value of this amount of carbon could be as much as $6.6 million. If the Kyoto Protocol were to recognize this effort, it would provide further incentive to farmers and policy makers to adopt conservation management practices in farming. One important implication obtained in this analysis is that the system with no-till alone would not be effective in increasing organic matter if there were not a sufficient amount of residue added to the soil. The key factor is adding more residue year after year and not disturbing the soil, which seems to be the reason for the superiority of System 4.

Discussion and Conclusion

We compared four alternative cotton management systems to find the best management system in two different planning horizons, using several possible discount rates suggested by the IPCC and also Weitzman’s newly proposed gamma sliding discount rate. Our analysis indicates that if these systems are compared within a 300-year planning horizon, all of them are sustainable using weak sustainability. However, strong sustainability criteria would indicate that only System 4 is sustainable, as it would maintain or exceed the current level of organic matter throughout the planning horizon. When the net present value is calculated using the gamma sliding rule, the value was equivalent to a lower rate of discount as proposed using the social rate of time preference. The net present value is higher if the discount rate considered is lower, which happens when the analysis is based on the social rate of discount.

This implies that greater equivalency between the future and the present in the decision maker's time preferences will result in his or her perception of greater returns to selecting a cropping systems that maximizes carbon sequestration.

When the analysis was conducted within the farmer's planning horizon, we found that three of the four systems did not meet the criterion of weak sustainability. Only System 4 emerged as the preferred alternative management system for cotton farming in Georgia. Soil organic matter would double if this management system were to be practiced in Georgia or in cotton-producing regions with a similar kind of soil.

The benefit of adopting this management system is not only its sustainability, but also its capacity to help the U.S. meet the Kyoto Protocol's requirements. Even within the farmer's planning horizon, the soil in the cotton-producing region of Georgia can gain as much as 21,434 tons of carbon, a 20% gain in soil organic matter above current levels. The value of this organic matter can be as much as $6.6 million at a given rate of carbon abatement cost. Compared to a conventional system, an alternative management system such as System 4 proposed would produce carbon savings of $20 million (calculated based on 3.7 million acres in the Southeast and a 30 year time horizon) in the Southeast region for cotton production alone. This demonstrates the large incremental effect of altering a single cropping systems in one region of the country. Therefore, policy makers should consider encouraging farmers to undertake this or a similar productivity-increasing, carbon-abating farming method.

We showed that agricultural soil can be a net sink for CO_2 in the form of organic matter, although the amount of the total carbon sequestered varies with the management type and the source of nutrients applied in the production process. As observed in this study, the steady state or maximum level of organic matter differs depending on the management system and the soil type. The maximum potential gain in carbon is the difference between the current carbon status and the steady-state level.

We also observed that due to low machinery expenses (including fuel and lube expenses), a conservation system can thrive even if a fuel tax is implemented to curtail the global-warming problem. Environmentalists and economists should emphasize adopting a similar kind of system for other crops capable of sequestering carbon and emerging as a sustainable agricultural system. It is also likely that crops such as sorghum, corn and soybeans could benefit from the conservation system even more than cotton, although cotton fared well in this study. The study can be extended to other crop production areas with different cropping management practices to find the total economic value of adopting conservation practices.

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Table 1. Treatments Causing the Major Cost Differences in Four Systems

Treatment	System 1	System 2	System 3	System 4
	$/acre			
Fertilizer	35.00	32.00	35.00	32.00
Herbicides	48.00	48.00	71.55	71.55
Machinery	196.04	196.04	164.88	164.88
Labor	29.65	29.65	27.47	27.47

Table 2. Comparison of four alternative management systems within a 300-year planning horizon

Variable	Annuity Value based on the Market Rate of Discount ($/acre)[1]				Annuity Value Based on the Social Rate of Discount ($/acre)[1]					Total NPV from Sliding Gamma
	% Discount rate				% Discount rate					
	3	4	5	6	0.5	1	1.5	2	2.5	
System 1	259[2] (8,642)	257 (6,414)	256 (5,124)	257 (4,285)	297 (46,106)	284 (26,944)	274 (18,038)	267 (13,303)	262 (10,481)	22818
System 2	311 (10,370)	295 (7,377)	286 (5,713)	280 (4,665)	435 (67,471)	395 (37,493)	363 (23,948)	340 (16,966)	323 (12929)	32222
System 3	273 (9,085)	269 (6,722)	268 (5,360)	269 (4,478)	312 (50,012)	304 (28,909)	291 (19,194)	282 (14,076)	276 (11,048)	24568
System 4	345 (11,510)	327 (8,181)	317 (6,335)	310 (5,172)	493 (76,539)	444 (42,163)	406 (26,765)	379 (18,890)	359 (14,365)	36333

[1] Discount rate used is in accordance with the IPCC recommendation.

[2] The upper value is the annuity value. The value in parentheses is the net present value at the given discount rate.

Table 3. Comparison of four alternative management systems within a farmer's (30 years) planning horizon

Variable	Annuity Value based on the Market[1] Rate of Discount ($/acre)				Annuity Value Based on the Social Rate of Discount[1] ($/acre)					Total NPV from Sliding Gamma	Min. %OM
	% Discount rate				% Discount rate						
	3	4	5	6	0.5	1	1.5	2	2.5		
System 1	245[2] (4,794)	247 (4,278)	250 (3,847)	253 (3,484)	238 (6,610)	239 (6,171)	240 (5,775)	242 (5,416)	243 (5,090)	4894	0.88
System 2	259 (5,084)	260 (4503)	261 (4019)	263 (3615)	257 (7,148)	258 (6,648)	258 (6,197)	258 (5,789)	259 (5,420)	5214	0.96
System 3	255 (5,006)	258 (4,466)	261 (4,016)	264 (3,636)	248 (6,906)	250 (6,447)	251 (6,032)	253 (5,657)	254 (5,316)	5211	0.91
System 4	288 (5,650)	289 (5,003)	290 (4,464)	292 (4,014)	286 (7,945)	286 (7,390)	287 (6,888)	287 (6,434)	288 (6,023)	5793	1

[1] Discount rate used is in accordance with the IPCC recommendation.

[2] The upper value is the annuity value. The value in parentheses is the net present value at the given discount