

Meeting the Kyoto Target Through Conservation Tillage and Its Implication for Natural Capital Maintenance, Production Efficiency, and Sustainability

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200 Word Abstract

According to Article 3.4 of the Kyoto Protocol, agricultural soil could be used as a sink for carbon sequestration and hence it may provide an alternative venue to sequester the greenhouse gas emission. US plans to reduce the carbon emission amount by seven percent below the 1990 level within the target date of 2008-2012. The major approaches to achieve the goal targeted by Kyoto Protocol in US are through fossil fuel tax and increasing forest area by afforestation. This means fossil fuel price will increase which will have a direct impact to conventional tillage cost. As a result farmers would be motivated to use less machinery operation in farming and hence may use conservation tillage in farming practices. Rather than cause and effect relationship created by fuel price increase, conservation tillage itself has been considered as a method suggested to increase carbon sequestration. We analyze the economic and environmental roles of conservation tillage in carbon sequestration. The use of conservation tillage helps to sequester carbon in the form of soil organic matter. We examined the potential of conservation tillage in sequestering carbon and its role in increasing soil natural capital and thus the productivity of soil. We then used the concept of production efficiency to calculate the benefits of soil carbon sequestration using sustainability criteria.

The detail of carbon sequestration and soil natural capital buildup were demonstrated using conservation tillage practiced in cotton production in Georgia. Four systems of conservation tillage encompassing both chemical and organic source of plant nutrients were compared for their capacity to sequester carbon. Organic matter buildups were faster in a system with conservation tillage and organic sources of nutrient compared to conventional tillage. Result indicated that in a system with a slow buildup of natural capital, production efficiency was not significant. This has resulted the system to be unprofitable in the short run and unsustainable in the long run. The system with a high amount of organic matter increases the production efficiency of applied inputs and also plays an important role in substituting chemical fertilizers. Alternative tillage management systems were evaluated for their sustainability using total factor productivity. It was found that conservation tillage meets criteria of sustainability more often than the management system containing conventional tillage. Conservation tillage was found to be the best alternative not only to sequester carbon but also developing natural capital-based sustainable system.

Meeting the Kyoto Target Through Conservation Tillage and Its Implication for Natural Capital Maintenance, Production Efficiency, and Sustainability

Agriculture is both the source and sink of carbon dioxide, one of the major global warming causing gases. Conventional agriculture practices are responsible for increasing the out flux of greenhouse gases from soil into the environment. Contrarily, a responsive agricultural practice can sequester carbon in the form of organic matter, reduce total machinery and fuel consumption, and increase the productivity of soil there by reducing the total input cost in agriculture. Our objective in this paper is to analyze the potential of conservation tillage and organic sources of plant nutrients in sequestering carbon in the form of organic matter and the effect of organic matter on soil productivity, production efficiency, and sustainability of a farming system. If alternate management systems can increase soil organic matter, then it should help US to meet the goal set forth in Kyoto protocol with less negative impact in the economy.

If US is to implement according to Kyoto protocol, it has to reduce 7 percent of the total global warming causing gases by 2008-2012 from the base (1990) level. One of the main complains that the US has about the Kyoto protocol is the lack of developing countries participation in meeting the target. Although the US has signed the protocol, the final approval should come from the senate. If the senate approves the Kyoto protocol, that means US needs to meet the 7 percent reduction target set forth in the protocol within 2008-2012. The two major ways to meet this target level are increase afforestation and implementation of a carbon tax mechanism. However, both of these practices may be unpractical as afforestation needs conversion of agricultural land into forestry. Given the continuous increase in population,

conversion of agricultural land to forestry may not seem very practical. The second alternative, the carbon tax, helps to decrease the gasoline consumption but given the policy in the US, it is unlikely that carbon tax is going to be viewed positively by the citizens. Nevertheless, the most likely step that will be taken by the government to meet the target set forth in Kyoto protocol could be to increase fuel tax. According to Department of Energy report, abating a ton of carbon could cost as much as \$357. Farmers are likely to be negatively impacted by increased fuel tax. Francé *et al.* report that compliance with the protocol could increase farm expenses between \$10 and \$20 billion per year and decrease farm income by as much as 48 percent. These results indicate that if traditional farming practice is to be continued it is going to greatly impact the profitability of farmers in the US and their competitiveness in the international market.

Article 3.4 of the Kyoto protocol identifies that agricultural soil could be used as a sink for carbon sequestration. Therefore, it may provide an alternative venue to sequester the greenhouse gas emission. Agricultural management practices are the key factor in changing the soil carbon balance. Three potential ways to increase carbon storage in soil are by increasing organic carbon inputs, by decreasing decomposition rate, and by reducing the amount of carbon dioxide produced per unit of organic matter decomposed. There is need to identify alternates to an existing agriculture practice capable of increasing soil organic matter. We suggest that farmers use organic source of crop nutrients and adopt conservation tillage to decrease the net flux of carbon into the environment and to avoid the possible hike in fuel prices. We demonstrate why the use of organic source of nutrient and conservation tillage can reduce the total carbon emission and increase farmers profit, production efficiency, and sustainability. Use of conservation tillage and organic source of nutrients will allow US to meet the goal set forth in Kyoto Protocol less

expensively. Given the problems of continuous deterioration in soil productivity and problem of disposing animal manure, the method suggested here could gain popularity among farmers to increase soil productivity and to solve animal waste disposal problem in the US, at the same time increasing carbon sequestration and maintaining natural capital in soil. We use cotton production in Georgia as an example and show how alternate management systems can help to sequester carbon and provide an alternative profitable cropping system.

Role of organic matter in soil quality improvement

Soil organic carbon is the most frequently reported attribute from long-term studies and 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 is composed of soil organic carbon and is the foundation for 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 low fertility, less water availability, compaction, and erosion become more common with the reduced amount of organic matter. 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 increases 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 nutrient. 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 poultry manure 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 equipments are used (Camberdella and Elliott).

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 nutrient such as poultry litter into the soil. The nutrient content of poultry litter varies but on average nutrient content in dry litter average 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. Poultry litter has been used as a source of nitrogen for cotton in Alabama (Mitchell *et al.* 1995). 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. Experiment results show that the addition of poultry litter with winter cover crop residue increases the organic matter in soil (Cabrera *et al.*).

Organic matter simulation model

In agricultural systems, the principal means of manipulating soil organic matter are through cover crop selection, nutrient application, and tillage practices which affect residue accumulation. We develop the relationship between organic matter accumulation under the tested management systems and cotton yield, and the net return associated with them.

No-till cultivation in cotton is not popular in the Georgia Piedmont, as residue needs to be destroyed because boll weevils overwinter in it. Alternatives management could involve a winter cover crop as a source of residue with no-till or conventional cultivation and poultry litter or chemical fertilizer. Poultry litter provides an additional source of organic matter. The alternative systems have potential to increase soil organic matter.

The dynamic path of organic matter development differs between conventional tillage and no-till land. There is less decomposition of accumulated organic matter in no-till than conventional tillage field and more rapid accumulation of residues. Nutrient sources are another difference in organic matter accumulation between different systems. When poultry litter is applied, it not only supplies necessary plant nutrients but also provides an additional source of carbon in the soil from which organic matter is formed.

Organic matter development and change take place slowly in soil. Several long-term experiments have emphasized the need to look at the change in organic matter over long periods in a given management system to evaluate the sustainability of the management system (Cassman *et al.*). Most of the pools of soil organic carbon have long periods of turnover, so the effect of change in organic matter due to management difference takes place slowly. Steady state development of organic matter cannot be observed in a short period of time. This is because soil

organic matter has a turnover period of between one to 2000 years depending upon the pool where it exists. This analysis focuses on organic matter, because it integrates changes in production and decomposition over time. It is also central to the cycling of plant nutrients, influences water retention, and is a key factor in soil structure. The major constituent of organic matter is organic carbon. Therefore, the dynamics of soil organic carbon can reveal much about the dynamics of organic matter in soil (Dalal and Myers; Parton *et al.* 1988).

The long-term effects of tillage, nutrient source, and crop residue in organic matter buildup is simulated for four different systems based on the century model (Parton *et al.* 1987). There are four pools of organic matter: structural, metabolic, active, and slow. The divisions of organic matter in these different pools are based on the turnover period. Plant residue is divided into structural pools and metabolic pools depending upon a lignin-to-nitrogen ratio which ultimately transfers into an active or passive pool. Poultry litter transfers into structural, metabolic, and active pools. The division of poultry litter into different pools is based on the study by Gordillo and Cabrera. In the century model developed by Parton *et al.* (1987), five pools of organic matter are recognized. Nevertheless, only four essential pools are considered in this study to simplify the model and facilitate the estimation of parameters.

The decay rate constants are assumed 30 percent higher for the conventionally tilled soil. Our assumption is consistent with the long-term decay rate difference in no-till and conventional tillage by Jenkinson *et al.* and Paustian *et al.* (1992). The decay rate denotes the turnover period of organic matter from one pool to another. The decomposition rate of any pool of organic matter depends on temperature and precipitation. The maximum decomposition of any pool occurs when temperature is 95 degrees F. When temperature increases or decreases from this level, the

decomposition rate declines. Tillage increases the rate of oxidation, and hence there is a higher loss of organic carbon in the form of carbon dioxide in conventionally tilled soil.

To provide a robust test of the model predictions, decay rate constants were obtained from Parton *et al.*(1987) and modified to reflect the four pool situation (figure 1). These modified rate constants are used to predict the organic matter buildup under poultry litter decomposition and sorghum residue decomposition in cecil soil dominant in the Georgia Piedmont. The model predicted the organic matter buildup correctly when sorghum residue is added as evidenced from the study by Bruce and Langdale. The decay rate also gave a consistent estimate of the poultry litter decomposition when compared to the study by Braun. These calibrated parameters are used in this study for the cover crop residue and poultry litter decomposition and transformation into organic matter.

The baseline organic matter content of soil was assumed to be one percent of soil weight in the top 8 inches of soils with a bulk density of 1.5 grams per cubic centimeter of soil. Hendrix reports that organic carbon content from soil under virgin forests, fescue sods, and old fields are around four percent on assumed bulk density and depth profile distribution of carbon. This value may represent an upper limit to carbon storage in Piedmont soil receiving inputs from *in situ* plant production. Recent geographical data estimates, as well as measurement in this region, indicated base soil organic matter to be around one percent. Hendrix further reports that it might be possible to reach to the four percent level of organic matter in soil if proper management

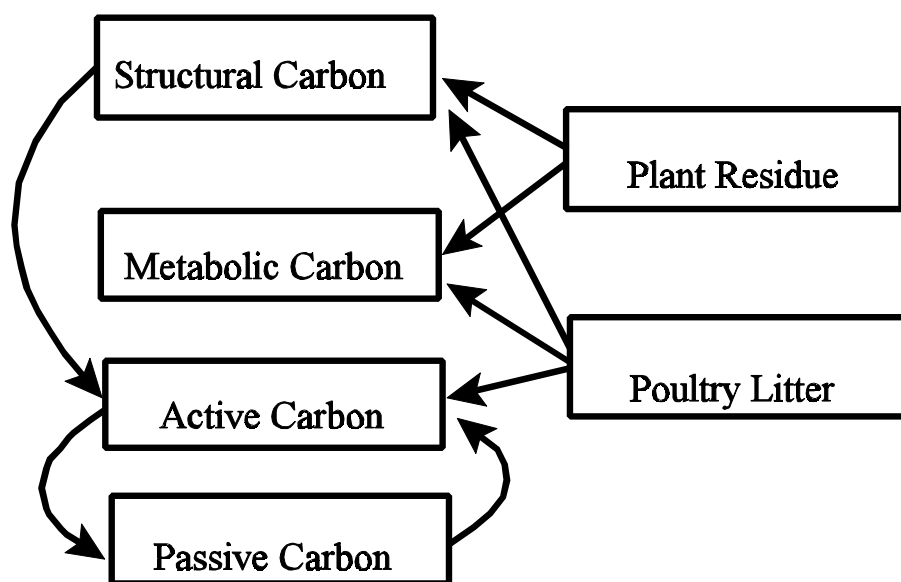


Figure 1 Schematic diagram of the century model used to simulate organic matter accumulation

practice is followed. Organic matter content shown by soil carbon in each of the systems is simulated for field conditions in the Georgia Piedmont to find the maximum upper bound of organic matter accumulation. However, the economic decision process is limited to a farmer's planning horizon of 30 years, so costs and revenue associated with the system rely on organic matter accumulation only for that period. For system profitability and sustainability, the cost of maintaining organic matter at a lower level is calculated. The net revenue associated with each option is calculated and compared.

System description

To validate our hypothesis of carbon sequestration and efficiency, we chose an ongoing experiment study site located at the J. Phil Campbell, Sr., Natural Resource Conservation Center in Watkinsville, Georgia. The station has representative soil and weather for the Georgia Piedmont. The soil is cecil sandy loam with zero to two percent slope. The plot was planted with corn using no-till and a winter wheat cover crop in the three years preceding the start of the experiment in winter 1995.

Four management systems are compared at the experimental site. The simulated planting schedule is the same as the one followed in the experimental plot. For each management system, the winter wheat cover crop is planted in October by overseeding into standing cotton stalks. The

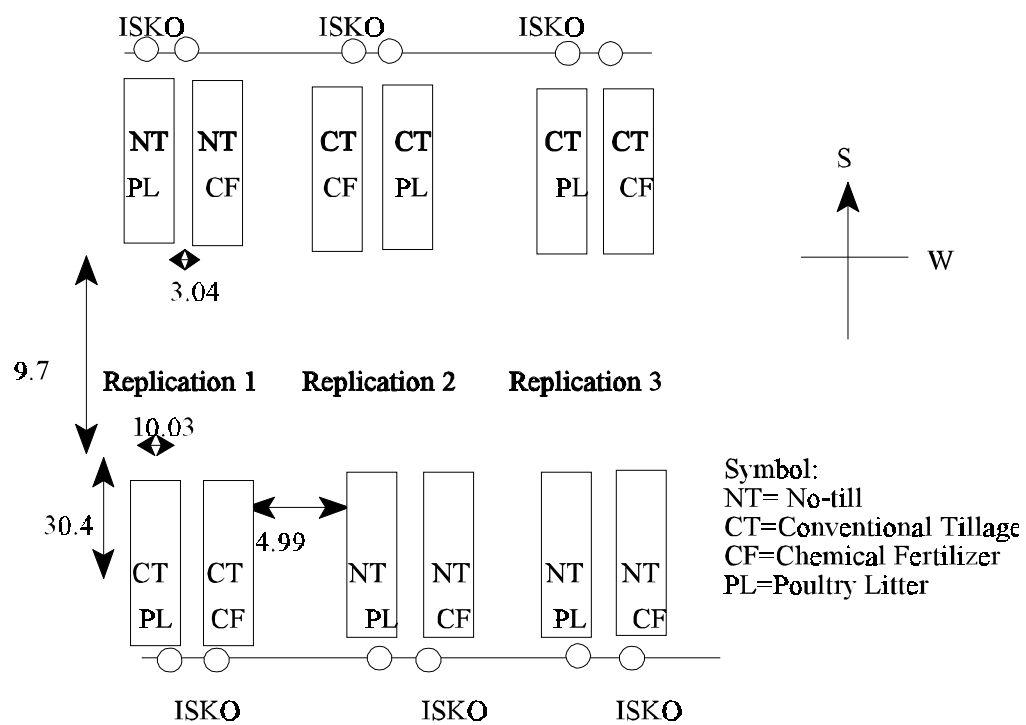


Figure 2. Layout of the four systems in the experimental plot

Table 1. Key Management Operations in Four Systems

Treatment	System 1	System 2	System 3	System 4
Nitrogen Source	Ammonium Nitrate	Poultry Litter	Ammonium nitrate	Poultry litter
Fertilizer	At planting	At planting	At planting	At planting
Application	Side dressing		Side dressing	
Herbicides	At planting	At planting (Prowl™,	At planting (Prowl™,	At planting (Prowl™,
Application	(Prowl™, Cotoran™, and Temik™)	Cotoran™, and Temik™)	Cotoran™, and Temik™)	Cotoran™, and Temik™)
			Post-emerge (Select™)	Post-emerge (Select™)
			Post directed (Select™)	Post-directed (Select™)
Tillage	Chisel and Disk	Chisel and Disk	No-till planter	No-till
Growth	Pix™	Pix™	Pix™	Pix™
Regulator and Defoliant	Harvade™ and Prep™	Harvade™ and Prep™	Harvade™ and Prep™	Harvade™ and Prep™

cover crop is killed in April with the spray application of Roundup™ or Paraquat™. The plot is mowed with a rotary mower after the cover crops are killed.

The experimental design in this study is a factorial design with tillage and nitrogen with three replications of each system. Therefore, there are 12 plots in this study. The plot map and design are shown in figure 2. The plot size is 30.4 X 10.03 square meters. The space between two plots is 3.04 meters and the space between two replications located in the same side are 4.99 meters apart from each other. Two replications on opposite sides are located at a distance of 9.7meters. Sequential samplers are located at the north and south sides of the outer parts of the experimental plots. These samplers were used to measure the runoff and leaching from the experimental plots.

The key management operations for each of the four systems are outlined in table 1. The detail management practice of each system are described in the following text. In system 1, the plot is plowed with a chisel plow followed by disking. Nitrogen is applied in the form of ammonium nitrate at a rate of 60 pounds per acre. The plot is light disked after herbicide or pesticide application to incorporate fertilizer and pesticides. Nitrogen is applied at the rate of 40 pounds per acre during planting and the remaining amount as a top dressing before squaring. This is considered a conventional tillage chemical nitrogen system.

In system 2, a primary tillage operation is done using a chisel plow followed by disking. Cotton is planted by using row planters, and poultry litter is applied at the rate of two tons to supply 60 pounds of available nitrogen per acre, then spread using a poultry litter spreader at planting. This is considered a conventional tillage poultry litter system.

In both systems 1 and 2, a chisel and disk plow are used. After three weeks of germination, both systems are cultivated using a rototiller and again a month later to control weeds.

In system 3, cotton is planted using a no-till planter at a row spacing of 30 inches. Nitrogen is applied at the rate of 60 pounds in the form of ammonium nitrate. Forty pounds of nitrogen is applied at the time of planting and 20 pounds as top dressing. *Amaranthus* and crab grass are controlled using SelectTM and ParaquatTM herbicides, respectively. This system is considered a no-till chemical fertilizer system.

In system 4, cotton is planted using a no-till planter at a row spacing of 30 inches. Nitrogen is applied in the form of poultry litter at a rate of two tons per acre. This supplies nitrogen at 60 pounds per acre. Poultry litter is spread in the field using a poultry litter spreader. To control *Amaranthus* and crabgrass, SelectTM and ParaquatTM are applied during the cotton growing season as post emergent and post emergent directed herbicides, respectively. This system is considered a no-till poultry litter system.

Each system is planted with a cover crop, and two weeks before cotton planting, the cover crop is killed using RoundupTM or GrammaxoneTM. The cover crop supplied the source of residue needed for land cover during the growing season. Cotton variety Stoneville 474 is planted in May. In each system during the time of planting, TemikTM is used to control thrips and nematodes at the rate of four pounds per acre. CotoranTM is applied as a broadleaf herbicide and used at the rate of two pints per acre. ProwlTM is applied at the rate of 1.5 pints per acre to control annual grass and broad leaf weeds. PixTM is applied as a growth regulator soon after the bloom, and HarvadeTM and PrepTM

are applied as defoliant and boll opener. Cotton is hand harvested in November to find the yield in each system.

Maximum organic matter development

The time paths of organic matter development for all four systems are shown in figure 3. As shown in table 2, systems containing no-till and poultry litter and conventional tillage and poultry litter are supplied with two tons of poultry litter and two tons of crop residue per acre per year. Systems containing conventional tillage and chemical fertilizer and conventional no-till and chemical fertilizer are supplied with only cover crop residue at the rate of two tons per acre. Cover crop is assumed to add two tons of residue per acre. The poultry litter application in system 2 and system 4 provides an additional source of carbon for organic matter and 60 pounds of available nitrogen per acre for cotton production.

Each of these systems are allowed to reach the steady state level of organic matter. All of these systems took about 500 years to reach the steady state level of organic matter. The steady state level of organic matter in soil was found to be 1.25 percent for system 1, 2.02 percent for system 2, 1.42 for system 3, and 2.37 percent for system 4. When poultry litter is applied as a source of fertilizer, organic matter content is higher. No-till increases organic matter but this increase is not as high as when poultry litter is applied. For example, system 2 consists of application of poultry litter but is tilled using conventional tillage. The organic matter content is higher in system 2 than in system 3 even though system 3 follows no-till management. When no-till is coupled with poultry

litter application, organic matter buildup is faster and reaches a higher level than when only crop residue is added.

In each of these systems, there is a decrease in organic matter initially. In systems 1 and 3, this trough lasts longer than in systems 2 and 4. The trough in the organic matter

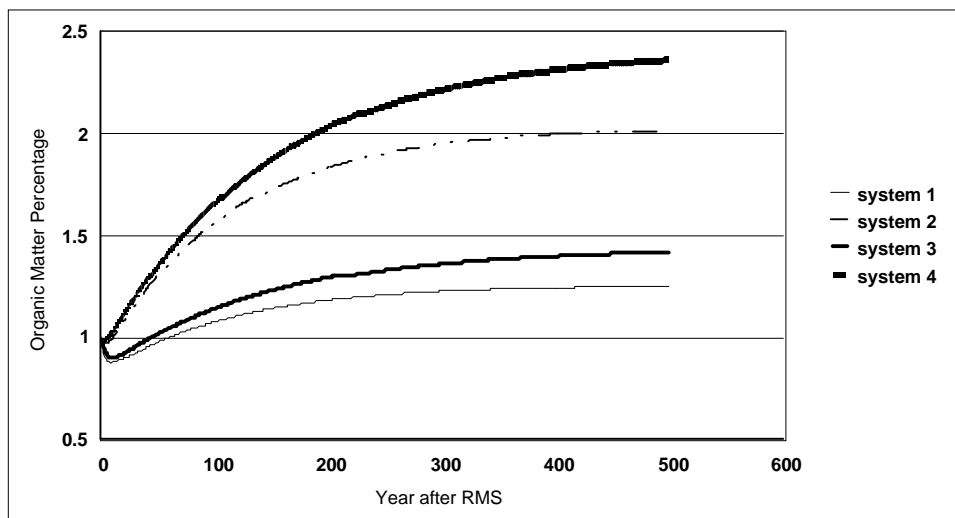


Figure 3. Organic matter dynamics in four systems for five hundred years

Table 2. Components of Organic Matter Development Model in STELLA

Components	No-till	Conventional Tillage
Added crop residue	2 tons/acre	2 tons/acre
Poultry litter	2 tons/acre	2 tons/acre
<i>Rate constants</i>		
Structural	0.085	0.11
Metabolic	0.31	0.403
Slow	0.0719	0.091
Passive	0.00013	0.000169

development function may be caused by either a lack of sufficient residue-breaking micro organisms to convert residue into carbon or a lack of sufficient carbon sources to offset the loss of existing soil carbons in the form of carbon dioxide in soil. This kind of trend is common in the model simulated with the century model (Paustian *et al.* 1992). Since a farmer's planning horizon is only 30 years, one would like to see the change in organic matter within this planning horizon. In figure 4, 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 is lower than the one percent level at the end of thirty years in both systems 1 and 3. These are the systems without poultry litter treatment. The two other systems, where poultry litter is added, show that organic matter first decreases and then increases. For example, in system 4 organic matter decreases in the first four years but starts building up from the fifth year. In system 2, organic matter is greater than one percent only after 11 years. The organic matter percent at the end of a 30-year planning horizon in system 1, 2, 3, and 4 are 0.92, 1.15, 0.96, and 1.2 percent, respectively.

Enterprise budgets for management systems

Enterprise budgets were developed based on the assumptions that 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. There are also other necessary machinery and equipment needed for cotton farming. The prices of inputs and outputs reflect 1998 prices and are obtained from different sources such as National

Agricultural Statistics Service and enterprise budgets developed by the University of Georgia Cooperative Extension Service (Givan and Shurley). 1998 prices are chosen to develop the enterprise budget because the base year in the Laspeyres index is the current period. We are using Laspeyres index to measure the sustainability of four different systems. Associated with

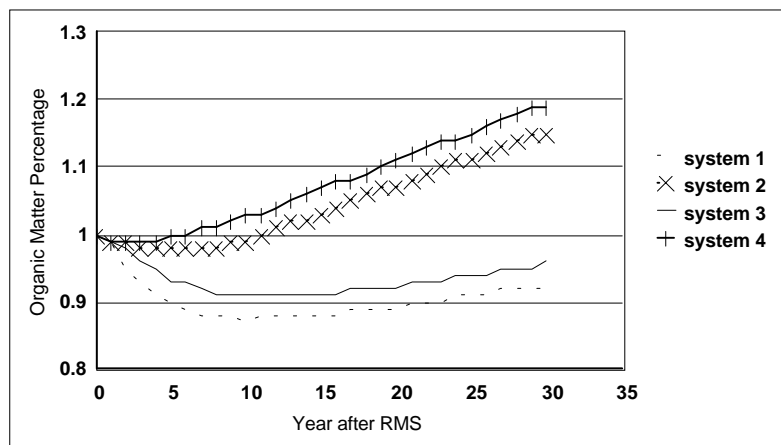


Figure 4. Organic matter development dynamics in four systems for 30 years

each system are different management operations which are outlined in table 3. These enterprise budgets are based on the highest cotton yield with one percent organic matter under different systems. In this text, the major difference in costs and sources of those differences are outlined.

Nutrients are supplied in all systems either through chemical fertilizer or through poultry litter. Poultry litter cost is 16.5 percent higher than chemical fertilizer costs at 30 pounds of nitrogen that was obtained from the Mitscherlich-Baule production function. Mitscherlich-Baule production function is selected among different production functions based on the joint p-test.

All management systems used chemicals to control insects and weeds. The selection of these chemicals represents the most common chemicals used in the cotton production in the Piedmont region. In a conventional tilled plot, herbicides such as Cotoran and Prowl are applied. Both herbicides are applied during planting. In the case of no-till plots, FusilladeTM and RoundupTM are applied as over-the-top and post-emergent herbicides, respectively. Cover crops are killed in both conventional and no-till plot using Roundup. The cost difference of herbicides between no-till and conventionally tilled plot is 49 percent. Insecticides are applied at the same rate in all systems, so 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 is due to the difference in tillage equipment. Associated with the machinery is fuel cost, which is shown together with the machinery cost.

Machine use cost in table 4 reflects both fixed and variable costs. The variable cost associated with machinery use includes the cost of repair and maintenance and the cost of fuel. In the conventional tillage treatment, the total cost of machine use is 18.8 percent higher than no-till treatments. The labor costs are lower in the no-till treatment

Table 3. Key Management Operation in Four Systems

Treatment	System 1	System 2	System 3	System 4
Nitrogen Source	Chemical	Poultry litter	Chemical	Poultry litter
	fertilizer		fertilizer	
Nitrogen	At planting	At planting	At planting	At planting
Application	Side dressing		Side dressing	
Herbicides	At planting	At planting	At planting	At planting
Application			Post-emerge	Post-emerge
			Post-directed	Post-directed
Tillage	Conventional	Conventional	No-till	No-till

Table 4. Treatments Causing the Major Cost Differences in Four Systems

Treatment	System 1	System 2	System 3	System 4
	\$/acre			
Fertilizer	27.45	32.00	27.45	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

than the conventional tillage treatment. The labor cost difference between conventional tillage treatment and no-till treatment is 7.9 percent.

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

Total variable costs, total fixed costs, and net revenue under the four systems for the same level of yield is shown in table 5. Total variable cost is the highest in system 4 and lowest in system 1. The high variable cost in system 4 is due to the cost of additional herbicides. There is a four percent difference in cost between these two systems. Total fixed cost is highest in system 2 and lowest in system 3. Use of both poultry litter and conventional tillage caused this 12.9 percent difference in the fixed cost. Total cost is therefore highest in system 2 and lowest in system 3. Net return is highest in system 3 and lowest in system 2. The difference in net return between these two systems is 26.4 percent. This illustrates the benefit of using no-till in terms of net revenue increase. However, the production function in any system depends upon the organic matter content of the system at that time. If one system is better in maintaining organic matter, that system should produce higher profit and provide higher annual return to the cotton

producer.

**Table 5. Total Variable Cost, Total Fixed Cost, and Net Return in Four Systems
With the Maximum Cotton Lint Yield (682.65 pounds/acre) Obtained at the One
Percent Organic Matter Level**

Component	System 1	System 2	System 3	System 4
	\$/acre			
Total Variable Cost	324.17	328.72	332.84	337.39
Total Fixed Cost	158.62	159.19	141.01	141.58
Net Return	58.20	53.09	67.15	62.02

Organic matter and efficiency

Erosion productivity Impact calculator (EPIC) simulation is conducted to find the effect of cotton yield at different organic matter level in four different systems. We examined the efficiency of N input due to organic matter increase. First, we simulated cotton yield at four different organic matter level - 1, 2, 3, and 4 percentage with the same amount of variable inputs except nitrogen. Nitrogen is applied at various rate at each level of organic matter in each of the four management systems considered here. Relationship between cotton yield and nitrogen is estimated using four most used production function in economics. The joint p-test indicated that Mitscherlich-Baule gives the best fitting production function for the data obtained. Production function estimated at four different levels of organic matter shows that the parameters of nitrogen (N) input is significantly different at each level of organic matter. Also, within the same organic matter level, yield is higher in system that has uses not ill and poultry litter. Due to space limitation, we could not report all the results here but interested readers can contact authors for detail results.

Organic matter and sustainability

A winter cover crop is continuously planted to find the organic matter development and its relationship to yield via its relationship to input efficiency. Productivity index, profitability index, annualized net return, and total costs are compared among four different systems. Systems are ranked based on their performance in sustainability and profitability. The threshold level of organic matter is considered to be 0.8 percent, below which soil loses

most of the productive capacity and is rendered unprofitable for cotton cultivation.

All management systems are simulated to find the path of organic matter development and yield associated with the organic matter level. Organic matter content in soil is related to the appropriate MB production function. If average organic matter level during the cotton growth season falls below one percent, the threshold level production function is used. If the organic matter is between one and two percent, the production function used is obtained from the one percent level. The profitability index, productivity index, and net revenue in each system is calculated for each year. The profitability index is calculated for each year by dividing total revenue by total cost. The productivity index is calculated by using base period prices for both inputs and outputs.

Table 6 summarizes annualized net returns, average profitability index, and average productivity index in the four systems. Annualized net return is highest in system 4 and lowest in system 3. Annualized net return is \$60.88 in system 4 and \$48.81 in system 3, a 24 percent difference. The average profitability index is calculated by averaging the profitability index of each year for thirty years. The lowest average profitability index is 1.10 and occurs in system 1 and system 3. Thus on average, the total revenue is 10 percent higher than total cost. This reveals that all systems are sustainable according to the profitability index criteria.

The productivity index is calculated using the initial year as the base year. Therefore, price information from 1998 is used in calculating the index. This is similar to the concept used in the Laspeyres index, except here output is calculated using the MB production function. The table shows the average productivity index calculated for 30

years. The average productivity index is highest in system 4, and is equal to one. Generally, a productivity index of one indicates that the productivity has remained constant over time. None of the four management systems showed a productivity index of greater than one, which indicates that with the continuous cover crop planting, none of the systems shows an increase in productivity. The lowest productivity index is 0.98, which was obtained in system 1 and system 3. The productivity index is lower than one on average because yield fell when organic matter dropped below one percent. This caused the yield to decline and hence the decline in the productivity index. None of the systems have organic matter greater than two percent; therefore, the production function of all the systems uses either one percent organic matter level or the threshold level production function.

Table 6. Annualized Net Return, Productivity and Profitability Index of Four Management Systems for 30 Years with Continuous Cover Crop

Component	System 1	System 2	System 3	System 4
Annualized Net Return (\$/acre)	49.70	53.35	48.81	60.88
Average Profitability Index	1.10	1.11	1.10	1.13
Average Productivity Index	0.98	0.98	0.99	1

Continuous planting of a cover crop shows the highest annualized return for system 4. Average profitability calculated for the thirty years duration is 1.13, which showed that gross income is generally 13 percent higher than the total cost. All systems were sustainable when based on the profitability index but found to be sustainable only in system 4 based on the productivity index. However, the productivity index does not fluctuate much over the planning horizon, indicating that all of the systems may be stable.

Conclusion

Organic matter production is simulated for each management system to find the maximum steady state organic matter possible under each system. Organic matter more than doubled in system 4 after 500 years of residue management. System 2 also showed an increase in organic matter which is double the initial period of organic matter after 500 years of simulation. The system reached a steady state after 500 years. However, system 1 and system 3 did not reach the two percent level in organic matter. Organic matter was at the lowest level in the system with continuous tillage and chemical fertilizer.

Economic returns and sustainability of the three different systems were calculated assuming a 30-year planning horizon. With a planning horizon for 30 years and cover crop planted every year, the annualized net revenue is highest in system 4. The reason is that in system 4, the organic matter is higher than one percent for 25 out of 30 years. The four systems with continuous cover crop are ranked in table 7. The systems are ranked based on three criteria: annualized net return, average profitability index, and average productivity index. If all three criteria are equally weighted, system 4 ranks highest,

Table 7. Ranking of Four Systems Based on Three Criteria When a Cover Crop is Continuously Planted (1 To 4 Scale, 1=best, 4=worst)

Component	System 1	System 2	System 3	System 4
Annualized Net Return (\$/acre)	3	2	4	1
Average Profitability Index	3	2	3	1
Average Productivity Index	3	3	2	1

followed by system 2 and systems 1, with system 3 ranking last. System 4 consistently ranks higher according to all three criteria. The profitability index indicated that all of these systems are sustainable but the average productivity index did not reflect this fact. The average productivity index is less than one in all four systems. from the increase in soil organic matter. The increase in soil organic matter increases the efficiency of applied nitrogen, which results in higher yield and net return. Organic matter declines in soil with continuous tillage.

Our analysis indicated that alternative management systems involving no-till and organic sources of plant nutrient can sequester carbon higher than the other systems considered in this study. Not only organic matter is higher in a system with no-till and organic source of plant nutrient but also it is profitable, efficient, and sustainable compared to the alternative management systems.

We also observed that due to low expenses in machinery (including fuel and lube expenses) conservation system can thrive better even if fuel tax is implement to curtail the global warming problem. Environmentalist and economist should emphasize similar kind of system in other crops which is capable of sequestering carbon and emerging as a sustainable agricultural system. It is also likely that crops such sorghum, corn, and soybean benefit more with the conservation system than the cotton although cotton being a low residue producing cover also fared well in this study. If the management practice outlined in this is adopted it will be tremendously helpful in meeting the target of increased carbon sequestration (or reduction in carbon dioxide) set forth by the Kyoto protocol.

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