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POTENTIAL FOR SOIL CARBON SEQUESTRATION IN COTTON PRODUCTION SYSTEMS OF THE SOUTHEASTERN USA

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Abstract

Conservation tillage, crop intensification, sod-based rotations, and judicious application of fertilizers and herbicides are agricultural practices that are not only agronomically sound, but could increase soil C sequestration. These practices have great potential for adoption by cotton (*Gossypium hirsutum L*) producers in the southeastern USA. This paper reviews literature and discusses the impact and potential of best management practices by cotton producers to sequester C in the southeastern USA. The current political scenario and future probabilities for cotton producers to benefit from C sequestration, either directly through existing and proposed farm policies or indirectly through increased soil productivity are outlined. Current C prices are $3 per ton of C on the USA voluntary market. Carbon sequestration rates with adoption of no-tillage management of cotton production systems averaged 428 lb C acre^{-1} yr^{-1}. In the future, a landowner could receive additional income by trading C credits or from government incentives like the Conservation Security Program.

The Southeastern USA

With sound soil and crop management, the potential for soil organic C sequestration in the region may be higher than in more temperate regions of North America because the warm and humid climate with a long growing season allows for high cropping intensity and biomass production; which translates into high potential for photosynthetic C fixation (Reeves and Delaney, 2002). Surface residue management is especially critical in the southeastern USA, because soils are highly erodible and high-energy rainstorms occur during the growing season (Blevins et al., 1994). Soils of the region have low soil organic C, partly because of the prevailing climatic conditions and soil mineralogy (Jenny, 1930), but also due to historical mismanagement that exposed the soil surface to rapid biological oxidation and extreme soil erosion (Trimble, 1974; Harden et al., 1999). Cotton is one of the most important crops in Alabama, Georgia, Mississippi, and eastern Texas. Cotton production has high potential profitability, but historically has been detrimental regarding sustainability of natural resources for the region (Reeves, 1994).

Management Strategies to Sequester Soil Organic C

Conservation tillage

When crop residues and cover-crop mulch are left on the surface, they protect the soil against erosion, increase water infiltration, decrease soil water evaporation, and increase soil organic C near the surface. Plant residues decompose slower on the soil surface than when incorporated into soil. Conservation tillage is defined as any system that provides >30% residue cover on the surface after planting. This practice, coupled with efficient management of inputs, can lead to sequestration of soil organic C, while at the same time increasing cotton lint and seed yield. Yield benefits of conservation tillage have not always been observed, especially in 1- to 2-year studies. The benefit of conservation tillage will often be expressed most significantly in long-term evaluations. We reviewed the literature for data comparing soil organic C in no-tillage versus conventional tillage in cotton production systems of the Southeast and estimated the potential for C sequestration. Soil organic C sequestration in the southeastern USA with adoption of no-tillage averaged 428 lb C acre^{-1} yr^{-1}. This rate of soil organic C sequestration for the southeastern USA is nearly identical to an assumed value of 445 lb C acre^{-1} yr^{-1} used by Lal et al. (1998) for the entire USA. From 96 observations of all cropping systems in the southeastern USA, Franzluebbers (2005) reported soil organic C sequestration of 374 $\pm$ 410 lb C acre^{-1} yr^{-1}. West and Post (2002) calculated average soil organic C sequestration of

428 ± 116 lb C $acre^{-1}$ yr^{-1} for no tillage compared with conventional tillage from 93 observations around the world. All of these estimates were similar in magnitude, although they suggest a great deal of variation among individual sites within these reviews. Recent soil organic C sequestration estimates from conservation-tillage management systems in other regions of the USA include: 428 ± 526 lb C $acre^{-1}$ yr^{-1} in the central USA (Johnson et al., 2005), 267 ± 187 lb C $acre^{-1}$ yr^{-1} in the southwestern USA (Martens et al., 2005), 240 ± 169 lb C $acre^{-1}$ yr^{-1} in the northwestern USA and western Canada (Liebig et al., 2005). Clearly, adoption of conservation tillage in the southeastern USA has potential for some of the highest rates of soil organic C sequestration in the nation.

Crop Rotation and Cover Cropping

When practiced in monoculture or even in double cropping, conservation tillage is an imperfect and incomplete system. Perhaps more than any other crop, good residue management is critical in cotton, because of its sparse residue production. Good residue management can be achieved with a sound crop rotation and use of cover crops in combination with conservation tillage. Unfortunately, higher profitability of cotton in relation to other cropping alternatives often leads to cotton monoculture (Reeves, 1994). Scientific literature addressing the impact of crop rotation on soil organic C under cotton production in the southeastern USA is rather scarce. The ‘Old Rotation’ experiment at Auburn University was initiated in 1896 to determine (1) the effect of rotating cotton with other crops to improve yields and (2) the effect of winter legumes in cotton production systems (Mitchell and Entry, 1998). Seed cotton yield during a 10-year period from 1986-1995 was greater in rotation with corn and winter legumes than under monoculture cropping. Mitchell and Entry (1998) demonstrated a positive association of soil organic C with cotton seed yield, suggesting that higher biomass inputs from cover crops and corn in rotation with cotton improved soil organic C sequestration and cotton productivity. With 98 years of cultivation, 2- and 3-year rotations of cotton with corn (*Zea mays*) and soybean (*Glycine max*) resulted in soil organic C concentration of 1 %, while soil organic C under continuous cotton with legume cover crop was 0.75 % and under continuous cotton without cover crop was 0.39 % (Reeves, 1997). With the introduction of conservation tillage to the experiment in 1995, the benefits of crop rotations and cover crops to cotton productivity and soil organic C concentration have been enhanced (Mitchell et al., 2002; Siri-Prieto et al., 2002).

Reeves and Delaney (2002) compared monoculture cotton with an intensive cropping system that maintained actively growing cash or cover crops about 330 days of the year using sun hemp (*Crotalaria juncea* L.) and ultra-narrow row cotton (UNR; 20-cm row spacing) in a rotation with wheat (*Triticum aestivum* L.) and corn. All UNR systems exhibited higher net returns than traditional row spacing with highest net return over variable costs obtained using continuous no-tillage UNR cotton ($104.57 $acre^{-1}$ yr^{-1}), which was a function of higher cotton yield and commodity support programs for cotton. The no-tillage, intensive-cropping system had the second highest net return ($97.20 $acre^{-1}$ yr^{-1}). Although short-term economics are important to producers, maintenance or improvements in soil organic C will increase productivity and sustainability in the long-term.

Fertilizers and Manures

Fertilizer or manure application would be expected to increase soil organic C, because of greater C input associated with enhanced primary production and crop residues returned to the soil. Only limited data are available in the southeastern USA to assess long-term fertilization effects on soil organic C sequestration. Using available data from six literature sources of various crops in the region, Franzluebbers (2005) estimated that the net C offset due to N fertilization could be optimized at 214 lb C $acre^{-1}$ yr^{-1} with the application of 95 lb N $acre^{-1}$ yr^{-1}. This N rate is within the range of extension recommendations for cotton in most southeastern states. This calculation assumed a C cost of 2.7 lb C lb^{-1} N fertilizer for the manufacture, distribution, and application of fertilizer N (Izaurralde et al., 1998). Assuming that the application of N fertilizer would also lead to increased nitrous oxide (N_2O) emission, which has 296 times the global warming potential of CO_2 (IPCC, 1997), net C offset from N fertilization would be maximized at 62 lb C $acre^{-1}$ yr^{-1} with the application of 21 lb N $acre^{-1}$ yr^{-1}. These calculations suggest a positive, but diminishing return of investment with increasing application of N fertilizer, regarding mitigation of greenhouse gas emission.

Nutrients from animal manure (e.g. poultry litter, confined dairy, or beef cattle) represent a valuable agricultural resource that is not currently widely and fully utilized. Georgia and bordering states produce about 42% of the poultry in the USA, but only a small percentage of the litter is utilized as fertilizer in crop land. Nyakatawa et al. (2001) suggested that poultry litter application to cropping systems with winter annual cover crops could be an environmentally suitable practice to reduce reliance on commercial fertilizer and dispose of large quantities of waste from a burgeoning poultry industry. Endale et al. (2002) found that combining no tillage with poultry litter application produced up to 50% greater cotton lint than conventionally tilled and fertilized cotton in the Southern Piedmont. Parker et al. (2002) reported 7 to 20% greater organic C in the surface 5 cm of soil in a cotton/rye (*Secale cereale* L.) cropping system with poultry litter than with commercial fertilizer application in the Tennessee Valley. Application of dairy manure increased soil organic C (1.2 tons/acre) in a cotton-corn rotation with cover crops in the Coastal Plain (J. Terra, unpublished data).

Sod-Based Crop Rotation

Soil organic C sequestration under grass management systems in the southeastern USA can exceed sequestration rates observed under crop management systems. From 12 observations of various grass establishment studies, soil organic C sequestration was 917 $\pm$ 802 lb C acre^{-1} yr^{-1} during an average of 15 years of investigation (Franzluebbers, 2005). Rotation of crops with pastures could take advantage of high soil organic C and promote higher productivity under ideal conditions, because surface soil would be enriched in soil organic matter and organically bound nutrients, some weed pressures could be reduced, soil water storage could be enhanced, and disease and pest pressures could be reduced. Successful crop and pasture rotation systems have been developed with conservation tillage in South America (Diaz-Zorita et al, 2002; Garcia-Prechac et al., 2004). These studies have demonstrated that soil organic C can be preserved following rotation of pasture with crops when using conservation tillage. Although some soil physical limitations can develop under heavily trafficked pastures, the accumulation of soil organic C at the surface can buffer this impact (Franzluebbers et al., 2001).

At the Wiregrass Research and Extension Center in Alabama, soil organic C concentration of the surface 2 inches in a long-term cotton-peanut (*Arachis hypogaea L*) rotation (initially 0.76 %) increased to 0.94 % following introduction of winter annual pasture [oat (*Avena sp*) or ryegrass (*Lolium sp*)] for three years (G. Siri-Prieto, unpublished data). Winter-annual grazing rotation with cotton also increased net returns.

Predicting Soil Organic C Changes in Cotton Production Systems

The Soil Conditioning Index (SCI) is a tool currently used by the USDA-Natural Resources Conservation Service to predict trends in soil organic C, as affected by cropping system and tillage management (Hubbs et al., 2002). The SCI has been incorporated into the Revised Universal Soil Loss Equation (RUSLE2) to assist district staff members of the Natural Resources Conservation Service working with local producers to plan and design crop and residue management practices for overcoming issues of low soil organic matter, poor soil tilth, and other soil quality-related problems. When SCI is negative, soil organic C is predicted to decline. When SCI is positive, soil organic C is predicted to increase. The magnitude of the SCI value is more related to the probability of achieving a change rather than determining an absolute value of that change. The SCI is being used by the Natural Resources Conservation Service to calculate payments to landowners enrolled in the Conservation Security Program.

In the following sections, we present some scenarios of common crop and tillage management systems being used in two major land resource areas of the southeastern USA. All cropping systems include cotton as a primary crop, either in monoculture or in rotation with other common crops of the region.

Coastal Plain

All conventional-tillage scenarios in the Coastal Plain region would cause loss of soil organic C (Table 1). Soil management strategies to increase soil organic C sequestration included the use of conservation tillage, greater cropping diversity with high residue-producing crops such as corn and cover crops, application of animal manure, and inclusion of sod-based rotations. Subsoiling with bent leg subsoilers (i.e. a paratill) has been found to help alleviate soil compaction due to traffic and natural reconsolidation, which can constrain root grow in many Coastal Plain soils. However when paratill was simulated using the SCI in monoculture cotton with conservation-tillage planting at Shorter AL, soil organic C was predicted to decline. Only in a cotton-corn rotation was SCI positive when paratill was performed.

Table 1. Management scenarios and soil conditioning index (SCI) for the Coastal Plain region. CT is

conventional tillage and NT is no tillage.

Soil Series	Slope (%)	Soil Texture	Location / Scenario	SCI Monoculture Cotton CT	SCI Monoculture Cotton NT	SCI Rotated Cotton* NT
Bendale	2	SL	Brewton AL,no manure, no paratill	-1.2	0.21	0.50
Norfolk	3	LS	Florence SC, no manure, no paratill	-0.41	0.44	0.60
	4	LS	Goldsboro NC, no manure, no paratill	-0.62	0.31	0.58
Dothan	2	SL	Headland AL, no manure, no paratill	-0.94	0.23	0.54
			grazed annual ryegrass, no paratill			0.42
			grazed annual ryegrass, with paratill			0.12
Bama	2	SL	Shorter AL, no manure, no paratill	-0.84	0.28	0.54
			With manure, no paratill	-0.63	0.47	0.60
			No manure, with paratill	-0.84	-0.27	0.45
			Intensive rotation**, no paratill			0.65
			Intensive rotation**, with paratill			0.56

* Base rotation is cotton / rye (*Secale cereale* L.) cover – corn / rye cover
** Similar rotation to that described in Reeves and Delaney (2002): corn / sun hemp cover / wheat – cotton / white lupin (*Lupinus albus* L.) + crimson clover (*Trifolium incarnatum* L.) cover

Southern Piedmont

All conventional-tillage scenarios in the Southern Piedmont region would cause loss of soil organic C (Table 2). Monoculture cotton production with conservation tillage would increase soil organic C, but including a winter cover crop or grain in the rotation would enhance soil organic C sequestration even further. Increasing crop rotation complexity with short-term sod would have high potential for soil organic C sequestration. In the Southern Piedmont, cotton was the dominant crop for more than 150 years and soil erosion scars in this sloping physiographic region suggest that crop residues were poorly managed for as long (Langdale et al., 1994). Despite adequate rainfall, high water runoff and crusting contribute to low soil water storage under conventional tillage. Hence, maintaining sufficient residue cover is particularly important for reducing surface sealing, water runoff, soil loss, and runoff of agricultural chemicals (Raczkowski et al., 2002). Research on these soils has demonstrated that conservation tillage leads to greater soil organic C storage, improvement in soil quality, and greater cotton yield (Franzluebbers et al., 1999; Schomberg et al., 2003). Deep tillage (such as subsoiling without inversion of soil) may be required only initially during transition to conservation tillage management to overcome the lack of soil structure following decades of intensive tillage.

Table 2. Management scenarios and soil conditioning index (SCI) for the Piedmont region.

Location	Soil Series	Soil Texture	Slope (%)	Scenario	SCI
Watkinsville GA	Cecil	SL	4	Monoculture cotton, spring-chisel tillage	-1.10
				Monoculture cotton, fall-chisel tillage	-1.80
				Monoculture cotton, no tillage	0.12
				Cotton / rye cover, no tillage	0.36

				Cotton – corn – corn – tall fescue (*Festuca arundinacea* Schreb. pasture (3years)	0.61
Auburn AL	Marvyn	LS	3	Monoculture cotton, fall-disk tillage	-0.82
				Monoculture cotton, no tillage	0.27
				Cotton / grazed rye cover, no tillage	0.42
				Cotton / wheat, no tillage	0.69

Politics and Programs to Foster Soil Organic C Sequestration

Although the USA has not ratified the Kyoto Protocol, sufficient political pressure exists for the USA to reduce or mitigate greenhouse gas emissions. In February 2002, the USDA received specific instructions from President Bush to design incentives for landowners to adopt production practices and land uses that increase C sequestration. The Bush administration has committed to reduce greenhouse gas emission intensity (i.e. emission per unit of economic activity) 18% by 2012 (Hayes and Gertler, 2002). This goal consists of a voluntary program criticized by some environmentalists, who advocate a mandatory system. Since multinational corporations face emission caps for their operations in Kyoto-ratifying countries, the uncertainty of future emission caps in the USA place business assets at risk and have stimulated a private market for C trading. Current indications are that a mandatory greenhouse gas emission cap would unlikely be legislated in the USA (Young, 2003).

Currently, there are two reasonable scenarios in which farmers in the USA might be additionally compensated for the environmental service of soil organic C sequestration. One compensation scenario is through government incentives and the other is through a private trading market that allows emitters to buy offset credits from sequesters.

Government Incentive Programs

Current government incentive programs do not specifically address C sequestration. The following two programs are administered by the USDA–Natural Resources Conservation Service and indirectly address soil C sequestration in agricultural production systems.

Environmental Quality Incentives Program (EQIP)

Provides financial and technical assistance to farmers and ranchers who adopt environmentally sound practices on eligible agricultural land. National priorities addressed by EQIP are:

- reduction of non-point source pollution such as nutrients, sediment or pesticides
- reduction of groundwater contamination
- conservation of ground and surface water resources
- reduction of greenhouse gas emissions
- reduction in soil erosion and sedimentation from unacceptable levels on agricultural land
- promotion of habitat conservation for at-risk species

Contracts provide incentive payments and cost-sharing to implement conservation practices subject to technical standards adapted for local conditions.

Conservation Security Program (CSP)

This voluntary program provides financial and technical assistance to agricultural producers who conserve and improve the quality of soil, water, air, energy, plant and animal life, and support other conservation activities. Soil and water quality practices include conservation tillage, crop rotation, cover cropping, grassed waterways, wind barriers, and improved nutrient, pesticide, or manure management. Maximum annual payments vary from $20,000 to $45,000, depending on the tier of participation. Contracts are valid for 5 to 10 years.

In fiscal year 2004, the CSP provided funding to 18 watersheds in the USA. About 27,300 farms and ranches were within these watersheds, covering 14 million acres. In the southeastern USA, three watersheds were targeted: (1) Hondo River in Texas, (2) Little River in Georgia, and (3) Saluda River in South Carolina. An enrolled landowner in a one of these watersheds would receive a payment of the SCI value for practices employed times \$11.60 acre^{-1}, up to a maximum SCI value of 2.5. Cotton farmers using conservation tillage could be expected to receive anywhere from no payment to \$8 acre^{-1} with an average of \$3.36 acre^{-1} based on SCI values derived from Tables 1 and 2.

Carbon Trading Market

The magnitude of uncertainty associated with a possible limit on greenhouse gas emission has drawn the attention of both sides of a C market trading system. The interest of energy industries in a C trading system could also be linked to a desire to project a positive image to the public of their concern for environmental health. Another interest of participants might be to explore business opportunities at a currently lower cost in anticipation of future emission caps. The opportunities for farmers to benefit from a trading system with credits derived from soil organic C sequestration will depend on the demand for and competitiveness of C credits and the future roles of aggregators and government programs.

The Iowa Farm Bureau (http://www.iowafarmbureau.com) is working to aggregate credits from soil organic C sequestration for sale on the Chicago Climate Exchange (CCX) (http://www.chicagoclimatex.com). To be eligible for Exchange Soil Offset (XSO), the land must be under continuous conservation tillage (no till, strip till, or ridge till) and must not have soybean planted for more than two years. XSOs have been issued at the rate of 303 lb C acre^{-1} yr^{-1} for commitment to conservation tillage and 454 lb C acre^{-1} yr^{-1} for commitment to perennial grass cover. Transfer price of XSOs would be the sales price as determined by sale through the CCX less a 10% service fee. Weighted average price has been \$3 ton^{-1} CO_2-C (Sandor, 2003).

Considering the average soil organic C sequestration rate of 428 lb C acre^{-1} yr^{-1} for conservation-tillage cotton production systems in the southeastern USA (Table 1) and the average price of a C credit on the CCX at \$3.00 ton^{-1} CO_2-C, a cotton producer in the southeastern USA might expect to receive \$0.64 acre^{-1} yr^{-1}, assuming soil organic C sequestration credits could be aggregated and sold today. Important to note is that selling C credits would not prevent producers from getting additional income from government incentive programs [Conservation Security Program (CSP) or EQIP]. With current information, a cotton producer could expect to get a lower payment from a C credit market than from land enrolled in CRP.

The currently low prices of C credits in the USA are a consequence of a voluntary market trading system. If emission caps were to be enforced, C credit prices would certainly rise.

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