Conservation Rotations for Cotton Production and Carbon Storage

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ABSTRACT

Intensive cropping and conservation tillage can increase soil organic C (SOC) and improve soil quality, however, economic reality often dictates cotton (*Gossypium hirsutum* L.) monoculture. We conducted a study on a Compass loamy sand (coarse-loamy, siliceous, subactive, thermic Plinthic Paleudults) from 1998-2001 to compare an intensive conservation cropping system to standard cotton production systems used in the southeastern USA. The system uses sunn hemp (*Crotalaria juncea* L.) and ultra-narrow row (UNR; 8-inch drill) cotton in a rotation with wheat (*Triticum aestivum* L.) and corn (*Zea mays* L.). The standard systems used continuous cotton (both standard 40-inch rows and ultra-narrow row) and a corn - cotton rotation with standard row widths. A cover crop mixture of black oat (*Avena strigosa* Schreb.)/rye (*Secale cereale* L.) was used in all systems preceding cotton and a white lupin (*Lupinus albus* L.)/crimson clover (*Trifolium incarnatum* L.) mix was used before corn in the corn-cotton and intensive system. All systems were tested under conservation and conventional tillage in a split plot design of four replications; main plots were cropping systems and subplots were tillage. We used extension budgets to calculate net returns over variable costs and determined C balance of all residues returned to the soil. At the end of the experiment, soil C was determined by dry combustion (0-0.4, 0.4-2, 2-4, 4-8, and 8-12 in depths). Cropping system had a more consistent effect on cotton yield than tillage system. Four-yr average lint yields were 872, 814, 711 and 663 lbs acre^{-1} for continuous UNR, intensive, corn-cotton, and continuous 40-in cotton systems, respectively. The UNR systems with conservation tillage had the highest net returns [\$105 acre^{-1} yr^{-1} (continuous) and \$97 acre^{-1} yr^{-1} (intensive)] while the conventional tillage continuous 40-in system had the lowest returns (\$36 acre^{-1} yr^{-1}). Conservation tillage increased SOC concentration in the top 2-in of soil 46% compared to conventional tillage. Cropping system affected SOC levels to the 4-in depth and the corn-cotton rotation resulted in the lowest SOC levels of all systems. Results suggest that small grain cover crops and wheat for grain in the intensive system were the dominate factor in SOC changes. For these drought-sensitive soils, UNR cotton production systems with conservation tillage and small grain cover or cash crops have the potential to rapidly increase soil organic matter; improving soil productivity and enhancing economic sustainability of cotton production in the southeastern USA.

KEYWORDS

Soil C, cropping intensification, cover crop, conservation tillage, economics, C sequestration

INTRODUCTION

Carbon sequestration has become a popular term among scientists, environmental advocates, agricultural producers, energy policy makers and government agencies in recent years. Within the agricultural arena, the term describes the process of photosynthetic fixation of atmospheric CO_2 into plant tissue and/or soil organic matter. There is debate regarding the potential to mitigate global climate change through C sequestration, however, there is ample research to show that increasing soil C improves soil quality and agronomic productivity (Reeves, 1997; Machado and Silva, 2001; Dìaz-Zorita *et al.*, 2002).

Research from Brazil and other countries in subtropical and tropical regions has shown that warm humid climates have great potential to increase soil C (Sá *et al.*, 2001). For example, calculated values for C sequestration potential in southern Brazil range from 9.37 to 12.54 Tg C yr^{-1} (10.3 to 13.8 million tons yr^{-1}; Bayer *et al.*, 2000b; Sá *et al.*, 2001). Although warm humid climates like those in the southeastern USA favor rapid decomposition of soil organic matter, the capacity for C fixation in subtropical and humid tropical regions can be greater than in temperate regions. Compared to cooler temperate regions, the Southeast has longer

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growing seasons, a greater capacity for cropping intensification and biomass production, and fewer agroecological constraints to adoption of conservation tillage; which more than compensates for this region's higher rate of organic matter decomposition.

Soil management strategies for increasing C sequestration and improving soil quality on existing arable land include conservation tillage, cropping intensification, application of animal manures, and inclusion of sod-based or pasture rotations. Crop rotation is critical to cropping intensification and has long been recognized as being agronomically beneficial (Reeves, 1994; Bayer *et al.*, 2000b). In addition, the need for sound rotation practices is even greater for conservation tillage systems than for conventional tillage systems (Reeves, 1997). Intensive cropping systems, using high-residue crops in rotations coupled with conservation tillage, can dramatically improve soil quality and productivity. Unfortunately, government farm policies, agricultural mechanization and specialization, and economic reality often discourages cropping diversity and intensification.

Brazilian scientists are world leaders in crop rotation and conservation tillage research (e.g., Sá *et al.*, 2001; Bayer *et al.*, 2000a; Bayer *et al.*, 2000b; Machado and Silva, 2001). Transposing their principles and techniques to the subtropical region of the southeastern USA, we established a study to compare an intensive cropping system, maximizing the production of crop residues and legume N inputs, to standard cotton (*Gossypium hirsutum* L.) production systems used in the southeastern USA. The specific objectives of the research were to: 1) develop a cotton production system that maximizes soil carbon inputs; 2) determine the impact of the system on soil quality and productivity; and 3) determine the most economically favorable cropping system compared to standard cotton production systems.

MATERIALS AND METHODS

The system used sunn hemp and ultra-narrow row (UNR) cotton (drilled in 8-in rows) in an intensive rotation with wheat and corn. Soybean [*Glycine max* (L.) Merr.] could be substituted for cotton in this rotation, following wheat, but cotton currently enjoys a comparative economic advantage in the southeastern USA compared to soybean because of the risk from short-term drought and favorable government commodity support programs for cotton. Control systems used continuous cotton (both standard 40-in rows and ultra-narrow row) and a corn - cotton rotation (row widths of 30-in and 40-in, respectively). All systems were tested under conservation and conventional tillage.

We began the experiment in August of 1997 with the planting of sunn hemp on a Compass sandy loam in east-central AL. Cropping systems were imposed through 2001. The site had previously been a tillage study with a corn-soybean rotation and a winter cover crop of crimson clover for the past 10 years. The previous study had conservation (no-tillage; with and without in-row subsoiling to 16-in depth) and conventional (disk-chisel-disk-field cultivate; with and without in-row subsoiling) tillage variables. Prior to starting this cropping system study, the entire area was non-inversion deep-tilled with a Paratill® bent-leg subsoiler (AgEquipment Group, Lockney, TX 79241) to 16-in. Research has shown that some form of in-row subsoiling is needed for this soil to disrupt an inherent root-restricting hardpan (Reeves and Mullins, 1995; Reeves and Touchton, 1986). Consequently, non-inversion subsurface tillage (in-row subsoiling or paratilling) was done for all plots each year, regardless of surface tillage practices. Specially designed equipment enable this to be done in high residue with very little disturbance of crop residue and soil; and for practical purposes emulates no-tillage.

Tillage treatments in the cotton systems study were arranged to maintain the integrity of the previous 10-years conservation and conventional tillage treatments. The experiment design was a split plot arrangement of treatments in a randomized complete block of four replications. Main plots were cropping systems and subplots were tillage, i.e., the previous conventional and conservation tillage treatments maintained. Cropping systems were: 1) intensive system; 2) cotton-corn rotation with standard row widths (40-in for cotton and 30-in for corn); 3) continuous cotton with standard rows; and 4) continuous ultra-narrow row cotton (8-in drill width).

The intensive system maintained actively growing cash or cover crops about 330 days of the year. Corn was planted in early April and harvested in August; followed immediately by sunn hemp, which was terminated in early November when wheat was drilled. Ultra-narrow row cotton was drilled following wheat harvest in early to mid-June. Following cotton harvest in October, a white lupin - crimson clover mixed cover crop was drilled prior to the following corn crop that started another rotation cycle. In the continuous cotton (both 40-in and 8-in row widths) and corn-cotton rotation treatments, a black oat - rye cover crop mix was used prior to cotton and the white lupin-crimson clover cover crop was used prior to corn. All phases of each rotation were present each year in all cropping systems, to eliminate confounding year effects with system effects.

All cover crops were killed 14-21 days prior to planting using glyphosate and a mechanical roller (Ashford *et al.*, 2000). Weeds were controlled with glyphosate over-the-top at 4 true leaves; in 1999 preemergence applications of fluometuron and pendimethalin were also applied. Nitrogen was broadcast applied to the black oat/rye cover crop, wheat and ultra-narrow row cotton, and banded beside the row for standard row width cotton and corn. Rates were 30 lbs N acre^{-1} for black oat/rye, 150 lbs N acre^{-1} for corn, and 120 lbs N acre^{-1} for cotton and wheat. Standard row cotton was harvested with a spindle picker and ultra-narrow row cotton was harvested with a stripper fitted with a finger harvester.

The critical factor in agricultural sustainability is economic viability. We used Auburn University Extension Budgets, adjusted for differences in actual practices that varied from inputs in the standard budgets, to calculate four year average (1998-2001) net returns over variable costs for the cropping/tillage systems. We allowed a deduction for UNR cotton lint (fiber) of US$0.04 lbs^{-1} in calculations.

In addition to harvested yield determinations, we also measured biomass returned to the soil from all cash crops and cover crops in the various tillage/cropping system treatments. Total C was determined in biomass samples by dry combustion (Yeomans and Bremner, 1991). In March 2002, soil C was determined by dry combustion from samples taken at depths of 0-0.4, 0.4-2, 2-4, 4-8, and 8-12 inches, following grinding in a roller mill (Kelly, 1994). For these soils, total C is equivalent to soil organic C (SOC), as they contain no appreciable carbonate-C.

RESULTS AND DISCUSSION

As expected cotton yields varied with year (Table 1); with the exception of 2000, summer crops grown were subjected to extreme drought stress every season. Tillage system effect was not consistent; no-tillage (with subsoiling or paratilling) resulted in greater yields in 1998, while conventional tillage (chisel/disk + subsoiling) resulted in higher yields in 1999. In 2000 and 2001, cotton lint yields were similar with either tillage system.

Cropping system or rotation had a more consistent effect on cotton lint yield than tillage system (Table 1). Ultra-narrow row systems (continuous cotton and the intensive system) resulted in the highest lint yields and continuous cotton in 40-in rows resulted in the lowest yields. The corn-cotton rotation with 40-in rows consistently resulted in slightly higher lint yields than the continuous cotton grown with 40-in rows, however, the increase was significant only in 2001, the one season without severe drought stress on the cotton. The ultra-narrow row cotton in the intensive system was double-cropped behind wheat, and was planted later than the continuous ultra-narrow row cotton in most years. Ultra-narrow row cotton has a compressed flowering and boll set period compared to standard row width cotton, and our data suggest that this narrower window for reproductive growth may increase risk from short-term droughts compared to standard row width cotton, which can compensate for short-term drought with a longer boll set window. This is illustrated by the lower yield of the UNR cotton in the intensive system in 1999, which was planted later than the other systems and was impacted by severe drought at flowering and boll set.

A major benefit of cropping diversification and in-

Table 1. Cotton lint yields (1998-2001) as affected by cropping-tillage systems imposed on a sandy coastal plain soil with a hardpan in east-central Alabama. Within cropping systems, regular denotes the common 40-in row spacing, whereas UNR denotes an ultra narrow 8-in row spacing.

	Cropping system				
	Intensive	Corn-Cotton	Continuous cotton		
Year	Regular	Regular	Regular	UNR	$LSD_{0.10}$
	lbs lint acre^{-1}				
1998	712	505	491	729	36.2
1999	395	577	566	613	120.1
2000	953	765	716	858	70.9
2001	1194	996	880	1286	88.8
Mean	814	711	663	872	-

	Tillage system		
Year	Chisel/disk	No-tillage	$LSD_{0.10}$
	lbs lint acre^{-1}		
1998	596	623	20.2
1999	563	513	49.1
2000	810	837	62.1 ns
2001	1085	1093	78.2 ns
Mean	764	767	-

Table 2. Four year (1998-2001) mean economic return over variable costs of cropping-tillage systems imposed on a sandy coastal plain soil with a hardpan in east-central Alabama. Within cropping systems, regular denotes the common 40-in row spacing, whereas UNR denotes an ultra narrow 8-in row spacing.

	Cropping system			
	Intensive	Corn-Cotton	Continuous cotton	
Tillage system	Regular	Regular	Regular	UNR
	---------------------$ acre^{-1} year^{-1}			---------------------
No-tillage	97.20	40.17	44.30	104.57
Chisel/disk	76.46	40.80	36.00	95.12

tensification is reduction in economic risks. All UNR or high-density cotton systems exhibited higher net returns than standard 40-in row spacing cotton systems (Table 2). The highest net return over variable costs was obtained with continuous no-tillage UNR cotton (\$104.57 acre^{-1} yr^{-1}). This was a function of higher cotton yields with this monoculture system coupled with the comparative advantage for cotton due to favorable commodity support programs. Lowest net return (\$36.0 acre^{-1} yr^{-1}) was obtained with the conventional grower practice of monocropped cotton in 40-in rows using a chisel plow/disking conventional tillage system. The no-tillage intensive cropping system had the second highest net return (\$97.20 acre^{-1} yr^{-1}) of any of the tillage/cropping system combinations.

Economics dictates short-term sustainability, but maintenance or improvements in soil C impact productivity and sustainability in the long-term. As expected, conservation tillage resulted in increased SOC concentrations in the top 2-in of soil (Table 3). Tillage systems were imposed on this site since 1988, but all plots were subjected to the same cropping systems until 1998, when this study was begun. Cropping systems imposed for only 4 yr (1998-2001) also affected SOC to the 4-in depth (Table 3). Surprisingly, the corn-cotton rotation resulted in the lowest SOC concentrations among the cropping systems. This despite the fact that the amount of C returned to the soil averaged 1.65 tons C acre^{-1} yr^{-1} with the corn-cotton system, compared to 1.36 tons C acre^{-1} yr^{-1} with the 40-in row continuous cotton system. The intensive system averaged 2.3 tons C acre^{-1} yr^{-1} and ultra-narrow row cotton averaged 1.15 tons C acre^{-1} yr^{-1}. All systems used in this experiment incorporated the use of a winter cover crop; a small grain (black oat/rye mix) before cotton and a winter legume (crimson clover/white lupin mix) before corn. The winter legume biomass and C were

Table 3. Soil organic C (SOC) concentrations by depth as affected by cropping-tillage systems imposed on a sandy coastal plain soil with a hardpan in east-central Alabama. Within cropping systems, regular denotes the common 40-in row spacing, whereas UNR denotes an ultra narrow 8-in row spacing.

	Cropping system				
	Intensive	Corn-Cotton	Continuous cotton		
Depth	Regular	Regular	Regular	UNR	$LSD_{0.10}$
-- inches--	------------------------------		%	----------------------------------	
0 - 0.4	1.14	0.95	1.21	1.02	0.187
0.4 - 2	0.84	0.73	0.87	0.86	0.112
2 - 4	0.65	0.57	0.62	0.65	0.035
4 - 8	0.42	0.42	0.49	0.38	0.084 ns
8 - 12	0.28	0.29	0.35	0.28	0.084 ns

	Tillage system		
Depth	Chisel/disk	No-tillage	$LSD_{0.10}$
-- inches--	--------------	% -------------------	
0 - 0.4	0.690	1.440	0.094
0.4 - 2	0.700	0.920	0.067
2 - 4	0.640	0.590	0.053 ns
4 - 8	0.450	0.400	0.047
8 - 12	0.290	0.300	0.057 ns

greatly reduced compared to the black oat/rye that preceded cotton. We speculate that the reduced biomass from the winter legume used with corn (compared to small grain cover or cash crop) diminished the benefit of increased biomass production from corn, and more importantly, provided a more favorable C:N ratio to mineralize C in residues. Further laboratory C and N analyses underway may confirm this theory. Potter *et al.* (1997) and Torbert *et al.* (1998) reported that grain sorghum [*Sorghum bicolor* (L.) Moench.] and corn resulted in greater biomass inputs than wheat (*Triticum aestivum* L.) in tillage/rotation studies conducted in Texas but wheat resulted in greater SOC storage. The small grain covers in this study used before cotton likely would have a similar effect. We wish to emphasize that conventionally tilled cotton without a cover crop would have returned only 0.36 tons C $acre^{-1}$ yr^{-1} to the soil (data not shown). The data suggest that the inclusion of wheat in the intensive rotation mitigated the negative effect of the winter legume-corn phase used in this rotation on SOC, as opposed to the alternating winter legume/corn - small grain/cotton rotation.

CONCLUSIONS

Cropping system had a more consistent effect on cotton yield than tillage system. The UNR systems with conservation tillage had the highest yields and net returns, \$105 $acre^{-1}$ yr^{-1} for continuous UNR cotton and \$97 $acre^{-1}$ yr^{-1} for UNR double-cropped with wheat in rotation with corn in the intensive system. The conventional tillage continuous cotton 40-in system had the lowest returns (\$36 $acre^{-1}$ yr^{-1}). Conservation tillage increased SOC concentration in the top 2-in of soil 46% compared to conventional tillage. Cropping system affected SOC levels to the 4-in depth and the corn-cotton rotation resulted in the lowest SOC levels of all systems. Results suggest that small grain cover crops and wheat for grain in the intensive system were the dominate factor in SOC changes. For these drought-sensitive soils, UNR cotton production systems with conservation tillage and small grain cover or cash crops have the potential to rapidly increase soil organic matter; improving soil productivity and enhancing economic sustainability of cotton production in the southeastern USA.

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