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Title: Simulating Soil Organic Carbon Sequestration in Cotton Production Systems with EPIC and the Soil Conditioning Index in the Southeastern USA

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Simulating Soil Organic Carbon Sequestration in Cotton Production Systems with EPIC and the Soil Conditioning Index in the Southeastern USA

ABSTRACT: Models are being developed and utilized by scientists and government agencies to quantify the potential for carbon storage in soil. We used the EPIC v. 3060 model and the soil conditioning index (SCI) to estimate long-term SOC storage at Temple TX, McColl SC, and Watkinsville GA using four management systems: (a) cotton (*Gossypium hirsutum* L.) with conventional tillage, (b) cotton with no tillage, (c) corn (*Zea mays* L.)–cotton rotation with no tillage, and (d) bermudagrass (*Cynodon dactylon* L.)–corn–cotton rotation with no tillage. All no-tillage systems used wheat (*Triticum aestivum* L.) as a cover crop. Simulated SOC sequestration averaged 0.46 Mg ha^{-1} yr^{-1} under the three no-tillage management systems and -0.03 Mg ha^{-1} yr^{-1} under conventional tillage with EPIC. The SCI also predicted a strong difference in SOC sequestration between conventional and no tillage. Differences in SOC sequestration among crop rotations were not readily apparent with EPIC, but were with SCI. Predictions of SOC sequestration with EPIC were related to the SCI, but not necessarily in a linear manner as previously suggested. Under the simulated management and environmental conditions selected, the SCI appears to be a valuable method for making reasonable, cost-effective estimates of potential SOC sequestration in the southeastern USA, although validations under actual field conditions are still needed.

Keywords: Conservation tillage, cover cropping, crop rotation, modeling, water-use efficiency

Carbon sequestration in soil has emerged as a technology with significant potential for stabilizing atmospheric concentrations of greenhouse gases at non-threatening levels (Izaurralde et al., 2006). Estimates of long-term soil organic carbon (SOC) storage in agricultural cropping systems are needed to evaluate the effectiveness of different management systems across a wide range of soils, crop, and climate conditions (Causarano et al., 2006).

The southeastern USA is a warm, humid region conducive to high C fixation in plant biomass, but also known for high rates of decomposition (Franzluebbers, 2005). The region can be defined as an area from eastern Texas to Virginia and southwards (Figure 1). The impact of agricultural management practices on SOC will vary depending on climatic conditions that influence plant and soil processes driving soil organic matter dynamics (Ogle et al., 2005). Comparing regions of North America, the effect of conservation tillage on SOC sequestration was greatest in the central and southeastern USA and lowest in the northeastern USA and eastern Canada (Franzluebbers and Follett, 2005). In the southeastern USA, SOC sequestration was most significant with forage management systems, cover cropping, manure application, and conservation tillage (Franzluebbers, 2005).

Agronomic and environmental benefits of conservation tillage may be greatly enhanced by diverse crop rotations and cover cropping (Reeves, 1994; Lal, 2003). In addition, several studies have shown how conservation tillage can improve yield and crop water use efficiency (WUE), as well as reduce water runoff and soil erosion (Unger and Vigil, 1998; Norwood, 1999; Hatfield et al., 2001;

Reddy et al., 2004; Truman et al., 2005). Conservation tillage, winter cover cropping, crop rotation, and residue management improve soil quality, which avails plant nutrients, conserves soil moisture, improves infiltration, and reduces erosion, runoff, and surface crusting.

Sandy soils, such as those typical of the Coastal Plain region, are naturally low in SOC. Coarse-textured soils provide less protection of SOC as residues decompose and exhibit higher decomposition rates than fine-textured soils (Franzluebbers, 1999; Krull et al., 2001). Before modern conservation tillage technology was available, increasing SOC was believed to be nearly impossible in sandy Coastal Plain soils. However, on a sandy soil in the South Carolina Coastal Plain, long-term conservation tillage of row crops was shown to be a viable method for increasing SOC (Hunt, et al., 1996). On coarse-textured soil in the Coastal Plain of Alabama, SOC sequestration was 6 to 10 Mg ha^{-1} with high-residue-producing conservation systems and dairy manure application for 3 years, which was much greater than expected for degraded soils of the southeastern USA (Terra et al., 2005). Under forage management systems on medium-textured soils in Virginia, Conant et al. (2003) found that SOC sequestration averaged 0.41 Mg C ha^{-1} yr^{-1}. In the Georgia Piedmont, particulate and biologically active soil C fractions increased in all forage management systems, but more so in grazed than in ungrazed systems, because of the return of feces to soil (Franzluebbers and Stuedemann, 2003).

The amount of SOC sequestered in a field or region is costly to measure and monitor with time, and protocols are still being developed making it difficult to base policies directly on environmental performance (Feng et al., 2004). There are relatively few long-term management studies within the southeastern USA that holistically address SOC sequestration. Simulation modeling may be the most efficient method for estimating management effects on soil properties for a wide range of soil and climatic conditions (Williams et al., 1984).

The Erosion Productivity-Impact Calculator (renamed the Environmental Policy Integrated Climate, EPIC) model simulates a multitude of important soil, crop, and environmental processes relevant to ecosystem functioning (Williams et al., 1984; Williams, 1990; Gassman et al., 2004). EPIC was recently updated to include a C- and N-transformation submodel with concepts and equations derived from the CENTURY model (Izaurralde et al., 2006). The revised EPIC model (v. 3060) was tested against field data from a 6-year experiment at five sites in the Great Plains USA and from a 61-year agronomic experiment near Breton, Canada. The model accounted for 91% of the variability in SOC at Breton, but overestimated SOC at the Great Plains sites when initial SOC was low and underestimated SOC when initial SOC was high (Izaurralde et al., 2006). After optimization of the humus fraction in the passive C pool, the model was able to simulate the observed decline in SOC with continuous conventional tillage and that of restored grassland areas at three locations in central Texas (Gassman et al., 2004).

The soil conditioning index (SCI) was recently incorporated into the Revised Universal Soil Loss Equation 2, a model containing both empirical and process-based science to predict erosion from rainfall and runoff (USDA-NRCS, 2006). The USDA–Natural Resource Conservation Service uses the SCI to predict changes in SOC based on different agricultural management practices employed. The magnitude of the SCI is used to calculate payments to landowners enrolled in the USDA-NRCS Conservation Security Program (Hubbs et al., 2002). The SCI is a function of three components known to affect SOC: (1) organic material grown on or added to soil, (2) field operations that alter organic material placement in the soil profile and that stimulate organic matter breakdown, and (3) erosion that removes and sorts surface soil organic matter (from sheet, rill, or wind erosion, but not from concentrated flow erosion such as ephemeral or gully erosion) (USDA-NRCS, 2003). Testing of the SCI has been limited, suggesting that research is greatly needed to document to what extent the model can be successful and under what conditions the model may be deficient. In addition, long-term model projections of SOC and WUE based on various conservation management systems are lacking in the literature.

The objectives of our study were to (1) simulate long-term SOC, yield, and WUE under conventional and conservation management systems using EPIC v. 3060 in three major land resource areas (MLRAs) of the southeastern USA and (2) compare predictions of SOC change using EPIC and SCI. The management systems represented a gradient of conservation management and crop diversity, which were expected to affect soil disturbance and C input.

Methods and Materials

Simulations were conducted for locations in the Blackland Prairie in eastern Texas, the Southern Piedmont in northern Georgia, and the Coastal Plain in South Carolina (Figure 1). Soil properties at the three locations were obtained from the USDA-NRCS SSURGO and STATSGO databases (http://soils.usda.gov/) included with the EPIC model (Table 1).

The Blackland Prairie site was located on a Houston Black clay soil near Temple, TX at 31^{o} 5’ N, 97^{o} 35’ W, elevation 689 feet (210 m). Grain sorghum

[*Sorghum bicolor* (L.) Moench], cotton, corn, small grains, and forage grasses are common in the MLRA. Precipitation ranges from 30 to 45 inches (750 to 1150 mm), annual temperature ranges from 63^{o} F to 70^{o} F (17^{o} C to 21^{o} C), and the growing season lasts 230 to 280 days.

The Coastal Plain site was located on a Norfolk loamy sand near McColl, SC at 34° 67’ N, 79° W, elevation 185 feet (56 m). Cotton, tobacco (*Nicotiana tabacum* L.), soybean [*Glycine max* (L.) Merr.], peach [*Prunus persica* (L.) Batsch], hay, wheat, and corn are common in the MLRA. Precipitation averages 48 inches (1219 mm), annual temperature averages 74° F (23° C), and the growing season is 290 days.

The Southern Piedmont site was located on a Cecil sandy clay loam near Watkinsville, GA at 33º 54´ N, 83º 24´ W, elevation 751 feet (229 m). Cotton, corn, small grains, and forage grasses are common in the region. Precipitation averages 45 inches (1143 mm), annual temperature averages 63° F (17^{o} C), and the growing season lasts 200 to 250 days.

EPIC v. 3060 without calibration was used to simulate four management systems in each MLRA, including (1) monoculture cotton with conventional tillage (CT), (2) cotton/wheat cover under no tillage (NT), (3) corn/wheat cover (4-yr)–cotton/wheat cover (4-yr) rotation under NT, and (4) bermudagrass (*Cynodon dactylon* L.) pasture (5-yr)–corn/wheat cover (5-yr)–cotton/wheat cover (5-yr) under NT. Management characteristics can be found in Table 2. Planting dates were from averages reported in USDA-NASS (1997). Fertilizer application to bermudagrass was based on a recommendation for the region (Dwight Fisher, personal communication, 2006). Climatic inputs were generated using WXGEN in the EPIC model (Williams and Sharpley, 1989), based on long-term climatic conditions at weather stations near the three locations (http://www.ncdc.noaa.gov/oa/climate/datasel.html). The potential heat unit threshold to simulate cotton yield was set at 2800 in a standard simulation, but was allowed to be lower (automatically set by the model) in a companion simulation to evaluate the effect of altered yield on SOC sequestration.

Yearly estimates of SOC (0-2-m depth), crop yield, and WUE were simulated by EPIC for a 50-yr period. Water-use efficiency (kg mm^{-1}) was calculated as simulated yield (lint for cotton and grain for corn) divided by simulated evapotranspiration during the growing season (generally May to October for cotton and April to August for corn). Simulated estimates of yield and WUE within a MLRA and management system were averaged across years prior to analysis of variance. Simulated SOC estimates were regressed on year in each MLRA and management system to obtain a linear rate of change with time. Yearly estimates of SOC within a MLRA and management system were also fitted to a non-linear exponential model [$Y = A + B \cdot (1 - e^{-k \cdot t})$] to obtain total SOC sequestered during 50 years. The resultant single estimates for yield, WUE, and SOC for each MLRA and management system were used as independent estimates in an analysis of variance that included MLRA as a blocking variable (n = 3) and management system as a response variable (n = 4). Significance among means with true replications was declared at $P \leq 0.1$. To test for potential interactions between MLRA and management system, despite not having replication of MLRA estimates, we used consecutive 5-year mean slope values of SOC as pseudoreplications within the 50-year evaluation period. Significance among means with pseudoreplications was declared at $P \leq 0.01$.

Using the same management conditions as for EPIC simulations, SCI values for a 50-year period were developed for the four management scenarios and three MLRAs using RUSLE2 (USDA-NRCS, 2006).

The relationship between SOC sequestration predicted by EPIC and SCI was determined with linear regression (all 12 paired estimates) and non-linear regression (excluding the NT bermudagrass−corn−cotton rotation, which deviated the most from the linear regression). General linear models were analyzed with SAS for Windows 9.1. Regressions were performed with SigmaPlot for Windows 8.02.

Results and Discussion

EPIC simulations of soil organic C. Organic C content within the surface 2 m of soil generally remained unchanged with time under CT and increased with time in all NT management systems (Figure 2). Averaged across MLRAs, the rate of simulated SOC sequestration (Mg ha^{-1} yr^{-1}) was greater under NT management systems than under CT (Table 3). The total quantity of SOC sequestered during the 50 years of simulation was also greater under NT management systems (27.0 ± 7.7 Mg ha^{-1}) than under CT (-1.5 Mg ha^{-1}). There was no statistical difference in the simulated rate of SOC sequestration or total amount of SOC sequestered among the three NT management systems.

The absolute amount of C in the soil profile was different among the three MLRAs, but the relative change in SOC due to management did not differ among MLRAs (Figure 2). The main effect of greater SOC sequestration rate with NT systems than with CT (Table 3) did not interact significantly with MLRA (*P* = 0.28). The interaction test used 5-year rates of SOC sequestration as observations.

Mean ± standard deviation among the 5-year rates was 0.00 ± 0.22 Mg ha^{-1} yr^{-1} under CT cotton, 0.51 ± 0.65 Mg ha^{-1} yr^{-1} under NT cotton/wheat cover, 0.52 ± 0.69 Mg ha^{-1} yr^{-1} under NT corn/wheat cover–cotton/wheat cover, and 0.59 ± 2.43 Mg ha^{-1} yr^{-1} under NT bermudagrass–corn/wheat cover–cotton/wheat cover. A relatively large variation in the SOC sequestration rate was observed in all four management systems, likely due to weather variations that may have affected crop production and soil organic matter decomposition. Particularly large variation was observed in the bermudagrass−corn−cotton rotation. The mean and standard deviation of SOC sequestration rate under NT cotton and NT corn/wheat cover–cotton/wheat cover were similar to those reported for 96 observations of NT versus CT in 10 ± 5-year-long studies across the southeastern USA region (0.42 ± 46 Mg ha^{-1} yr^{-1}; Franzluebbers, 2005). Therefore, simulation of SOC sequestration with EPIC was generally consistent with field-based data.

EPIC simulated very large SOC sequestration in the bermudagrass phase of the bermudagrass−corn−cotton rotation and large declines immediately thereafter (Figure 2). The large decline in SOC following termination of pasture was unrealistic, since crops were managed under no tillage (Garcia-Prechac et al., 2004). Although forage management systems have shown potential for high SOC sequestration in the southeastern USA (1.03 ± 0.90 Mg ha^{-1} yr^{-1}; Franzluebbers, 2005), the simulated rate of SOC sequestration during the bermudagrass phase of 6.06 ± 0.94 Mg ha^{-1} yr^{-1} was larger than expected and not justified by experimental evidence. Therefore, simulation of SOC under forage management systems should be reevaluated in EPIC v. 3060 to produce more accurate predictions. The SOC module of EPIC v. 3060 was tested against data collected in various locations and management conditions (Gassman et al., 2004; Williams et al., 2004;

Izaurralde et al., 2006), but most of these conditions were under cropping systems. Calibration of the model appears to be necessary for predicting SOC sequestration in long-term forage management systems and for locations other than the few already tested. Calibration would provide a better understanding of parameter sensitivity, which would have implications for transfer of results across a region (Abrahamson et al., 2005). Efforts are currently underway to test EPIC v. 3060 as a decision-making tool for C management based on remotely sensed residue management and tillage practices in the midwestern USA (NASA, 2005). A similar effort would be useful in portions of the southeastern USA to verify that EPIC could accurately simulate long-term changes in SOC throughout the entire southeastern USA.

Soil conditioning index prediction of soil organic C change and relationship to EPIC predictions. The SCI predicted that SOC would decline with time under CT and increase with time under all three NT management systems (Table 3). The SCI also suggested that including 5 years of pasture in the cropping system would lead to greater SOC than simpler NT crop rotations (P = 0.10). These results were qualitatively consistent with the predictions from EPIC, although EPIC simulation of SOC sequestration was not statistically different between NT rotation systems.

From the four management systems on three MLRAs, SCI was linearly related to SOC sequestration simulated by EPIC (Figure 3). The greatest deviation from this relationship was in the bermudagrass–corn/wheat cover–cotton/wheat cover system. Excluding this management system, the best fit between EPIC and SCI was an exponential growth function that suggested SOC sequestration was insensitive to SCI $\leq$0, but increased dramatically with values >0. Hubbs et al.

(2002) presented linear relationships between the percent C change in soil and SCI. Although the simulation results reported here were in general agreement with the relationships in Hubbs et al. (2002), there is a need for much further evaluation of SCI since both linear and non-linear relationships with SOC sequestration appear to be possible, reflecting unexplained sources of variation. An even greater need is to validate SCI against actual field data of SOC sequestration under a wide range of agricultural systems with long-term management. The relationships reported in Figure 3 should not be considered quantitative or be used as a predictive tool, since SOC sequestration estimates were obtained only with EPIC v. 3060 and not actual field data.

EPIC simulations of crop yield and water-use efficiency (WUE). Cotton lint yield was greater under CT than under NT management systems when averaged across MLRAs (Table 4). There were no differences in simulated lint yield among the three NT management systems. Cotton lint WUE was not different among any of the treatments, averaging 2.4 kg mm^{-1} (Table 4). No tillage was able to reduce evaporation from soil compared with CT, resulting in similar WUE, despite a difference in yield. Although simulations of cotton lint yield were relatively high (mean of 1.41 Mg ha^{-1} under CT and 1.24 Mg ha^{-1} under NT systems) compared with actual field observations of 0.98 ± 0.30 Mg ha^{-1} under CT and 1.05 ± 0.22 under NT (Johnson et al., 2001; Endale et al., 2002; Busscher and Bauer, 2003; Schomberg et al., 2003), relative differences among treatments were expected to occur to a similar extent, irrespective of absolute values. Calibration of EPIC to specific growing conditions in these environments appears to be necessary to improve yield estimates.

Simulation of 12 ± 6% lower cotton lint yield with NT management systems compared with CT was different than reported for most field observations. In a review of tillage impacts on soil and crop responses in the southeastern USA, cotton lint yield across 18 pairs of observations (CT vs NT) averaged 1.1 Mg ha^{-1} and was not different between tillage systems (Franzluebbers, 2005). Seed cotton yield across 9 pairs of observations was 2.59 Mg ha^{-1} under CT and 2.69 Mg ha^{-1} under NT. Terra et al. (2005) reported 17 ± 9% greater seed cotton yield under NT than under CT. The negative effect of NT management on simulated cotton lint yield during 50 years of management mandates that calibration of EPIC v. 3060 to specific conditions at a site will be needed to account for differences among management systems.

Cotton lint WUE from a silt loam soil in Alabama was 3.0 ± 1.4 kg mm^{-1} under both CT and NT, when using precipitation from May to September in calculations (Reddy et al., 2004). On a loamy sand in South Carolina, cotton lint WUE was 1.3 ± 0.3 kg mm^{-1} under both CT and NT (Busscher and Bauer, 2003). On a silt loam in Mississippi, cotton lint WUE was 2.5 ± 0.8 kg mm^{-1} under CT and 2.2 ± 0.6 kg mm^{-1} under NT (Pettigrew and Jones, 2001). On a sandy loam soil in Alabama, seed cotton WUE was 5.1 ± 2.0 kg mm^{-1} under CT and 5.3 ± 2.0 kg mm^{-1} under strip tillage (Gordon et al., 1990). On a silt loam in Mississippi, seed cotton WUE was 4.2 ± 1.4 kg mm^{-1} under CT and 4.9 ± 1.9 kg mm^{-1} under NT (Triplett et al., 1996). The effect of tillage system on WUE in cotton has generally been relatively small and inconsistent, and therefore, simulations of similar cotton WUE efficiency between CT and NT systems during 50 years were reasonable compared with available field data.

Simulated corn grain yield averaged 9% greater under the NT corn-cotton rotation than under the NT pasture-crop rotation system (Table 4). Simulated corn grain yield production was well within observed production levels of 6.7 ± 1.8 Mg ha^{-1} under CT and 7.6 ± 1.7 Mg ha^{-1} under NT on soils in the same three MLRAs evaluated (Hargrove, 1985; Karlen et al., 1989; Wagger and Denton, 1992; Torbert et al., 2001; Terra et al., 2005). Water-use efficiency of corn was not different between the two rotations, averaging 17.6 ± 1.4 kg grain mm^{-1} precipitation. On a clay soil in Texas, corn grain WUE was 8.8 ± 4.6 kg mm^{-1} under CT and 11.5 ± 3.5 kg mm^{-1} under NT (Torbert et al., 2001). Under dryland conditions in Kansas, corn grain WUE was 10.0 ± 4.9 kg mm^{-1} under CT and 12.8 ± 4.3 kg mm^{-1} under NT (Norwood, 1999). On a fine sandy loam in Alabama, corn grain WUE was 20.1 ± 6.3 kg mm^{-1} under continuous corn and 21.3 ± 6.2 kg mm^{-1} under wheat/soybean−corn (Edwards et al., 1988).

Effect of altered crop yield prediction on soil organic C. By lowering the threshold heat unit level from 2800 to 2000, cotton lint yield increased 36% from a mean of 1.28 Mg ha^{-1} to 1.75 Mg ha^{-1}, averaged across treatments (data not shown). However, SOC sequestration declined from a mean of 0.34 Mg ha^{-1} yr^{-1} to 0.28 Mg ha^{-1} yr^{-1}. Although conversion of crop-derived C into SOC cannot be treated as a direct function of crop yield, the small decline in SOC sequestration with a relatively large increase in crop yield suggests that simulated SOC sequestration values may be less variable across a range of environments than crop yield.

Summary and Conclusions

Simulations with the uncalibrated EPIC v. 3060 strongly suggested that no-tillage management of cropland in the southeastern USA would lead to significant sequestration of soil organic C compared with conventional-tillage management. Increasing crop rotation diversity did not significantly alter simulated soil organic C sequestration and cotton lint water-use efficiency. The soil conditioning index also indicated that soil organic C sequestration would be greater with no-tillage management than with conventional-tillage management, but in addition suggested greater soil organic C sequestration with a more diverse crop rotation system than with continuous cotton under no tillage. With the limited number of simulations (12), the soil conditioning index was related to EPIC-simulated soil organic C sequestration during 50 years. Relationships suggested that soil organic C sequestration would be highly significant with relatively small changes in positive values of the soil conditioning index. Long-term changes in soil organic C appeared to be reasonably predicted with both EPIC v. 3060 and the soil conditioning index. These prediction tools will be of great importance to land managers and policy makers for making decisions to improve soil quality for future use, but there is still an urgent need for long-term, field-based data to improve these tools.

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Figure 1. Location of the three simulation sites within the Blackland Prairie, Coastal Plain, and Southern Piedmont major land resource areas in the southeastern USA.

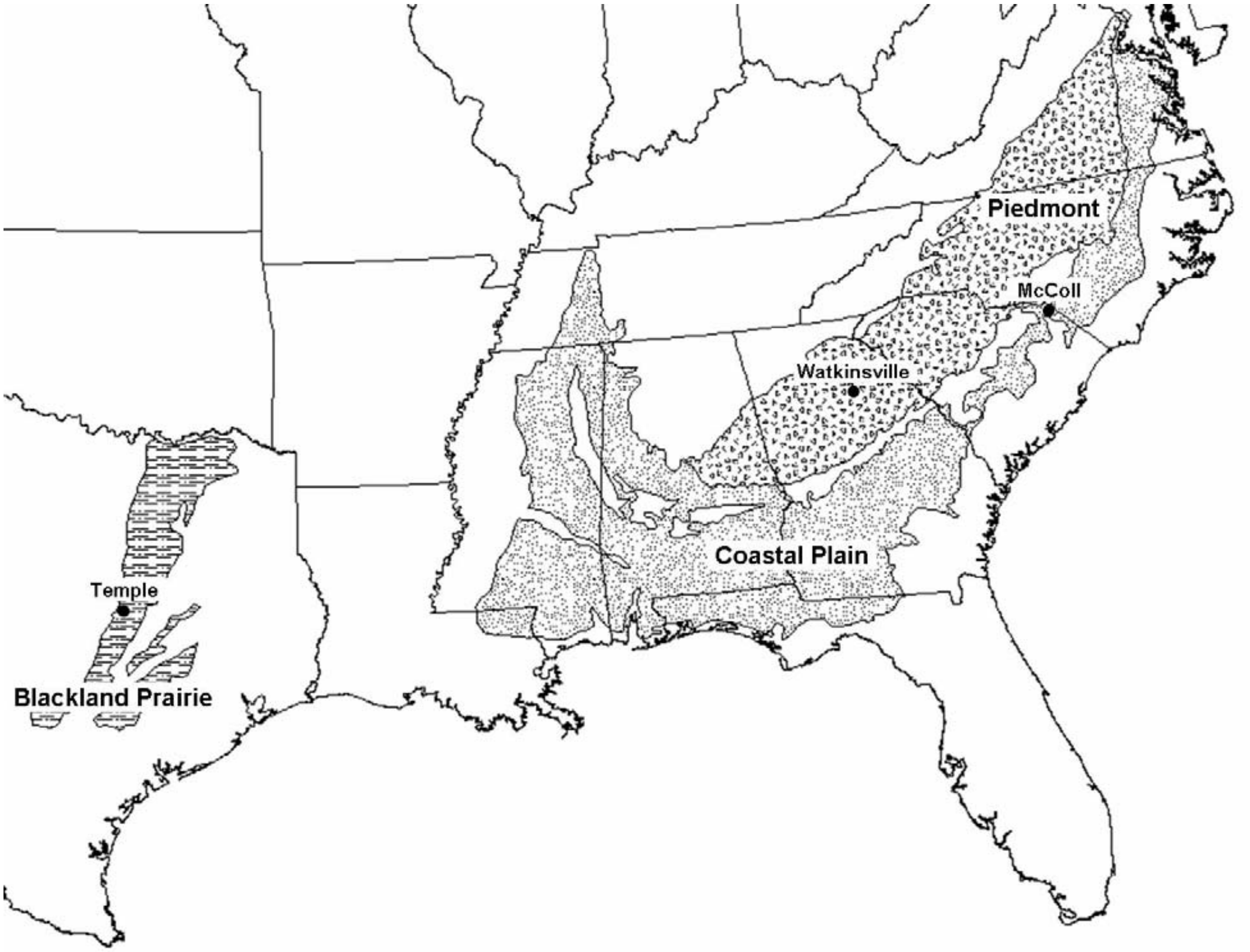

Figure 2. Simulated soil organic C during 50 years by the Environmental Policy Integrated Climate (EPIC) model in three major land resource areas as affected by four management systems.

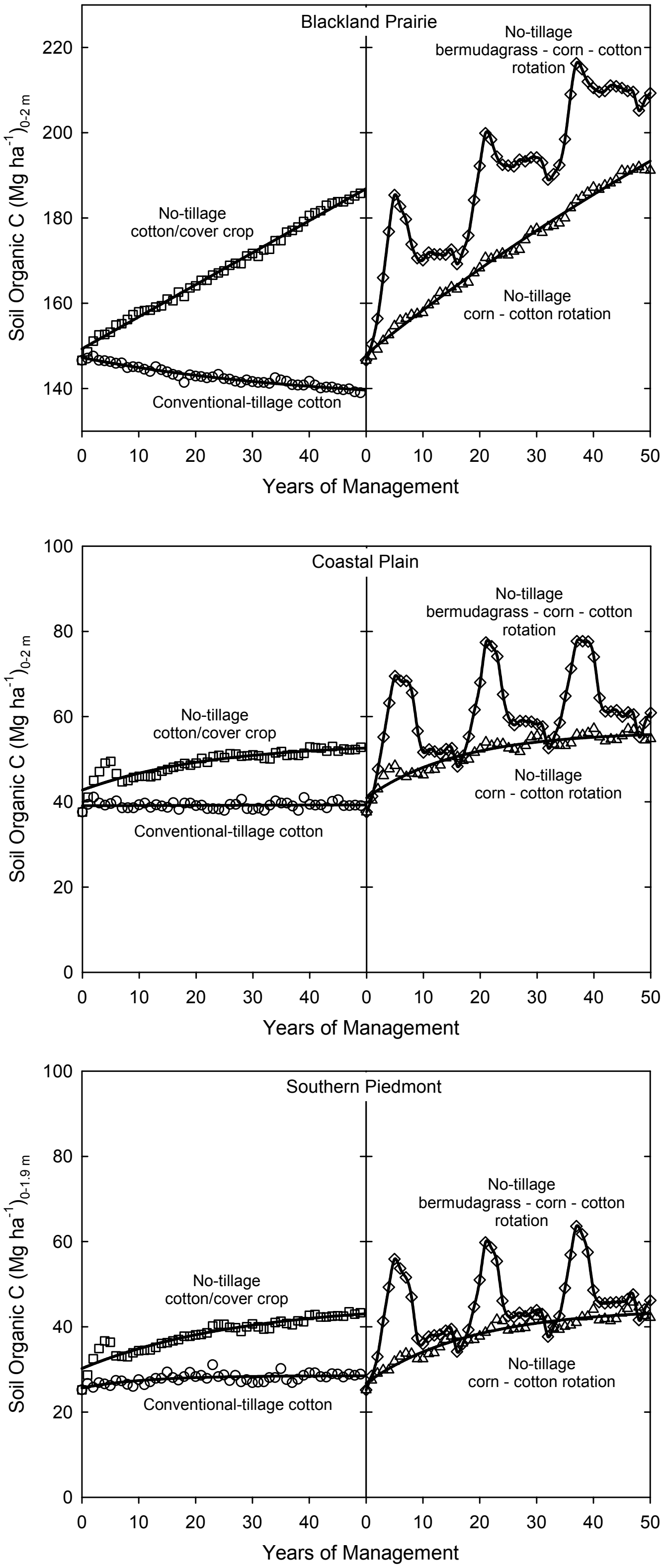

Figure 3. Soil organic C (SOC) sequestration simulated by the Environmental Policy Integrated Climate (EPIC) model in the surface 2 m of soil on a yearly basis (top panel) and throughout a 50-year period (bottom panel) in relationship with the soil conditioning index (SCI). Linear relationships were developed with all 12 observations (4 management systems x 3 major land resource areas). Exponential growth curves were fitted to data, excluding the bermudagrass–corn/wheat cover–cotton/wheat cover system under no tillage (NT). CT is conventional tillage.

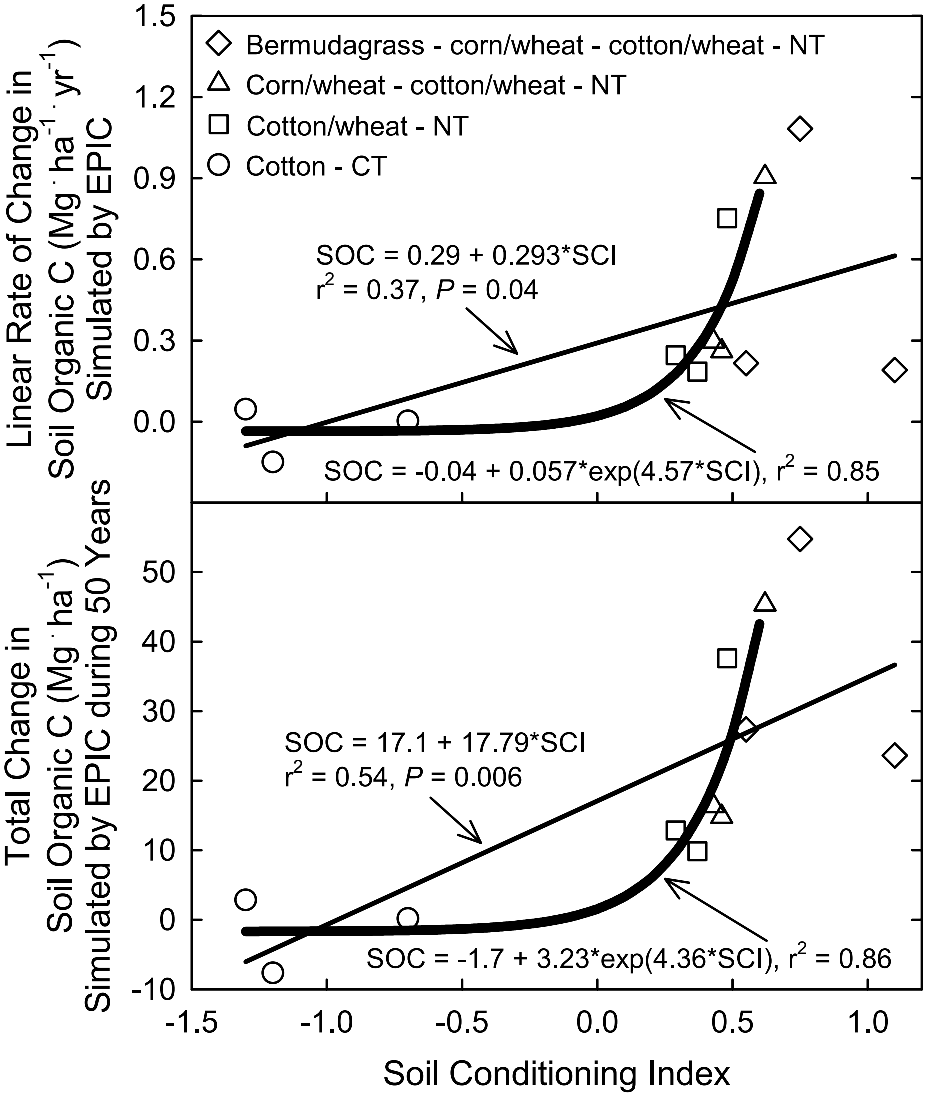

Table 1. Selected initial soil parameters from the SSURGO database used for the 50-yr simulations with the Environmental Policy Integrated Climate (EPIC) model.

Depth (m)	Bulk density	Sand	Silt	pH	Soil organic C
	Mg m^{-3}	----- kg kg^{-1} -------			g kg^{-1}
---------------------- Blackland Prairies (Houston Black clay) ----------------------					
0.01-0.18	1.3	0.07	0.36	8.0	15
0.18-0.48	1.2	0.05	0.39	8.3	13
0.48-1.0	1.3	0.06	0.35	8.0	9
1.0-1.5	1.4	0.06	0.40	8.3	4
1.5-2.0	1.3	0.07	0.42	8.2	3
---------------------- Coastal Plain (Norfolk loamy sand) ----------------------					
0.01-0.18	1.6	0.76	0.22	4.9	6
0.18-0.48	1.7	0.55	0.25	4.7	2
0.48-1.0	1.4	0.56	0.13	4.6	<1
1.0-1.5	1.3	0.62	0.12	4.6	1
1.5-2.0	1.3	0.41	0.24	4.5	<1
----------------- Southern Piedmont (Cecil sandy clay loam) -----------------					
0.01-0.18	1.6	0.68	0.20	5.5	4
0.18-0.28	1.5	0.55	0.17	5.0	2
0.28-1.2	1.4	0.18	0.29	5.0	1
1.2-2.0	1.7	0.45	0.26	4.5	<1

Table 2. Management characteristics for 50-yr simulations by the Environmental Policy Integrated Climate (EPIC) model in each of the three major land resource areas and four management systems.

	Date of operation		
Management operation	Blackland Prairie	Coastal Plain	Southern Piedmont
Monoculture cotton with conventional tillage			
Fertilizer / plant cotton (150-37 kg N-P ha^{-1})	25 May	5 May	25 Apr
Cultivate	15 Jun	10 Jun	10 Jun
Harvest cotton	15 Nov	25 Oct	30 Oct
Offset disk	15 Nov	5 Nov	5 Nov
Tandem disk	30 Nov	30 Nov	30 Nov
Rotation repeated yearly			
Cotton / wheat cover crop with no tillage (NT)			
Cut / bale wheat	20 May	1 May	20 Apr
Fertilize / plant cotton (150-37 kg N-P ha^{-1})	25 May	5 May	25 Apr
Harvest cotton	25 Oct	30 Oct	30 Oct
Fertilize / plant wheat (56 kg N ha^{-1})	30 Oct	30 Oct	5 Nov
Rotation repeated yearly			
Corn / wheat cover (4 yr) – cotton / wheat cover (4 yr) with NT			
Years 1-4: Cut / bale wheat	25 Apr	10 Apr	25 Mar
Fertilizer / plant corn (168-37 kg N-P ha^{-1})	30 Apr	15 Apr	1 Apr
Harvest corn	5 Sep	1 Sep	5 Aug
Fertilizer / plant wheat (56 kg N ha^{-1})	10 Sep	10 Sep	5 Oct
Years 5-8: Cut / bale wheat	15 Apr	1 May	25 Mar
Fertilize / plant cotton (150-25 kg N-P ha^{-1})	25 May	5 May	25 Apr
Harvest cotton	15 Nov	25 Oct	30 Oct
Fertilize / plant wheat (56 kg N ha^{-1})	20 Nov	30 Oct	5 Nov
Rotation repeated every 8 years			
Bermudagrass (5 yr) – corn / wheat cover (5 yr) – cotton / wheat cover (5 yr) with NT			
Year 1: Fertilize / plant bermudagrass (80-37 kg N-P ha^{-1})	15 Mar	15 Mar	15 Mar
Cut bermudagrass	15 Jun	15 Jun	15 Jun
Fertilize bermudagras (50 kg N ha^{-1})	15 Jul	15 Jul	15 Jul
Cut bermudagrass	15 Aug	15 Aug	15 Aug
Year 2: Fertilize bermudagrass (80 kg N ha^{-1})	15 Mar	15 Mar	15 Mar

Cut / bale bermudagrass	30 Apr	30 Apr	30 Apr
Fertilize bermudagrass (50 kg N ha^{-1})	1 May	1 May	1 May
Cut / bale bermudagrass	15 Jun	15 Jun	15 Jun
Fertilize bermudagrass (50 kg N ha^{-1})	20 Jun	20 Jun	20 Jun
Cut / bale bermudagrass	1 Aug	1 Aug	1 Aug
Fertilize bermudagrass (50 kg N ha^{-1})	15 Aug	15 Aug	15 Aug
Years 3-5: Fertilize bermudagrass (80 kg N ha^{-1})	15 Mar	15 Mar	15 Mar
Initiate grazing of bermudagrass	15 Apr	15 Apr	15 Apr
Fertilize bermudagrass (80 kg N ha^{-1})	15 Jun	15 Jun	15 Jun
Fertilize bermudagrass (50 kg N ha^{-1})	15 Aug	15 Aug	15 Aug
End grazing of bermudagrass	15 Sep	15 Sep	15 Sep
Years 6-10: Culture of corn with NT as above			
Years 11-15: Culture of cotton / wheat with NT as above			
Rotation repeated every 15 years			

Table 3. Estimates of soil organic C (SOC) sequestration (0- to 2-m depth) during 50 years of simulation by the Environmental Policy Integrated Climate (EPIC) model and the Soil Conditioning Index (SCI), averaged across three Major Land Resource Areas (i.e., Blackland Prairies, Coastal Plain, and Southern Piedmont).

	EPIC		**SCI**
Management system	**Linear rate of SOC sequestration (Mg ha^{-1} yr^{-1})**	**Total quantity of SOC sequestration (Mg ha^{-1})**	**Unit-less relative change**
(1) CT cotton	-0.03	-1.5	-1.07
(2) NT cotton/wheat cover	0.39	20.1	0.38
(3) NT corn/wheat cover–cotton/wheat cover	0.49	25.5	0.50
(4) NT bermudagrass–corn/wheat cover–cotton/wheat cover	0.50	35.3	0.80
Analysis of variance	--------------------------- **Pr > F** ---------------------------		
CT vs NT systems (1 vs 2-3-4)	0.03	0.008	<0.001
NT ungrazed vs grazed (2-3 vs 4)	0.77	0.16	0.10
NT monoculture vs rotation (2 vs 3)	0.68	0.57	0.58

Table 4. Mean cotton lint and corn grain yields and their water-use efficiencies averaged across three Major Land Resource Areas (i.e., Blackland Prairie, Coastal Plain, and Southern Piedmont) during 50 years of simulation by the Environmental Policy Integrated Climate (EPIC) model.

Management system	**Yield**		**Water-use efficiency**	
	Cotton lint	**Corn grain**	**Cotton lint**	**Corn grain**
	--------- Mg ha^{-1} ---------		**--------- kg mm^{-1} ---------**	
(1) CT cotton	1.41	N.A.	2.45	N.A.
(2) NT cotton/wheat cover	1.15	N.A.	2.29	N.A.
(3) NT corn/wheat cover–cotton/wheat cover	1.32	7.53	2.41	18.5
(4) NT bermudagrass–corn/wheat cover–cotton/wheat cover	1.24	6.90	2.34	17.0
Analysis of variance	**-------------------------- Pr > F --------------------------**			
CT vs NT systems (1 vs 2-3-4)	0.06	N.A.	0.22	N.A.
NT ungrazed vs grazed (2-3 vs 4)	0.96	0.04	0.90	0.24
NT monoculture vs rotation (2 vs 3)	0.11	N.A.	0.21	N.A.

N.A. is not applicable.