Using the CENTURY Model to Simulate C Dynamics in an Intensively Managed Alabama Ultisol

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ABSTRACT

Increasing soil organic carbon (SOC) storage is essential for improving soil quality and mitigating greenhouse gas emissions. Studies have shown that cultivated soils in the Southeastern USA have substantial potential for sequestering SOC. The use of validated models to simulate soil management effects on the SOC pool is critical for growers, researchers, and policy makers. We evaluated the ability of the CENTURY model to simulate SOC dynamics in a tillage and crop rotation experiment (ca. 1988) located in Milstead, central AL. Soils consisted of coarse-loamy, siliceous, subactive, thermic Plinthic Paleudults. Tillage treatments included surface tillage (no tillage and conventional tillage) and subsurface tillage (one-time subsoiling on narrow centers, annual in-row subsoiling, and no subsoiling) cropped to a corn (*Zea mays* L.)-soybean (*Glycine max* (L.) Merr.) rotation with a winter crimson clover (*Trifolium incarnatum* L.) cover crop from 1988 to 1996. From 1997 to 2001, plots were planted to three different crop rotations that basically consisted of either a corn-cotton (*Gossypium hirsutum* L.) rotation or continuous cotton with one or two biomass producing cover crops each year. Significant differences (*P* = 0.10) in SOC existed between many of the tillage-rotation treatments. The average SOC for the conventional tillage plots was 6.6 tons C acre^{-1} (14.8 Mg C ha^{-1}), which CENTURY overestimated by 57%. The average SOC for the no surface tillage plots was 8.2 tons C acre^{-1} (18.4 Mg C ha^{-1}), which CENTURY overestimated by 32%. CENTURY overestimated SOC for most treatments, did not simulate the magnitude of the differences between the treatments, but did simulate the general trend in SOC dynamics within certain rotations. The aggregate of data suggests changes in SOC occur more rapidly than CENTURY simulates for Southeastern USA cropping systems.

KEYWORDS

CENTURY, soil organic carbon, conservation tillage, Ultisols.

INTRODUCTION

Soil organic carbon (SOC) is critical for assessing soil quality. Studies have shown that in most environments, SOC improves soil aggregation and structure, increases infiltration, prevents surface crusting, reduces erosion, and improves crop productivity (Reeves, 1997). Soil organic matter can also serve as a source or a sink for atmospheric carbon, helping to mitigate greenhouse gas emissions.

Modeling can be used to estimate SOC storage in soils under different agricultural management practices. CENTURY is an empirical model that was originally developed to model long-term C, N, P, and S dynamics in grassland systems (Parton *et al.*, 1987; Smith *et al.*, 1997). CENTURY has been has been modified to include forest, savannah, and agricultural systems. Major input variables include monthly average maximum and minimum air temperature, monthly precipitation, lignin content of plant material, plant N, P, and S content, soil texture, atmospheric and soil N inputs, and initial soil C, N, P, and S pools (Parton *et al.*, 1992). Soil organic matter is divided into three pools: active, slow, and passive, and litter is split into two pools: metabolic and structural, based on lignin content (Smith *et al.*, 1997). Theoretically, the active pool is microbial and labile SOC that turns over in < 5 years, the slow pool is relatively more resistant and has a turnover period of 20 to 40 years, and the passive pool is relatively stable (Parton *et al.*, 1987).

CENTURY has been successfully used to model SOC dynamics in long-term experiments in several climates (Smith *et al.*, 1997). Some researchers have found CENTURY to be more accurate for croplands and grasslands as compared to forested systems (Kelly *et al.*, 1997). Parton and Rasmussen (1994) found that observed versus CENTURY simulated SOC levels were similar (R^2 = 0.77) for a long-term wheat (*Triticum aestivum* L.)-fallow-residue management experiment in Oregon. These authors con-

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cluded the model could predict SOC change within 5% for 57 % of the time. Gisjman *et al.* (1996) found CENTURY did not simulate C, N, and P well in grassland savannahs comprised of Colombian Oxisols. These authors provided suggestions for improving the model for these tropical regions. There has been little validation of this model in cropping systems and soils of the Southeastern USA.

Our goal was to validate the CENTURY model for Southeastern crop management systems. We used a long-term (ca. 1988) experiment in central Alabama with a diverse tillage and crop rotation history to evaluate the model.

METHODS AND MATERIALS

Field Experiment

We used CENTURY to model SOC in an experiment established in 1988 as described by Reeves *et al.* (1992), Lee *et al.* (1996), and Reeves and Delaney (2002). The experiment was located at the E.V. Smith Research Center of the Alabama Experiment Station, near Shorter, AL. Soils were described, sampled, and characterized according to standard techniques (Soil Survey Investigations Staff, 1996), and were composed mostly of Compass sandy loam (coarse-loamy, siliceous, subactive, thermic Plinthic Paleudults) (Table 1).

The experiment was established to evaluate tillage, equipment trafficking, and crop rotation effects on crop yields and soil quality. The trafficking component was conducted from 1988 to 1996, however, Lee *et al.* (1994), found trafficking had no significant effect on SOC, thus, traffic effects were not included in our simulations. Tillage treatments consisted of a surface and a subsurface tillage component. The surface tillage treatments were conventional tillage (disked, chisel plowed, disked, and field cultivated every spring) and no surface tillage. The subsurface tillage treatments included a one-time complete disruption that consisted of subsoiling on 10-inch centers, annual in-row subsoiling, and no subsurface tillage. From 1988 to 1996 the plots were planted in a corn -soybean rotation with a winter crimson clover cover crop.

From 1997–2001, the plots were planted in various cropping rotations (Table 2). Subsurface tillage was modified so that all treatments were non-inversion deep-tilled with a Paratill® (AgEquipment Group, Lockney, TX 79241) or subsoiler annually; surface tillage regimes remained the same as 1988-1996. Rotation 1 consisted of sunn hemp (*Crotalaria juncea* L.)-wheat (*Triticum aestivum* L.)- cotton (*Gossypium hirsutum* L.)-lupin (*Lupinus albus* L.) and crimson clover mix-corn rotation. Rotation 2 consisted of a black oat (*Avena strigosa* Screb.) and rye (*Secale cereale* L.) mix-cotton-lupin and clover mix-corn rotation. Rotation 3 consisted of a continuous cotton-black oat and rye mix rotation. These rotations were placed in two year cycles and were planted in two phases in order to have each phase of the rotation present each year. Since 1997, a portion of the cotton was planted as ultra narrow row (UNR, 8- inch drill). We did not account for this in the simulations. Further discussion of treatments can be found in Reeves and Delaney (2002).

Table 1. Soil characterization data for a sampled pedon for the E.V. Smith sites. CEC is the cation exchange capacity and ECEC is the effective cation exchange capacity.

Hor	Depth	sand	silt	clay	Ca	Mg	K	Na	Al	CEC	ECEC
	cm	pct < 2 mm			<----------------------$cmol_c\ kg^{-1}$---------------------->						
		coarse-loamy, siliceous, subactive, thermic Plinthic Paleudult									
Ap1	0-7	82.8	14.1	3.1	0.60	0.44	0.08	0.00	0.12	2.39	1.25
Ap2	7-30	82.1	16.4	1.4	0.86	0.42	0.04	0.00	0.12	1.78	1.45
BE	30-44	72.5	18.5	9.0	0.92	0.82	0.12	0.04	0.11	2.81	2.02
Bt	44-62	69.4	17.4	13.2	1.26	1.40	0.19	0.12	0.19	3.17	3.16
Btv	62-82	74.6	16.5	8.9	0.63	0.57	0.10	0.06	0.26	2.30	1.63
B/E	82-94	75.4	17.5	7.2	0.21	0.25	0.04	0.01	1.25	1.45	1.76
Btvx1	94-114	74.0	16.4	9.7	0.19	0.18	0.06	0.02	1.94	2.02	2.39
Btvx2	114-150	72.9	14.2	12.9	0.20	0.17	0.06	0.00	2.47	2.88	2.91

Table 2. The three crop rotations in two phases (1997-2001) for a Compass loamy sand in east-central, Alabama. The years listed are the first three years of the rotation; rotations were repeated through 2001. Planting and harvesting dates are approximate. UNRC is ultra narrow row cotton.

		Rotation					
		1		2		3	
Year	Month	a	b	a	b	a	b
1997	Aug.	Sunn Hemp					
	Sept.						
	Oct.			Oat-Rye	Lupin-Clover	Oat-Rye	Oat-Rye
	Nov.		Lupin-Clover				
	Dec.	Wheat					
1998	Jan.						
	Feb.						
	March						
	April						
	May		Corn	Cotton	Corn	Cotton	
	June						
	July	Cotton (UNRC)					Cotton (UNRC)
	Aug.						
	Sept.		Sunn Hemp		Oat-Rye		
	Oct.						
	Nov.	Lupin-Clover		Lupin-Clover		Oat-Rye	Oat-Rye
	Dec.		Wheat				
1999	Jan.						
	Feb.						
	March						
	April						
	May	Corn		Corn	Cotton	Cotton	
	June						
	July		Cotton (UNRC)				Cotton (UNRC)
	Aug.						
	Sept.						
	Oct.						

CENTURY MODELING

The values for the soil parameters for the CENTURY model (texture and bulk density by horizon) were obtained from soil characterization data (Table 1). Weather data were obtained from the National Climactic Data Center for Milstead, AL (NOAA, 2002). The SOC pools were initialized [SOC=7.1 tons C acre^{-1} (16.0 Mg C ha^{-1})] using data from a neighboring conventional tillage experiment and the SOC was partitioned according to the CENTURY 4 parameterization workbook (Pulliam, 1996).

Parameterization files are used to provide input values for the model. These files assign quantitative values to processes such as harvesting or cultivating for running the simulations. CENTURY possesses readily accessible parameter files (ASCII text files) by which input values can be modified. The sunn hemp and the lupin-clover mix were not originally in the model, therefore, parameterization files were created for these cover crops. We modified the biomass production levels and C:N ratio for sunn hemp according to Mansoer *et al.* (1997) and lupin-clover mix according to Noffsinger *et al.* (1998) and Odhiambo and Bomke (2001). We used the oat parameters to simulate the oat-rye mixture and the grass-clover pasture parameters to simulate clover. We also modified tillage operation parameter files to more adequately represent tillage operations. Disking operations were simulated by modifying the cultivator parameters so that more surface litter was incorporated. The parameters for plowing were used to simulate chisel plowing.

Table 3. Measured SOC and CENTURY simulated SOC for a Compass loamy sand in east-central, Alabama. NT is no surface tillage, CT is conventional tillage, NS is no subsoiling, 1XCD is one time complete disruption, AS is annual in-row subsoiling. Rotations are defined in Table 2.

Surface tillage (1988-2001)	Subsurface tillage (1988-1996)	Rotation (1996-2001)	Measured SOC		CENTURY output SOC	
			tons C A^{-1}	Mg C ha^{-1}	tons C A^{-1}	Mg C ha^{-1}
NT	NS	1a	8.1	18.1	11.0	24.7
NT	NS	1b	8.4	18.8	11.5	25.8
NT	NS	2a	7.6	17.0	11.3	25.3
NT	1XCD	1a	7.8	17.6	11.0	24.6
NT	1XCD	3a	8.3	18.6	10.0	22.4
NT	1XCD	3b	9.5	21.3	10.0	22.4
NT	AS	2a	8.3	18.7	11.3	25.3
NT	AS	2b	6.3	14.2	11.3	25.3
NT	AS	3a	9.5	21.2	9.9	22.3
CT	NS	1a	6.3	14.2	10.6	23.8
CT	NS	1b	6.3	14.2	11.2	25.0
CT	NS	2a	6.3	14.1	11.0	24.6
CT	1XCD	1a	6.0	13.4	10.6	23.8
CT	1XCD	3a	6.9	15.5	9.6	21.6
CT	1XCD	3b	6.9	15.3	9.6	21.6
CT	AS	2a	6.3	14.1	9.4	21.1
CT	AS	2b	6.3	14.1	11.3	25.3
CT	AS	3a	8.1	18.1	9.9	22.3
$LSD_{0.10}$			1.4	3.1		

Model Validation

Soil organic carbon was composite sampled in each plot for the 0-5 and 5-20 cm depths. Samples were air-dried, crushed, and carbon was measured using dry combustion (Yeomans and Bremmer, 1991). Bulk density was measured at the 0-5 and 5-20 cm depths using the method of Blake and Hartge (1986). The simulations were run from 1988 to 2001, and output was compared to measured SOC values.

RESULTS AND DISCUSSION

Significant differences ($P = 0.10$) in SOC concentrations existed between many of the treatments (Table 3). Similar to other findings, when averaged overall, the no tillage systems had higher SOC levels (8.2 tons C $acre^{-1}$) than the conventional tillage systems (6.6 tons C $acre^{-1}$) (Table 3). Further discussion of treatment effects on the SOC pools for this experiment can be found in Reeves and Delaney (2002).

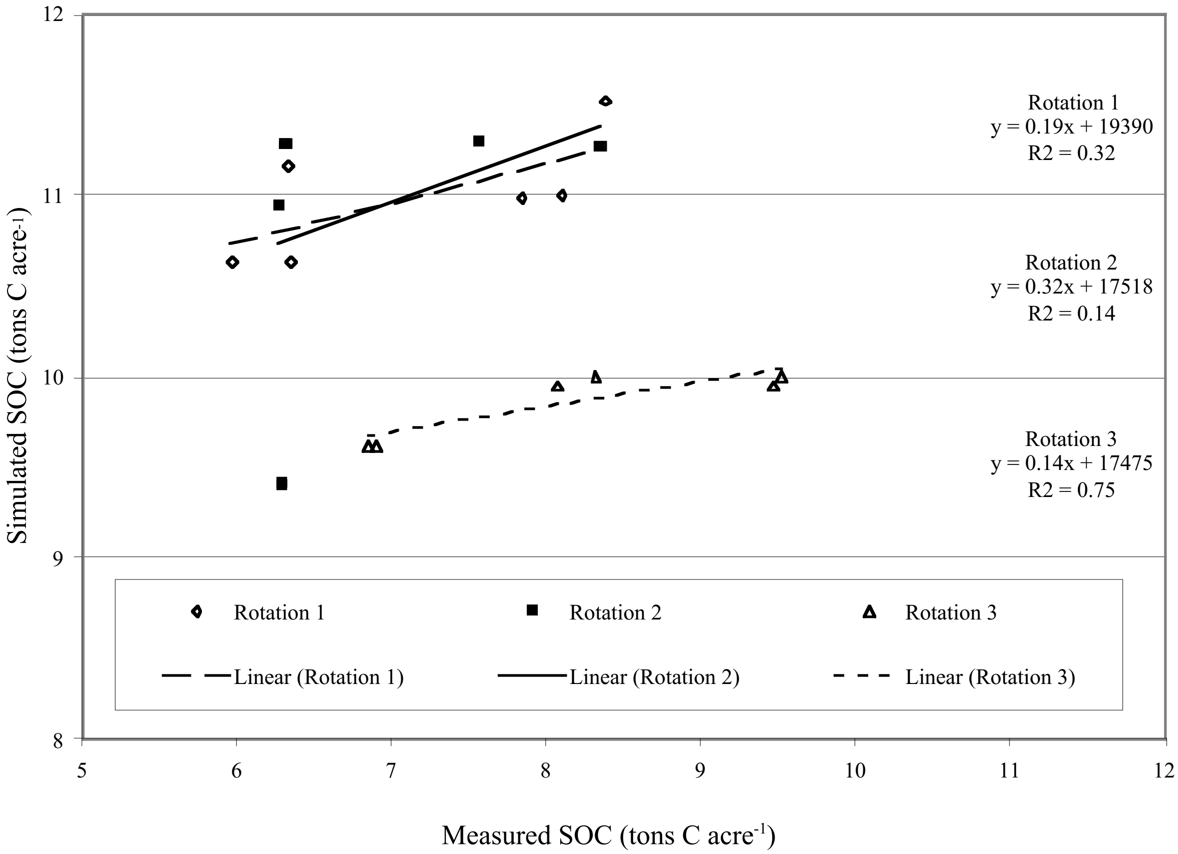

Fig. 1. Measured versus CENTURY simulated SOC by Rotation. Rotations are given in Table 2.

The average CENTURY output for the conventional tillage plots was 10.4 tons C acre^{-1} (23.2 Mg C ha^{-1}), which is 57% higher than the average of the measured values (6.6 tons C acre^{-1}). The average CENTURY output for the no surface tillage plots was 10.8 tons C acre^{-1} (24.2 Mg C ha^{-1}), 32% above the average of the measured values (8.2 tons C acre^{-1}). In addition, when measured SOC values were compared to simulated SOC data, a fairly high Root Mean Square Error (RMSE) was observed (3.5 tons C acre^{-1}). Our findings indicate that CENTURY overestimated SOC for most treatments.

Differences in CENTURY's ability to simulate SOC trends as affected by tillage within each rotation were evident (Figure 1). CENTURY simulated trends in tillage effects most accurately within rotation 3 ($R^2 = 0.75$), which was the most simple rotation consisting only of a cotton-oat and rye cover crop rotation. In addition, CENTURY more accurately depicted SOC quantities within rotation 3 [RMSE=1.9 tons C acre^{-1} for rotation 3 versus 3.9 and 4.2 tons C acre^{-1} for rotation 1 and 2 (see table 2 for rotations), respectively]. These findings suggest that as cropping system becomes more diverse and/or intensive, the accuracy of CENTURY output decreases.

Century estimated SOC to within the LSD (1.4 tons C acre^{-1}) for treatments with the highest SOC. For the no surface tillage treatment in rotation 3a, measured SOC was 9.5 tons C acre^{-1} (21.2 Mg C ha^{-1}), which CENTURY estimated to be 9.9 tons C acre^{-1} (22.3 Mg C ha^{-1}). Similarly, for the no surface tillage within rotation 3b, SOC was 9.5 tons C acre^{-1} (21.3 Mg C ha^{-1}), which CENTURY estimated as 10.0 tons C acre^{-1} (22.4 Mg C ha^{-1}). On the treatment with the lowest SOC (conventional tillage within rotation 1a), CENTURY overestimated the SOC by 78%.

CONCLUSIONS

CENTURY overestimated SOC in most of the treatments for this tillage/rotation experiment. The model simulated most accurately the treatments with the highest SOC levels (no surface tillage), but did not do well with the SOC levels found in conventional tillage plots. CENTURY output showed as much difference between the crop rotations as between tillage treatments; however, measured data suggested significant differences in SOC between tillage treatments. Despite these errors, CENTURY can accurately model SOC trends within certain cropping systems.

Overall, we feel the model could be improved by: 1) providing a chronological output of agronomic operations based on user input and, 2) adding additional crop (in particular, cover crops) and tillage parameter sets necessary to simulate many Southeastern management systems.

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