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Soil carbon storage beneath recently established tree plantations in Tennessee and South Carolina, USA ☆,★★

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Abstract

Rates of soil carbon (C) accumulation under 7 recently established tree plantations in Tennessee and South Carolina (USA) were estimated by comparing soil C stocks under the plantations to adjacent reference (nonplantation) sites. Estimated rates of C accumulation in surface (0–40 cm) mineral soil were 40–170 g C m^{-2} yr^{-1} during the first decade following plantation establishment. Most soil C at each site was found in mineral-associated organic matter (i.e., soil C associated with the silt–clay fraction). Soils with high sand content and low initial C stocks exhibited the greatest gains in particulate organic matter C (POM-C). Labile soil C stocks (consisting of forest floor and mineral soil POM-C) became an increasingly important component of soil C storage as loblolly pine stands aged. Rates of mineral soil C accumulation were highly variable in the first decade of plantation growth, depending on location, but the findings support a hypothesis that farm to tree plantation conversions can result in high initial rates of soil C accumulation in the southeastern United States. Published by Elsevier Science Ltd.

Keywords: Soil C sequestration; Soil nitrogen; Particulate organic matter; Mineral-associated organic matter; Loblolly pine; tree plantations

1. Introduction

Cultivation has resulted in substantial losses of soil organic matter from agricultural land in the United States [1]. Approximately 90% of the forest C storage in the Upper Piedmont, in Georgia, was lost from presettlement (1770) through 1870 by land use change to agriculture [2]. The loss of soil C following conversion of forest land to agriculture is typically 20–40% within a few years after initial cultivation [3,4]. Most of this loss is from labile soil C pools through accelerated microbial decomposition when physically protected organic matter is released by soil disturbance [5,6].

There has been considerable recent interest in reversing past declines in soil C through practices that promote soil C sequestration. Soil C accumulation is one potential added benefit of short-rotation woody plantations. Based on limited information, Grigal and Berguson [7] hypothesized that soil C stocks might

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increase at a rate on the order of 100–200 g C m^{-2} yr^{-1} over a 10- to 15-year rotation, but they found no differences in C storage under agricultural land, hay pastures, and 6- to 15-year old hybrid poplar plantations in Minnesota. The absence of difference among various land cover types was attributed to soil C losses in the years immediately following plantation establishment. Prior studies of short-rotation hybrid poplar indicated that a soil C accumulation rate of ≈160 g C m^{-2} yr^{-1} is feasible [8].

Numerous studies indicate that conversion of agricultural land to permanent perennial vegetation creates conditions favoring C accumulation. Recent analyses indicate that land use change (i.e., forest regrowth on abandoned agricultural land) is a significant contributor to the historical aboveground C accumulation in eastern US forests [9]. Findings with respect to soil C accumulation following conversion of agricultural land to tree plantations are far more diverse. Some studies indicate relatively large increases in surface soil C stocks [10,11] while other studies have concluded that there is a very limited capacity for soil C accumulation [12]. Additional studies are needed on the potential for soil C accumulation under tree plantations in the southeastern US.

The purpose of this research was to estimate short-term rates of soil C accumulation under tree plantations recently established on abandoned agricultural land in Tennessee and South Carolina. In addition, total soil C stocks were partitioned between forest floor organic matter, particulate organic matter (POM), and mineral-associated organic matter (MOM) to determine the relative recovery of different soil C pools. Estimated changes in soil C inventories soon after tree plantation establishment (4–11 years) were compared with other estimates of soil C accumulation from prior studies.

2. Materials and methods

2.1. Study sites

Mean annual temperature and precipitation at each study site, based on 30-year climatological normals (1961–1990), were obtained from the Southeast Regional Climate Center in Columbia, SC. A brief description of each site (site codes are in parenthesis) follows by county:

McNairy County, TN [35°16′N, 88°29′ W]—A loblolly pine (*Pinus taeda* L.) plantation (LP-04) belonging to International Paper (formerly Champion International Corporation) was sampled in west Tennessee. The plantation was established in 1995 in a bottomland agricultural field. The remaining adjacent old field served as a reference site. For McNairy County, mean annual temperature was 14.9°C and mean annual precipitation was 146 cm.

Abbeville County, SC [34°26′ N, 82°20′ W]—Two adjacent loblolly pine plantations belonging to International Paper were sampled at an upland location. One was planted in November 1993 (LP-05) and the other in June 1993 (LP-06). Reference soil samples were collected from an adjacent old field. For Abbeville County, mean annual temperature was 15.6°C and mean annual precipitation was 125 cm.

Newberry County, SC [34°12′ N, 81°46′ W]—Two adjacent loblolly pine plantations with different ages were sampled at an upland location belonging to International Paper. One plantation was established in 1990 (LP-08) and the other in 1988 (LP-10) on an agricultural field. An adjacent fallow field was sampled as a reference site. For Newberry County, mean annual temperature was 15.6°C and mean annual precipitation was 125 cm.

Roane County, TN [35°54′ N, 84°20′ W]—Adjacent sweetgum (*Liquidambar styraciflua*) (SG-11) and sycamore (*Platanus occidentalis*) (SY-11) plantations were sampled in East Tennessee on the US Department of Energy's Oak Ridge Reservation. Both plantations were planted on a bottomland old field in early 1988. A remaining old field adjacent to these plantations was sampled as a reference site. For Roane County, mean annual temperature was 14.7°C and mean annual precipitation was 154 cm.

With the exception of Newberry County, vegetation at the reference sites adjacent to each forest plantation consisted of therophytes (annuals) and chamaephytes (primarily perennial grasses) typical of secondary succession on abandoned agricultural land in the southeastern US. The fallow field used for a reference site in Newberry County was mostly bare ground, except for scattered stubble from a prior year's crop. According to International Paper personnel, who were familiar with the history of each site, land use at the McNairy, Abbeville, and Newberry County sites prior to plantation establishment was agriculture. Land cover at the Roane County site was herbaceous (old field) vegetation prior to plantation establishment, but the land use was probably agriculture prior to acquisition of the property by the US Government in 1942.

2.2. Field sampling

Field sampling was conducted during May 1999. Four organic horizon samples and 4–8 mineral soil samples were collected within 10 m of a center point at each sampling site. Each sample of organic horizons ($O_i + O_e + O_a$) was collected by cutting and removing the organic layers from a 189 cm^2 area of ground. Organic horizons were transported to the laboratory in air-tight plastic bags and refrigerated until sample processing. Surface organic matter samples were not obtained when organic horizons were not present (i.e., at the McNairy County site). Mineral soil samples were collected to a depth of 50 cm in removable butyrate plastic liners (2.4 cm diameter) using a soil recovery probe with hammer attachment (AMS Soil Sampling Equipment, American Falls, ID). Plastic tubes containing the soil cores were capped, transported to the laboratory, and refrigerated prior to sample processing.

2.3. Sample preparation

Organic horizons were oven dried (70°C) and weighed to determine dry mass per unit area of ground. Each sample was then homogenized and ground to fine powder using a Tekator® sample mill. Soil cores were extruded from the plastic liners and surface debris was removed from the top of the mineral soil. Each mineral soil core was cut into 10-cm increments. Occasionally, the 40–50 cm increment was broken or missing. This resulted in missing data that precluded the calculation of cumulative soil C stocks over a 50-cm soil depth. For this reason, a decision was made to include only soil cores with intact increments to a depth of 40 cm in the analysis of cumulative soil C stocks.

Increments of fresh soil were air-dried (21°C) for 7–10 days (in a room with a dehumidifier) and weighed to determine soil bulk density (dry g cm^{-3}). Bulk density was corrected for coarse fragment content by sieving crushed soil samples through a 2 mm sieve and weighing the soil fractions >2 mm (rock and gravel) and <2 mm (mineral soil fraction). A portion of the mineral soil fraction was homogenized and ground with a mortar and pestle to pass a #35 sieve (0.5 mm). The remaining mineral soil fraction (crushed but not ground) was stored in an air-tight glass bottle.

2.4. Soil texture

Soil texture (percentages of sand, silt, and clay) was determined by the hydrometer method [13] on two or more surface (0–40 cm) soil samples from each study site. Forty grams of the crushed mineral soil (<2 mm) were dispersed by shaking overnight in an aqueous solution of sodium hexametaphosphate (5 g l^{-1}) prior to particle size analysis.

2.5. Particulate organic matter

Organic matter in surface (0–40 cm) soil samples was separated into particulate organic matter (POM) and mineral-associated organic matter (MOM) by wet sieving [14]. Separations were performed on four soil samples from each study site. Twenty grams of dry mineral soil (<2 mm) were dispersed by shaking overnight in a 100-ml solution of sodium hexametaphosphate (5 g l^{-1}). The mixture was then sieved through a 0.053-mm sieve. The POM ($\geqslant 0.053$ mm) was recovered by back-washing the sieve followed by filtration (Whatman filter paper #541). POM consisted of free organic debris and some larger fragments of organic matter released by dispersion of soil aggregates. The MOM fraction (<0.053 mm) was recovered by evaporation. MOM consisted of soil C associated with silt and clay size particles and some smaller fragments of organic matter released by dispersion of soil aggregates. Both fractions were weighed after oven drying (65°C) and ground using a mortar and pestle to pass a #35 sieve (0.5 mm).

Soil C in the POM or MOM fraction (g C g^{-1} soil) was calculated by multiplying the dry mass of each part (g part g^{-1} soil) by the respective C concentration (g C g^{-1} part). In each soil core, the fraction of total soil C in MOM (F_m) was calculated as: $F_m = \text{MOM-C}/(\text{POM-C} + \text{MOM-C})$, where POM-C and MOM-C are amounts of soil C (g C g^{-1} soil) in the POM and MOM fractions, respectively. The

Table 1
Mean (±SE) dry mass, C and N content, and C:N ratio for the organic horizons at six tree plantations (based on 4 replicate samples at each site)

Plantation type	Site	Mass ($g\ m^{-2}$)	C content ($g\ C\ m^{-2}$)	N content ($g\ N\ m^{-2}$)	C:N ratio
Loblolly	LP-05	525±34	251±29	3.5±0.5	73.2±9.3
	LP-06	785±146	320±53	5.1±1.2	68.1±7.9
	LP-08	2597±90	1255±46	24.2±1.4	52.3±2.1
	LP-10	3428±438	1604±227	29.1±2.3	54.3±3.8
Sweetgum	SG-11	541±41	161±17	4.6±0.5	34.8±0.3
Sycamore	SY-11	918±125	389±63	11.4±1.6	34.0±0.9

fraction of soil C in the POM part (F_p) was equivalent to $1 - F_m$. Inventories of mineral-associated C (g C m^{-2}) were calculated by multiplying F_m by the cumulative soil C inventory in the surface 40 cm of soil. The inventory of C in the POM part was calculated, in a similar manner, by substituting F_p for F_m.

2.6. Sample analysis

Ground samples were analyzed for total C and N using a Perkin Elmer 2400 Series II CHNS/O Analyzer. Tyrosine ($0.597\ g\ C\ g^{-1}$; $0.077\ g\ N\ g^{-1}$) and tetraoctadecylammonium bromide ($0.786\ g\ C\ g^{-1}$; $0.012\ g\ N\ g^{-1}$) were used as calibration standards. Coefficients of variation associated with repeated elemental analysis of the standards ($n = 89$) were $<2\%$ for C and $<8\%$ for N.

2.7. Calculations

Rates of soil C accumulation were estimated by comparing soil C inventories under tree plantations with nearby reference sites. Soil C inventories (S, $g\ C\ m^{-2}$) were calculated from the following equation: $S = (d)(b)(c)$, where, d is the length of the soil increment (m), b the bulk density for the soil increment (kg dry soil m^{-3}), and c the soil C concentration ($g\ C\ kg^{-1}$ dry soil). Cumulative inventories in the top 40 cm of mineral soil were calculated by adding C inventories in the 0–10, 10–20, 20–30, and 30–40 cm soil increments. Total soil C inventories were apportioned between labile soil C and mineral-associated soil C. The former pool was calculated as the sum of C stocks in the forest floor organic horizons ($O_i + O_e + O_a$) and the POM fraction from the mineral soil. Labile soil C is a relatively small but dynamic soil C pool [15]. Analysis of variance (ANOVA) was used to test for statistically significant differences in soil C stocks. Mean values were compared by least significant difference (LSD) [16].

3. Results

3.1. Climate and soil texture

The climate was similar (temperate and humid) for all four counties. Mean annual temperatures differed by $<1^{\circ}C$ and annual precipitation was >120 cm. Soil texture analysis indicated that the tree plantations in Tennessee (LP-04, SG-11, and SY-11) were located on loam soils while those in South Carolina were located on sandy clay loams (LP-05, LP-08, and LP-10) or sandy clays (LP-06).

3.2. Forest floor carbon and nitrogen inventories

Properties of the organic soil horizons in pine and deciduous plantations were analyzed separately. There were significant differences among the loblolly plantations in O-horizon mass ($F_{3,12} = 35.6, P < 0.001$, LSD=726 $g\ m^{-2}$), C content ($F_{3,12} = 32.1$, $P < 0.001$, LSD = 368 $g\ C\ m^{-2}$), and N content ($F_{3,12} = 78.1$, $P < 0.001$, LSD = 4.6 $g\ N\ m^{-2}$). All three attributes of the forest floor increased with stand age (Table 1). Over the first 10 years of tree growth, the indicated rate of forest floor C accrual was ≈50 and 160 $g\ C\ m^{-2}\ yr^{-1}$, respectively, at sites in Abbeville and Newberry Counties. Forest floor

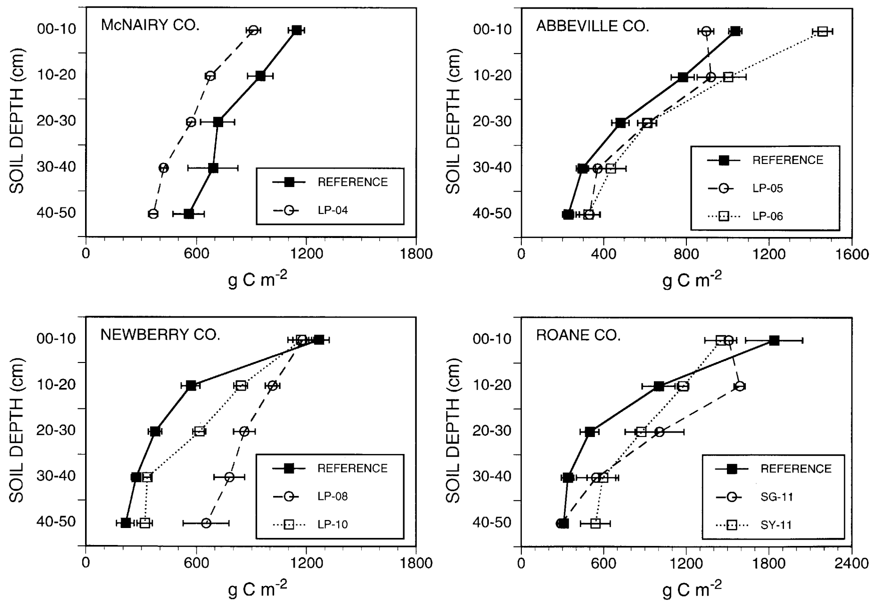

Fig. 1. Vertical profiles of mean (±SE) soil C inventories at the various study sites. "REFERENCE" indicates reference soil, and LP-04, LP-05, LP-06, LP-08, and LP-10 denote 4-, 5-, 6-, 8-, and 10-year old loblolly pine plantations. SG-11 and SY-11 denote, respectively, 11-year old sweetgum and sycamore plantations.

C:N ratios were not significantly different among the four loblolly plantations ($F_{3,12} = 2.5$, $P > 0.10$). However, as a group, mean (±SE) forest floor C:N ratios in loblolly stands (62.0 ± 3.7) were significantly greater than those in deciduous stands (34.4 ± 0.5) ($F_{1,22} = 27.1$, $P < 0.001$). Forest floor C:N ratios in the sweetgum and sycamore stands, in Roane County, were not significantly different ($F_{1,6} = 0.7, P > 0.10$). The sycamore plantation had significantly more dry mass ($F_{1,6} = 8.1$, $P < 0.05$), C content ($F_{1,6} = 12.2$, $P < 0.05$), and N content ($F_{1,6} = 15.5, P < 0.01$) in the forest floor than the sweetgum plantation, but the two 11-year old deciduous stands had much lower forest floor C and N inventories than the 10-year old loblolly plantation, LP-10 (Table 1).

3.3. Vertical profiles in soil carbon inventories

Carbon inventories decreased with soil depth at all study sites (Fig. 1). In McNairy County, soil C stocks under the 4-year old loblolly plantation (LP-04) were significantly less than those in reference soils for the 0–10 cm ($F_{1,10} = 13.5$, $P < 0.01$), 10–20 cm ($F_{1,10} = 20.5$, $P < 0.01$), 30–40 cm ($F_{1,10} = 7.9$, $P < 0.05$), and 40–50 cm ($F_{1,9} = 7.6$, $P < 0.05$) soil increments. This pattern was mostly reversed at the remaining study sites. In Abbeville County, the 6-year old plantation (LP-06) had significantly more soil C than the reference soil in the 0–10 cm soil increment ($F_{2,21} = 53.8$; $P < 0.001$). Differences at deeper soil depths (10–50 cm) were not statistically significant ($P > 0.05$). In Newberry County, soil C stocks at the top of the soil profile (0–10 cm) in the 8- and 10-year old plantations (LP-08 and LP-10, respectively) were not significantly different from those at the reference site ($F_{2,20} = 0.8, P > 0.1$), but there was significantly more C beneath both loblolly stands in the 10–20 cm ($F_{2,20} = 27.1, P < 0.001$) and 20–30 cm ($F_{2,20} = 27.7$, $P < 0.001$) soil increments. Significantly greater soil C stocks beneath loblolly pine continued to the 50-cm soil depth for the 8-year old plantation (LP-08). Soil C stocks in the 30–40 cm ($F_{2,20} = 27.2$, $P < 0.001$) and the 40–50 cm ($F_{2,20} = 7.1$, $P < 0.01$) increments were significantly greater at LP-08 relative to the

Table 2
Mean (±SE) mineral soil C stocks (0–40 cm) beneath tree plantations and reference sites, soil C:N ratios (0–40 cm), and the estimated annual rate of mineral soil C sequestration (ΔC, g C m^{-2} yr^{-1}) beneath young tree plantations

Site	Soil C inventory (g C m^{-2})		Soil C:N	ΔC	F-value	P
	Plantation	Reference				
LP-04	2568±73 (8)	3492±322 (4)	13.0±0.6	−231	14.8	0.01
LP-05	2791±155 (8)	2595±110 (8)	17.5±1.3	39	1.1	ns
LP-06	3505±170 (8)	2595±110 (8)	15.6±1.8	152	20.3	0.001
LP-08	3834±137 (8)	2483±144 (7)	15.0±1.0	169	45.9	0.001
LP-10	2956±82 (8)	2483±144 (7)	14.9±0.6	47	8.7	0.05
SG-11	4649±289 (4)	3676±82 (4)	11.1±0.1	88	10.5	0.05
SY-11	4100±239 (4)	3676±82 (4)	14.9±0.7	39	2.8	ns

Sample size is indicated in parenthesis; P= probability level (α) for the statistical comparison of soil C inventories between each plantation and reference site; *ns*= not statistically significant ($P > 0.05$).

reference site. In Roane County, soil C stocks at the top of the soil profile (0–10 cm) under sweetgum (SG-11) and sycamore (SY-11) were not significantly different ($F_{2,9} = 2.3$, $P > 0.1$) from those in the reference old field. However, soil C stocks in the 10–20 cm ($F_{2,9} = 15.4$, $P < 0.01$) and 20–30 cm ($F_{2,9} = 4.2$, $P = 0.05$) increments were significantly greater under the sweetgum plantation than under the old field (Fig. 1).

3.4. Differences in soil C:N ratios

There were no differences in soil C:N ratios between study sites within each county, but there were differences among counties ($F_{6,41} = 2.6$, $P < 0.05$) that are probably related to natural geographic variation in soil type (Table 2). The highest mineral soil C:N ratios were measured under stand LP-05 and the lowest C:N ratios were measured under stand SG-11. Soil C:N ratios were positively correlated with forest floor C:N ratios ($r = +0.90$, $P < 0.05$).

3.5. Cumulative inventories and rates of soil carbon accumulation

Carbon inventories in the surface 40 cm of mineral soil at the various study sites are presented in Table 2. Carbon accumulation was estimated as the difference between soil C stocks under tree plantations and reference sites. There was no discernible correlation between soil C accumulation rates and stand age. Furthermore, soil C accumulation rates less than ≈40 g C m^{-2} yr^{-1} (i.e., sites LP-05 and SY-11) were not significantly different from zero. The data indicated that all plantations studied, with the exception of LP-04, were sequestering soil C at rates ranging from ≈40 to 170 g C m^{-2} yr^{-1}.

3.6. Partitioning of soil carbon

In McNairy County, 10 ± 1% (mean ± SE) of the soil C inventory was associated with the POM fraction (Fig. 2). A significantly ($F_{3,40} = 4.1$, $P < 0.05$) higher percentage of the soil C inventory was associated with POM at sites in Abbeville County (20 ± 1%) and Newberry County (17 ± 2%). In Roane County, there was significantly ($F_{2,9} = 6.4$, $P < 0.05$) more soil C in the POM fraction at the reference site (27%) than at the 11-year old sycamore (SY-11) and sweetgum (SG-11) plantations.

Soil C stocks in the POM and MOM fractions from the 4-year old loblolly stand in McNairy County (LP-04) were 26% less than those at the reference site. At older loblolly stands in Abbeville and Newberry Counties, soil C stocks in the POM and MOM fractions increased between 8% and 54% relative to the reference sites. At the 11-year old sweetgum (SG-11) and sycamore (SY-11) stands in Roane County, soil C stocks in the MOM fraction increased (49% and 31%, respectively) and those in the POM fraction decreased (34% and 42%, respectively) relative to the reference site (Fig. 2). Across all sites,

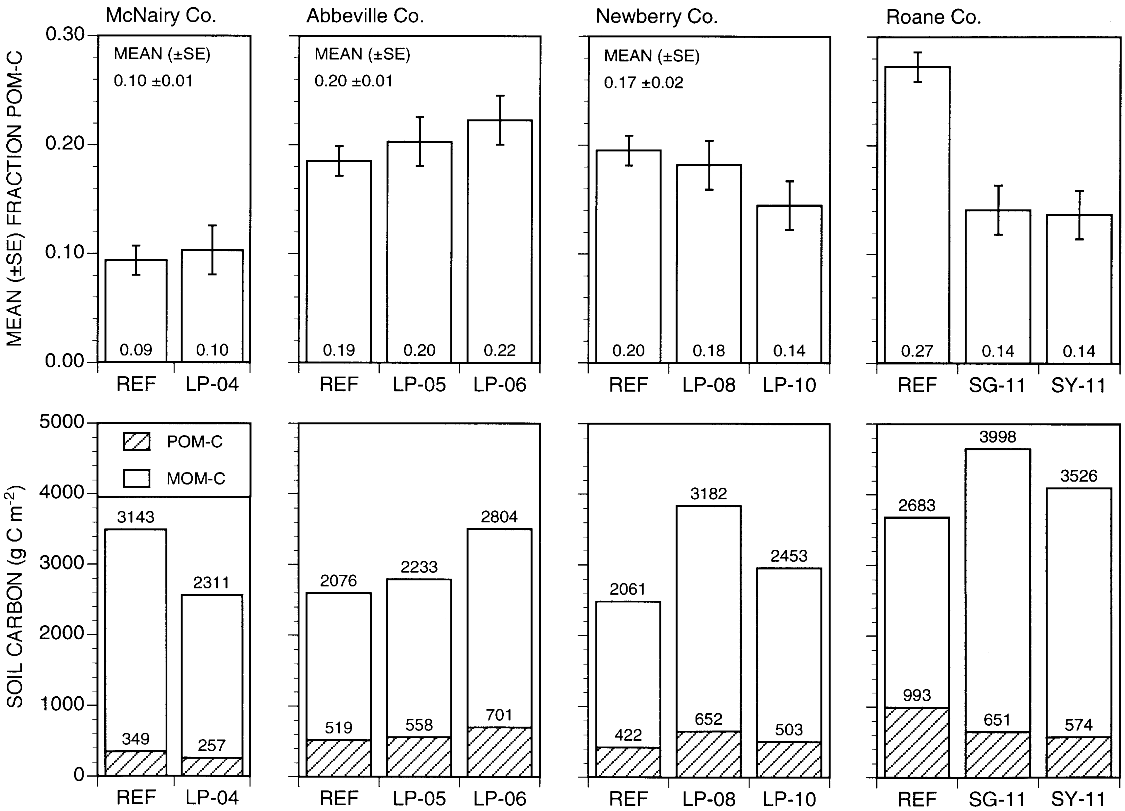

Fig. 2. Upper panels: mean (±SE) fraction of the soil C inventory associated with particulate organic matter (POM) in mineral soil samples (0–40 cm) from each study site. Lower panels: Soil C inventories (g C m^{-2}) in POM and mineral-associated organic matter (MOM) fractions at each study site. "REF" indicates reference soil, and LP-04, LP-05, LP-06, LP-08, and LP-10 denote 4-, 5-, 6-, 8-, and 10-year old loblolly pine plantations. SG-11 and SY-11 denote, respectively, 11-year old sweetgum and sycamore plantations.

the relative change in POM-C was correlated with percent sand ($r = +0.88$, $P < 0.01$), percent silt ($r = -0.90$, $P < 0.01$), and the soil C inventory at the reference site ($r = -0.93$, $P < 0.01$). Soils with a high sand content and low initial C stocks exhibited the greatest gains in POM-C.

Final partitioning of soil C at the 7 plantation sites is presented in Table 3. Carbon stocks in the forest floor (Table 1) and the POM fraction (Fig. 2) were summed to estimate labile soil C [15]. Even though 10–11-year old plantations (LP-10, SY-11, and SG-11) had similar total soil C inventories, there was relatively less labile soil C in deciduous stands (17–22%) than in the loblolly plantation (46%). This difference was due primarily to the lower forest floor mass in deciduous stands (Table 1).

Table 3
Stocks of labile, mineral-associated (MOM-C), and total soil C (40 cm soil depth) at seven recently established tree plantations in the southeastern United States. The last column shows the percent of total soil C in the labile pool (O-layer + POM-C)

Site	Soil C inventory (g C m^{-2})			(% Labile)
	Labile C	MOM-C	Total	
LP-04	257	2311	2568	10
LP-05	809	2233	3042	27
LP-06	1021	2804	3825	27
LP-08	1907	3182	5089	37
LP-10	2107	2453	4560	46
SG-11	812	3998	4810	22
SY-11	963	3526	4489	17

4. Discussion

A necessary assumption in this study was that soil C inventories were identical at each paired plantation and reference site prior to plantation establishment. The latter assumption is reasonable given the proximity of each reference site to its companion plantation. It is also assumed that soil C stocks at the reference site had not changed significantly between the time of plantation establishment and soil sampling. Soils data are not available to test this latter assumption, but individuals familiar with the study sites indicated that the reference areas were essentially unchanged in appearance since plantation establishment. Hence , there was no indication of disturbance that could have substantially altered the reference soil C stocks and thereby invalidated comparisons with soil C stocks under the tree plantations. Although this comparative approach has limitations, it has been frequently used when data on soil C stocks prior to land use conversion are not available. For example, most of the data reviewed by Post and Kwon [17] on potential rates of soil C accumulation following the conversion of agricultural land to perennial vegetation were derived using a comparative method.

Estimated rates of soil C accumulation at most of the tree plantations in this study were considerably greater than rates of soil C accumulation summarized for warm temperate forests from the southeastern US by Post and Kwon [17]. The latter estimates were based on comparisons between forest and reference sites that spanned a time frame of 40–200 years. Post and Kwon acknowledged uncertainties in estimated rates of soil C accrual that arise from long averaging times (typically several decades) and the potential for nonlinear dynamics in soil C accumulation under perennial vegetation. Rates of forest soil C accumulation may be underestimated if the rate of soil C accrual is highest immediately after tree establishment but declines with stand age. Other studies indicate potentially high rates of C accrual immediately after forest establishment followed by lower rates of C storage with declining dry matter production [10,18]. Rates of soil C accumulation in pine and hardwood plantations examined during the current study ranged from $\approx$40 to 170 g C m^{-2} yr^{-1} during the first decade of tree growth. These rates are in accord with those reported for newly established hybrid poplar plantations ($\approx$160 g C m^{-2} yr^{-1}) in the North Central US [8].

Only the McNairy County site (LP-04) indicated a net loss of mineral soil C stocks following plantation establishment. This was the youngest plantation sampled and the only plantation that did not have a closed forest canopy. Temporary losses of soil C can accompany plantation establishment [7,8], depending on the methods used for site preparation [19], followed by net gains as the stand matures [7,8]. However, it is also possible that antecedent conditions differed between the reference and forested site in McNairy County. Vertical profiles of soil C stocks at the remaining plantations indicated a tendency for significant soil C accrual with depth (particularly at 10–30 cm). Greater mineral soil C stocks with depth under plantations, as compared to reference sites, can be attributed to the turnover of deeper tree roots. The majority of the mineral soil C inventory at each site was found in the silt–clay size soil fraction or mineral-associated organic matter (Fig. 2). Gains in MOM-C at tree plantations in Abbeville, Newberry, and Roane Counties are important to soil C sequestration because MOM-C appears to have a longer turnover time than POM-C [20].

High rates of C accumulation in mineral soils under tree plantations in the southeastern US are not in accord with some published reports. Studies along loblolly pine chronosequences in Virginia indicate that reforestation of abandoned old fields can result in substantial increases in ecosystem C storage, but only 10% of the total ($\approx$25 g C m^{-2} yr^{-1}) can be ascribed to C accumulation in mineral soil [10]. Richter et al. [12] concluded that surface mineral soils under loblolly pine at the Calhoun Experimental Forest, in South Carolina, had an even more limited capacity for mineral soil C accumulation ($\approx$4 g C m^{-2} yr^{-1} or <1% of total ecosystem C accretion). They noted that the latter rate was relatively low compared to previous estimates of forest soil C accumulation. The low rate was attributed to rapid decomposition of organic matter in a warm climate, and coarse textured soils with a clay mineralogy that did not promote physical protection of soil C [12].

Accelerated decomposition rates under warm climates cannot, alone, explain low rates of soil C accumulation. Even subtropical soils can exhibit relatively rapid rates of soil C accumulation after abandonment of cultivation. For example, soils in Puerto Rico accumulated ≈30–50 g C m^{-2} yr^{-1} and soil C was restored to ≈90% of that found in mature forests in 50 years of secondary forest succession [21]. Estimated rates of surface soil C accumulation under loblolly plantations in the present study are more in accord with studies by Van Lear et al. [11] who reported soil C gains on the order of 3–4% yr^{-1} (over a period of 55 years) at the Clemson Experimental Forest in Clemson, SC.

Despite a tendency to focus on larger, older, and more recalcitrant soil pools as being the main determinants of global soil C dynamics [22–24], it is important to not overlook the potential for rapid C accumulation in labile soil C pools and their importance to soil quality [15]. Labile soil C pools, like forest floor litter layers and free POM, are comprised of undecomposed and partially decomposed organic debris. Although POM can be protected through soil aggregate formation [25–27], the assumption in defining labile soil C (Table 3) is that larger sized POM ($\geqslant 0.053$ mm) in the mineral soil is mostly free (or "unprotected"), especially in sandy soils that exhibit poor soil aggregate stability. Smaller sized organic matter (< 0.053 mm) is mostly protected from decomposition through associations with silt and clay or inclusion within soil aggregates. In the current study, calculations indicated high rates of accrual for forest floor soil C stocks (≈50–160 g C m^{-2} yr^{-1}) under recently established loblolly pine stands. Although forest floor organic matter is not a reservoir for long-term soil C storage, it is an important substrate from which POM-C and MOM-C in the mineral soil are ultimately derived. Even studies indicating a limited potential for mineral soil C sequestration under tree plantations report relatively high rates of soil C storage (≈40–100 g C m^{-2} yr^{-1}) in forest floor O-horizons following plantation establishment [10,12,18,28].

Although there was a tendency for MOM-C to increase with stand age (Table 3), much of the soil C accrual under loblolly pine was due to the accumulation of forest floor organic matter. After only one decade, labile soil C accounted for almost half of the total soil C inventory at the 10-year old plantation in Newberry County (LP-10). The strong differences in labile soil C beneath similar aged loblolly (LP-10) and deciduous stands (SY-11 and SG-11) (Table 3) are attributed to a lower C:N ratio in leaf litter and a more mesic environment at the deciduous plantations; both factors promote more rapid decomposition and lower standing stocks of deciduous forest floor litter mass (Table 1).

In summary, soil C accumulation can be highly variable, even within the same general geographic region, but high rates of soil C accumulation are apparently possible following farm to tree plantation conversions in the southeastern US. Although the turnover time of labile soil C is inversely related to mean annual temperature [15,20,29], a warm climate does not necessarily preclude rapid accumulation of soil C under young, aggrading tree plantations. More research is needed to improve our understanding about: (1) the factors controlling rates of soil C accumulation in temperate-zone tree plantations, (2) the potential importance of forest floor litter and POM as pools for short-term soil C storage, and (3) improvements in soil quality that accrue through the accumulation of organic matter under newly established tree plantations in the southeastern US.

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