Land Management Effects on Near-Surface Soil Properties of Southeastern U.S. Coastal Plain Kandiudults

M.R. Levi*
J.N. Shaw
C.W. Wood
Agronomy and Soils Dep.
202 Funchess Hall
Auburn Univ.
Auburn, AL 36849

S.M. Hermann
Dep. of Biological Sciences
331 Funchess Hall
Auburn Univ.
Auburn, AL 36849

E.A. Carter
USDA Forest Service
520 Devall Dr.
Auburn, AL 36849

Y. Feng
Agronomy and Soils Dep.
202 Funchess Hall
Auburn Univ.
Auburn, AL 36849

The National Cooperative Soil Survey is evaluating techniques for better characterization of near-surface, management-dependent soil properties associated with soil change (decade to century time scale). The U.S. Soil Taxonomy and soil surveys have been developed with emphasis on subsoil properties to reduce the impacts of management on taxonomic placement. Considering the importance of near-surface properties on ecosystem function, however, some degree of characterization of these properties is essential. The objectives of this study were to evaluate land use effects on management-dependent soil properties, C stocks, and soil quality of mature longleaf pine (*Pinus palustris* Miller) systems relative to more intensively cultivated land use systems in the southeastern U.S. Coastal Plain. Sites in Thomas County, Georgia, representing well-drained, upland Kandiudults, were selected in each of three land use systems for comparison of near-surface soil properties. Studied land use systems were mature, multi-aged longleaf pine forest (LL), slash pine (*Pinus elliottii* Engelm.) plantation (PP), and conventional row crop (RC) systems. Concentrations of microbial biomass C (0–5 cm) in LL were 69% greater than RC, and LL sequestered 64% more total organic C than RC systems. Inputs of fertilizer were evident in RC (0–30 cm) based on greater exchangeable K (433% greater in LL), base saturation, and extractable P (1700% greater in LL). The soil infiltration rate was 1015% greater in LL than in PP. Principal component analyses indicated that 80% of data variability was explained by exchangeable bases, C pools, and hydraulic soil properties. Clustering suggested that near-surface soil properties were more similar by land use than by taxonomic-based soil map units. Land use changed many of the investigated surface soil properties (0–30 cm) at these Coastal Plain sites, resulting in functional and interpretive differences of these soils within similar taxa.

Abbreviations: AWHC, available water holding capacity; BS, base saturation; CEC, cation exchange capacity; C_{min}, potentially mineralizable C; ECEC, effective cation exchange capacity; IR, infiltration rate; LL, longleaf pine forest; PC, principal component; PCA, principal component analysis; POM, particulate organic matter; PP, slash pine plantation; RC, conventional row crop; ρ_b, bulk density; SS, soil strength; TOC, total organic carbon; TON, total organic nitrogen; WDC, water-dispersible clay; WSA, water-stable aggregates.

A comparative assessment of land management systems and relatively undisturbed ecosystems is useful for evaluating anthropogenic impacts on soil properties (Larson and Pierce, 1994). Such information is useful for the restoration and evaluation of C sequestration potential. Comparison of disturbed with natural ecosystems allows the measurement of soil properties associated with soil change, with a particular emphasis on those that change due to management (Tugel et al., 2005).

Dynamic soil properties are defined as properties that change across human time scales (decadal to centurial) due to natural, human, and other factors (Tugel et al., 2008). Soil properties in the near surface (often described as the upper 0.5 m) that change at human time scales due to management (termed *management-* or *use-dependent* properties) fit within this concept (Richter and Markewitz, 2001; Tugel et al., 2005; Smeck and Olson, 2007). In addition, there is a link between

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*Corresponding author (mrlevi21@email.arizona.edu)

management-dependent soil properties and soil quality (Norfleet et al., 2003). Doran and Parkin (1994) defined soil quality as the capacity of a soil to function, and it is often described as having both dynamic and inherent aspects (Norfleet et al., 2003; Tugel et al., 2005). The assessment of management-dependent properties is often equated with the dynamic component of soil quality.

Considering that soil quality is a relative interpretation of a soil's condition, several researchers have proposed a minimum data set of soil properties for use in this assessment (Doran and Parkin, 1994; Larson and Pierce, 1994). Similarly, measures of certain soil properties have been proposed for the evaluation of soil change (Tugel et al., 2008). Several soil physical, chemical, and biological properties have been suggested (Karlen et al., 1992; Tugel et al., 2008), with the understanding that the criteria change for each desired use (Nortcliff, 2002). In addition, regional variation of soil properties complicates the assessment and comparison of these properties (Brejda et al., 2000). Fractions (size and density) and distributions of C and N pools (Wood et al., 1992), particulate organic matter (POM) (Cambardella and Elliott, 1992), bulk density (ρ_b), soil strength (SS) (Blanco-Canqui et al., 2005), hydraulic conductivity (Seobi et al., 2005), aggregate stability (Ashagrie et al., 2007), soil water retention, and the infiltration rate (IR) (Fesha, 2004) are just some of the properties that have been investigated in dynamic soil property assessment of near-surface samples.

Incorporating sets of multiple soil properties (i.e., multivariate data) into an analysis of soil change and quality is useful for interpreting land use effects because it can both provide a holistic comparison and highlight dynamic soil properties that are most definitive in particular regions or landscapes. Multivariate statistical techniques can reduce data to facilitate interpretation and identify properties that describe the majority of the data variability, thereby allowing development of minimum data sets and clusters or groups with similarity for comparing data. Applying these techniques to soil properties can provide a more holistic interpretation of the soil condition as well as facilitate comparisons among land use systems. Common methods include factor analysis, principal component analysis (PCA), and cluster analysis. Factor and principal component (PC) analyses create independent factors or components of linear combinations of data (Andrews et al., 2002; Sena et al., 2002), whereas cluster analysis links data into natural clusters or groups (Sena et al., 2002). Common clustering techniques utilize isodata or fuzzy *k*-mean approaches (Irvin et al., 1997). Past studies have used multivariate approaches to characterize dynamic soil properties (Duffera et al., 2007; Liebig et al., 2004; Wander and Bollero, 1999).

Incorporation of functional aspects of soil change with soil inventory and natural resource planning has been suggested as a necessary component of the National Cooperative Soil Survey (Tugel et al., 2005, 2008). The heterogeneity (spatial variability) of soils is compounded by temporal variability often resulting from anthropogenic processes. The U.S. Soil Taxonomy was developed with an emphasis on subsoil properties to reduce the impacts of management on taxonomic placement. Although it is difficult to inventory near-surface soil properties in taxonomic-based soil surveys, it is recognized that characterizing the variability of these properties and associating these with a particular management can improve soil survey interpretations. Evaluation of the relationships between management-dependent and inherent soil properties can potentially improve ecosystem management and soil interpretation (Norfleet et al., 2003).

In the southeastern United States, the inclusion of a relatively undisturbed ecosystem in soil dynamic property assessment has been rare due in part to the scarcity of undisturbed land. Before European settlement, the southern United States had an estimated 37 million ha of LL habitat (Frost, 1993). Due to conversion of these forests to agricultural land and the decimation of LL by logging and turpentining, only 3% of the original acreage currently supports LL (Frost, 1993). In the Eastern Gulf Coastal Plain, LL–wire grass (*Aristida stricta* Michx.) habitat is important for endangered species such as the red cockaded woodpecker (*Picoides borealis* Vieillot) and gopher tortoise (*Gopherus polyphemus* Daudin) (Van Lear et al., 2005). This native ecosystem is among the most plant-species-rich ecosystems in temperate regions (Brockway et al., 2005; Peet and Allard, 1993), and numerous restoration projects are underway in an effort to expand current acreage and recover this once widespread forest ecosystem (Van Lear et al., 2005). Thus, for these systems, an improved understanding of soil change due to management can be useful for C sequestration and LL forest restoration efforts. Furthermore, a better understanding of the management dependency of soils can also contribute to the development of a minimum data set for assessing soil change and quality in this region.

Thus, considering the importance of soil change to the National Cooperative Soil Survey and the relevance of C sequestration and restoration of LL–wire grass habitat to many entities, our objectives were to: (i) evaluate land use effects on management-dependent soil properties, C stocks, and soil quality of mature LL–wiregrass systems compared with PP and RC land use systems in the southeastern U.S. (Georgia) Coastal Plain, (ii) determine the soil properties important for evaluating soil change in these systems, and (iii) assess near-surface soil property relationships between taxonomic-based soil map units and land use systems. Addressing these objectives will improve our understanding of soil change in typical southeastern U.S. Coastal Plain landscapes.

MATERIALS AND METHODS

Land Use Systems

Land use impacts were evaluated on Coastal Plain soils in Thomas County, Georgia. Our experiment was considered a "space-for-time" study (Tugel et al., 2008), where measurements are made on systems that are already in place as opposed to monitoring with time. Descriptions of the three land use systems are as follows:

Longleaf (LL) consisted of mature, multi-aged longleaf pine forest with intact native ground cover. Previous work on this site documented trees ranging in age from seedlings to 200+ yr (Platt et al., 1988) and described a ground layer of grass (i.e., wire grass, legume, and composite species (Hermann, 1993). Fire, both prescribed (lately) and natural (historical), plays a major role in these systems. Pines are replenished by natural regeneration, and the canopy is generally open. Soils have been subjected to minimal surface disturbance within the last several decades.

Planted pine (PP) consisted of 22-yr-old planted slash pine stands in the first rotation managed for poles or saw timber. These sites were subjected to infrequent fire and mechanical treatment, with the most substantial soil disturbance taking place during site preparation. Land use before the current slash pine rotation is unknown.

Row crop (RC) sites have been in continuous agricultural cropping for 30 to 35 yr with a rotation of corn (*Zea mays* L.)–peanut (*Arachis hypogaea* L.)–soybean [*Glycine max* (L.) Merr.], and infrequent fallowing. Soils are under conventional tillage management with major soil disturbance (e.g., plowing, disking, cultivating, and harvesting) taking place annually.

Map Unit Selection and Pedon Characterization

Selection of sampling locations and map units involved the use of soil survey, digital ortho-quadrangle maps, and ground truthing. Soil map units that represented well-drained upland soils were selected for this study. Soils that typified map units were described, sampled by horizon, analyzed in the laboratory, and classified according to Soil Taxonomy (Soil Survey Staff, 2003). Laboratory analyses of soil horizons for pedon characterization and soil classification included particle size determination by the <2-mm pipette method following soil organic matter removal with H_2O_2 and dispersion with sodium hexametaphosphate (Kilmer and Alexander, 1949), cation exchange capacity (CEC) and base saturation (BS) (Ca, Mg, K, and Na) by the NH_4OAc method (pH 7) using an autoextractor, extractable Al using 1 mol L^{-1} KCl (Al concentrations were determined via titration), and effective CEC (ECEC) by combining extractable Al with exchangeable bases (Soil Survey Investigation Staff, 2004).

Soils (nine pedons) that typified the map units were classified as: (i) fine, kaolinitic, thermic Typic Kandiudults (n = 3) (FaB, Faceville loamy sand, 0–5% slopes); (ii) fine-loamy, kaolinitic, thermic Typic Kandiudults (n = 2) and a fine-loamy, kaolinitic, thermic Typic Kanhapludult (n = 1) (OrB, Orangeburg loamy sand, 0–5% slopes); and (iii) loamy, kaolinitic, thermic Arenic Kandiudults (n = 2) and a loamy, kaolinitic, thermic Arenic Kandiudalf (n = 1) (LuB, Lucy loamy sand, 0–5% slopes).

For this study, Kandiudults (clay content does not decrease $\geq$20% relative to the maximum within 1.5 m) and Kanhapludults (clay content does decrease $\geq$20%) were considered similar. Soils were grouped by map unit; thus, three map units were investigated.

The experimental design was a randomized complete block with three blocks (soil map units of FaB, OrB, and LuB) of three land use types (LL, PP, and RC), for a total of nine sites. Land use systems were located within 15 km of each other, and the sites were clustered within each land use (0.5–1.5 km). We utilized natural boundaries of the soil map units for blocking; therefore, differences between soils were assumed to reflect land use and management.

Field Sampling Procedures

The nine sites were sampled in 2006 to 2007 for chemical, biological, and physical analyses. Each site represented a map unit–land use combination and all sampling was conducted within the natural boundaries of each respective map unit and located within a 3-m radius of a geographic positioning system (GPS) location. Organic horizons were sampled in forested sites (three 0.25-m^2 quadrats), and these horizons were removed before taking mineral soil samples. Composite soil samples (20 cores taken with hand probes) were taken from three depths (0–5, 5–15, and 15–30 cm) before being transferred to cool storage for transport. Undisturbed ρ_b samples (three at each site) were obtained using a slide hammer (4.7-cm-diameter cores) at depths of 0 to 5, 5 to 15, and 15 to 30 cm.

Three random samples at each site were taken at two depths (0–5 and 5–15 cm) for the determination of water-stable aggregates (WSA). Undisturbed soil cores (6 cm high by 5.4-cm diameter) (three at each site–depth combination) were taken at three depths (0–6, 7–13, and 20–26 cm) for measurement of the soil water holding capacity at field capacity (10-kPa matric suction).

Laboratory Procedures

Composite soil samples were used for the majority of the laboratory analyses. Field-moist samples were sieved (2 and 4 mm for mineralizable C and N and microbial biomass C, respectively) to remove plant materials and other debris. Soil microbial biomass C was determined by a chloroform fumigation–incubation technique (Alef and Nannipieri, 1995). Potentially mineralizable C and N (C_{min} and N_{min}, respectively) were determined using a 31-d aerobic incubation technique described by Wood et al. (1992). Soil total organic C (TOC) and total organic N (TON) were determined by the dry combustion method with a TruSpec CN analyzer (Leco Corp., St. Joseph, MI) (Yeomans and Bremner, 1991). Carbon turnover and relative N mineralization were calculated as the ratio of C_{min} and N_{min} to TOC and TON, respectively. Air-dried samples were used to determine POM C and N (>53 μm) (Cambardella and Elliott, 1992). Mineral-associated C and N (<53 μm) were determined by difference (i.e., TOC or TON minus POM C or N). Aggregate-protected organic matter was not differentiated in this study. Organic horizons (O) were air dried and weighed, thoroughly mixed, and sampled for analysis of TOC and TON by dry combustion (CN-2000, Leco Corp.). Two grab samples were taken from each field sample, and values were averaged to represent the sample.

Chemical analyses of mineral soil samples for the 0- to 5-, 5- to 15-, and 15- to 30-cm depths were performed on air-dried samples (<2 mm). The CEC, BS, extractable Al, and ECEC were determined as above, extractable nutrients (P, Fe, Mn, Zn, Cu, and B) were measured using the Mehlich 1 (double-acid) technique (Hue and Evans, 1986), and soil pH was measured in 1:1 soil/water (Soil Survey Staff, 2004).

Air-dried samples (<2 mm) were used to determine water-dispersible clay (WDC), particle size distribution, and soil water holding capacity at 1.5 MPa. Determination of particle size by the <2-mm pipette method followed the method described above. The amount of WDC was determined using a modification of the method outlined by Miller and Miller (1987). Four laboratory replicates of WDC were averaged to represent each site. Water-stable aggregates was determined according to the method of Kemper and Rosenau (1986). Oven-dry ρ_b was determined for samples after drying at 105°C for 48 h, and calculations were made according to the method outlined by Blake and Hartge (1986).

Gravimetric water holding capacity (w/w) was determined at field capacity (10-kPa matric suction) ($\theta_{g,10kPa}$) on undisturbed cores, and at the permanent wilting point (1.5-MPa matric suction) ($\theta_{g,1.5MPa}$) on disturbed samples with pressure plates (Klute, 1986). The available water holding capacity (AWHC) was determined as the difference between the gravimetric water content at 10 kPa ($\theta_{g,10kPa}$) and at 1.5-MPa matric suction ($\theta_{g,1.5MPa}$).

In Situ Field Measurements

Soil strength (0–50 cm) was measured using a CP40II recording cone penetrometer (ICT International Pty. Ltd., Armidale, NSW, Australia). Each datum represents the average of 10 insertions, with readings taken in 1-cm increments. The surface IR was determined (two per site) with plant residue intact using a Cornell Sprinkle Infiltrometer (Ogden et al., 1997). The saturated hydraulic conductivity (K_{sat}) (three per site) at a depth of 15 ± 1 cm was determined using a compact, constant-head permeameter (Amoozemeter) (Ksat Inc., Raleigh, NC). Tap water (pH = 7.6, electrical conductivity = 3.46 mS m^{-1}) was used for on-site hydraulic measurements. All in situ measurements were taken within approximately 3 m of the GPS locations, and field replicates were averaged to represent individual sites.

Statistical Analysis

Analysis of variance was performed using SAS (SAS Institute, Cary, NC) to test the main effects and interactions. Where depth was a factor, the data were analyzed using PROC GLM as a split plot with land use system as the main plot and depth as the subplot. Parameters without a depth factor were analyzed as a randomized complete block using PROC GLM with the soil map unit as the blocking factor. Least significant differences were determined using PROC GLM. All statistical tests were made at the $\alpha = 0.10$ significance level to facilitate exploration of land management effects on soil properties useful for future research. In this study, C and N pools and base cations are reported as both concentrations (g kg^{-1} or mg kg^{-1}) and masses (kg ha^{-1}).

Multivariate analyses (using SAS) were used to explore the relationships among soil properties across land use systems and to identify the soil properties most critical for separating land use systems. Pearson linear correlation coefficients were used to relate the selected soil properties to each other ($\alpha = 0.10$). A weighted average (0–30 cm) of data for the three depths (0–5, 5–15, and 15–30 cm) was normalized (0–100) before PCA and multivariate clustering. The criteria for PC selection included: (i) eigenvalues >1, and (ii) the proportion of variance explained >5%. Single-linkage Euclidean clustering was performed between normalized, multivariate data (Der and Everitt, 2002), and a dendrogram depicting soil similarity was created. Pools of C and N were expressed as masses for PCA and clustering analyses, and as concentrations for correlation analysis. Exchangeable base and extractable Al and P data were analyzed as masses for all multivariate analyses.

RESULTS AND DISCUSSION

Soils

Our soils represent common upland, well-drained, acid, low-activity (as evidenced by kandic horizons) soils of the southeastern Coastal Plain. Eight of the nine pedons classified as Ultisols, while one pedon classified as an Alfisol (RC, LuB). The high BS (>35%) in the lower portion of the Alfisol was influenced by anthropogenic amendment additions (e.g., Ca in lime and gypsum applications) and it was considered to be a "cultural Alfisol." As a check, a pedon in an adjacent wooded area (not recently cultivated) was sampled and analyzed, and classified as an Ultisol.

We compared univariate properties between land use systems, followed by multivariate analyses (principal components and isodata clustering) of all properties for a holistic assessment. For discussion purposes, we made comparisons between forested sites (LL and PP) and RC sites, and in other comparisons, we considered LL as relatively undisturbed and RC and PP as disturbed or cultivated sites.

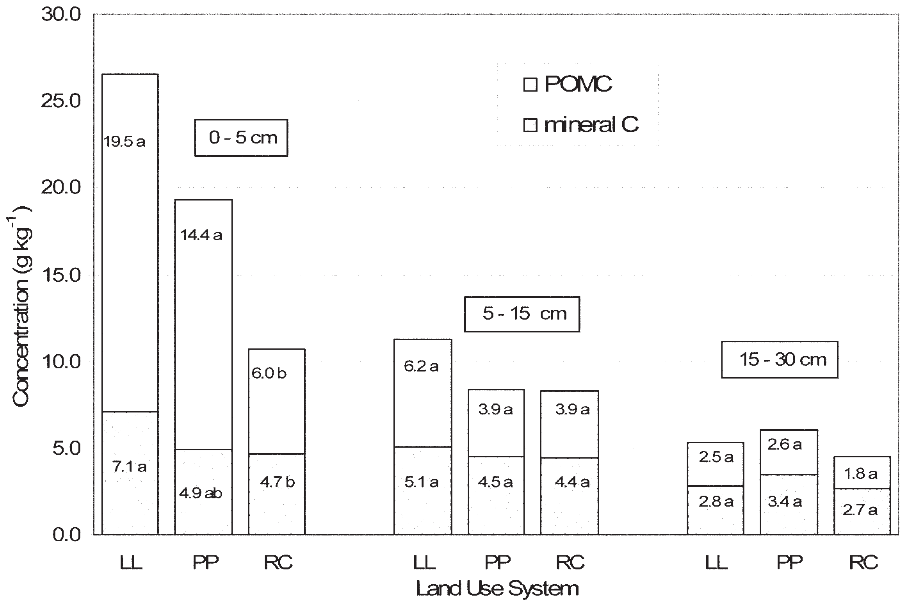

Fig. 1. Particulate organic matter (POM) C (>53 μm) and mineral C (<53 μm) pools in longleaf pine forest (LL), slash pine plantation (PP), and conventional row cropping (RC) land use systems in the South Georgia Coastal Plain. Mineral C + POM C = total organic C. Different letters for the same C pool column at the same depth indicates significant difference at the 0.10 confidence level as determined by LSD comparison.

Total Organic Carbon and Nitrogen

The TOC concentrations of surface soils (0–5 cm) under LL land use systems were greater than those under RC systems (Fig. 1), similar to the findings of other researchers (Ashagrie et al., 2007; Malo et al., 2005). The concentrations of TOC at the 0- to 5-cm depth (Fig. 1) in the forested systems (average of 22.9 g kg^{-1}) were twice as large as those found by Wood et al. (1992) in Alabama Coastal Plain forests (average of 11.4 g kg^{-1}). We found that land use did not significantly affect the TON concentrations of the investigated soils (Fig. 2); however, the TON concentrations at the same depth in the forested systems (average of 0.67 g kg^{-1}) were also greater than those found by Wood et al. (1992) (average of 0.47 g kg^{-1}). The TOC and TON values were similar to data reported by Echeverría et al. (2004) in U.S. Coastal Plain soils under pine. Soil tillage probably reduced the TOC in RC land use systems in our study, as this increases both the oxidation of organic matter and the erosion potential. This is similar to findings reported by Wood et al. (1992), who found less organic C and N in surface soils (0–5 cm) in pine monocultures than in more species-rich hardwood–loblolly pine (*Pinus taeda* L.) communities.

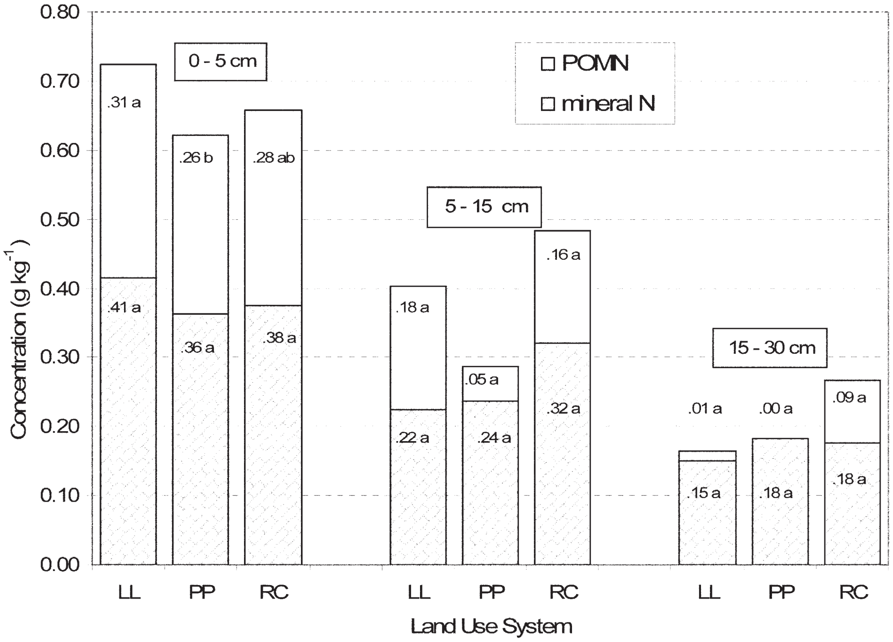

Fig. 2. Particulate organic matter (POM) N (>53 μm) and mineral N (<53 μm) pools in longleaf pine forest (LL), slash pine plantation (PP), and conventional row cropping (RC) land use systems in the South Georgia Coastal Plain. Mineral N + POM N = total organic N. Different letters for the same N pool column at the same depth indicates significant difference at the 0.10 confidence level as determined by LSD comparison.

The C/N ratio of the mineral soil was significantly different among land use systems (Table 1). Forested land use systems had similar ratios (32, 0–30 cm), but the C/N values for the RC systems (17, 0–30 cm) were approximately half of the forested systems for all depths. This is probably due to reduced organic matter as a result of soil disturbance coupled with the addition of N inputs of fertilizer and legumes (i.e., soybean and peanut). A portion of the N differences may also be attributed to N loss via NH_3 volatilization in the forested systems subjected to prescribed burning (Binkley et al., 1992; Gray and Dighton, 2006). Our results are in agreement with Ashagrie et al. (2007), who found that cultivation of previously forested sites significantly reduced (forest was 33% greater than cultivated sites) the C/N ratio of the mineral soil relative to adjacent forested sites after 26 yr.

Table 1. Soil microbial biomass C, potential C and N mineralization (C_{min} and N_{min}), C turnover (C_{min}/total organic C), relative N mineralization (N_{min}/total organic N), C/N mineralized (calculated from C_{min} and N_{min}), and C/N of soils (calculated from total organic C and N concentrations) for three land use systems in the South Georgia Coastal Plain.

Land use system†	Depth	Biomass C		C_{min}	N_{min}	C turnover	Relative N mineralization	C/N mineralized	C/N soil
		2006	2007						
	cm	mg kg^{-1}				%			
LL	0–5	560	522	2014	8.62	19.02	2.4	365	37
	5–15	214	183	920	5.69	9.37	5.83	171	29
	15–30	94	91	857	3.07	27.91	6.19	274	32
	Mean	289	265	1264	5.79	18.77	4.8	270	32
PP	0–5	–	481	2126	6.47	10.78	1	360	31
	5–15	–	156	1294	3.37	16.97	1.59	437	31
	15–30	–	134	775	2.05	12.05	1.29	514	33
	Mean	–	257	1398	3.96	13.27	1.29	437	32
RC	0–5	278	309	1876	16.09	18.25	3.57	118	16
	5–15	193	182	1208	10.70	13.96	2.72	113	17
	15–30	77	70	872	4.68	13.71	2.88	193	19
	Mean	182	187	1318	10.49	15.31	3.06	141	17
Land use system mean	0–5	419	437	2005	10.39	16.02	2.32	281	28
	5–15	203	174	1141	6.59	13.43	3.38	240	26
	15–30	85	98	834	3.26	17.89	3.45	327	28
	Mean	236	236	1327	6.75	15.78	3.05	283	27
				ANOVA ($P > F$, LSD 0.1)					
Land use (L)		0.183	0.074, 57	0.706	0.031, 3.32	0.55	0.293	0.089, 206	0.031, 8
Depth (D)		<0.001, 49	<0.001, 30	<0.001, 272	0.001, 2.40	0.744	0.755	0.511	0.565
L × D		0.002, 120	<0.001, 67	0.661	0.313	0.498	0.792	0.581	0.468

† LL, mature longleaf pine forest; PP, managed slash pine plantation; RC, conventional row crop management.

Significant land use system effects on the mass (kg ha^{-1}) of TOC or TON were not observed, even when TOC and TON in the organic horizons of the forested systems were added to the 0- to 30-cm mineral soil depth. Although the LL systems had higher TOC concentrations, the substantially lower bulk density values for these systems translated to masses of C similar to the other systems. Although not significant, the LL system sequestered 64% more TOC than the RC systems on a mass basis (0–30 cm plus O horizons). The stratification ratios (i.e., greater concentrations in the surface soils relative to lower depths) of the C and N pools were significantly different (Fig. 3). The stratification ratios of soil TOC concentrations were significantly greater in the LL land use systems than the PP and RC systems (Fig. 3). Similarly, stratification of TON was significantly greater in the LL land use systems relative to the RC systems, with PP being intermediate. The PP and RC systems had similar TOC stratification. Higher stratification ratios of C and N pools have been equated to better soil quality and soil ecosystem functioning (Franzluebbers, 2002).

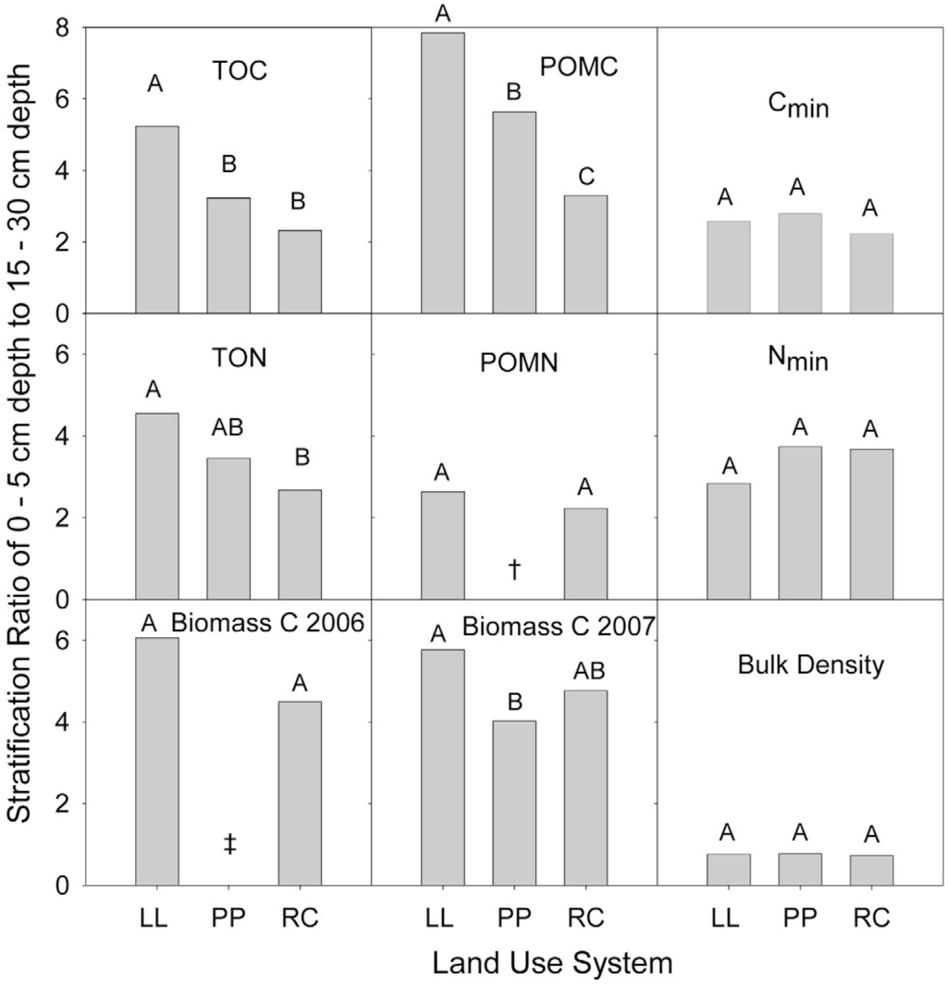

Fig. 3. Stratification ratios of two depths of total organic C (TOC), particulate organic matter (POM) C (>53 μm), potentially mineralizable C (C_{min}), total organic N (TON), POM N (>53 μm), potentially mineralizable N (N_{min}), soil microbial biomass C in 2006 and 2007, and bulk density averaged by longleaf pine forest (LL), slash pine plantation (PP), and conventional row cropping (RC) land use system. Different letters for columns in the same plot indicate significant difference at $P \leq 0.01$ as determined by LSD comparison. † Stratification ratio could not be determined because the value for the 15–30-cm depth was 0. ‡ No data.

Mineral and Particulate Organic Matter Fractions of Total Organic Carbon and Nitrogen

Particulate organic matter is the fraction of soil organic matter mainly composed of plant matter, and C and N in Coastal Plain soils have been shown to concentrate in POM (Echeverría et al., 2004). Similar to the findings of Ashagrie et al. (2007), the POM fractions in our study were influenced by land use system (Fig. 1 and 2). We found that the fraction of TOC composed of POM C was greatest in the forested systems (0–5 cm) (74%), and similar to what Echeverría et al. (2004) found in Lower Coastal Plain pine plantations.

The mineral-associated fractions (<53 μm) of C in the surface (0–5 cm) were significantly greater in the LL (7.1 g kg^{-1}) than RC systems (4.7 g kg^{-1}) (Fig. 1); however, mineral-associated N was not affected by land use system (Fig. 2). Other researchers have found that TOC concentrates in soil aggregates >53 μm (45% of TOC) in sandy (<5% silt + clay) Coastal Plain soils (Sarkhot et al., 2007). Aggregate-protected TOC was not determined in this study; however, mineral-associated fractions of C (<53 μm) were assumed to include any C protected by aggregates >53 μm, as the aggregates would have been destroyed by the technique used (Cambardella and Elliott, 1992). The relatively higher clay content in our soils (compared with Sarkhot et al., 2007) may protect the organic matter in the mineral-associated fractions of these land use systems. Particulate fractions (>53 μm) of C and N were significantly smaller with depth ($P <$ 0.001). Forested systems had more than twice the POM C of RC systems in the surface (0–5 cm), but lower depths displayed no significant land use system effects (Fig. 1). The POM N in the surface (0–5 cm) in LL was significantly greater (19% greater) than in PP. Forested systems had nearly undetectable levels of POM N in the 15- to 30-cm depth.

The stratification of POM C was significantly different among all land use systems, with the largest ratio in LL (7.8) followed by the PP (5.6) and RC (3.3) systems (Fig. 3). Thus, increased soil disturbance reduced the stratification of POM fractions, similar to the results of Franzluebbers (2002). The POM C stratification ratios separated land use systems more than the TOC ratios, supporting stratification ratios of POM C as a sensitive measure for assessing land use differences. The stratification ratios of POM N were not significantly affected by management.

Microbial Biomass Carbon

In 2006 and 2007, the interaction between depth and land use system affected microbial biomass C (Table 1). Our data are in agreement with Fesha (2004), who found that microbial biomass C and soil depth were inversely related. Stratification ratios (0–5- to 15–30-cm depths) of microbial biomass C were not significantly affected by land use system in either year (Fig. 3) and were larger than those reported by Franzluebbers (2002) for cropped soils in Texas and Georgia. Considering that the lower depth of sampling for our sites was 30 cm, whereas they had lower depths of 15 and 20 cm, higher ratios in our study would be expected. Inclusion of deeper sampling depths in stratification ratios of microbial biomass C results in larger values due to the inherent stratification of microbial communities in surface soils. Microbial biomass C can change with seasonal patterns and varying soil moisture (van Veen et al., 1984; Srivastava 1992). Therefore it is important to make this measure between soils with similar water contents, as we have done here (Alef and Nannipieri, 1995).

Potentially Mineralizable Carbon and Nitrogen

There were no significant land use system effects on the concentrations of C_{min}, but C_{min} significantly decreased with depth (Table 1). Overall, the concentrations of C_{min} in surface soils (0–5 cm) were 76% greater than those at 5 to 15 cm. The potential C mineralization values found in all land use systems of this study were more than twice those reported by Wood et al. (1992) for pine communities. Stratification of C_{min} was not significantly different among land use systems (Fig. 3).

Land use system and depth significantly affected N_{min} concentrations, with RC land use systems having the most potentially mineralizable N (Table 1). This is probably due to N inputs into RC systems, including fertilizer amendments and legume residues. Levels of N_{min} decreased with depth, similar to data reported by Egelkraut et al. (2003) on a Georgia Coastal Plain site. The PP systems had the smallest amount of N_{min} and were not significantly different from LL land use systems. Stratification ratios of N_{min} did not significantly differ across land use systems (Fig. 3).

Carbon turnover and relative N mineralization were not significantly different among land use systems (Table 1). The ratio of C_{min} to N_{min} was significantly affected by land use system, with the lowest ratio in RC systems (141, 0–30 cm), reflecting more N with depth in the RC systems relative to the forested systems (Table 1). The greatest ratio of C_{min} to N_{min} was in PP (437, 0–30 cm), further substantiating the effect of land use and management on C/N ratios.

Soil pH and Extractable Aluminum

Soil pH was significantly affected by both land use system and depth, with no significant interaction between the factors (Table 2). The greatest pH values were in RC systems (5.43), while PP (4.75) land use systems were the most acidic (0–30 cm). The pH values of both forested land use systems were significantly lower than RC systems. We found a significant interaction of depth and land use system for extractable Al concentrations (Table 2). In summary, the lower pH and extractable Al in the forested sites was probably due to both an acid-producing litter

Table 2. Cation exchange capacity at pH 7 (CEC7), exchangeable cation exchange capacity (ECEC), NaOH-extractable bases, KCl-exchangeable Al, base saturation (BS), and 1:1 soil/water pH for three land use systems in the South Georgia Coastal Plain.

Land use system†	Depth	CEC7	ECEC	Ca	Mg	K	Na	Al	BS	pH
	cm	cmol kg^{-1}							%	
LL	0–5	6.84	3.13	1.77	0.48	0.05	0.02	0.81	33.8	4.85
	5–15	2.79	1.24	0.44	0.17	0.02	0.01	0.60	24.0	4.90
	15–30	2.07	0.96	0.14	0.15	0.01	0.01	0.64	19.2	4.70
	Mean	3.90	1.78	0.78	0.27	0.03	0.02	0.68	25.7	4.82
PP	0–5	4.69	2.75	1.89	0.37	0.12	0.03	0.34	51.0	4.86
	5–15	3.18	1.91	1.06	0.23	0.06	0.01	0.56	41.9	4.79
	15–30	3.88	2.29	0.89	0.34	0.06	0.02	0.98	33.8	4.60
	Mean	3.92	2.32	1.28	0.32	0.08	0.02	0.63	42.2	4.75
RC	0–5	3.46	2.64	1.97	0.43	0.19	0.01	0.03	76.2	5.65
	5–15	3.19	2.06	1.52	0.30	0.18	0.01	0.06	63.2	5.47
	15–30	3.82	1.81	1.24	0.32	0.10	0.00	0.15	47.6	5.17
	Mean	3.49	2.17	1.58	0.35	0.16	0.01	0.08	62.3	5.43
Land use system mean	0–5	5.00	2.84	1.88	0.43	0.12	0.02	0.39	53.6	5.12
	5–15	3.05	1.74	1.01	0.23	0.09	0.01	0.40	43.1	5.05
	15–30	3.26	1.69	0.76	0.27	0.06	0.01	0.59	33.5	4.83
	Mean	3.77	2.09	1.21	0.31	0.09	0.01	0.46	43.4	5.00
				ANOVA ($P > F$, LSD 0.1)						
Land use (L)		0.859	0.341	0.019, 0.34	0.255	0.002, 0.03	0.127	0.053, 0.39	0.026, 17.2	0.001, 0.26
Depth (D)		<0.001, 0.55	<0.001, 0.45	<0.001, 0.36	0.001, 0.08	0.001, 0.02	0.017, 0.01	0.045, 0.14	<0.001, 6.3	<0.001, 0.08
L × D		<0.001, 1.79	0.098, 0.91	0.393	0.118	0.148	0.391	0.016, 0.40	0.546	0.106

† LL, mature longleaf pine forest; PP, managed slash pine plantation; RC, conventional row crop management.

Table 3. Mehlich I extractable nutrients and total organic C (TOC) for three land use systems in the South Georgia Coastal Plain.

Land use system†	Depth	P	B	Cu	Fe	Mn	Zn	TOC‡
	cm	mg kg^{-1}						kg ha^{-1}
LL	0–5	2.6	0.3	2.6	22.7	20.4	1.0	52,856
	5–15	2.0	0.2	2.7	19.6	7.2	0.8	
	15–30	1.5	0.1	3.0	12.5	3.6	0.8	
	Mean	2.0	0.2	2.8	18.3	10.4	0.9	
PP	0–5	24.1	0.3	1.0	20.0	31.1	2.1	46,641
	5–15	13.2	0.2	1.3	17.2	14.9	1.0	
	15–30	4.4	0.2	1.1	13.6	13.6	0.7	
	Mean	13.9	0.2	1.1	16.9	19.9	1.3	
RC	0–5	52.3	0.3	1.6	9.3	13.5	5.6	32,245
	5–15	41.0	0.2	1.1	11.6	11.0	4.3	
	15–30	17.3	0.1	2.1	9.1	6.5	1.7	
	Mean	36.8	0.2	1.6	10.0	10.3	3.9	
Land use system mean	0–5	26.3	0.3	1.7	17.3	21.6	2.9	–
	5–15	18.7	0.2	1.7	16.1	11.1	2.0	
	15–30	7.7	0.2	2.1	11.7	7.9	1.1	
	Mean	17.6	0.2	1.8	15.0	13.5	2.0	
		ANOVA ($P > F$, LSD 0.1)						
Land use (L)		0.037, 18	0.983	0.008, 0.6	0.055, 5.3	0.058, 6.6	0.017, 1.3	
Depth (D)		0.001, 7	<0.001, <0.1	0.039, 0.3	0.005, 2.6	<0.001, 2.8	0.005, 0.8	0.407
L × D		0.035, 19	0.958	0.051, 0.6	0.138	0.028, 7.1	0.049, 1.7	

† LL, mature longleaf pine forest; PP, managed slash pine plantation; RC, conventional row crop management.

‡ 0–30 cm including organic horizons of forested sites.

from the coniferous (pine) vegetation and the addition of lime to the row crop lands.

Exchangeable Cations

Exchangeable bases generally decreased with depth, and RC land use systems had the greatest levels of Ca and K across depths relative to the LL and PP land use systems (Table 2). Concentrations of Ca were significantly affected by land use system; however, differences in Mg were not significant (Table 2). The RC systems had the greatest Ca concentrations at all depths, followed by PP and LL. The addition of Ca-bearing amendments (i.e., lime and gypsum) to RC lands probably resulted in these differences. Depth was significant for both Ca and Mg, which generally decreased with increasing depth (Table 2). The greatest stratification of extractable Ca and Mg was in LL, and both Ca and Mg decreased with increasing depth. Our data are in agreement with other researchers (McCracken et al., 1989; Fesha, 2004), who have found greater extractable bases in cultivated than uncultivated lands.

There were significant land use system and depth effects on exchangeable K concentrations (Table 2). Cultivated systems had more K at all depths, with RC land use systems having more K than PP. The highly weathered Ultisols in our study expressed characteristically low base status, and the increased K levels in RC systems probably reflect the response of these systems to fertilizer amendments.

Mehlich Nutrients

Double-acid-extractable P showed a significant interaction between land use system and depth (Table 3). Our data reflect the influence of P additions in RC sites, as these sites had greater stratification (Table 3). Brye (2006) found that prescribed burning significantly decreased extractable P. Thus, differences in extractable P among land use systems in our study are possibly due to both amendments and fire regime.

Micronutrients showed varying degrees of land use system effects. Interactions between depth and land use system were significant for Mehlich-extractable Cu, Mn, and Zn (Table 3). Extractable Fe was significantly affected by land use system, with more Fe in soils with lower pH (forested) than in soils with greater pH (RC). Stratification of Fe, Mn, and Zn was generally more pronounced in LL relative to the other land use systems.

Cation Exchange and Base Saturation

A significant interaction between land use system and depth was observed for CEC and ECEC, with the highest values at 0 to 5 cm (Table 2). We found that greater CEC tended to occur in the forested soils, which had greater TOC and related pools than the other systems. The greatest stratification of CEC and ECEC was in LL, probably reflecting the influence of organic matter in the surface soils. It has also been suggested that ash resulting from burning contributes to elevated CEC (Sherman et al., 2005).

Land use system significantly affected BS, with the highest values at the surface and decreasing with depth (Table 2). The BS (0–30 cm) was greatest in RC (62%) land use systems, followed by PP (42%) and LL (26%). For all depths, RC had more than twice the BS of the LL systems. The elevated BS in RC probably reflects the addition of amendments (e.g., lime and fertilizer),

Table 4. Bulk density (ρ_b), water-dispersible clay (WDC), water-stable aggregates (WSA), gravimetric soil water content at field capacity ($\theta_{g,10kPa}$) and the wilting point ($\theta_{g,1.5MPa}$), available water holding capacity ($\theta_{g,10kPa} - \theta_{g,1.5MPa}$), infiltration rate (IR), and saturated hydraulic conductivity at 15-cm depth (K_{sat}) averaged across three replications for three land use systems in the South Georgia Coastal Plain.

Land use system†	Depth	ρ_b	WDC	WSA	$\theta_{g,10kPa}$	$\theta_{g,1.5MPa}$	AWHC	IR	K_{sat}
	cm	g cm^{-3}	%		kg kg^{-1}			cm h^{-1}	
LL	0–5	1.16	2.1	91.5	0.15	0.07	0.08	42.5	13.0
	5–15	1.18	2.9	95.0	0.14	0.05	0.09		
	15–30	1.54	3.2	ND‡	0.12	0.06	0.06		
	Mean	1.29	2.7	93.3	0.14	0.06	0.07		
PP	0–5	1.34	2.3	95.8	0.11	0.05	0.07	3.8	5.7
	5–15	1.63	3.0	96.4	0.10	0.04	0.06		
	15–30	1.72	5.2	ND	0.14	0.09	0.05		
	Mean	1.56	3.5	96.1	0.12	0.06	0.06		
RC	0–5	1.30	1.2	74.3	0.11	0.04	0.07	13.9	6.2
	5–15	1.58	1.7	84.5	0.10	0.04	0.06		
	15–30	1.78	4.2	ND	0.12	0.07	0.05		
	Mean	1.55	2.4	79.4	0.11	0.05	0.06		
Land use system mean	0–5	1.26	1.9	87.2	0.13	0.05	0.07		
	5–15	1.46	2.5	92.0	0.11	0.05	0.07		
	15–30	1.68	4.2	ND	0.13	0.07	0.05		
	Mean	1.47	2.9	89.6	0.12	0.06	0.06		
				ANOVA ($P > F$, LSD 0.1)					
Land use (L)		0.029, 0.15	0.457	0.984, 12.7	0.434	0.764	0.059, 0.01	0.038, 21.0	0.359
Depth (D)		<0.001, 0.09	0.011, 1.2	<0.001, 1.4	0.476	0.038, 0.02	0.014, 0.01		
L × D		0.179	0.621	0.004, 12.1	0.388	0.289	0.604		

† LL, mature longleaf pine forest; PP, managed slash pine plantation; RC, conventional row crop management.

‡ ND, not determined.

whereas the BS in the LL and PP systems is more reflective of plant biocycling.

Bulk Density

Values of ρ_b were significantly affected by both land use system and depth, with values increasing with depth (Table 4). Cultivated systems (PP and RC) had similar ρ_b values (1.55 g cm^{-3}), which were significantly greater than the LL systems (1.29 g cm^{-3}) (Table 4). Other researchers have also found that increased cultivation causes greater ρ_b (Blanco-Canqui et al., 2005; Tan et al., 2007). Relative to the other land use systems, PP had the greatest ρ_b in the surface soils (0–15 cm), while ρ_b at the 15- to 30-cm depth was greatest in the RC systems. Annual tillage and trafficking has probably resulted in the greater compaction and ρ_b at 15 to 30 cm in the RC systems.

Soil Aggregation and Dispersion

Wet aggregate stability is often used to assess management effects on soil properties, because researchers have found increased WSA in uncultivated vs. cultivated soils (Eynard et al., 2004; Rachman et al., 2003). We found a significant interaction between land use system and depth for WSA in our study (Table 4). Although not significant, numerical differences among PP, LL, and RC systems suggested a relationship with organic matter pools (0–15 cm).

Some researchers (Rhoton et al., 2002; Shaw et al., 2002) have found that WDC increases with increased cultivation; however, we found no significant differences in WDC attributable to land use system (Table 4). The WDC values significantly increased with depth, and there are probably several causes for this finding. Besides the fact there was more total clay with depth (we found a direct relationship between WDC and total clay [r^2 = 0.50; data not shown]), clays that are water dispersible would be most susceptible to eluviation within the profile (already removed) and thus might concentrate with depth in the upper solum. In addition, WDC values have been shown to increase with decreased soil organic matter (Rhoton et al., 2002), which is concentrated in surface soils.

Soil Strength

Measured SS was greatest for cultivated land use systems (below 10 cm) relative to LL (Fig. 4). The SS in LL generally increased with depth and had a narrower range of values relative to the other land use systems. The cultivated land use systems had a depth (15–35 cm) of relatively increased SS, probably coinciding with a traffic or tillage pan. Duffera et al. (2007) noted increased SS at similar depths in cultivated soils of the North Carolina Coastal Plain. We found that SS decreased below this compacted layer, which is similar to the findings of Busscher and Bauer (2002) for Coastal Plain soils of South Carolina. These findings suggest the possible utility of SS measurements for identifying previously cultivated systems.

A comparison of 10-cm increments (averaged data) of SS data illustrated significant differences in PP and LL soils for the

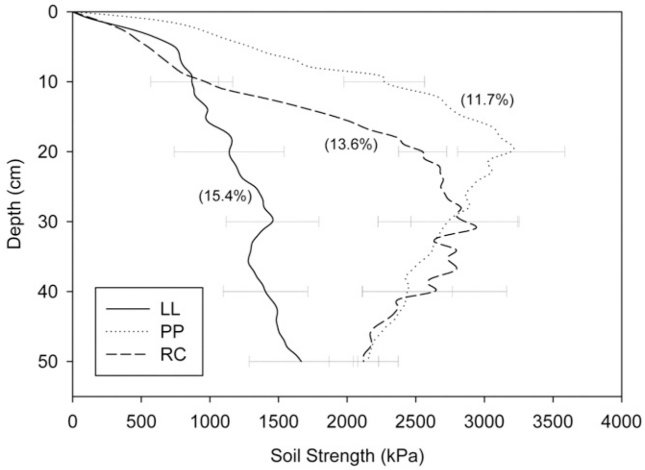

Fig. 4. Soil strength averaged for three replicates in longleaf pine forest (LL), slash pine plantation (PP), and conventional row cropping (RC) land use systems in the South Georgia Coastal Plain. Values in parentheses are average gravimetric moisture contents for the 0- to 50-cm depth (*n* = 3). Bars represent standard errors of 10 cm averages for each land use system.

10- to 20- and 20- to 30-cm depths ($P = 0.029$ and 0.081, respectively; data not shown). We found lower shallow SS (0–10 cm) in the RC land use systems that probably resulted from loosening by tillage (Busscher and Bauer, 2002). At the 30- to 40-cm depth, the SS under the RC systems was significantly greater than under LL ($P = 0.010$). The residual effects of management may have contributed to greater SS in cultivated land use systems with depth (Busscher and Bauer, 2002).

Hydraulic Soil Properties

Land use system did not significantly affect gravimetric water content at field capacity ($\theta_{g,10kPa}$) or the permanent wilting point ($\theta_{g,1.5MPa}$) (Table 4). There were significant differences among land use systems for AWHC ($\theta_{g,10kPa} - \theta_{g,1.5MPa}$). A greater mean AWHC was found in LL systems compared with the cultivated land use systems (Table 4), suggesting that LL land use systems may be more drought tolerant than cultivated systems.

The surface IR affects the amount of precipitation entering the soil system (Blanco-Canqui and Lal, 2007). Land use system significantly affected the surface IR of the investigated soils (Table 4). We found that the IR in the LL systems (42.5 cm h^{-1}) was 207 and 1015% greater than in the RC (13.9 cm h^{-1}) and PP (3.8 cm h^{-1}) land use systems, respectively. Increased surface residues, WSA, and soil organic matter probably contributed to the greater IR in LL relative to the cultivated systems. The RC and PP systems had similar IR values, and increased compaction probably reduced the IR in cultivated relative to LL systems. Values of K_{sat} measured at 15 cm were not significantly affected by land use system (Table 4).

Relationships among Soil Properties

Soil properties highly correlated with multiple other properties are parameters that might be useful for evaluating soil change. Total organic C, an important measure of soil quality in southeastern U.S. soils, was highly related to several soil properties including ρ_b, BS, N_{min}, and AWHC (Table 5). This is not surprising, considering the direct and indirect effects that TOC (and its related pools) has on other soil properties (Rhoton et al., 2002; Liebig et al., 2004). In fact, organic matter pools are recognized as indicators of management effects because they influence other important soil properties (Cambardella and Elliott, 1992). Both TOC and POM C were significantly related to seven additional investigated properties, and soil microbial biomass C was related to six other properties (Table 5). The interrelationships of TOC and other properties important to soil change coupled with the relative ease of TOC measurement make this parameter desirable for assessing management effects in these soils.

Bulk density and AWHC were also correlated with several other properties. The surface IR was negatively related to indicators of soil compaction (ρ_b and SS) and positively correlated to C pools (TOC and POM C) (Table 5). These findings seem logical, as compaction often reduces permeability, and indicators of soil compaction are often negatively related to TOC (Blanco-Canqui et al., 2005). Furthermore, the surface IR is dependent on soil aggregation and structural development (Blanco-Canqui and Lal, 2007), which is largely influenced by organic matter content (Blanco-Canqui et al., 2005). Similar to the surface IR, significant negative correlations were found between ρ_b and both K_{sat} and AWHC. Conversely, a significant positive relationship was found between ρ_b and SS, similar to the findings of Duffera et al. (2007) in North Carolina and Blanco-Canqui et al. (2005) in Ohio.

Principle Component Analysis

We utilized a multivariate approach (PCA) to provide a comprehensive evaluation of all data and a holistic comparison between systems. Four principal components explained 86% of the soil data variability across all nine sites (Table 6). The first PC explained 40% of the data variability, and loading factors were highest for exchangeable bases, ρ_b, and soil P. Loading factors for PC2 (29% of the variability) were highest for C and N pools and CEC, whereas physical soil properties (surface IR, AWHC, and SS) were highlighted in PC3 (11%). The fourth PC was somewhat mixed and explained less data variability (6%). Similar to our results, Duffera et al. (2007) found that four PCs developed from near-surface soil physical properties explained 90% of the data variability in some soils of the North Carolina Coastal Plain.

Selection of soil properties sensitive to land use and management is critical for the establishment of minimum data sets for soil change and soil quality assessment. Our PCA analyses indicated that exchangeable bases, ρ_b, microbial biomass C, TOC, mineral-associated C, CEC, surface IR, and SS are properties that are most different among these systems. These properties are suggested as important because they had the highest loading factors in the first three principal components. Other studies indicate similar soil properties as sensitive metrics of soil change. For example, Yemefack et al. (2006) identified five soil properties (pH, exchangeable Ca, extractable P, ρ_b, and organic C as indicators of cultivation systems in southern Cameroon, while Wander and Bollero (1999) suggested four soil properties (POM C, mean weight wet diameter, ρ_b, and penetration resistance) sensitive to management practices in Illinois Mollisols and Alfisols.

Cluster Analysis

Cluster analyses, developed using a composite of soil properties, are used to provide a holistic comparison between systems. Isodata clustering of normalized data revealed that cultivation (i.e., mechanical disturbance) reduced the variability of near-surface soil properties (0–30 cm) across soil map units (Fig. 5). This was indicated by the linking of PP and RC sites together as one unit, before linkage with the LL sites in the cluster dendrogram (Fig. 5). Soil properties in PP sites were most similar to each other (i.e., relatively shorter distance between PP sites) (Fig. 5). The LL sites clustered together; however, the relatively longer distance between individual sites indicated more variability within the LL land use system relative to the other systems. The OrB RC site was isolated from the other RC sites due to higher N pools, SS, and BS, and lower C stocks, IR, and AWHC.

The cluster dendrogram illustrates that the aggregate of near-surface soil properties were more similar by management than soil map unit in these systems representative of southeastern U.S. Coastal Plain ecosystems. Considering that these analyses only incorporated measures of the upper 30 cm, this is not surprising or novel. A study in Argentina conducted by Guiffré et al. (2006) also found that cultivated sites clustered together separate from uncultivated (grassland and undisturbed) sites. It does illustrate, however, that management, rather than genetic soil differences emphasized in soil taxonomic placement and conveyed through soil survey map unit placement, has more influence on certain soil properties (measured in this study) at these depths and landscape settings. Considering the importance of near-surface horizons in ecosystem function, maintenance, and restoration, this finding is of note.

Table 5. Pearson linear correlation coefficients of near-surface soil properties† of nine Coastal Plain sites.

Property	CEC	ECEC	BS	P	SMBC	N_{min}	C_{min}	TON	TOC	POM N	POM C	Mineral N	Mineral C	IR	K_{sat}	AWHC	SS	WDC	WSA
ρ_b	0.32	0.75*	0.54	0.52	−0.39	0.24	0.23	−0.07	−0.58‡	−0.28	−0.70*	0.19	−0.22	−0.89**	−0.65‡	−0.75*	0.77*	0.15	−0.33
CEC	1	0.71*	−0.16	0.11	0.31	−0.26	0.64‡	0.17	0.44	−0.53	0.22	0.72*	0.70*	−0.05	−0.47	0.09	0.21	0.45	−0.17
ECEC		1	0.27	0.29	−0.08	−0.07	0.63‡	−0.09	−0.13	−0.53	−0.26	0.40	0.12	−0.63‡	−0.58‡	−0.57	0.47	0.54	−0.20
BS			1	0.80**	−0.70*	0.67*	0.21	0.32	−0.80**	0.57	−0.83**	−0.14	−0.52	−0.50	0.00	−0.76*	0.30	−0.16	−0.42
P				1	−0.63‡	0.69*	0.29	0.29	−0.56	0.50	−0.60‡	−0.09	−0.33	−0.37	−0.17	−0.53	0.31	−0.26	−0.65‡
SMBC					1	−0.92***	−0.06	−0.16	0.79*	−0.50	0.79*	0.28	0.57	0.23	−0.09	0.42	0.11	0.18	0.62‡
N_{min}						1	−0.04	0.42	−0.68*	0.64‡	−0.69*	−0.11	−0.47	−0.05	0.10	−0.28	−0.23	−0.34	−0.79*
C_{min}							1	0.23	0.25	−0.05	0.08	0.31	0.48	0.00	−0.26	−0.11	0.02	0.74*	0.08
TON								1	0.06	0.55	−0.12	0.63‡	0.35	0.31	−0.17	0.11	−0.26	0.12	−0.32
TOC									1	−0.33	0.94***	0.37	0.82**	0.63‡	−0.06	0.75*	−0.31	0.39	0.45
POM N										1	−0.29	−0.29	−0.31	0.30	0.39	−0.03	−0.32	−0.33	−0.21
POM C											1	0.13	0.58	0.62‡	0.05	0.70*	−0.38	0.27	0.48
Mineral N												1	0.69*	0.07	−0.55	0.15	0.03	0.42	−0.20
Mineral C													1	0.48	−0.24	0.64‡	−0.11	0.49	0.28
IR														1	0.54	0.89**	−0.83**	−0.04	0.12
K_{sat}															1	0.33	−0.56	−0.47	0.11
AWHC																1	−0.58‡	−0.04	0.22
SS																	1	−0.03	0.10
WDC																		1	0.41

* Significant at the 0.05 level.

** Significant at the 0.01 level.

*** Significant at the 0.001.

† ρb, soil bulk density (0–30 cm); CEC, cation exchange capacity (0–30 cm); ECEC, effective cation exchange capacity (0–30 cm); BS, base saturation (0–30 cm); P = Mehlich 1 extractable P (0–30 cm); SMBC, soil microbial biomass C (0–30 cm); N_{min} and C_{min}, potentially mineralizable N and C (0–30 cm); TON and TOC, total organic N and C (0–30 cm); POM N and C, particulate organic matter N and C (0–30 cm); mineral N and C, mineral-associated N and C (0–30 cm); IR, surface infiltration rate; K_{sat}, saturated hydraulic conductivity at 15 cm; AWHC, available water holding capacity (0–30 cm); SS, soil strength (0–50 cm); WDC, water-dispersible clay (0–30 cm); WSA, water-stable aggregates (1–2-mm size) (0–5 cm).

‡ Significant at the 0.1 level.

CONCLUSIONS

Land use effects were evident for several measured soil properties in these southeastern Coastal Plain systems. In LL, a better perceived soil quality was suggested by lower ρ_b and SS and greater C concentrations, IR, and AWHC. Although not significant, LL sequestered 13 and 64% more TOC than the PP and RC systems, respectively, suggesting the potential of LL ecosystems for storing terrestrial C. The IR in LL was greater than in the RC and PP land use systems and decreased with increasing ρ_b and SS. Thus, compaction due to management (e.g., machinery traffic) reduced water infiltration in these soils. Increased water infiltration in LL is important for recharging groundwater and reducing runoff that may contribute negatively to surface water quality. In addition, these soils hold more water in the near surface, resulting in a more favorable plant establishment environment.

The differences in several management-dependent soil properties suggest that soil change induced by land use is significant in these systems. Univariate analyses identified significant differences among several properties (POM C, soil C/N ratios, N_{min}, exchangeable bases, BS, extractable P, soil pH, surface IR, ρ_b, and SS) as a result of land use system, and these properties are suggested as important for monitoring soil change. Selection of soil properties based on linear correlation with other parameters indicated that TOC, POM C, microbial biomass C, N_{min}, ρ_b, and AWHC are useful indicators of the soil condition for these land use systems. These properties shared significant correlations with at least six other measured properties, suggesting their utility as important soil change metrics. In addition, the stratification ratios of TOC, TON, and POM C are helpful for differentiating land use effects, suggesting the importance of measurements at the 0- to 5-cm depths. Similar to the results of other studies, fractionation of C into POM C proved to be more useful than TOC for separating land use systems. Furthermore, multivariate analyses indicate that 80% of the soil data variability was explained by exchangeable bases, C pools, and hydraulic properties. Thus, the aggregate of our results suggest soil properties that could comprise a minimum data set for assessing soil change and quality in these settings.

Table 6. Loading factors of the first four principal components (PCs) of selected near-surface soil properties of nine Coastal Plain sites.

Property†	PC1	PC2	PC3	PC4
ρ_b	0.28	0.13	−0.18	−0.03
CEC	0.08	0.29	0.30	−0.08
ECEC	0.20	0.26	−0.03	0.16
BS	0.27	−0.15	−0.08	0.04
Ca	0.30	0.02	0.06	−0.16
Mg	0.27	0.16	0.02	0.05
K	0.32	−0.02	0.10	0.04
Al	−0.12	0.26	−0.21	0.34
P	0.26	−0.12	0.07	−0.07
SMB	−0.05	0.31	−0.15	−0.38
N_{min}	0.23	−0.21	0.15	0.16
C_{min}	0.24	0.18	0.01	0.29
TON	0.23	−0.03	0.30	−0.04
TOC	−0.15	0.30	0.20	−0.08
POM N	0.12	−0.30	0.08	0.09
POM C	−0.23	0.20	0.07	−0.05
Mineral N	0.15	0.22	0.27	−0.13
Mineral C	0.03	0.30	0.29	−0.09
IR	−0.22	−0.11	0.40	0.09
K_{sat}	−0.13	−0.24	−0.01	−0.05
AWHC	−0.23	−0.03	0.37	−0.09
SS	0.16	0.16	−0.32	−0.35
WDC	0.01	0.24	0.06	0.59
WSA	−0.19	0.11	−0.27	0.15
Eigenvalue	9.57	6.98	2.64	1.42
Proportion of variance explained, %	40	29	11	6
Cumulative variance explained, %	40	69	80	86

† ρ_b, soil bulk density (0–30 cm); CEC, cation exchange capacity (0–30 cm); ECEC, effective cation exchange capacity (0–30 cm); BS, base saturation (0–30 cm); Ca, Mg, and K, NH_4OAc-extractable Ca, Mg, and K (0–30 cm); Al, KCl-extractable Al (0–30 cm); P, Mehlich 1 extractable P (0–30 cm); SMB, soil microbial biomass C (0–30 cm); N_{min} and C_{min}, potentially mineralizable N and C (0–30 cm); TON and TOC, total organic N and C (0–30 cm); POM N and C, particulate organic matter N and C (0–30 cm); mineral N and C, mineral-associated N and C (0–30 cm); IR, surface infiltration rate; K_{sat} , saturated hydraulic conductivity at15 cm; AWHC, available water holding capacity (0–30 cm); SS, soil strength (0–30 cm); WDC, water-dispersible clay (0–30 cm); WSA, water-stable aggregates (1–2-mm size) (0–5 cm).

Near-surface property values in some upland soil map units of the southeastern U.S. Coastal Plain were obtained, providing base knowledge of management-induced, and hence decade-scale, temporal variability. These data also illustrate the magnitude of anthropogenic changes to surface soils in these settings. Clustering of normalized data suggested that anthropogenic influences reduced the inherent variability of near-surface properties, whereas soils under LL expressed higher variability among soil map units. The multivariate clustering also indicated that soil management resulted in greater similarity in near-surface properties than soil taxonomic placement.

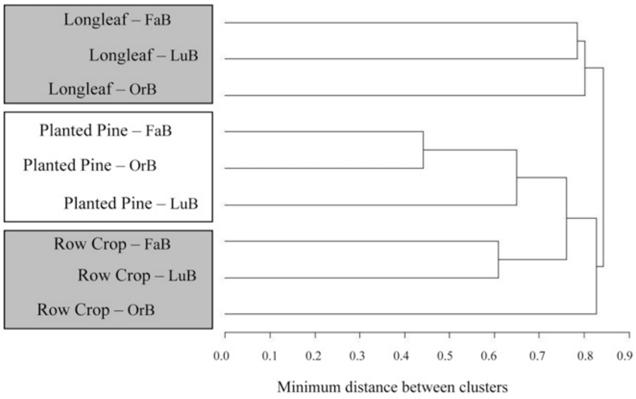

Fig. 5. Multivariate clustering dendrogram of near-surface soil properties (normalized 0–100) for pedons of Faceville loamy sand (FaB), Lucy loamy sand (LuB), and Orangeburg loamy sand (OrB) in the South Georgia Coastal Plain.

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