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Soil-profile organic carbon and total nitrogen during 12 years of pasture management in the Southern Piedmont USA

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ABSTRACT

Soil organic C (SOC) and total soil N (TSN) sequestration estimates are needed to improve our understanding of management influences on soil fertility and terrestrial C cycling related to greenhouse gas emission. We evaluated the factorial combination of nutrient source (inorganic, mixed inorganic and organic, and organic as broiler litter) and forage utilization (unharvested, low and high cattle grazing pressure, and hayed monthly) on soil-profile distribution (0–150 cm) of SOC and TSN during 12 years of pasture management on a Typic Kanhapludult (Acrisol) in Georgia, USA. Nutrient source rarely affected SOC and TSN in the soil profile, despite addition of 73.6 Mg ha^{-1} (dry weight) of broiler litter during 12 years of treatment. At the end of 12 years, contents of SOC and TSN at a depth of 0–90 cm under haying were only 82 ± 5% (mean ± S.D. among treatments) of those under grazed management. Within grazed pastures, contents of SOC and TSN at a depth of 0–90 cm were greatest within 5 m of shade and water sources and only 83 ± 7% of maximum at a distance of 30 m and 92 ± 14% of maximum at a distance of 80 m, suggesting a zone of enrichment within pastures due to animal behavior. During 12 years, the annual rate of change in SOC (0–90 cm) followed the order: low grazing pressure (1.17 Mg C ha^{-1} year^{-1}) > unharvested (0.64 Mg C ha^{-1} year^{-1}) = high grazing pressure (0.51 Mg C ha^{-1} year^{-1}) > hayed (−0.22 Mg C ha^{-1} year^{-1}). This study demonstrated that surface accumulation of SOC and TSN occurred, but that increased variability and loss of SOC with depth reduced the significance of surface effects.

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1. Introduction

Sequestration of soil organic C (SOC) and conservation of N in soil are of keen scientific and political interests as management pathways to help mitigate the emission of greenhouse gases (i.e., CO_2 and N_2O), which contribute to global warming (Izaurralde et al., 2001). Total soil N (TSN) is associated with SOC and plays a key role in building soil fertility and enhancing soil productivity. The primary factors affecting SOC and TSN are (1) climatic conditions, such as temperature and precipitation, (2) plant productivity, (3) soil texture and its association with internal drainage, and (4) agricultural management practices, especially those that affect the type and amount of organic matter inputs to soil and the extent of soil disturbance (Paul et al., 1997). Agricultural practices are important variables within a given climatic zone that control (1) the quantity, quality, and placement of organic matter inputs via crop selection, crop rotation, fertilization, organic amendment, and tillage type and frequency and (2) the loss of organic matter via plant harvest, erosion, and enhanced microbial decomposition (Magdoff and Weil, 2004).

In the warm, humid region of the southeastern USA, pastures are recognized as an important land use capable of storing a large quantity of SOC and TSN (Franzluebbers, 2005). However, only few data are available that describe how pasture management can influence the long-term dynamics of SOC and TSN. In the southeastern USA (including the states of AL, AR, DE, FL, GA, LA, MD, MS, NC, SC, TN, and VA), pasture land accounts for 13.8 Mha or 34% of the total farm land (USDA-National Agricultural Statistics Service, 2004). Establishment of switchgrass (*Panicum virgatum* L.) for bioenergy production resulted in a rate of SOC sequestration to a depth of 30 cm ranging from 0.5 Mg C ha^{-1} year^{-1} during 10 years in Alabama (Ma et al., 2000) to 2.9 Mg C ha^{-1} year^{-1} during 5 years at five locations in eastern Texas (Sanderson et al., 1999). During the first 5 years of bermudagrass (*Cynodon dactylon* L.) management in Georgia, SOC sequestration in the surface 6 cm was 1.4 Mg C ha^{-1} year^{-1} when grazed by cattle in summer and 0.5 Mg C ha^{-1} year^{-1} when not grazed (Franzluebbers et al., 2001).

Relatively little is known about SOC and TSN sequestration throughout the soil profile. Whether positive effects of pasture management on SOC and TSN in surface soil might continue to

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accumulate at deeper layers has received relatively little attention, despite a recognition that deep-rooted plant species might contribute significantly to SOC sequestration (Fisher et al., 1994). Sequestration of SOC and TSN deeper in the soil profile could provide longer-term benefits that would not be as susceptible to loss from decomposition and erosion with future surface-soil disturbances. A difference in SOC between adjacent cropland and 5-years-old conservation reserve grassland in the Great Plains USA was detected in various increments to 40-cm depth, but not in depth increments from 40 cm to 300 cm below the surface (Gebhart et al., 1994). Summed to 100-cm depth, SOC content was not different between cropland and conservation reserve. In a shortgrass-steppe with 56 years of grazing in Colorado, SOC was not different between unharvested and lightly grazed rangeland at any soil depth increment to 90 cm (Reeder et al., 2004). In contrast, SOC was greater in four of seven depth increments to 90 cm under heavily grazed compared with unharvested rangeland. At the end of 12 years of grazing on a previously ungrazed mixed-grass rangeland in Wyoming, SOC and TSN were greater with light and heavy stocking than an ungrazed exclosure at a depth of 0–30 cm, but statistically similar between treatments at a depth of 0 cm and 60 cm (Schuman et al., 1999). At the end of 5 years of bermudagrass management in Georgia, SOC sequestration occurred in the surface 15 cm and small declines (although statistically significant in only 6 of 24 comparisons) occurred at lower depths to 150 cm (Franzluebbers and Stuedemann, 2005). Likewise, TSN sequestration occurred primarily in the surface 15 cm and both small declines (significant in 2 of 24 comparisons) and small increases (significant in 2 of 24 comparisons) occurred at lower depths. These data suggest that relatively low SOC and TSN concentrations with increasing depth compared with surface-soil concentrations combined with equally high random variation would limit our ability to detect management-induced changes in SOC and TSN sequestration throughout the profile.

We hypothesized that detailed research with at least a decade of consistent management would be needed to detect significant changes in soil-profile distribution of SOC and TSN under pastures. A comparison of analysis techniques indicated that linear regression of SOC and TSN changes with time produced lower variation than point-in-time measurements at the end of an evaluation period (Franzluebbers and Stuedemann, 2005). Therefore, our objectives were to (1) compare the effects of nutrient source and forage utilization strategies on SOC and TSN at the end of 12 years of pasture management, (2) determine the rates of change in SOC and TSN with various depth increments throughout the soil profile based on sampling at 0, 5, and 12 years of management, and (3) quantify the extent of potential spatial redistribution of SOC and TSN induced by cattle behavior within a pasture.

2. Materials and methods

2.1. Site characteristics

A 15-ha upland field (33°22′N, 83°24′W) in the Greenbrier Creek subwatershed of the Oconee River watershed near Farmington Georgia USA had previously been conventionally cultivated with various row crops for several decades prior to grassland establishment by sprigging of 'Coastal' bermudagrass [*Cynodon dactylon* (L.) Pers.] in 1991. Grassland management from 1991 to 1994 consisted of a low level of fertilizer input and periodic mowing to control growth. From 1994 to the end of summer in 1998, bermudagrass was the dominant forage (Franzluebbers et al., 2004). 'Georgia 5' tall fescue (*Lolium arundinaceum* Schreb. S.J. Darbyshire) was drilled (approx. 28 kg seed ha^{-1}) directly into existing bermudagrass sod during November 1998, 1999, and 2000. Dry winter conditions and shallow seed placement prevented adequate establishment in 1998 and 1999 and the need for repeated sowing. Long-term mean annual temperature was 16.5 °C, rainfall was 1250 mm, and potential pan evaporation was 1560 mm. Dominant soils at the site were Madison, Cecil, and Pacolet sandy loam [fine, kaolinitic, thermic Typic Kanhapludults (USDA), Acrisols (FAO)].

2.2. Experimental design

The experimental design was a randomized, complete block with treatments in a split-plot arrangement in each of three blocks, which were delineated by landscape features (i.e., slight, moderate, and severe erosion classes). Main plots were nutrient source ($n = 3$) and split-plots were forage utilization ($n = 4$) for a total of 36 experimental units. Grazed plots (i.e., paddocks) were 0.69 ± 0.03 ha. Spatial design of paddocks minimized runoff contamination and facilitated handling of cattle (*Bos taurus*) through a central roadway. Each paddock contained a 3 × 4 m shade, mineral feeder, and water trough placed in a line 15-m long at the highest elevation. Unharvested and hayed exclosures (100 m^2) were randomly placed side-by-side in paired low- and high-grazing pressure paddocks of each nutrient source.

Nutrient-source treatments from 1994 to 1998 were (1) inorganic fertilizer as NH_4NO_3 broadcast in May and July, (2) crimson clover (*Trifolium incarnatum* L.) cover crop + inorganic fertilizer (half of N assumed fixed and released by clover cover crop during spring and the other half as NH_4NO_3 broadcast in July), and (3) chicken (*Gallus gallus*) broiler litter broadcast in May and July. Nutrient-source treatments were modified after the first 5 years of management (Table 1). Fertilizer application was targeted to supply 200 kg N ha^{-1} year^{-1} during the first 5 years [see Franzluebbers and Stuedemann (2005) for management details] and targeted to supply 270 kg N ha^{-1} year^{-1} during the next 7 years. From 1999 to the end of summer 2005, the three nutrient sources were: (1) inorganic fertilizer as NH_4NO_3 broadcast in three applications in February–April, May–July and September–November, (2) single application of broiler litter broadcast in February–April and supplemented with inorganic fertilizer as NH_4NO_3

Table 1
Characteristics and rates of fertilizer sources applied to pastures

Year	Inorganic	Low broiler litter[a]		High broiler litter	
	kg N ha^{-1}	Mg C ha^{-1}	kg N ha^{-1}	Mc C ha^{-1}	kg N ha^{-1}
1994	211	NA	211	1.83	195
1995	202	NA	101	2.05	216
1996	250	NA	132	1.69	164
1997	238	NA	120	1.93	223
1998	224	NA	111	1.66	172
1999	276	0.96	337	2.87	393
2000	285	0.90	281	2.69	300
2001	267	0.96	291	3.00	318
2002	270	1.11	289	3.17	288
2003	283	1.11	302	3.36	333
2004	271	1.11	301	2.74	294
2005[b]	177	1.33	219	2.28	220
Mean annual	246 ± 36	0.62 ± 0.56	261 ± 44	2.44 ± 0.60	260 ± 71

NA is not applicable.

[a] Low broiler litter treatment was inorganic only in 1994 and crimson clover (*Trifolium incarnatum* L.) cover crop + inorganic fertilizer from 1995 to 1998 with an additional 110 kg N ha^{-1} year^{-1} assumed to be released from biologically fixed N in clover crop biomass from 1995 to 1998.

[b] Fertilizer treatments were terminated at the end of summer in 2005, and therefore, represented only two applications instead of three applications from 1999 to 2004.