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Impact of Cattle and Forage Management on Soil Surface Properties in the Southern Piedmont USA

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Abstract

Forages are an integral part of the agricultural landscape in the southeastern USA. Although the benefit of forages on soil physical, chemical, and biological properties has been fairly well documented following the implementation of the Conservation Reserve Program (CRP) in the USA, less information is available on the effects of cattle grazing on soil properties. We summarized some physical, chemical, and biological soil responses to different forages with and without cattle grazing from several recent experiments conducted in the Southern Piedmont region of Georgia. Forages have great potential to naturally loosen surface soil due to the accumulation of soil organic matter, which buffers against animal traffic. The return of feces to the soil surface with grazing is beneficial to the sequestration of soil organic C and N. Animal grazing of forage has large and immediate positive impacts on soil microbial biomass and potential activity. These results indicate that utilization of forages with cattle grazing can enhance the beneficial effects of forages on soil surface properties.

Keywords: Bermudagrass; Bulk density; Grazing pressure; Microbial biomass; Mineralizable nitrogen; Soil organic carbon; Tall fescue

Introduction

Forages are an integral part of the agricultural landscape in the southeastern USA. In the Southern Piedmont region, pastures represent more than 50% of the land area in agricultural production (Census of Agriculture, 1992). Although sod-based crop rotations were part of traditional cultural practices to build soil fertility prior to the mid 20th Century in the USA, they are not common now. Integration of cattle grazing and crop production is even less common. The benefit of forages on soil physical, chemical, and biological properties has been fairly well documented following the implementation of the Conservation Reserve Program (CRP). On a Fragiudalf in northern Mississippi, soil loss during rainfall simulations was several-fold greater following a 9-month bare fallow tilled plot compared with a 6-year-old tall fescue plot (Gilley and Doran, 1997). This increase in erosion with tillage was associated with lower soil organic C, lower soil microbial biomass C and N, and potential N mineralization. On a Haplaquoll and a Hapludoll in Iowa, plowing of an eight-year-old CRP site greatly reduced soil organic C and N and potential C mineralization compared with undisturbed CRP and no-tillage crop establishment (Gilley et al., 1997). Gebhart et al. (1994) observed significant increases in soil organic C at several locations in the Great Plains following establishment of perennial grass through the CRP. Lindstrom et al. (1994) reviewed a number of studies that detailed the benefits of grass on soil structural properties.

Less information is available on the effects of cattle grazing on soil properties. On a western rangeland in Wyoming, soil bulk density of the 0-2" depth increased by 0.09 g/cc in the fall compared to the spring due to cattle grazing in one year, but was unaffected by sampling time in another year (Abdel-Magid et al., 1987). A positive effect of cattle grazing compared with unharvested management on soil organic C storage was observed on a mixed-grass prairie in Wyoming (Manley et al., 1995; Schuman et al., 1999). Biologically active soil C and N pools increased with grazing intensity in a wildlife refuge in Tanzania (Reuss and McNaughton, 1987) and in Wyoming (Frank and Groffman, 1998). Length of grazing in a semi-arid wildlife refuge in New Mexico had no impact on total and biologically active soil C pools (Kieft, 1994). In tropical woodland sites in Australia, soil microbial biomass C declined significantly due to overgrazing (Holt, 1994). Both negative and positive effects of cattle grazing on soil properties can occur, depending upon ecosystem resilience and disturbance feedbacks, which are primarily controlled by climatic conditions and grazing management variables.

This report summarizes some soil responses to different forages with and without cattle grazing from several recent experiments conducted in the Southern Piedmont region of Georgia.

Materials and Methods

Several field studies were conducted at the J. Phil Campbell Sr. Natural Resource Conservation Center in Watkinsville GA (33 N latitude, 83 W longitude, 760' above sea level). The location is characterized by mean annual temperature of 62 EF, mean annual precipitation of 49", and mean annual pan evaporation of 62". Soils consisted of Cecil-Madison-Pacolet associations of sandy loam to sandy clay loam texture (clayey, kaolinitic, thermic Typic Kanhapludults). All surface residue and soil samples were dried at 130 EF for at least 48 h and weighed. Soil was gently crushed to pass a 0.19" screen prior to biological analyses. Stones >0.19" were removed from soil samples.

Long-term land-use comparison

Fourteen fields were selected to represent different land uses in the region (Franzluebbers et al., 2000a, b; Franzluebbers and Stuedemann, 2002). Comparisons included:

(1) Conversion of conventionally tilled cropland to conservation tillage versus conversion to tall fescue-common bermudagrass pasture. Prior to 1974, a single field was managed under conventional-tillage cropping. From autumn 1974 onwards, one portion was managed with conservation-tillage (double-cropping of soybean, sorghum, cotton, wheat, rye, barley, and crimson clover. The other portion continued to be managed with conventional-tillage cropping until autumn of 1978, when ‘Kentucky-31' tall fescue was planted.

(2) Grazing versus haying of hybrid bermudagrass. Grazed pastures were two 15-year-old and one 19-year-old stands of ‘Tifton 44'. Hayed fields were two 15-year-old stands of ‘Coastal’ and one 19-year-old stand of ‘Tifton 44'.

(3) Stand age of grazed 'Kentucky-31' tall fescue (i.e., 10, 17, and 50 years) and of hayed 'Coastal' bermudagrass (i.e., 6, 15, and 40 years). The 10- and 17-year-old pastures were replicated field experiments and the 50-year-old pasture was a single field.

(4) Longest-term continuous land management systems of forestland, cropland, hayland, and grazingland. Forestland was a planted loblolly pine (*Pinus taeda*) plantation established after the Civil War (1860s), with pines harvested in the mid 1960s and hardwoods (*Quercus, Carya,* and *Pinus*) allowed to regrow. Cropland was the 24-year-old conservation tillage system described in Contrast 1. Hayland and pastureland were the 40-and 50-year-old bermudagrass and tall fescue systems, respectively, described in Contrast 3.

Soil samples were collected from each field (7±5 acres) in four zones, which served as pseudoreplicates for analyses. Surface residue (all organic material at 0-2" height above mineral soil) was cut and collected. The soil surface under forest contained a thick organic layer, therefore we defined the soil surface as the mineral layer and placed the Oi and Oa horizons into the surface residue component. One soil core (1.6" diam) within each ring was divided into 0-2", 2-5", and 5-8" increments. A second core to a depth of 2" within the ring was added to the first core. Samples from six sites within each zone were composited.

Tall fescue study

'Kentucky-31' tall fescue paddocks (1.7-2 acres each) with low and high endophyte infection and low and high N fertilization were evaluated (Franzluebbers et al., 1999, 2000a). A total of 12 paddocks (3 sets) were sampled. One set of paddocks was planted to (i) high-endophyte-infected tall fescue (80% seed infection) and (ii) low-endophyte-infected tall fescue (<7% seed infection) in autumn 1981 and reseeded again in spring 1982 to increase stand. These paddocks received annual applications of 300-75-150 lb N-P_2O_5-K_2O/acre. A second set of paddocks was established at the same time and in the same way, except with annual applications of 120-30-60 lb N-P_2O_5-K_2O/acre. A third set of paddocks was fertilized according to the first set, but planted to 100%-infected tall fescue in autumn 1987 and to 0%-infected tall fescue in autumn 1988 (same 100%-infected seed source was incubated at ambient temperature for one year to reduce endophyte viability). All paddocks were grazed with Angus cattle each year following establishment, primarily in spring and autumn.

Soil samples were collected in January-February 1997 at depths of 0-1", 1-3", 3-6", and 6-12" at distances of 3', 33', 100', 167', and 267' from permanent shade and water sources, which were located 67' apart along one edge of each paddock. Eight cores (1.6" diam) were composited within each depth and distance.

Bermudagrass management study

'Coastal' bermudagrass was established on eroded land following decades of conventionally tilled cropland (Franzluebbers et al., 2001, 2002; Franzluebbers and

Stuedemann, 2001, 2003). Main plots were fertilization strategy (n=3) and split-plots were harvest strategy (n=4) for a total of 36 experimental units. Individual paddocks were 1.7±0.1 acres. Unharvested and hayed exclosures within each paddock were 1111 sq. ft. Fertilization of 200 lb N/acre/year was targeted using either (1) inorganic only as ammonium-nitrate broadcast in split applications in May and July, (2) crimson clover cover crop plus supplemental inorganic fertilizer (with half of the N assumed fixed by clover biomass and the other half as ammonium-nitrate broadcast in July), and (3) broiler litter (broadcast in split applications in May and July). Crimson clover was direct drilled in clover treatments at 1 lb/acre in October each year. All paddocks were mowed in late April following soil sampling and residue allowed to decompose. Harvest strategy mimicked a gradient in forage utilization consisting of (1) unharvested (biomass cut and left in place at the end of growing season), (2) low grazing pressure (put-and-take system to maintain a target of 1.3 ton/acre of available forage), (3) high grazing pressure (put-and-take system to maintain a target of 0.7 ton/acre of available forage), and (4) hayed monthly to remove above-ground biomass at 2" height. Yearling Angus steers grazed paddocks from mid May until early October each year.

Soil and surface residue were sampled yearly in February-April prior to grazing. Sampling locations (7±1) within grazed paddocks were within a 10' radius of points on a 100' grid. Two sampling locations were fixed within each hayed and unharvested exclosure. Surface residue was collected from a 2.8 sq. ft. area at each sampling point following removal of vegetation at a height of 2". Soil was sampled at depths of 0-0.8", 0.8-1.6", and 1.6-2.4". In February 1999, three zones within paddocks (i.e., 0-100', 100-233', and 233-400' distances from livestock shades) were sampled to depths of 0-1.2", 1.2-2.4", 2.4-4.7", and 4.7-8" by compositing eight different cores (1.6" diam).

Soil properties

Soil bulk density was calculated from the oven-dried soil weight (130 EF, 72 h) and volume of cores (226 to 990 cc).

Soil organic C and total soil N were determined from a 0.7-1 oz. soil subsample ground to a fine powder in a ball mill for 3 min prior to analysis of total C and N with dry combustion at 2460 EF. It was assumed that total C was equivalent to organic C because soil pH of all samples was <6.5.

Potential C and N mineralization were determined from aerobic incubation of soil at 77 EF for 24 d in sealed jars in the presence of 1 *M* NaOH to trap CO_2. Soil inorganic N was determined by salicylate-nitroprusside (NH_4-N) and Cd-reduction (NO_2-N + NO_3-N) autoanalyzer techniques following extraction in 2 *M* KCl. Potential N mineralization was calculated as the difference in the quantity of inorganic N at 0 and 24 d of incubation.

Soil microbial biomass C was calculated as the quantity of CO_2-C evolved during 10 d of aerobic incubation at 77 EF following $CHCl_3$ fumigation divided by an efficiency factor of 0.41.

Results and Discussion

Soil bulk density

Soil bulk density is an indicator of compaction, where soil weight is determined within a known volume. Soil bulk density was not different between grazed and hayed hybrid bermudagrass fields (15-19 years old), averaging 1.08, 1.60, and 1.64 g/cc at depths of 0-2", 2-5", and 5-8" depths, respectively (Franzluebbers et al., 2000a). In conversations with animal producers, soil compaction is often a concern and is thought to increase with animal trampling on pastures. These results suggest that any negative long-term impacts of animal traffic on soil compaction when pastures were grazed were matched equally with machine traffic when fields were hayed.

At the soil surface (0-0.8"), bulk density was lower under grazed than under hayed management (Franzluebbers et al., 2001). This positive effect of grazing was countered with an equally negative effect at a depth of 0.8-1.6". Within the top 2.4" of soil, bulk density became stabilized at 1.3 g/cc after 2 years of hayed management, but continued to decline to 1.15 g/cc at the end of eight years of unharvested management (Fig. 1). The effect of cattle grazing was intermediate to these extremes. These data suggest that cattle densities of 2-4 head/acre of yearling steers continuously grazing bermudagrass during 4 ½ months in the summer did not contribute to excessive soil compaction.

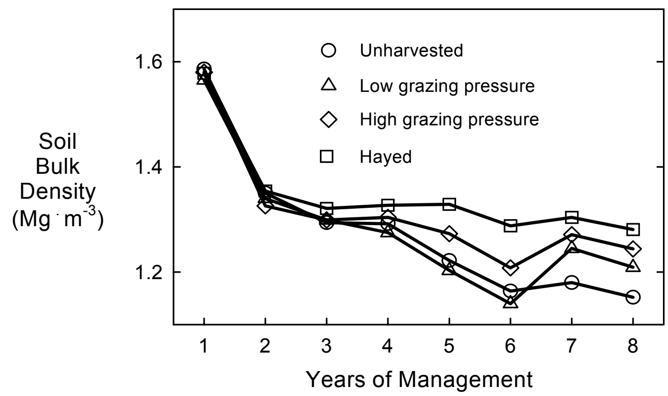

Fig. 1. Soil bulk density at a depth of 0-2.4" as a function of time since adoption of bermudagrass harvest strategy (data from Franzluebbers et al., 2001).

Soil bulk density was significantly lower under long-term grazed pasture than under conservation-tillage cropland at depths of 0-2" (1.12 vs. 1.31 g/cc, $p < 0.01$) and 2-5" (1.54 vs. 1.63 g/cc, $p < 0.01$) and equivalent at a depth of 5-8" (1.65 vs. 1.69 g/cc, $p > 0.1$) (Franzluebbers et al., 2000a). Comparing the results from two different studies on the same soil type (non-statistically), long-term

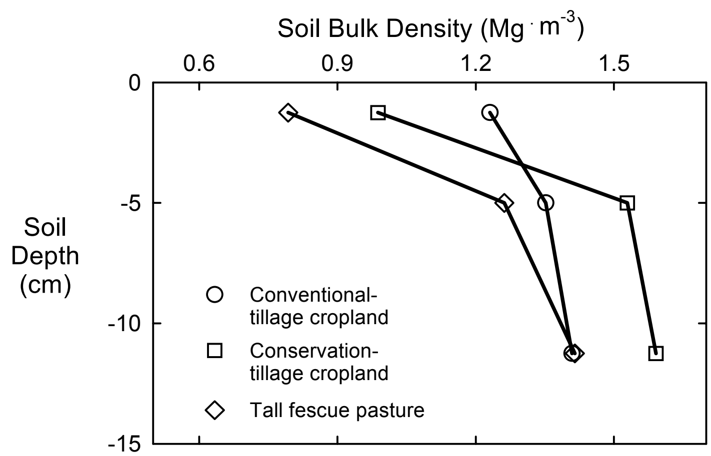

Fig. 2. Soil bulk density as a function of depth and land use. Data from Franzluebbers et al. (1999a, b).

tall fescue pasture also had lower soil bulk density at all depths compared with conservation-tillage cropland to a depth of 6" and compared with conventional-tillage cropland to a depth of 3" (Fig. 2).

Comparing long-term land use systems, soil bulk density at a depth of 0-8" was 1.32 ± 0.05 g/cc under 130-year-old forest, 1.38 ± 0.02 g/cc under 50-year-old grazed tall fescue, 1.52 ± 0.02 g/cc under 40-year-old hayed bermudagrass, and 1.57 ± 0.04 g/cc under 24-year-old conservation-tillage cropland (Franzluebbers et al., 2000b). In these same comparisons, aggregate stability indices were similar among forested, grazed, and hayed land uses, which were all higher than under cropped land use.

Soil organic C and N

Soil organic C and N were greater under long-term grazed than under hayed bermudagrass (Table 1). In addition, grazing led to greater surface residue C and N contents than under haying. Grazing is beneficial to storage of soil organic C and N by recycling the undigested forage back to the pasture as excreta. Haying removes nutrients and reduces the amount of decomposable substrates added to the soil, which affect soil organic C and N pools and processes.

Table 1. Surface residue and soil organic C and N contents under grazed and hayed bermudagrass (15-19-years old). Data from Franzluebbers et al. (2000a).

Property	Grazed		Hayed
	Carbon (ton/acre)		
Surface residue	0.8	**	0.5
Soil (0-5 cm)	8.2	***	6.0
Soil (5-12.5 cm)	5.3		4.7
Soil (12.5-20 cm)	3.4		3.1
Soil (0-20 cm)	17.0	*	13.9
Total stock	17.8	*	14.4
	Nitrogen (lb/acre)		
Surface residue	71	***	27
Soil (0-5 cm)	1286	***	786
Soil (5-12.5 cm)	857		697
Soil (12.5-20 cm)	473		473
Soil (0-20 cm)	2625	**	1956
Total stock	2697	**	1991

Soil organic C and N increased with time following establishment of all bermudagrass harvest strategies (Fig. 3). However, the rate of accumulation was greater with cattle grazing than without. Soil organic C accumulated at a rate of 1250 lb/acre/year under both cattle grazing pressures, at a rate of 580 lb/acre/year under unharvested management, and at a rate of 260 lb/acre/year under hayed management. Cattle consumed forage and deposited feces back to the soil where this organic matter quickly became a part of the soil organic pool. Total soil N accumulated at a rate of 146 lb/acre/year under high grazing pressure, 131 lb/acre/year under low grazing pressure, 65 lb/acre/year under unharvested management, and 27 lb/acre/year under hayed management. With an average rate of N applied of 195 lb/acre/year, sequestration of N into the surface 2.4" of soil organic matter was equivalent to 75% of total N applied under high grazing pressure, 67% of total N applied under low grazing pressure, 33% of total N applied under unharvested management, and 14% of total N applied under hayed management. This suggests that fertilizer applications to pastures during early years contributes to the long-term fertility of soil, especially near the surface where it can be readily utilized by subsequent plant roots.

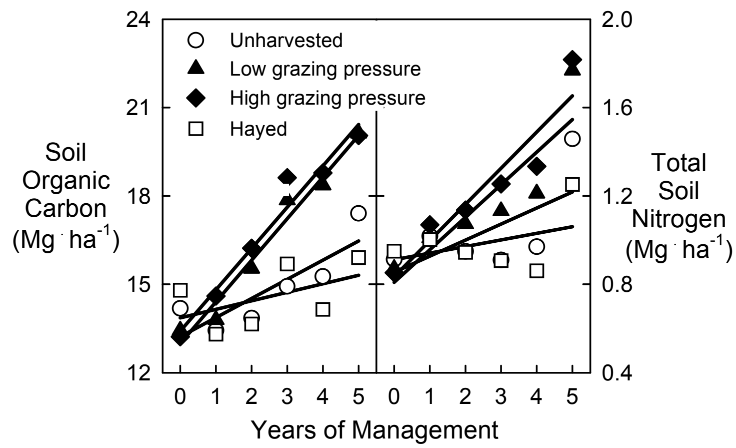

Fig. 3. Soil organic C and total soil N at a depth of 0-2.4" as a function of bermudagrass harvest strategy and time since establishment. Data from Franzluebbers et al. (2001) and Franzluebbers and Stuedemann (2001).

From two forage chronosequences, estimates of soil organic C accumulation were 889 lb/acre/year under grazed tall fescue and 290 lb/acre/year under hayed bermudagrass during the first 10 years of establishment (Franzluebbers et al., 2000a). Corresponding total soil N accumulation rates were 65 lb/acre/year under grazed tall fescue and 14 lb/acre/year under hayed bermudagrass. Accumulation estimates during the 10-30-year period were approximately half of those during the first 10 years. The chronosequence regression approach suggested that maximum soil organic C and N content could be achieved at 30-40 years following establishment of forages.

Comparison of soil organic C from different land uses suggests that the vast majority of organic matter that accumulated with forage management systems occurred within the surface few inches (Fig. 4). Any forage management strategy that allows sufficient surface residue accumulation and a high quantity of herbage production should lead to an accumulation of soil organic C and N.

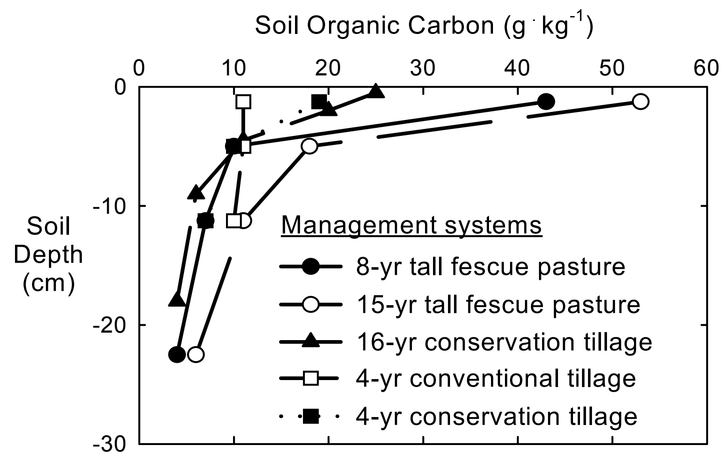

Fig. 4. Soil organic C concentration as a function of depth and land use. Taken from Schnabel et al. (2001).

Soil microbial biomass and potential activity

Soil microbial biomass and its activity are important mediators of organic matter decomposition, plant-available nutrient supplies, and formation of soil structure. Since the majority of microorganisms in soil are heterotrophic (i.e., they obtain their food and energy through decomposition of organic substrates), the accumulation of soil organic matter is an important process necessary for the development of a large and diverse microbial community capable of cycling and sequestering soil nutrients and processing the organo-mineral matrix into stable aggregates.

Soil microbial biomass C was greater under grazed than under hayed management, not only at the soil surface where concentrations were highest due to surface litter and root inputs, but also deeper in the soil where concentrations were lower due to root inputs only (Fig. 5). Fresh, sustained inputs of organic matter are necessary for the development of soil microbial biomass. This is exemplified with the data from the forage chronosequences, where the ratio of soil microbial biomass-to-soil organic C declined from 4.3% at 5 years to 3.9% at 25 years from establishment (Franzluebbers et al., 2000a).

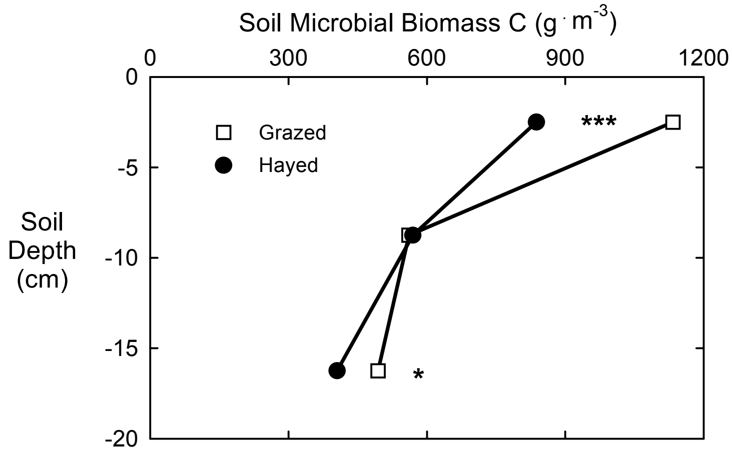

Fig. 5. Soil microbial biomass C concentration as a function of depth and 15-19 years of bermudagrass harvest strategy. Data from Franzluebbers et al. (2000a). * and *** indicate significance at $p < 0.1$ and $p < 0.001$, respectively.

Soil microbial biomass C and potential C and N mineralization increased linearly during the first four years of bermudagrass establishment (Table 2). Increases were greater with than without cattle grazing. Soil microbial biomass C also increased more with hay than with unharvested management, despite the continuous removal of aboveground forage assumed to be necessary for growth and development of the soil microbial community. It appears that both above-ground and below-ground C inputs were important to the dynamics of soil microbial biomass C. The curvilinear response in soil microbial biomass C

Table 2. Net annualized change in soil microbial biomass C (SMBC), potential C mineralization (CMIN), potential N mineralization (NMIN), ratio of SMBC-to-soil organic C (SOC), and ratio of CMIN-to-SOC during four years of bermudagrass harvest management (UH is unharvested, LG is low grazing pressure, HG is high grazing pressure, and H is hayed). Data from Franzluebbers and Studemann (2001, 2003).

Soil property	Intercept	Harvest strategy UH	LG	HG	H
(0-2.4")	lb/acre	---------- lb/acre/year ----------			
SMBC	446	46	86	106	66
CMIN	204	76	118	146	102
NMIN	44	-3	-2	-2	-4
	%	--------------- %/year ---------------			
SMBC/SOC	3.66	0.26	0.30	0.38	0.46
CMIN/SOC	1.64	0.55	0.66	0.79	0.77

accumulation as a function of forage utilization suggests that the quantity of cattle dung supplied to the soil may have stimulated soil microbial biomass C compared with above-ground residue supply alone, since there was a large response to grazed compared with unharvested forage. The positive, linear response in the portion of soil organic C as microbial biomass C as a function of forage utilization suggests that below-ground C inputs via roots must also be a significant substrate for the accumulation of soil microbial biomass C. Increasing intensity of forage removal has been hypothesized to stimulate root exudation and root regeneration (Bardgett et al., 1998), which could contribute to soil microbial biomass development without increasing soil organic C content. However, overgrazing of pastures can lead to a significant reduction in soil microbial biomass C compared with well managed pastures (Holt, 1997).

Conclusions

Results of soil bulk density under different land uses suggests that forages have great potential to naturally loosen surface soil. This occurs due to the extensive permanent surface root systems that both (1) penetrate soil and (2) leave behind large quantities of sloughed organic materials, which are utilized by soil microorganisms in the formation of water-stable aggregates and creation of semi-permanent biopores. Our results also suggest that cattle grazing forages may actually enhance soil loosening, because of the deposition of feces to the soil surface, which enhances soil organic matter accumulation. It is likely that excessive cattle traffic with overgrazing by limiting plant productivity would result in soil compaction and a detriment to the soil environment. Determining a sustainable balance between forage utilization and soil quality requires further research under a diversity of environmental conditions.

Forage management strategies are effective at sequestering soil organic C and N in previously cropped soils of the Southern Piedmont region. The return of feces to the soil surface with grazing is beneficial to the sequestration of soil organic C and N. Although not investigated, it is possible that mismanagement through long-term overgrazing, which would reduce the photosynthetic capacity of a forage stand, could lead to a reduction in soil organic C and N and consequent increase in soil erosion and reduction in environmental quality.

Animal grazing of forage has large and immediate positive impacts on soil microbial biomass and potential activity. The high microbial biomass and activity under grazed forages (1) stimulates decomposition of organic residues derived from senescent above- and below-ground plant materials and from animal feces, (2) temporarily immobilizes nutrients that are needed by the plant, but that become slowly available for extended periods of time thereafter, and (3) stabilizes soil aggregates necessary for efficient water infiltration and air transport to and from the soil and atmosphere.

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