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The Salem Road Study: Restoration of Degraded Land with Pasture – Soil Quality and Carbon Sequestration

Alan J. Franzluebbers and John A. Stuedemann
USDA–Agricultural Research Service, 1420 Experiment Station Road, Watkinsville, GA 30677

Summary

Pasture management is of importance to the understanding of agronomic and animal productivity, soil quality, greenhouse gas emissions, and environmental quality. Pastures have the potential to serve as a significant sink for carbon (C) sequestered in soil organic matter. Efficient utilization of nitrogen (N) is of concern agronomically and environmentally. Plant production can be limited by low levels of available phosphorus (P) due to high P fixation capacity in soils of the southeastern USA. On the other hand, there is increasing concern about the excessive application of P to soil, especially when manure application rate is based upon N content.

We evaluated changes in surface residue C-N, soil C-N-P, and soil bulk density during the first five years of bermudagrass [*Cynodon dactylon* (L.) Pers.] management varying in fertilization [(1) inorganic, (2) crimson clover (*Trifolium incarnatum* L.) cover crop plus inorganic, and (3) chicken (*Gallus gallus*) broiler litter] and harvest strategies [(1) unharvested, (2) low and (3) high cattle (*Bos taurus*) grazing pressure, and (4) haying).

Fertilization strategy had the greatest impact on total and extractable soil P, while soil organic C and total soil N were minimally affected. At a depth of 0 to 6 cm, extractable soil P increased at a rate of 0.8 mg · kg^{-1} · yr^{-1} (4 % of total P added) with inorganic only, 2.4 mg · kg^{-1} · yr^{-1} (9 % of total P added) with clover + inorganic, and 8.7 mg · kg^{-1} · yr^{-1} (6 % of total P added) with broiler litter fertilization. At the end of five years of broiler litter application to grazed land, extractable soil P was 135, 50, 22, and 4 mg · kg^{-1} higher than with inorganic fertilization at depths of 0 to 3, 3 to 6, 6 to 12, and 12 to 20 cm, respectively, primarily because of greater P application with broiler litter.

Harvest strategy had large impacts on all soil elements. Soil organic C sequestration during the first five years of management was similar between low and high cattle grazing pressures (140 g · m^{-2} · yr^{-1}), but much less in unharvested (65 g · m^{-2} · yr^{-1}) and hayed (29 g · m^{-2} · yr^{-1}) management. Most of the net change in soil organic C and total soil N occurred in the 0- to 2-cm depth. Surface residue C accumulated early in the study under low grazing pressure and unharvested management, but declined to lower levels thereafter. At the end of five years the portion of total standing stock of C (20-cm depth) as surface residue C was 6.0, 4.7, 3.5, and 2.3% under unharvested, low grazing pressure, high grazing pressure, and hayed management, respectively. With cattle grazing of forage, fertilizer applications contributed to forage and animal production and 67 to 75% of the total N applied was subsequently stored as total soil N. Cattle grazing shunted C and N more directly from forage to the soil, which contributed to greater sequestration of soil organic C and total soil N than with haying or unharvested management. With time, soil bulk density at a depth of 0 to 6 cm was positively related with the level of forage utilization, i.e. highest bulk density under hayed management and lowest bulk density under low grazing pressure and unharvested management.

In contrast to results from more arid regions, our results from the humid region of the southeastern USA suggest that well-managed cattle grazing systems can improve soil quality and enhance soil C sequestration, while maintaining high animal productivity. Further research is needed to identify how long these benefits can be maintained, and if this trend reverses, then identify which management systems will cause the most rapid and extensive deterioration to the environment.

Rationale

Soils in the humid southeastern USA have undergone severe erosion and degradation as a result of historically intensive conventional tillage for crop production (Trimble, 1974; Langdale et al., 1992). Soil organic C levels following long-term cultivation have been reported to be as low as 30% of precultivation levels (Giddens, 1957). Extreme losses of soil organic C have occurred in this region, because of accelerated decomposition with cultivation and erosive forces, which preferentially remove the lower density components of soil (i.e., organic matter) concentrated near the surface (Lowrance and Williams, 1988). Sequestration of organic C in previously degraded soils is necessary to not only improve the physical, chemical, and biological properties of soils (Follett et al., 1987), but also to help mitigate potential greenhouse effects from rising atmospheric CO_2 levels (Lal et al., 1998).

Restoration of eroded cropland in the southeastern USA is possible with conservation tillage systems, which minimize soil disturbance and maximize surface residue accumulation (Langdale et al., 1992). In the Southern Piedmont region, however, an increasing portion of land supports small-farm, cattle-grazing production systems (Census of Agriculture, 1992). Despite the abundance and importance of managed pastures in the southeastern

USA, relatively little information is available to describe rates of soil organic C and N accumulation under pasture management systems (Schnabel et al., 2001).

Grazing of a forage crop compared with haying returns much of the manure directly to the land with a positive impact on soil organic C and N accumulation (Franzluebbers et al., 2000), but the impact of stocking density on plant productivity, soil compaction, and soil organic C and S cycling is not well understood. Further, the impact of not harvesting forage on soil organic C and S deserves attention, based on the extent of land currently managed under the Conservation Reserve Program (CRP). Harvest management would be expected to alter the distribution of C and S among surface residue and the soil profile, because of the effects of animal traffic, ruminant processing of forage, and forage removal.

The effect of fertilization strategy on soil organic C dynamics in managed pastures is variable (Schnabel et al., 2001). In some cases, increased fertilization may improve forage yield but have little effect on soil organic C (Owensby et al., 1969; Jenkinson, 1988). In other cases, increased fertilization improves both forage yield and soil organic C in the long-term (Schwab et al., 1990; Haynes and Williams, 1992). The impact on soil organic C and N dynamics of whether fertilization comes from an organic or an inorganic source has received limited attention, but is a very important issue in the southeastern USA, where poultry production and associated availability of manure are abundant. Soil organic C was little affected whether grass received manure or inorganic fertilizer in a long-term experiment at Rothamsted (Jenkinson, 1988). However, greater accumulation of soil organic C was observed under fertilized ryegrass (*Lolium perenne* L.) than under ryegrass-white clover (*Trifolium repens* L.) (Hatch et al., 1991). Much more work is needed to understand the sequestration of soil organic C and N in response to organic and inorganic amendments to grazed and ungrazed pastures.

We hypothesized that with equivalent amounts of total N applied, fertilization strategy (i.e., inorganic and organic) could affect the availability of N to forage, and therefore affect the quality and quantity of forage leading to differences in soil organic C and N sequestration rates. In addition, we wanted to ascertain the impact of forage harvest strategy (i.e., grazed and ungrazed) on soil compaction and cycling of C and N during the first five years of grass management following conversion from long-term cultivated cropland.

Sampling and analyses

The previous paper in this series by Stuedemann describes the experimental setup. Soil and surface residue were sampled in April prior to grazing and in October following grazing during most years. Hayed and unharvested exclosures were sampled in July, rather than May during 1994. Sampling locations within grazed paddocks were within a 3-m radius of points on a 30-m grid. Due to the nonuniform dimensions of paddocks, sampling sites within a paddock varied from as few as four to as many as nine, averaging 7±1. Two sampling locations were fixed within each hayed and unharvested exclosure. Surface residue was collected from a 0.25-m^2 area at each sampling point following removal of vegetation at a height of -4 cm. Surface residue, including plant stubble, was cut to the mineral surface with battery-powered hand shears, bagged, and dried at 70 EC for several days. During 1994 and 1995, soil was sampled at depths of 0 to 2, 2 to 4, and 4 to 6 cm from the composite of two 8.5-cm-diam cores within each sampling location. From spring 1996 until the spring of 1998, soil was sampled to the same depths from the composite of nine 4.1-cm-diam cores within each sampling location. Soil was air-dried and ground to <2 mm in a mechanical grinder in 1994 and 1995. Soil was oven-dried (55 EC, 72 hr) and gently crushed to pass a 4.75-mm screen in all other years.

Beginning in February 1999, sampling strategy was changed to (1) collect surface residue and soil only once per year, (2) more directly address the zonal changes in pastures in response to animal behavior near shade and water sources, and (3) collect soil to deeper depths. Surface residue was collected from a composite of eight 0.04-m^2 areas randomly selected within each of three zones within paddocks (i.e., 0 to 30, 30 to 70, and 70 to 120 m distances from livestock shades) and within each exclosure. Surface residue was processed as described previously. A single 4.1-cm-diam soil core was collected from each of the eight residue sampling sites and composited. Soil was collected at depths of 0 to 3, 3 to 6, 6 to 12, and 12 to 20 cm, oven-dried (55 EC, 72 hr), and gently crushed to pass a 4.75-mm screen.

Soil bulk density was calculated from the oven-dried soil weight (55 EC) and pooled-core volume (2.26-8.45 x 10^{-4} m^3, depending upon depth of sampling). During 1994 and 1995, soil was collected by scooping to a particular depth by a highly experienced technician. To mechanize the process independent of experience, a tray with slots at 2, 4, and 6 cm for cutting soil sections with precision was used In 1996, 1997, and 1998. In 1999, soil was cut to depth inside the sampling tube. Surface residue was ground to <1 mm and a 20- to 30-g soil subsample from each composite sample was ground to a fine powder in a ball mill for 3 min prior to analysis of total C, N, and S with dry combustion at 1350 EC (Leco CNS-2000, St. Joseph, MI).[1] It was assumed that total C was equivalent to organic C because soil pH was near 6. Soil organic C and S, surface residue C and S, and soil bulk density were reported in Franzluebbers et al.(2001). Total soil and residue N were reported in Franzluebbers and Stuedemann (2001).

Mehlich-I extractable soil P (Nelson et al., 1953) was determined (10 g soil shaken with 40 mL of 0.05 *M* HCl + 0.0125 *M* H_2SO_4 for 15 minutes and filtered) with a molybdate autoanalyzer technique (Olsen and Sommers, 1982). Total soil P of the 0- to 3- and 3- to 6-cm depths was determined with inductively coupled plasma spectroscopy (ICPS) following perchloric acid digestion (Olsen and Sommers, 1982) for soils collected in February 1999, for which three subsampling units (i.e., 20 g from each of the samples representing the 0 to 30, 30 to 70, and 70 to 120 m distances from shade) within each grazed paddock were composited. The University of Georgia Agricultural and Environmental Services Laboratory conducted ICPS analyses. Although perchloric acid digestion may not yield 100% total P, the analysis of results should still be a good indication of changes in less labile forms of P due to pasture management strategies. Soil P was reported in Franzluebbers et al. (2002).

Table 1. Characteristics and rates of fertilizers applied ($kg \cdot ha^{-1} \cdot yr^{-1}$).

Variable	1994	1995	1996	1997	1998	5-yr mean
			Inorganic only			
Nitrogen	211	202	250	238	224	225
Phosphorus	0	24	24	24	7	16
Potassium	0	47	93	93	28	52
			Clover + inorganic[a]			
Nitrogen	211	101	132	120	111	135
Phosphorus	0	33	49	24	7	23
Potassium	0	62	93	93	28	55
			Broiler litter			
Dry mass	5220	6500	5190	5020	5040	5390
Moisture ($g \cdot g^{-1}$)	0.25	0.30	0.27	0.19	0.28	0.26
Carbon	1830	2050	1690	1930	1660	1830
Sulfur	20	26	26	23	17	22
Nitrogen	195	216	164	223	172	194
Phosphorus	118	141	112	69	178	124
Potassium	169	243	168	115	140	167

[a] An additional 110 $kg\ N \cdot ha^{-1} \cdot yr^{-1}$ was assumed to be supplied in clover cover crop biomass through biological N fixation from 1995 to 1998.

Data from multiple samples within an experimental unit were averaged and not considered as a source of variation in the analysis of variance (SAS Institute, 1990). Within-depth, across-depth, within-year, and across-year analyses were conducted according to the split-plot design with three blocks. Across-depth analyses considered the bulk density of soil in calculating standing stock values of soil organic C and total S. Across-year analyses considered years as repeated measures. Effects were considered significant at P#0.1.

Results and discussion

Application of fertilizers during the first five years of this experiment is described in Table 1. Phosphorus and potassium applications varied among treatments, because excess P and K were applied with broiler litter to meet N requirements, while diammonium phosphate and potash were applied based on soil testing recommendations.

Fertilization effects on C-N-P

Fertilization strategy of bermudagrass had little effect on the rate of accumulation of soil organic C and total soil N, but had a major impact on the accumulation of Mehlich-I-extractable soil P (Fig. 1). Soil organic C at a depth of 0 to 6 cm accumulated at an average rate of 940 $kg \cdot ha^{-1} \cdot yr^{-1}$ across fertilization regimes. Interestingly, the additional input of C with broiler litter fertilization did not translate into significantly greater accumulation of soil organic C. This may be due to the relatively warm and moist climatic conditions in the region, which favored rapid and near complete decomposition of the organic amendment.

Total soil N accumulated at an average rate of 103 $kg \cdot ha^{-1} \cdot yr^{-1}$ across fertilization regimes (Fig. 1). The lack

[1]Trade and company names are included for the benefit of the reader and do not imply any endorsement or preferential treatment of the product listed by the U.S. Department of Agriculture.

of difference among fertilization regimes in the rate of total soil N accumulation suggests that N application in each system may have led to similar plant production and transformation of plant decomposition products into soil organic matter. It is also possible that there may have been some shifts in the balance between quality and quantity of plant components in response to fertilization strategies, but these intermediate steps were not determined in this study.

Mehlich-I-extractable soil P accumulated at a rate of 11.5 kg · ha^{-1} · yr^{-1} with broiler litter fertilization and at an average rate of 1.4 kg · ha^{-1} · yr^{-1} with inorganic only and clover + inorganic fertilization (Fig. 1). Phosphorus inputs averaged 16, 23, and 124 kg · ha^{-1} · yr^{-1}, suggesting that Mehlich-I-extractable soil P accumulated at a rate of 10% of applied P with inorganic only fertilization, 6% of applied P with clover + inorganic fertilization, and 9% of applied P with broiler litter fertilization. Adsorption of P onto soil colloids was likely a major pathway that limited the accumulation of Mehlich-I-extractable soil P in these systems. Ultisols in southeastern USA, which have copious quantities of particulate and colloidal Fe- and Al-oxides, have a great affinity to adsorb P on these reactive surfaces (Anderson et al., 1996).

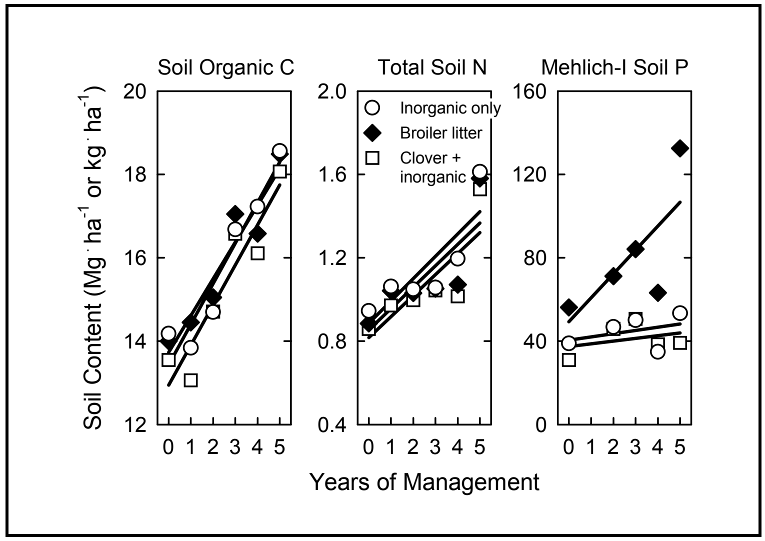

Figure 1. Changes in the contents of soil organic C (Mg · ha^{-1}), total soil N (Mg · ha^{-1}), and Mehlich-I extractable soil P (kg · ha^{-1}) with time at a depth of 0-6 cm as affected by fertilization strategy of 'Coastal' bermudagrass.

Forage utilization effects on C-N-P

The effects of forage utilization (or harvest strategy) with time were relatively consistent whether the response variable was soil organic C, total soil N, or Mehlich-I-extractable soil P (Fig. 2). The dominant harvest strategy effect was between grazed and ungrazed management systems. Soil organic C at a depth of 0 to 6 cm accumulated at a rate of 1400 kg · ha^{-1} · yr^{-1} under both grazing pressures, at a rate of 650 kg · ha^{-1} · yr^{-1} under unharvested management, and at a rate of 290 kg · ha^{-1} · yr^{-1} 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 at a depth of 0 to 6 cm accumulated at a rate of 164 kg · ha^{-1} · yr^{-1} under high grazing pressure, at a rate of 147 kg · ha^{-1} · yr^{-1} under low grazing pressure, at a rate of 73 kg · ha^{-1} · yr^{-1} under unharvested management, and at a rate of 30 kg · ha^{-1} · yr^{-1} under hayed management (Fig. 2). With an average rate of N applied of 218 kg · ha^{-1} · yr^{-1}, sequestration of N into soil organic matter of the surface 6 cm 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

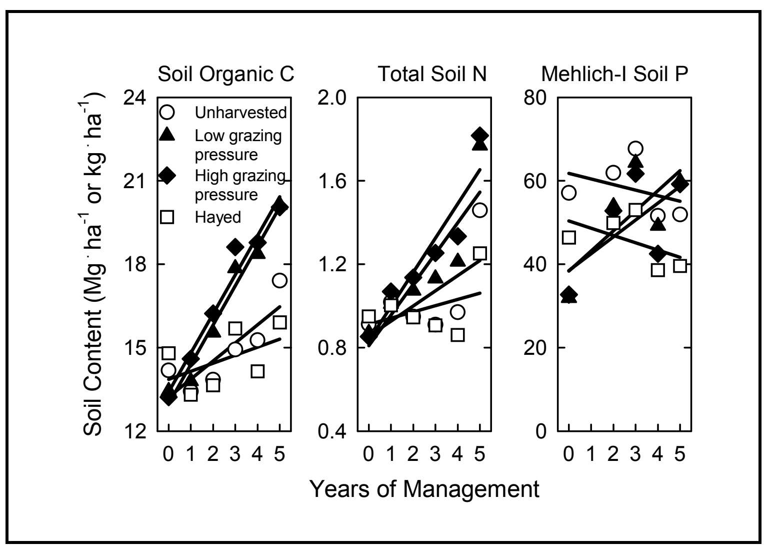

Figure 2. Changes in the contents of soil organic C (Mg · ha^{-1}), total soil N (Mg · ha^{-1}), and Mehlich-I extractable soil P (kg · ha^{-1}) with time at a depth of 0-6 cm as affected by harvest strategy of 'Coastal' bermudagrass.

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.

Mehlich-I-extractable soil P at a depth of 0 to 6 cm accumulated at a rate of 5 kg · ha^{-1} · yr^{-1} under high grazing pressure and at a rate of 4 kg · ha^{-1} · yr^{-1} under low grazing pressure (Fig. 2). In contrast, Mehlich-I-extractable soil P tended to decline with time under unharvested (-1 kg · ha^{-1} · yr^{-1}) and hayed (-2 kg · ha^{-1} · yr^{-1}) management. The removal of P with hay would have been expected to create a heavy demand on the labile pool of P. The relatively stable level of extractable soil P under unharvested management was mostly due to the fact that a few of the unharvested exclosures were located on areas with relatively high initial extractable soil P, which probably limited the release of P into the labile pool because of the reduced concentration gradient between total and labile pools. Cattle grazing returns most of the P consumed in forage back to the soil as feces, which led to an increase in the extractable soil P pool with recurring fertilization.

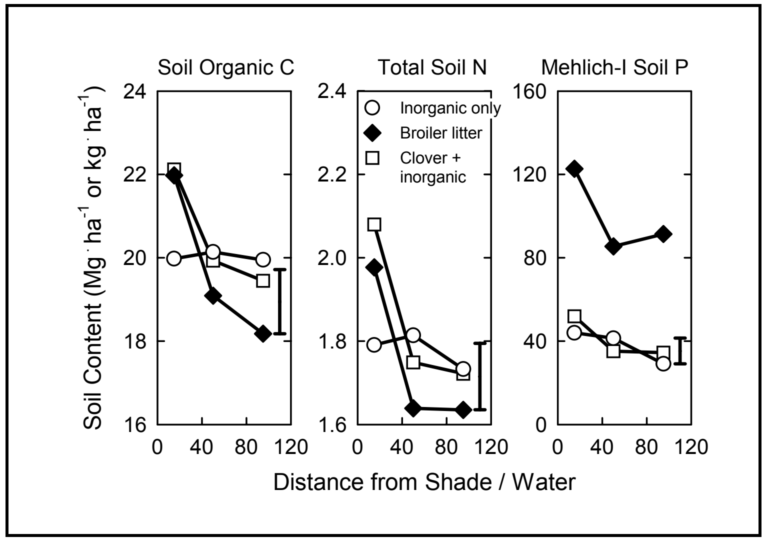

Figure 3. Spatial distribution within pastures at the end of 5 years in the contents of soil organic C (Mg · ha^{-1}), total soil N (Mg · ha^{-1}), and Mehlich-I extractable soil P (kg · ha^{-1}) at a depth of 0-6 cm as affected by fertilization strategy of 'Coastal' bermudagrass. Error bar indicates LSD at P=0.1.

Spatial distribution of C-N-P within pastures

Distribution of nutrients within grazed pastures was affected by proximity to shade and water sources (Fig. 5). Contents of soil organic C, total soil N, and Mehlich-I-extractable soil P in the surface 6 cm were greater in the 0-30-m zone around shade and water than farther away with broiler litter and clover + inorganic fertilization, but not with inorganic only fertilization. It is not clear why the spatial distribution of nutrients under inorganic only fertilization was different than under other fertilization strategies. Cattle spend a disproportionately greater amount of time near shade and water sources than other areas of a pasture, because of the need for water, minerals, and seeking relief from the sun.
Consequently, more feces and urine are deposited near shade and water sources than other areas of the pasture, resulting in accumulation of nutrients near shade and water sources.

Soil bulk density

Soil bulk density tended to decrease with increasing number of years under forage management (Fig. 4). At a depth of 0 to 6 cm when sampled in spring, soil bulk density decreased an average of 0.06 Mg · m^{-3} · yr^{-1}, based on the slope of a linear regression. Soil bulk density decreased with time, most likely because of the increase in soil organic matter near the soil surface, as well as greater volume of roots with time. Soil organic matter is lighter than mineral soil and is also a food

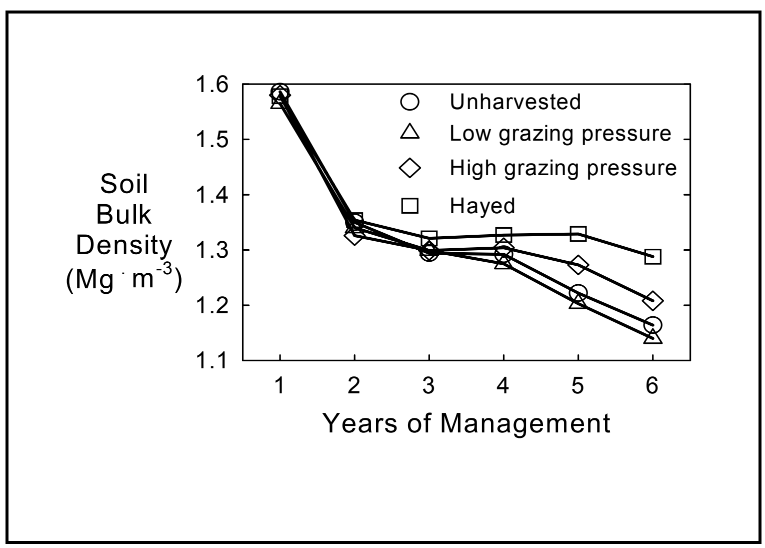

Figure 4. Soil bulk density at a depth of 0-6 cm as affected by harvest strategy of 'Coastal' bermudagrass.

source for soil organisms, which then contribute to increasing porosity and water-stable aggregation (Oades, 1993).

Soil organic C sequestration

The rate of accumulation in soil organic C during the first five years under hayed management (290 kg · ha^{-1} · yr^{-1}) was very similar to the estimated rate under hayed bermudagrass in a chronosequence study at a nearby location [350 kg · ha^{-1} · yr^{-1} interpolated from the first five years; Franzluebbers et al. (2000)]. In addition, our results of greater soil C sequestration under grazing compared with haying (a difference of 1110 kg · ha^{-1} · yr^{-1}) are somewhat higher than from observations between grazed and hayed bermudagrass at a nearby location [420 kg · ha^{-1} · yr^{-1} during a 15- to 19-year comparison; Franzluebbers et al. (2000)]. It could be expected that C sequestration rates in this previous study were higher during the initial five years compared with those 5 to 10 years later.

Soil organic C sequestration under unharvested management (650 kg · ha^{-1} · yr^{-1}) was similar to the estimated rate of soil organic C sequestration during five years of unharvested grass management under CRP at six locations in Kansas, Nebraska, and Texas [580±660 kg · ha^{-1} · yr^{-1} (0 to 20 cm) (Gebhart et al., 1994)]. We fertilized the unharvested management system to obtain a more direct comparison with other harvest management strategies, but most landowners are unlikely to fertilize unharvested grass in CRP on a yearly basis. Fertilization may have increased the rate of soil organic C sequestration by allowing more plant biomass to accumulate.

For the most part, broiler litter application did not affect soil organic C accumulation compared with inorganic and clover plus inorganic fertilization strategies. This was probably due to the relatively low rate of application (i.e., 5.4±0.6 Mg dry mass · ha^{-1} · yr^{-1}; Table 1). Broiler litter application (10.9±5.4 Mg dry mass · ha^{-1} · yr^{-1}) resulted in greater soil organic C concentration at a depth of 0 to 15 cm than without broiler litter in a survey of 12 paired pastures in northern Alabama at the end of 21±4 years (Kingery et al., 1994). The estimated mean rate of soil organic C accumulation due to broiler litter application in this Alabama survey was 300 kg · ha^{-1} · yr^{-1}, suggesting a retention rate in soil of -8% of applied C in broiler litter.

References

Anderson, S.J., K.E. Sanders, and K.J. Steyer. 1996. Effect of colloidal goethite and kaolinite on colorimetric phosphate analysis. J. Environ. Quality 25:1332-1338.

Census of Agriculture. 1992. Geographic area series 1B: U.S. summary and county level data. U.S. Dept. Commerce, Econ. and Statistics Admin., Bureau of the Census, Washington, DC.

Follett, R.F., J.W.B. Stewart, and C.V. Cole (ed.) 1987. Soil fertility and organic matter as critical components of production systems. Soil Sci. Soc. Am. Spec. Publ. 19, Madison, WI.

Franzluebbers, A.J., and J.A. Stuedemann. 2001. Bermudagrass management in the Southern Piedmont U.S. IV. Soil-surface nitrogen pools. The Scientific World 1(S2):673-681.

Franzluebbers, A.J., J.A. Stuedemann, H.H. Schomberg, and S.R. Wilkinson. 2000. Soil organic C and N pools under long-term pasture management in the Southern Piedmont USA. Soil Biol. Biochem. 32:469-478.

Franzluebbers, A.J., J.A. Stuedemann, and S.R. Wilkinson. 2001. Bermudagrass management in the Southern Piedmont USA. I. Soil and surface residue carbon and sulfur. Soil Sci. Soc. Am. J. 65:834-841.

Franzluebbers, A.J., J.A. Stuedemann, and S.R. Wilkinson. 2002. Bermudagrass management in the Southern Piedmont USA. II. Soil phosphorus. Soil Sci. Soc. Am. J. 66:291-298.

Giddens, J. 1957. Rate of loss of carbon from Georgia soils. Soil Sci. Soc. Am. Proc. 21:513-515.

Hatch, D.J., S.C. Jarvis, and S.E. Reynolds. 1991. An assessment of the contribution of net mineralization to N cycling in grass swards using a field incubation method. Plant Soil 138:23-.

Haynes, R.J., and P.H. Williams. 1992. Accumulation of soil organic matter and the forms, mineralization potential and plant-availability of accumulated organic sulphur: Effects of pasture improvement and intensive cultivation. Soil Biol. Biochem. 24:209-217.

Jenkinson, D.S. 1988. Soil organic matter and its dynamics. p. 564-607. *In* A. Wild (ed.) Russell's soil fertility. Pergamon Press, New York.

Kingery, W.L., C.W. Wood, D.P. Delaney, J.C. Williams, and G.L. Mullins. 1994. Impact of long-term land application of broiler litter on environmentally related soil properties. J. Environ. Qual. 23:139-147.

Lal, R., J.M. Kimble, and R.F. Follett (ed.) 1998. Management of carbon sequestration in soil. CRC Press, Boca Raton, FL.

Langdale, G.W., L.T. West, R.R. Bruce, W.P. Miller, and A.W. Thomas. 1992. Restoration of eroded soil with conservation tillage. Soil Technol. 5:81-90.

Lowrance, R., and R.G. Williams. 1988. Carbon movement in runoff and erosion under simulated rainfall conditions. Soil Sci. Soc. Am. J. 52:1445-1448.

Nelson, W.L., A. Mehlich, and E. Winters. 1953. The development, evaluation, and use of soil tests for phosphorus availability. Agronomy 4:153-158.

Oades, J.M. 1993. The role of biology in the formation, stabilization and degradation of soil structure. Geoderma 56:377-400.

Olsen, S.R., and L.E. Sommers. 1982. Phosphorus. p. 403-430. *In* A.L. Page, R.H. Miller, and D.R. Keeney (Eds.), Methods of soil analysis, Part 2, Chemical and microbiological properties, 2nd Ed. Agronomy No. 9, ASA, SSSA, Madison, WI.

Owensby, C.E., K.L., Anderson, and D.A. Whitney. 1969. Some chemical properties of a silt loam soil after 20 years nitrogen and phosphorus fertilization of smooth bromegrass (*Bromus inermus* Leyss). Soil Sci. 108:24-29.

SAS Institute. 1990. SAS user's guide: Statistics. Version 6 ed. SAS Inst., Cary, NC.

Schnabel, R.R., A.J. Franzluebbers, W.L. Stout, M.A. Sanderson, and J.A. Stuedemann. 2001. The effects of pasture management practices. p. 291-322. *In* R.F. Follett, J.M. Kimble, R. Lal (eds.) The potential of U.S. grazing lands to sequester carbon and mitigate the greenhouse effect. CRC Press, Boca Raton, FL.

Schwab, A.P., C.E. Owensby, and S. Kulyingyong. 1990. Changes in soil chemical properties due to 40 years of fertilization. Soil Sci. 149:35-43.

Trimble, S.W. 1974. Man-induced soil erosion on the Southern Piedmont, 1700-1970. Soil Conservation Society of America, Ankeny, IA. 180 pp.