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CHAPTER VIII

Soil organic carbon in managed pastures of the southeastern United States of America

Abstract

Grazing lands in the southeastern United States of America are managed primarily for introduced plant species that have high forage production potential or that fit in a niche within a farming system. Forages are typically managed with fertilization and grazing pressure on a seasonal basis, depending upon growth habit. Nitrogen (N) application is one of the key determinants of pasture productivity, although its effect on soil carbon (C) sequestration may be minimal, especially considering the associated carbon dioxide (CO_2) equivalence costs of fertilization. Fertilization with animal manures is effective and may provide additional soil C storage potential, although C may simply be transferred from one ecosystem to another. Moderate grazing of pastures may be the most effective strategy at storing soil organic carbon (SOC) in pastures. Return of dung to the soil surface has positive effects on soil surface properties, including soil microbial biomass and mineralizable C and N. Grazing land managed with a moderate grazing pressure, i.e. utilizing forage to an optimum level without compromising regrowth potential, can provide economic opportunities with low risk for landowners, improve degraded land by building soil fertility, improve water utilization and quality within the landscape, and help mitigate the greenhouse effect by storing C in soil as organic matter.

GRAZING LANDS IN THE UNITED STATES OF AMERICA

Grazing lands are extensively distributed throughout the United States (Follett, Kimble and Lal, 2001). The United States Department of Agriculture (USDA) Census of Agriculture for 2007 (http://www.agcensus.usda.gov/)

indicates that 1.1 million farms have 166 million ha of permanent pasture and rangeland, other than cropland and woodland pasture. Private and publicly owned grassland/grazing and hay lands were 456 million ha in 1948 and 342 million ha in 2002.

Humid grazing lands in the United States are predominantly in the eastern part of the country, as well as on the West Coast and high altitudes of the Rocky Mountain region (Figure 12). Pastures in the humid region are classified as permanent grasslands (21 million ha), forested grasslands (11 million ha) and cropland pasture (1.2 million ha) using the USDA Census of Agriculture database (Sheaffer *et al*., 2009). Using the 1992 National Resources Inventory, pastureland was estimated as 51 million ha of a total of 212 million ha of private grazing land throughout the United States (Sobecki *et al*., 2001).

Grazing lands of the southeastern United States (warm, humid region) are the focus of this review of research on how management affects SOC. Humid grazing lands differ substantially from rangelands in several important aspects:

- precipitation is greater, which allows greater production and greater diversity of management variables to consider;
- landscape distribution is often patchy because of smaller landholdings by individual farmers (e.g. mean farm size is 88 ha in Georgia and 519 ha in North Dakota; 2007 Census of Agriculture);
- introduced plant species are utilized to attain high productivity potential and high forage quality, and that respond to fertilizer and other management inputs;
- utilization of forage is diverse, including continuous stocking, management-intensive rotation and haying;
- nearly year-round grazing is possible in the southeastern region when utilizing both cool- and warm-season forages.

CARBON CYCLE

Global carbon (C) is partitioned into five major categories: oceanic (38 000 Pg), geologic (5 000 Pg), pedologic (2 500 Pg – 1 550 Pg as organic and 950 Pg as inorganic), atmospheric (760 Pg) and biotic (560 Pg) (Lal, 2004). SOC contains, therefore, two to three times the C as biotic and atmospheric pools. Soil organic carbon (SOC) is the dominant storage pool in cropland and grasslands, whereas it contains only about half of the C stored in forests (Table 14).

The terrestrial C cycle is dominated by two important fluxes, photosynthesis (net ecosystem uptake of carbon dioxide [CO_2] from the atmosphere) and respiration (release of C back to the atmosphere via plant, animal and soil microbial respiration) (Figure 13). Biochemical transformations occur at numerous stages in the C cycle, e.g. simple sugars in plants are converted into complex C-containing compounds, animals consuming plants create bioactive proteins, and exposure of plant and animal residues to soil micro-organisms and various environmental conditions creates humified soil organic matter complexes. Human intervention often results in harvest of enormous quantities of C as food and energy products. Unintended consequences of management can result in significant erosion of soil and leaching of nutrients.

Management of the C cycle to sequester C can be illustrated in this simple example. Assuming gross primary productivity of 10 Mg C/ha/year, then 5 Mg C/ha/year can be expected to be respired back to the atmosphere by plants themselves and 5 Mg C/ha/year will be fixed in plants as dry matter. Soil decomposers (e.g. bacteria, fauna, worms, and insects) have a strong affinity for consuming much of the plant material fixed in ecosystems. A key issue is how to manage land to reduce decomposition and convert more plant dry matter into SOC. If 10 percent of the C fixed by plants were converted to SOC, then 0.5 Mg C/ha/year could be sequestered in soil. This is a commonly reported sequestration rate for converting conventionally tilled cropland to no-tillage management (Lal, 2004). However, if 20 percent of the C fixed by plants were converted to SOC, then 1.0 Mg C/ha/year could be sequestered in soil. Research in the southeastern United States of America suggests that this higher rate of SOC sequestration can be possible with conversion of cropland into optimally grazed pastures. The following section outlines some of this research.

SOIL ORGANIC CARBON UNDER PASTURE COMPARED WITH OTHER LAND USES

Across a number of studies in different states throughout the southeastern United States, SOC was greater under grasslands than under croplands (Table 15). The average difference in SOC between grassland and cropland was 16.3 Mg C/ha, which would have represented a SOC sequestration rate of 0.33 Mg C/ha/year, assuming that 50 years of management had elapsed between the time of land-use change. (N.B. Many of these studies had not identified the length of time.) SOC under grasslands was not different from that under forest. Many of these surveys had single-field estimates of SOC and limited information on the type of management employed, yet pooling the data revealed reasonable conclusions about land use effects on SOC.

In a survey of agricultural land uses in the Piedmont and Coastal Plain regions of the southeastern United States, SOC under pastures was significantly greater in the 0–5 and 5–12.5 cm depths than under conventionally tilled cropland (Figure 14). SOC sequestration rate was greatest near the soil surface and declined with depth. No change in SOC between pasture and cropland occurred below a depth of 12.5 cm. Although information on pasture length and whether it was hayed or grazed was obtained in this study, more information on specific management practices employed would have been helpful for more insightful interpretation. The mean SOC sequestration rate of 0.74 Mg C/ha/year during 24 ± 11 years was lower than the value of 1.03 Mg C/ha/year during 15 ± 17 years reported for 12 other pasture vs. crop comparisons in the southeastern states (Franzluebbers, 2005). It is expected that effective SOC sequestration would decrease with longer periods of time.

How SOC sequestration changes with time is illustrated in several examples in Figure 15. These data suggest that about 50 percent of the maximum SOC accumulation will have occurred during the first ten years of pasture establishment, while about 80 percent of maximum storage could be expected with 25 years of management. The type of forage management had a large effect on the rate of SOC sequestration within the first 25 years, i.e. 0.21 Mg C/ha/year under hayed bermudagrass, 0.33 Mg C/ha/year under grazed bermudagrass, and 0.55 Mg C/ha/year under grazed tall fescue. Grazing increased SOC sequestration relative to haying, probably because of a return of faeces to land. The cool-season tall fescue increased SOC sequestration relative to the warm season bermudagrass, which may have been in response to different times of available moisture for plant growth and soil microbial decomposition.

PASTURE MANAGEMENT EFFECTS ON SOIL ORGANIC CARBON

Fertilization

The southeastern United States produces about three-quarters of the broiler chickens and one-third of the layer chickens in the entire country (http://www.agcensus.usda.gov). An enormous amount of poultry manure is therefore available for recycling of nutrients on to agricultural land. In a five-year evaluation of broiler litter application to coastal bermudagrass in Georgia, there was no difference in SOC accumulation rate between inorganic and organic nutrient sources (Figure 16). The conclusion from this study was that inorganic and organic fertilizer sources were equally effective in sequestering SOC, which averaged 0.94 Mg C/ha/year. From a compilation of studies around the world, Conant, Paustian and Elliott (2001) also reported no difference in SOC sequestration between inorganic and organic fertilization, which averaged 0.28 Mg C/ha/year.

With a broiler litter application rate of ~10 Mg fresh weight ha/year (2.44 Mg C/ha/year), SOC sequestration during 12 years was calculated as 0.16 Mg C/ha/year at a depth of 0–60 cm (Franzluebbers and Stuedemann, 2009). The sequestration rate represented only 6.6 percent retention in soil from the C applied as broiler litter. A similar C retention rate of ~8 percent from applied C in broiler litter was calculated from a survey of pastures in Alabama (Kingery *et al*., 1994). These low C retention rates are in contrast to higher retention rates observed in colder and drier climates. Franzluebbers and Doraiswamy (2007) reviewed the literature and estimated retention of C in soil from animal manure application of 23 percent in temperate/frigid regions and 7 percent in thermic regions.

Tall fescue pastures receiving low (134-15-56 kg N-P-K/ha/year) and high (336-37-139 kg N-P-K/ha/year) rates of inorganic fertilizer for 15 years resulted in significantly different SOC within the surface 30 cm (Table 16). A large portion of the change in total organic C was caused by accumulation of the intermediately decomposable fraction of particulate organic C. Higher fertilization improved plant production, which probably led to more roots, forage residues and animal faeces to supply the particulate and total organic C fractions. There was a trend for similar effects of fertilization across different soil C fractions when comparing effects at 0–30 cm depth, but C fractions responded differently to fertilization at different depths. The quality of substrates, therefore, appears to have been altered by fertilization effects on root and residue components.

The C cost of fertilization is substantial. Assuming a value of 0.98 kg CO_2-C/kg N applied (embedded in production, application and liming components [West and Marland, 2002]), the statistically significant difference of 2.6 Mg C/ha in SOC at the end of 15 years of fertilization was insufficiently matched by the 3.0 Mg C/ha embedded in the additional N fertilizer. Accounting for an additional C cost resulting from presumed nitrous oxide (N_2O) emission from N fertilizer of 1.6 kg CO_2-C/kg N applied (IPCC, 1997), the global warming potential at the end of 15 years of fertilization would be even more positive (i.e. 2.6 Mg CO_2eq-C/ha sequestered and 7.8 Mg CO_2eq-C/ha emitted). Evaluations of actual N_2O emissions under pastures are still needed under the variety of conditions throughout the southeastern United States.

Forage utilization

When animals graze pastures, they consume forage and gain body weight, but also leave behind a large quantity of manure that becomes available for storage as C in soil. As theorized by Odum, Finn and Franz (1979), pasture productivity could increase with a moderate level of grazing pressure and decline with time under excessive grazing pressure compared with no grazing. In a five-year evaluation of coastal bermudagrass in Georgia, mean annual forage productivity was 8.6 Mg/ha under unharvested management, 9.2 Mg/ha under low grazing pressure and 7.5 Mg/ha under high grazing pressure (Franzluebbers, Wilkinson and Stuedemann, 2004). Similar to the response in forage productivity, SOC stock at the end of five years of management was greatest at a moderate stocking rate (Figure 17). These data suggest that optimally stocked pastures can lead to SOC sequestration of 0.78 Mg C/ha/year compared with unharvested pasture during the first five years of management. At the end of 12 years of bermudagrass/tall fescue management in Georgia, SOC sequestration to a depth of 90 cm followed the order: low grazing pressure (1.17 Mg C/ha/year) > unharvested (0.64 Mg C/ha/year) = high grazing pressure (0.51 Mg C/ha/year) > hayed management (-0.22 Mg C/ha/year) (Franzluebbers and Stuedemann, 2009).

From a long-term pasture survey in Georgia, SOC was greater when bermudagrass was grazed than when hayed (Figure 18). Two pairs of pastures were 15 years old and one pair was 19 years old. Surface residue C was 1.8 Mg C/ha when grazed and 1.2 Mg C/ha when hayed. SOC to a depth of 20 cm was 38.0 Mg C/ha when grazed and 31.1 Mg C/ha when hayed. The difference in soil and residue C was 7.5 Mg C/ha, suggesting a SOC sequestration rate in response to grazing vs. haying of 0.46 Mg C ha/year.

Animal behaviour

Cattle tend to congregate around shade and water sources and, therefore, can affect the distribution of manure and C inputs in pastures. At the end of five years of management, SOC was greater nearest shade and water sources at 0–3, 3–6 and 6–12 cm depths (Figure 19). Total C in soil and residue was nearly 4 Mg C/ha greater near shade compared with further away, which was significant considering the stock of C was ~43 Mg C/ha throughout the pasture.

In tall fescue pastures grazed by cattle for eight to 15 years, SOC was greatest near shade and water sources and declined logarithmically with increasing distance. SOC to a depth of 30 cm was 46.0 Mg C/ha at 1 m from shade, 43.2 Mg C/ha at 10 m from shade, 39.9 Mg C/ha at 30 m from shade, 40.5 Mg C/ha at 50 m from shade and 39.4 Mg C/ha at 80 m from shade (Franzluebbers, Stuedemann and Schomberg, 2000). The zone within a 10–m radius of shade and water sources became enriched in SOC, most probably because of the high frequency of organic deposition from cattle defecation and urination, which would have increased fertility and subsequent forage growth. To minimize the probability of N contamination of surface and groundwater supplies (since total N also increased with SOC), shade/water sources are recommended to be moved periodically, positioned on the landscape to minimize flow of percolate or runoff directly from these areas to water supplies, or avoided during routine fertilization.

Tall fescue – endophyte association

Tall fescue is the most widespread cool season, perennial forage in the southeastern United States. It harbours a fungal endophyte that produces ergot alkaloids, which negatively affect animal performance and behaviour (Stuedemann and Hoveland, 1988). Pastures with high frequency of endophyte infection were observed to have greater SOC than pastures with low frequency of endophyte infection (Figure 20). Intriguingly, readily mineralizable C in these soils did not follow the typically strong relationship with SOC. Rather, specific mineralization of SOC was lower under pastures with high endophyte than with low endophyte. These data led to subsequent experimentation to isolate how this might have transpired.

The difference in whole-SOC between tall fescue-endophyte associations was found coincidentally within the macroaggregate fraction (Table 16). Macroaggregates are large water-stable conglomerations of minerals and organic matter that can be disrupted with tillage, but that serve as a key formation in surface soil to allow precipitation to enter soil without sealing of pores. Hence, they are important for getting more water into soil so that plants can make efficient use of precipitation. As observed earlier, biologically active fractions of soil organic matter were depressed with endophyte compared with those without endophyte. Reduced biologically active fractions of soil organic matter with endophyte infection of tall fescue is thought to result from an inhibition of soil microbial activity. In fact, experimental evidence has indicated that mineralizable C and microbial biomass C can indeed be inhibited by endophyte-infected compared with endophyte-free tall fescue leaves during a month-long incubation (Franzluebbers and Hill, 2005). In contrast, mineralizable N and soil microbial biomass N were stimulated by endophyte-infected compared with endophyte-free leaves. These results illustrate the strong influence that biologically active plant compounds might be exerting on soil organic matter dynamics under pastures.

Methane emissions

Approximately 28 percent of the total methane (CH_4) emission in the United States is from agriculture, specifically enteric fermentation and manure management (http://www.epa.gov/climatechange/emissions). With CH_4 having 23 times the global warming potential as CO_2 during a 100-year time span, only minor amounts of CH_4 need to be emitted to offset gains in CO_2 mitigation from SOC sequestration. Monteny, Bannink and Chadwick (2006) described some of the factors influencing CH_4 production from ruminant livestock, including level of feed intake, quantity of energy consumed and feed composition. Total CH_4 production increases with greater feed intake, but the proportion of gross energy consumed and converted to CH_4 is reduced. High-grain diets generally produce less CH_4 from cattle (as proportion of gross energy consumed) than low-grain diets (Beauchemin and McGinn, 2005). Cattle grazing poor quality pasture produced ~8 percent CH_4 from gross energy consumed, while cattle fed a high-grain diet produced ~2 percent CH_4 from gross energy consumed (Harper *et al.*, 1999).

Assuming 0.15 ± 0.08 kg CH_4 is emitted per head per day (Harper *et al.*, 1999) and there are 12 million head of cattle on 19 million ha of pasture in the southeastern United States (http://www.agcensus.usda.gov), this would result in 34 ± 18 kg CH_4/ha/year. Multiplied by the global warming potential of CH_4, the CO_2-Ceq of methane emission would be from 0.37 to 1.20 Mg CO_2eq-C/ha/year. Therefore, the quantity of CO_2 sequestered into soil organic matter under typical pasture management systems in the southeastern United States might simply nullify the global warming potential from CH_4 emission. Further research is needed in order to quantify these balances better.

SUMMARY

Establishment of perennial grass pastures in the southeastern United States can sequester SOC at rates of 0.25 to 1.0 Mg C/ha/year. Research has shown that SOC sequestration rate can be affected by forage type, fertilization, forage utilization, animal behaviour and soil sampling depth, although data have been derived from only a limited number of studies. SOC sequestration can be enhanced by management (N fertilization increases soil C storage and emissions, tall fescue stores more soil C than bermudagrass, grazing returns more C to soil than haying or unharvested management, and endophyte infection of tall fescue stores more soil C than endophyte-free pastures). SOC can also be spatially affected by animal behaviour and by soil depth. SOC storage under pastures is not only important for mitigating greenhouse gas emissions but, more important, on the farm level for improving water relations, fertility and soil quality.

RESEARCH NEEDS

- Sequestration of SOC under grassland management systems in the southeastern United States is significant, but there is a lack of actual data on how CH_4 and N_2O emissions might counteract this sequestration and lead to positive or negative CO_2eq balances.
- Rate of SOC sequestration under the wide diversity of pasture conditions in the United States is still largely unknown. Variations in climate, soil type and management conditions will probably interact to alter SOC sequestration rates. Much more research is needed to quantify medium and long-term rates.
- Greater collaboration is needed to utilize limited resources efficiently and understand better the impacts of diverse conditions on SOC sequestration. Such collaboration is needed among plant, animal, soil and water science disciplines at local, state, federal and international levels. In addition, long-term field studies need conceptual and financial support.

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