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## ABSTRACT

**Soil organic matter (SOM) is a key component of pasture production. This study investigated how management strategies that varied amount and form of N input in a long-term experiment affected concentrations and stocks of total-soil organic C and N, particulate organic carbon (POC), particulate organic nitrogen (PON), root and rhizome mass, C and N contents in topsoil of smooth bromegrass (*Bromus inermis* Leyss.) pastures with silty clay loam soils in a wet (2010) and dry (2012) year. Management strategies included: (i) unfertilized pasture grazed with unsupplemented beef cattle (CONT); (ii) unfertilized pasture grazed with dried distillers grains plus solubles (DDGS)-supplemented beef cattle (SUPP); and (iii) nitrogen-fertilized pasture grazed with unsupplemented beef cattle (FERT). After 8 yr, management strategies had similar concentrations and stocks of total-soil organic C and N, POC, and PON, and there were no management strategy × year interactions. From 2010 to 2012, total-soil organic C and N, POC, and PON stocks increased as soils dried and soil bulk density increased. The CONT and SUPP management strategies had less root and rhizome mass (concentrations and stocks) and greater soil bulk density than FERT. These below-ground responses were consistent with earlier research conducted at the site demonstrating greater herbage accumulation and litter deposition in FERT. Management strategies that vary amount and form of N inputs into pasture appear to have low potential to affect total-soil organic C and N concentrations in the short-term, but long-term effects of less root and rhizome contents remain unknown.**


Pasture management can influence soil organic C and N contents. Intensifying pastureland management through adoption of practices such as irrigation, fertilization, sowing of improved grasses and legumes, and rotational stocking provides a means to increase soil organic C and N contents (Conant et al., 2001; 2003). Systems with greater stocking rates, fertilizer inputs, and removal of C and N in exported products increased losses of C and N from temperate pastures in New Zealand but management that minimized soil erosion and disturbances improved soil C and N content (Schipper et al., 2010). Berg et al. (1997) reported a significant increase in soil organic C but no change in soil N after 5 yr of annual N fertilization in old world bluestem (*Bothriochloa ischaemum* L.) pasture. Silveira et al. (2013) indicated 2 yr of N fertilization in bermudagrass [*Cynodon dactylon* (L.) Pers.] did not affect soil C and N levels. Inconsistent results often can be attributed to the difficulty to detect small short-term changes in soil C relative to total-soil C (Conant et al., 2003) and the length of the studies (Dormaar and Willms, 1998; Apolinário et al., 2013). Other researchers indicated that measurement of active SOM pools can provide better insight into how management strategies impact soil C sequestration, soil fertility, and functioning of the soil-atmospheric interface in the short-term (Franzluebbers et al., 2000).

Particulate organic matter (POM), a labile intermediate in the continuum from fresh organic materials to humified SOM (Paul et al., 2001), can be a more sensitive indicator of changes in soil C as related to tillage management (Wander et al., 1998; Six et al., 1999), land use changes (Cambardella and Elliot, 1992; Franzluebbers et al., 2000), and pasture management (Franzluebbers and Stuedemann, 2002; Conant et al., 2003). After 15 yr of high N–P–K fertilization of tall fescue [*Schedonorus arundinaceus* (Schreb.) Dumort., formerly *Festuca arundinacea* Schreb.] stands, POC and PON increased by 14 and 34%, respectively, at a 0- to 30-cm depth compared to low N–P–K fertilization (Franzluebbers and Stuedemann, 2002). Roots and rhizomes constitute the largest input for SOM in grasslands (Burke et al., 1999; Gill et al., 2002), and thus, changes in soil organic C and N in response to pasture management may be observed only in the surface layers (0–15 cm) of

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**Abbreviations:** AUD, animal unit day; CONT, unfertilized pasture grazed with unsupplemented beef cattle; DDGS, dried distillers grains plus solubles; DM, dry matter; FERT, nitrogen-fertilized pasture grazed with unsupplemented beef cattle; POC, particulate organic carbon; POM, particulate organic matter; PON, particulate organic nitrogen; SOM, soil organic matter; SUPP, unfertilized pasture grazed with dried distillers grains plus solubles-supplemented beef cattle.

soil (Berg et al., 1997; Schuman et al., 1999) where roots and rhizomes are concentrated (Biondini et al., 1998).

In the north central region of the United States, N fertilization has been a long-term component of smooth bromegrass pasture management. With costs of N fertilizer application and awareness of environmental concerns rising, however, efforts have been underway to increase N use efficiency in grazing livestock. By-products from the corn (*Zea mays* L.) ethanol industry including DDGS have become available, and their feeding in pasture systems has provided a means to increase crude protein and digestible dry matter (DM) concentrations while substituting for forage in beef cattle diets (Klopfenstein et al., 2008). In 2005, a long-term experiment was initiated on smooth bromegrass pasture in Nebraska to compare effects of CONT, SUPP, and FERT management strategies on beef cattle gains and economics. Early research showed steers in SUPP had better body weight gains than steers in CONT and FERT (Greenquist et al., 2009; Watson et al., 2012), and the SUPP management strategy produced greater economic returns because of reduced N fertilizer costs and improved animal performance (Watson et al., 2012). Cessation of annual N fertilization in CONT and SUPP, however, decreased annual herbage accumulation and litter deposition while increasing presence of annual weeds compared to the long-term FERT strategy (Guretzky et al., 2013; 2014). These results suggest that cessation of annual N fertilization may also impact soil organic C and N pools.

To improve understanding of N cycling and efficiency in the vegetation and soil complex of perennial grass pasture, our previous research in Nebraska examined how management strategies affect herbage accumulation and botanical composition (Guretzky et al., 2013) and litter deposition and N return (Guretzky et al., 2014) in smooth bromegrass pasture. Objectives of the present study were to determine the impacts of these strategies on concentrations and stocks of total-soil organic C and N, POC, PON, root and rhizome mass, C and N contents in topsoil. We hypothesized cessation of N fertilization in CONT and SUPP would reduce POC and PON, as well as, root and rhizome contents relative to the long-term FERT strategy.

## MATERIALS AND METHODS

### Site Description

Research was established within an ongoing smooth bromegrass pasture experiment at the University of Nebraska Agricultural Research and Development Center near Mead, NE (96°33′ W, 41°11′ N), where beef cattle performance has been evaluated for CONT, SUPP, and FERT since 2005 (Greenquist et al., 2009; Watson et al., 2012; Moore et al., 2013). The soils were deep silty clay loams consisting of four series: Tomek (fine, smectitic, mesic Pachic Argialboll), Filbert and Filmore (both fine, smectitic, mesic Vertic Argialboll), and Yutan eroded (fine-silty, mixed, superactive, mesic Mollic Hapludalf) (USDA-NRCS, 2012). Pastures were seeded with smooth bromegrass in fall 1981, grazed by cattle at moderate to heavy stocking rates, and fertilized each year at 90 kg N ha$^{-1}$ until the DDGS supplementation study was initiated in 2005. In 2010, the pasture soils had a pH of 5.5 with 753 mg K kg$^{-1}$ and 16 mg P kg$^{-1}$ (Mehlich III) at the 0- to 15-cm depth. While these properties were elevated within a 5-m zone around the pasture entrances, water sources, and supplemental feed bunks, there were no effects of management strategy on these properties either within this zone or elsewhere across the pastures (unpublished data, 2010).

### Experimental Design

Treatments were (i) FERT, where N fertilizer was applied to pasture as urea at 90 kg N ha$^{-1}$ yr$^{-1}$ in late March to early April since before the experiment was initiated in 2005, (ii) unfertilized CONT pasture, and (iii) unfertilized SUPP pasture where steers were supplemented daily with DDGS at 0.6% of body weight from feed bunks placed near water tanks and entrances to each paddock. These treatments were arranged in a randomized complete block design with three replications and were assigned to experimental units split into six paddocks that were rotationally stocked from late April through September. Each paddock was 39.6 by 121.8 m in CONT and 27.4 by 121.8 m in FERT and SUPP. Total N fed through DDGS ranged from 43 to 49 kg N ha$^{-1}$ yr$^{-1}$ depending on stocking rate (Watson et al., 2012; Guretzky et al., 2013).

A complete description of grazing management and N balance in these pastures was documented in previous research (Greenquist et al., 2009, 2011; Watson et al., 2012; Guretzky et al., 2013, 2014). Briefly, there were five cycles of grazing per year in each set of six paddocks with grazing periods lasting from 4 to 6 d depending on the cycle and year. The goal was equal cumulative grazing pressures (32–39 animal unit days [AUD] Mg$^{-1}$ of forage DM produced) and equal residual forage mass (1500 kg DM ha$^{-1}$) among all experimental units at the end of each grazing season. Across years, stocking rates ranged from 222 to 256, 345 to 399, and 345 to 387 AUD ha$^{-1}$ in CONT, SUPP, and FERT, respectively (Watson et al., 2012; Moore et al., 2013). The experimental units with their six paddocks were 2.90 ha for CONT and 2.01 ha for FERT and SUPP to compensate for expected differences in herbage accumulation based on N fertilizer responses of smooth bromegrass (Colville et al., 1963), DDGS replacement of herbage (Greenquist et al., 2009), and long-term stocking rates recommended for the site (Waller et al., 1986). Tester animals were predominately Angus cross-bred steers with equitable initial body weights ranging from 300 to 325 kg and final body weights ranging from 434 to 492 kg, depending on performance (Watson et al., 2012; Moore et al., 2013).

### Soil Sampling Procedures

Soil samples were collected for measurement of total-soil organic C and N, POC, PON, root and rhizome mass, C and N contents at a depth of 0 to 15 cm with a 6.35-cm diam. probe from one paddock of each experimental unit in October 2010 and 2012. During each of these times, 24 samples were collected at random locations ranging from 6 to 118 m from the entrance to each paddock where the water tank and supplemental feed bunk were located to the back of each paddock. No samples were collected within 2 m of paddock cross fences, 6 m of water sources, and 4 m from the back of each paddock due to the potential for increased cattle traffic in these areas. The area represented by each core was ≈224 m$^2$ in CONT and 150 m$^2$ in FERT and SUPP, the difference due to the wider paddocks in the CONT treatment as means to compensate for less herbage production. Across experimental units, a total of 216 samples were collected during each sampling time.

Litter and plant residues on the soil surface were removed and discarded before collection of the soil cores. Upon their collection, each soil sample was placed in a paper bag and transported to the laboratory. Six of the 24 cores were then oven-dried at 60°C for 72 h for determination of bulk density using volume and dry weight of the samples. Large aggregates within the remaining 18 cores were broken up by hand and easily separated roots and rhizomes were removed and retained before determination of POM. Although changes in POM can be sensitive to management, we did not suspect year to be a significant factor affecting POC and PON, and thus, data were not collected in 2011. Due to the severity of drought, however, the same soil sampling procedures were repeated in 2012 to assess effects of management strategy on total-SOM, POM, and root and rhizome contents in a wet and dry year.

### Determination of Particulate Organic Matter and Root and Rhizome Mass

Particulate organic matter was fractionated into coarse (>250 µm) and fine (>53 µm) fractions using wet sieving (Cambardella and Elliot, 1992). The first step consisted of mixing 30 to 60 g of air-dried soil of each core with 90 mL of 5 g $L^{-1}$ sodium hexametaphosphate solution in 140 mL containers on a reciprocal shaker overnight at 140 strokes $min^{-1}$. The dispersed soil solution was then passed through 2000-, 250-, and 53-µm sieves by rinsing with distilled water sequentially from larger to smaller until the rinsate was clean. Rinsate passing through the sieves was not retained. Root and rhizomes on the 2000-µm sieve were combined with roots and rhizomes removed earlier by hand during initial processing of the soil cores. Material retained in the 250- and 53-µm sieves was backwashed into small pre-weighed aluminum pans. The pans were then dried at 60°C for 24 h and weighed to determine coarse and fine POM. The root and rhizome fraction, as well as the coarse- and fine-POM fractions, were then analyzed for C and N.

### Carbon and Nitrogen Analysis

Total-soil, POM, and root and rhizome samples were analyzed for C and N concentrations by dry combustion with a COSTECH Analytical Elemental Combustion System (ECS) 4010 (Costech Analytical Technologies, Inc., Valencia, CA). Carbon and N concentrations on POM fractions were expressed on an organic matter basis after correction for ash. Ash content was determined by drying 1 g of sample at 105°C and then heating the sample at 550°C for 6 h (Jacobs et al., 2011). Total-POC and PON were calculated by addition of C and N contents in coarse and fine POM fractions. Carbon and N stocks in total-soil, POM fractions, and roots and rhizomes were calculated from the C and N concentrations, the soil volume, and bulk density.

### Statistical Analysis

The study was conducted as a randomized complete block design with three replications. Data were analyzed using mixed model procedures (Littell et al., 1996). Management strategy and year were fixed effects in the model, while blocks were random. Contrast statements were used for single degree of freedom comparisons of management strategy effects on total-soil organic C and N, soil organic C/N ratio, POC, PON, POC/PON ratio, root and rhizome mass, C and N contents. Significant differences among management strategies, years, and their interactions, as well as orthogonal contrasts of management strategies, were declared significant at $P < 0.05$ probability levels.

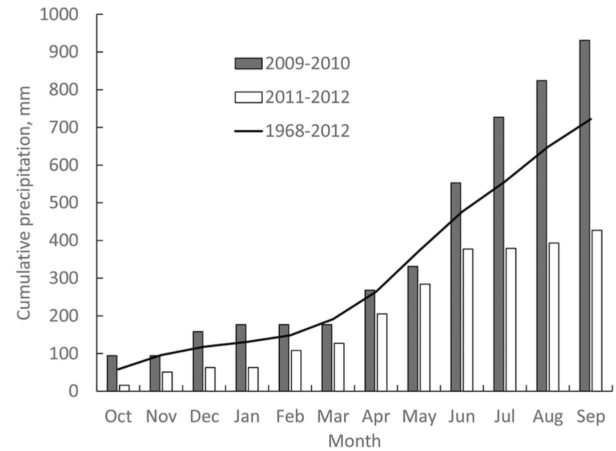


Fig. 1. Cumulative precipitation at the University of Nebraska Agriculture Research and Development Center at Mead, NE.

## RESULTS AND DISCUSSION

Soils were sampled for total-SOM, POM, and roots and rhizome contents after two markedly different growing seasons. From 1 October to 30 September, cumulative precipitation was 931 mm in 2009–2010 and 427 mm in 2011–2012 (Fig. 1). From 1968 to 2012, annual precipitation averaged 719 mm (High Plains Regional Climate Center, 2012). Precipitation was above average during peak growing season months of June and July in 2009–2010. In contrast, 2011–2012 was the driest summer (June–August) on record for the state of Nebraska (NOAA NCDC, 2012). Average annual temperature was 9.6°C in 2009–2010 and 12.3°C in 2011–2012 relative to long-term average of 10.0°C from 1968 to 2012 (High Plains Regional Climate Center, 2012).

### Total-Soil and Particulate Organic Carbon and Nitrogen

Total-soil organic C and N concentrations were similar among CONT, SUPP, and FERT averaging 23.5 g C $kg^{-1}$ and 2.29 g N $kg^{-1}$, although these values were greater after drought in 2012 (Table 1). Reduced decomposition with drier conditions may have contributed to the increase in total soil C and N from 2010 to 2012. Particulate organic matter, a labile intermediate in the continuum from fresh organic materials to humified SOM (Paul et al., 2001), can be a sensitive indicator of changes in SOM with management (Franzluebbers and Stuedemann, 2002; Conant et al., 2003), and thus, we were interested in whether POC and PON would respond to changes in amount and form of N input in smooth bromegrass pasture. It was our hypothesis that cessation of N fertilization in CONT and SUPP would reduce POC and PON relative to the long-term FERT strategy. In contrast to this hypothesis, however, we observed no response in POC and PON concentrations

Table 1. Effects of management strategy and year on C, N, and their ratios in total-soil and coarse-, fine-, and total-particulate organic matter (POM) fractions at a 0- to 15-cm depth in unfertilized (CONT), ration-supplemented (SUPP), and N-fertilized (FERT) smooth bromegrass pastures. Abbreviations include soil organic carbon (SOC), N, particulate organic carbon (POC), and particulate organic nitrogen (PON).

| Independent variable | Total | | | Coarse POM | | | Fine POM | | | Total POM | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SOC | N | SOC to N | POC | PON | POC to PON | POC | PON | POC to PON | POC | PON | POC to PON |
| | —g $kg^{-1}$— | | $kg\ kg^{-1}$ | —g $kg^{-1}$— | | $kg\ kg^{-1}$ | —g $kg^{-1}$— | | $kg\ kg^{-1}$ | —g $kg^{-1}$— | | $kg\ kg^{-1}$ |
| Strategy | ns† | ns | * | ns | ns | ns | ns | ns | * | ns | ns | ns |
| Year | ‡ | * | ns | ns | ns | ** | ‡ | ns | ** | ns | ns | *** |
| Strategy × Year | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| Orthogonal contrast | | | | | | | | | | | | |
| CONT vs. FERT | ns | ns | * | ns | ns | ns | ns | ns | * | ns | ns | ns |
| SUPP vs. FERT | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns | ns |
| Strategy effects | | | | | | | | | | | | |
| CONT | 24.4 | 2.32 | 10.5 | 1.49 | 0.09 | 17.2 | 3.23 | 0.28 | 11.5 | 4.71 | 0.37 | 12.8 |
| SUPP | 23.0 | 2.28 | 10.1 | 1.41 | 0.09 | 16.3 | 2.92 | 0.26 | 11.2 | 4.33 | 0.35 | 12.5 |
| FERT | 23.2 | 2.26 | 10.3 | 1.88 | 0.12 | 15.6 | 2.91 | 0.26 | 11.3 | 4.79 | 0.38 | 12.7 |
| Year effects | | | | | | | | | | | | |
| 2010 | 22.7 | 2.19 | 10.3 | 1.74 | 0.10 | 17.5 | 2.87 | 0.25 | 11.2 | 4.61 | 0.36 | 12.9 |
| 2012 | 24.4 | 2.38 | 10.3 | 1.44 | 0.09 | 15.3 | 3.17 | 0.28 | 11.5 | 4.61 | 0.37 | 12.4 |

* Significance at $P < 0.05$.
** Significance at $P < 0.01$.
*** Significance at $P < 0.001$.
† ns = nonsignificant variables.
‡ Significance at $P < 0.10$.

to management strategy and no interactions of management strategy and year (Table 1).

Management strategy effects were limited to total-soil organic C/N and fine-POC/PON ratios (Table 1). Cessation of N fertilization in CONT increased total-soil organic C/N and fine-POC/PON ratios relative to the more intensively-managed FERT strategy. Meanwhile, SUPP and FERT had similar total-soil organic C/N and coarse-, fine-, and total-POC/PON ratios demonstrating replacement of N fertilizer inputs through DDGS supplementation of cattle has had no immediate effect on SOM and POM pools relative to the long-term strategy of annual N fertilization in spring. The average total-POC/PON ratio of 12.7 kg $kg^{-1}$ across management strategies suggests more decomposed POM in these smooth bromegrass pastures compared to total-POC/PON ratios of 20 to 26 and 29 to 35 kg $kg^{-1}$ measured in grazed tall fescue and hayed bermudagrass pastures in Georgia, respectively (Franzluebbers et al., 2000).

Total-soil organic C and N, as well as coarse-, fine-, and total-POC and PON, also were similar among management strategies when examined on a land area basis (Table 2). Across years, total-soil organic C and N at 0 to 15 cm in this silty clay loam averaged 45.8 and 4.45 Mg $ha^{-1}$, respectively. For comparison, total-soil organic C averaged 38.0 Mg $ha^{-1}$ at 0 to 20 cm in grazed bermudagrass pasture (Franzluebbers et al., 2000) and 37.2 to 42.0 Mg $ha^{-1}$ at 0 to 20 cm in tall fescue pasture (Franzluebbers and Stuedemann, 2005) on sandy loam, loam, and sandy clay loam textured-soils in Georgia and 59.4 Mg $ha^{-1}$ at 0 to 15 cm in a smooth bromegrass hayfield on a loam soil in Alberta (Malhi et al., 1997). In these studies, total N averaged 2.94 Mg $ha^{-1}$ at 0 to 20 cm in the grazed bermudagrass pasture (Franzluebbers et al., 2000), 2.25 to 2.66 Mg $ha^{-1}$ at 0 to 20 cm in the tall fescue pasture (Franzluebbers and Stuedemann, 2005), and 18.3 Mg $ha^{-1}$ at 0 to 15 cm in the smooth bromegrass hayfield (Malhi et al., 1997). Meanwhile, total-POC and PON averaged 8.91 Mg $ha^{-1}$ and 708 kg $ha^{-1}$, respectively, for the 0- to 15-cm depth in our pastures (Table 2) compared to ranges of 10.8 to 12.7 Mg $ha^{-1}$ and 420 to 590 kg $ha^{-1}$ at a 0- to 20-cm depth in tall fescue pasture in Georgia (Franzluebbers et al., 2000). In another study with tall fescue in Georgia, total-POC ranged from 13.8 to 15.7 Mg $ha^{-1}$ at a 0- to 20-cm depth, respectively (Franzluebbers and Stuedemann, 2002).

The factor most influencing total-soil organic C and N and POC and PON stocks was year (Table 2). Greater soil bulk density with drought in 2012 contributed to increases in all of these fractions. Across management strategies, soil bulk density averaged 1.06 and 1.47 g $cm^{-3}$ in 2010 and 2012. There was a management strategy × year interaction, however. In 2010, the management strategies had the same soil bulk density. In 2012, soil bulk density was greater in CONT (1.50 g $cm^{-3}$) and SUPP (1.49 g $cm^{-3}$) than FERT (1.41 g $cm^{-3}$). Greater concentration of roots and rhizomes likely contributed to less compaction and soil bulk density in FERT as soils dried. Despite the differences in soil bulk density in 2012, there were no management strategy or management strategy × year interactions on total-soil organic C and N, POC, or PON stocks (Table 2).

Our previous research on herbage and litter responses suggested that cessation of annual N fertilization in CONT and SUPP may impact soil C and N relative to the long-term pasture management strategy of annual N fertilization in spring. Annual herbage accumulation and litter deposition is less and presence of annual weeds is greater in CONT and SUPP compared to FERT (Guretzky et al., 2013, 2014). Thus, we hypothesized that the long-term strategy of fertilizing pastures annually with N would maintain greater SOM and POM pools than strategies such as CONT and SUPP that would reduce these inputs. While there was a change in

Table 2. Particulate organic carbon (POC) and nitrogen (PON) in coarse-, fine-, and total-particulate organic matter (POM) fractions as measured on a land area basis at a 0- to 15-cm depth by management strategy and year in unfertilized (CONT), ration-supplemented (SUPP), and N-fertilized (FERT) smooth bromegrass pastures.

| Independent variable | Total | | Coarse POM | | Fine POM | | Total POM | |
|---|---|---|---|---|---|---|---|---|
| | SOC | N | POC | PON | POC | PON | POC | PON |
| | Mg $ha^{-1}$ | | | kg $ha^{-1}$ | Mg $ha^{-1}$ | kg $ha^{-1}$ | Mg $ha^{-1}$ | kg $ha^{-1}$ |
| Strategy | ns† | ns | ns | ns | ns | ns | ns | ns |
| Year | *** | *** | ns | ns | *** | *** | *** | *** |
| Strategy × Year | ns | ns | ns | ns | ns | ns | ns | ns |
| Orthogonal contrast | | | | | | | | |
| CONT and FERT | ns | ns | ns | ns | ‡ | ns | ns | ns |
| SUPP and FERT | ns | ns | ns | ns | ns | ns | ns | ns |
| Strategy effects | | | | | | | | |
| CONT | 48.0 | 4.55 | 2.87 | 171 | 6.32 | 548 | 9.18 | 719 |
| SUPP | 45.0 | 4.46 | 2.66 | 166 | 5.73 | 509 | 8.40 | 675 |
| FERT | 44.5 | 4.33 | 3.55 | 234 | 5.61 | 494 | 9.16 | 728 |
| Year effects | | | | | | | | |
| 2010 | 36.8 | 3.56 | 2.84 | 167 | 4.66 | 415 | 7.50 | 582 |
| 2012 | 54.8 | 5.33 | 3.21 | 213 | 7.11 | 619 | 10.32 | 833 |

*** Significance at $P < 0.001$.
† ns = nonsignificant variables.
‡ Significance at $P < 0.10$.

total-soil organic C/N and fine-POC/PON ratios, management strategy did not affect concentrations and stocks of total-soil organic C and N, POC, and PON, and thus, all three strategies appear sustainable. The absence of greater effects of strategies on these pools may have been limited by length of this experiment (8 yr in 2012), maintenance of nearly equal cumulative grazing pressure (32–39 AUD $Mg^{-1}$ of forage DM produced) across strategies, and the generally slow response of SOM to change of organic matter inputs. Studies that have detected changes in soil C and N in pastures have observed these responses under widely contrasting management strategies such as hayed vs. grazed pastures (Malhi et al., 1997; Franzluebbers and Stuedemann, 2010) and where cumulative grazing pressure has differed among strategies over long-time periods (Biondini et al., 1998; Dormaar and Willms, 1998; Schuman et al., 1999). For instance, positive effects of N fertilization on total-soil organic C and N were observed in a 27-yr study of smooth bromegrass managed for hay production (Malhi et al., 1997). A key difference with our study besides duration was return of nutrients in excreta and litter in all grazing strategies. Franzluebbers et al. (2000) observed a larger litter pool under grazing (1780 kg C $ha^{-1}$) than haying (1160 kg C $ha^{-1}$) thereby contributing to maintenance of SOM in tall fescue–bermudagrass pastures in Georgia. In another study with tall fescue–bermudagrass pastures in Georgia, intensity of forage utilization was the largest factor affecting soil properties, particularly those at shallow depths (Franzluebbers and Stuedemann, 2010).

Table 3. Root and rhizome mass, C and N contents (concentrations and stocks) as affected by management strategy and year in unfertilized (CONT), ration-supplemented (SUPP), and N-fertilized (FERT) smooth bromegrass pastures.

| Independent variable | Root and rhizome contents | | | | | | |
|---|---|---|---|---|---|---|---|
| | Mass | C | N | C/N | Mass | C | N |
| | g $kg^{-1}$ | | | kg $kg^{-1}$ | Mg $ha^{-1}$ | | kg $ha^{-1}$ |
| Strategy | * | * | * | *** | † | * | * |
| Year | *** | *** | ns‡ | *** | ns | ns | ** |
| Strategy × Year | ns | ns | ns | † | ns | ns | ns |
| Orthogonal contrast | | | | | | | |
| CONT and FERT | * | * | ** | *** | † | ns | * |
| SUPP and FERT | * | ** | † | ns | * | * | ns |
| Strategy effects | | | | | | | |
| CONT | 2.94 | 1.42 | 0.03 | 44.0 | 5.65 | 2.73 | 67 |
| SUPP | 2.87 | 1.32 | 0.04 | 33.7 | 5.40 | 2.45 | 76 |
| FERT | 3.53 | 1.70 | 0.05 | 35.8 | 6.50 | 3.11 | 89 |
| Year effects | | | | | | | |
| 2010 | 3.66 | 1.77 | 0.04 | 46.2 | 5.94 | 2.88 | 64 |
| 2012 | 2.57 | 1.18 | 0.04 | 29.4 | 5.75 | 2.65 | 90 |

* Significance at $P < 0.05$.
** Significance at $P < 0.01$.
*** Significance at $P < 0.001$.
† Significance at $P < 0.10$.
‡ ns = nonsignificant.

### Roots and Rhizomes

Roots and rhizomes were more sensitive to management strategy (Table 3) than total-soil and POM pools. Root and rhizome mass was 17% less in CONT and 19% less in SUPP than FERT when compared on an equal soil (g kg$^{-1}$ soil) basis (Table 3). No management strategy and year interactions occurred, but root and rhizome mass (g kg$^{-1}$ soil) was reduced by 30% from the relatively wet year of 2010 to the drought year of 2012. Meanwhile, root and rhizome C content (g kg$^{-1}$ soil) was 16 to 22% less in CONT and SUPP than FERT and declined by 33% from 2010 to 2012. Root and rhizome N content (g kg$^{-1}$ soil) was 40% less in CONT and 20% less in SUPP relative to FERT but did not vary with year (Table 3). Management strategies differed the most in root and rhizome C/N ratio (Table 3). Cessation of N fertilizer inputs in CONT increased root and rhizome C/N ratio by 23% relative to FERT pastures. A similar root and rhizome C/N ratio was maintained in unfertilized SUPP compared to FERT pastures, a result conceivably related to increased excretal N return in SUPP (Greenquist et al., 2011).

Management strategy and year effects also were found when root and rhizome mass, C and N contents were compared on an equal land area basis (Table 3). The CONT management strategy had similar root and rhizome C content but root and rhizome mass and N contents were reduced by 7 and 25%, respectively, relative to FERT. Meanwhile, the SUPP management strategy had 17 and 18% less root and rhizome mass and C contents, respectively, but similar root and rhizome N content as FERT. With the increased soil bulk density in 2012, root and rhizome N content increased by 29%, respectively, relative to 2010, but there were no differences in root and rhizome mass and C contents between years.

In general, greater root and rhizome mass, C and N contents on soil concentration (g kg$^{-1}$) and land area bases in FERT reflect the greater level of N inputs through annual fertilization (Greenquist et al., 2009) and are consistent with increased N returns in excreta (Greenquist et al., 2011), litter deposition (Guretzky et al., 2014), and herbage accumulation (Guretzky et al., 2013) with this system relative to CONT. After 8 yr, although supplementation of DDGS to cattle grazing unfertilized smooth bromegrass pasture resulted in similar SOM pools, it did not maintain the same root and rhizome mass and C contents as FERT, whether compared on equal soil mass or land area bases.

## CONCLUSION

Management strategies that vary amount and form of N inputs into pasture appear to have low potential to affect total-soil organic C and N concentrations at least in the short term. After 8 yr, the only differences we observed between CONT, SUPP, and FERT management strategies were in total-soil organic C/N and fine-POC/PON ratios. Contrary to our hypothesis, concentrations and stocks of fine-, coarse-, and total POC and PON were similar between strategies. Where management strategy had its greatest effect was on root and rhizome responses. Cessation of N fertilization in CONT reduced root and rhizome mass, C (concentration only), and N contents and increased root and rhizome C/N ratio relative to FERT. Meanwhile, the SUPP management strategy reduced root and rhizome mass and C contents but did not affect root and rhizome C/N ratio relative to FERT. These belowground responses are consistent with previous research demonstrating greater herbage accumulation, litter deposition, and litter N return with the FERT management strategy. Drought in 2012 influenced POM and root and rhizome responses relative to 2010, but other than for soil bulk density, there were no management strategy × year interactions. The C/N ratio of the POM fractions, root and rhizome mass, C content, and C/N ratio all decreased with drought. On a land area basis, increased soil bulk density with drought resulted in increased stocks of total soil organic C and N, POC, PON, and root and rhizome N contents in the topsoil.

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