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Soil Carbon, Nitrogen and Microbial Dynamics of Pasturelands: Impacts of Grazing Intensity and Planting Systems*1

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ABSTRACT

Management intensity critically influences the productivity and sustainability of pasture systems through modifying soil microbes, and soil carbon (C) and nutrient dynamics; however, such effects are not well understood yet in the southeastern USA. We examined the effects of grazing intensity and grass planting system on soil C and nitrogen (N) dynamics, and microbial biomass and respiration in a long-term field experiment in Goldsboro, North Carolina, USA. A split-plot experiment was initiated in 2003 on a highly sandy soil under treatments of two grass planting systems (ryegrass rotation with sorghum-sudangrass hybrid and ryegrass seeding into a perennial bermudagrass stand) at low and high grazing densities. After 4 years of continuous treatments, soil total C and N contents across the 0–30 cm soil profile were 24.7% and 17.5% higher at the high than at the low grazing intensity, likely through promoting plant productivity and C allocation belowground as well as fecal and urinary inputs. Grass planting system effects were significant only at the low grazing intensity, with soil C, N, and microbial biomass and respiration in the top 10 cm being higher under the ryegrass/bermudagrass than under the ryegrass/sorghum-sudangrass hybrid planting systems. These results suggest that effective management could mitigate potential adverse effects of high grazing intensities on soil properties and facilitate sustainability of pastureland.

Key Words: C allocation, grass species, microbial respiration, microbial biomass, pastureland sustainability, plant productivity

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Managed and semi-managed pastures represent about 26% of terrestrial ecosystems, covering an area of about 3.5 billion ha (FAO, 2006), and are a significant component of the global carbon (C) cycle. There is an estimation of 6.6–10.5 Pg of total C storage in these ecosystems (Tate *et al.*, 1997; Ford-Robertson *et al.*, 1999). It has recently been proposed that managed pastures provide the most realistic opportunity for C sequestration in agricultural systems (Scurlock and Hall, 1998; Conant *et al.*, 2001; Follett and Reed, 2010). However, many environmental factors and management practices would affect the productivity and soil C dynamics in these grasslands. Among them, plant species and grazing intensity (commonly expressed as stocking rate) can profoundly affect plant productivity and the allocation of plant photosynthates belowground (Van der Krift *et al.*, 2001; Valé *et al.*, 2005; Derner *et al.*, 2006). In managed ecosystems, plant productivity and grazing intensity are often interconnected because nutrient inputs are often higher under the high grazing intensity systems.

Grazing intensity exerts a major impact on plant growth and soil C and N balance (Frank and McNaughton, 1993; Dubeux *et al.*, 2006; Semmartin *et al.*, 2008; Franzluebbers and Stuedemann, 2009). On one hand, high grazing intensity leads to high grazing pressure, enhancing nutrient removal and reducing plant C allocation belowground (Han *et al.*, 2008; Franzluebbers and Stuedemann, 2009). Also, higher animal density introduces more frequent and severe perturbations to soil surface, facilitating residue decomposition and soil erosion (Evans, 1997; Zou *et al.*, 2007). On the other hand, dairy grazing systems in North America usually provide supplemental feed to animals based

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on the animal density (Soriano *et al.*, 2000; White *et al.*, 2002; Bargo *et al.*, 2003; Vibart *et al.*, 2008), which leads to enhanced nutrient inputs to soil through animal excreta (Frank and McNaughton, 1993; Haynes and Williams, 1993; Dubeux *et al.*, 2006).

Plant species also play significant roles in modulating soil C and N dynamics. Different plant species vary significantly in their productivity and biomass allocation patterns. Perennial species such as switchgrass (*Panicum virgatum* L.) allocate a higher proportion of their photosynthates belowground to roots and rhizomes in comparison to annual species such as corn (*Zea mays* L.) (Zan *et al.*, 2001). Litter quality has also been found to differ greatly among plant species (Poorter and Bergkotte, 1992). Some species such as legumes have high contents of N and low C:N ratios, which favors microbial decomposition (Hu *et al.*, 2001; Van der Krift *et al.*, 2001). For annual plant species, significant human activities such as tillage are also needed, leading to soil perturbations as well as surface residue mixture into deep soils. These activities will likely alter residue distribution in the soil profile as well as microbial access to these energy-rich materials.

The net effects of grass species and grazing intensity on soil C and N are also likely affected by local soil physical/chemical and climatic conditions. In the coastal regions of the southeastern USA, the soil texture is often very sandy, and high temperature and rainfall may facilitate residue decomposition (Cross and Grace, 2010). Under these climatic and soil conditions, the maintenance of soil organic matter is a very challenging task but is of particular importance in sustaining soil fertility and long-term productivity. Therefore, an understanding of the integrative effects of grazing intensity and plant species on soil C and N dynamics are of significance in identifying the best forage systems for sustainability. However, the effects of grass species and animal stocking rates on soil C and N dynamics are not understood well. In this study, we examined the impacts of different grass species and grazing pressures on soil C and N dynamics, and soil microbial biomass and activities, aiming to provide useful information for effective management practices that can mitigate potential adverse effects of high grazing intensity on soil properties and facilitate sustainability of pasturelands.

MATERIALS AND METHODS

Site description

The experimental site, established in 2003, was located at the Cherry Research Farm (35.38° N, 78.05° W), host of the Center for Environmental Farming Systems (CEFS) located near Goldsboro, North Carolina, USA. It is topographically located in the Mid-Atlantic Coastal Plain, with an average elevation above the sea level of approximately 24 m. Soils consist of ocean and fluvial deposited sediments of sand, silt, and clay. The soils differ based on topographic elements (*i.e.*, upland and river valleys), drainage class, thickness, texture and permeability, and by the textural class of the original sediments. The soil at the current experimental site was a Kenansville loamy sand soil, which had a grayish-brown loamy sand layer in the top 20 cm with a light yellowish brown loamy sand layer in the next 40 cm (USDA NCRS, 2002). Prior to the beginning of this experiment, the field site had been in conventional agricultural production for at least 75 years.

The relative depth to the water table is mediated by evapotranspiration, the distance from the study site to the discharge point of the stream, and the depth of the river valley (Scott *et al.*, 2003). The climate throughout the 4-year study period was generally characterized as mild with warm summers and moderate winters. The area has an annual mean temperature and precipitation of 21 °C and 1 220 mm, respectively. The long-term mean annual 2-m air temperature (1970–2002) was approximately 16.7 °C, and the mean annual precipitation was approximately 1 198 mm (NC CRONOS Database, State Climate Office of North Carolina, Goldsboro, USA).

Experimental design

A split-plot design was employed with grass planting systems as the main factors and grazing densities (stocking rate) as the subfactors. The grass planting systems consisted of 1) planting Marshall ryegrass (*Lolium multiflorum* Lam.) in late fall and a sorghum-sudangrass hybrid (*Sorghum bicolor* [L.] Moench (S) in late spring in a conventional-tillage annual rotation and 2) sod-seeding Marshall ryegrass each fall into a well-established Tifton-44 hybrid perennial bermudagrass (*Cynodon dactylon* (L.) Pers.) stand (B). The grazing intensities included 1) a low stocking rate/low supplementation initially at 2.47 cows ha^{-1} (L) and 2) a high stocking rate/high supplementation initially at 3.70 cows ha^{-1} (H). Therefore, there were a total of four treatments, L-B, H-B, L-S, and H-S, in a randomized arrangement with four replications. The size of each plot ranged from 1.1 to 1.5 ha, depending on grazing intensity.

Soil sampling

In June 2007, after 4 years of continuous treatment,