Soil and Root Attributes in Pastures Managed under Different Stocking Rates and Nitrogen Fertilization Levels

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Core Ideas
- Grassland is a widespread agroecosystem in the globe; however, not enough attention has been given to link grazing management to soil health.
- Grazing management practices greatly impact soil quality.
- Moderate stocking rate are more adequate to keep grassland stability.

ABSTRACT
Pasture management affects soil physical–chemical properties and root depth distribution. Adjusting grazing pressure and N fertilization are key management tools affecting these responses. This study evaluated the effect of N fertilization and stocking rate (SR) on soil physical and chemical attributes and root depth distribution in grazed elephantgrass (*Pennisetum purpureum* Schum. cv. 381) pastures (2009 and 2010). Treatments consisted of three SR (2.0, 3.9, and 5.8 AU ha\(^{-1}\); 1 AU = animal unit = 450 kg body weight) and three N doses (0, 150, and 300 kg N ha\(^{-1}\) yr\(^{-1}\)) on elephantgrass pastures. Response variables included soil bulk density (BD), particle density (PD), total porosity (TP), aggregate stability (AS), water infiltration rate (WIR), light fraction of soil organic matter (LF-SOM), soil fertility, root length density (RLD), and root biomass. Increased SR resulted in greater BD. Soil bulk density ranged from 1.42 to 1.58 g cm\(^{-1}\) for SR ranging from 2.0 to 5.8 AU ha\(^{-1}\), respectively. The C concentration of the LF-SOM decreased with increasing SR, ranging from 383 to 174 mg C kg\(^{-1}\) soil. Soil fertility, RLD, and the stock of C and N in the root system varied among soil layers. At the end of 2 yr, SR and N fertilization did not affect TP, WIR, and AS nor influenced soil fertility and root system distribution. Overgrazing led to soil compaction and reduced LF-SOM, indicating a trend of pasture degradation. Moderate SR resulted in greater LF-SOM, indicating a positive trend for C accumulation in the long term.

Changes in bulk density, soil porosity, soil compaction, water infiltration rate, organic C and aggregate stability, and root resistance to soil penetration in soil (Kurz et al., 2006; Ibáñez et al., 2007; Bell et al., 2011; Lima et al., 2018) interfere with root growth and...
development. Nitrogen fertilization is another factor that can modify plant growth, promoting greater biomass production and nutrient assimilation (Lee et al., 2017), besides increasing C storage in the soil (Silveira et al., 2013; da Silva et al., 2015). Because of the close correlation between C and N mineralization, when N fertilization is applied at a rate greater than the optimum, rapid mineralization contributes to the loss of soil organic matter (SOM) (Singh, 2018). Therefore, soil alteration in areas under grazing depends on grazing intensity, soil fertility, fertilizer application, SOM concentration, and the potential for root growth (Celik et al., 2004; Sarmento et al., 2008a, 2008b; du Toit et al., 2009).

Roots in grasslands play an important role as they affect aboveground biomass productivity and nutrient uptake. Roots also affect hydrological, ecological, and biochemical processes (Glab and Kacorzyk, 2011), but little research has correlated grazing management practices and N fertilizer application with root development and soil characteristics (Sarmento et al., 2008b). Belowground research, however, is critical for understanding the responses in C and N cycles. However, the results about those cycles in livestock grazing has been contradictory (Zhou et al., 2017). Regardless, currently root evaluation methods have advanced, especially with image analyses that facilitate root morphological characterization (Nelson et al., 2017). In addition, the better understanding of the root system under different management practices might be helpful when choosing species more adapted to the environment (Kanno et al., 1999), thereby improving ecosystem services.

We hypothesized that increasing SR would negatively affect belowground responses, but N fertilization could minimize negative impacts on soil physical characteristics and root distribution. Therefore, our research assessed the effect of N fertilization and stocking rate on soil physical and chemical attributes and root distribution in depth on elephant grass (Pennisetum purpureum Schum.) pastures. Our goal was to identify management practices that minimize the degradation of pastures and enhance sustainability of livestock production.

MATERIAL AND METHODS

Experimental Site

The research was conducted at the Agronomic Institute of Pernambuco (IPA) Experimental Station, located in Itambé, State of Pernambuco, Brazil (7°25’S and 35°6’W; 190 m asl). The average annual rainfall is 1200 mm, characterized by an irregular temporal distribution from May to September (ITEP, 2011; AGRITEMPO, 2012), and average temperature is 25°C (CPRH, 2003). Accumulated rainfall in 2009 and 2010 were 1328 and 910 mm, respectively (Fig. 1).

Previous experimental history of the study site included sorghum [Sorghum bicolor (L.) moench] variety trials from 1977 to 1980; signal grass ([Urochloa decumbens (Stapf.) R. D. Webster syn. Brachiaria decumbens Stapf.]) grazing trial from 1981 to 2001 (Teixeira et al., 2012), and elephant grass cv. 381 under grazing from 2003 to 2007 and following by a harvesting experiment during 2006 and 2007. After this period, from August 2007 to September 2008, a grazing experiment was conducted with three post-grazing stubble heights (40, 80, and 120 cm) fertilized with 300 kg N ha⁻¹ yr⁻¹ (Saraiva et al., 2014). At the beginning of the current experiment in January 2009, the treatments (stocking rate and N fertilization) were applied to each plot. It is important to mention that the plots were previously managed at 40, 80, and 120 cm of post-grazing stubble heights; in the current experiment, treatments were different stocking rates, 5.8, 3.9, and 2.0 animal units (AU) ha⁻¹, respectively.

Predominant soils at the experimental station are classified as a red-yellow Argissoil, Acrisol according to FAO–World Reference Base for Soil Resources (Chesworth et al., 2008). Soil samples were collected in five depths for the chemical (EMBRAPA, 1997) and textural (de Almeida et al., 2012) characterizations (Table 1).

Experimental Design and Management

Treatments were allocated in a split-plot randomized complete block design, with three replications. Main plot was the stocking rate (2.0, 3.9, and 5.8 AU ha⁻¹), and the N fertilization level: 0, 150,
and 300 kg N ha\(^{-1}\) yr\(^{-1}\)) the split-plot. The three levels of SR were chosen based on previous research (Saraiva et al., 2014), and they are considered low, moderate, and high. Because N fertilization could interact with SR, we wanted to assess the soil and root responses. The high SR allowed cattle to significantly defoliate the plants and reduce regrowth of elephantgrass. The main plot size was 833 m\(^2\) and the split-plot was 278 m\(^2\), with one N level randomly assigned to each plot. To avoid nutrient transfer via excreta from one plot to the other, each split-plot was fenced. The experimental units were grazed by cattle equally in each paddock according to soil testing recommendations.

### Soil Physical Properties

At the end of 2010, soil samples were collected for the determination of soil bulk density (BD), particle density (PD), total porosity (TP), aggregate stability index (ASI), water infiltration rate (WIR) and light fraction of soil organic matter (LF-SOM). Bulk density was determined by the volumetric ring method, where the non-deformed samples were collected at two depths (0–10 and 10–20 cm). Samples for PD were collected from the 0- to 20-cm depth. Total porosity was calculated based on the BD and PD data at the 20-cm soil depth (EMBRAPA, 1997). Water infiltration rate was determined using concentric-ring infiltrometers, monitoring the discharge through the measuring cylinder into the soil (Bouwer, 1986). Two infiltrometers were randomly placed in each experimental plot (the split-plot). Infiltration rate was considered constant when the saturated infiltration rate for the soil was reached.

Soil samples were collected in the 0- to 10-cm layer to assess the light fraction of SOM. This fraction (mg C kg\(^{-1}\) soil) was determined in water, where organic particles with density less than 1 kg dm\(^{-3}\) rose by flotation (Anderson and Ingram, 1989). The residue after oven drying at 65°C for 72 h was ground in a ball mill and weighed (10–15 mg) for the analysis of total C, determined by the dry combustion method, using the Flash EA 1112 series elemental analyzer.

Aggregate stability was determined using non-deformed soil samples collected in December 2010. Soil samples were collected at 0- to 2.5-, 2.5- to 7.5-, and 7.5- to 15-cm depths in three replicates per sub-plot constituting a composite sample. Soil samples were passed through 9.52-mm sieves and dried in the shade for 72 h. These samples were used to measure the distribution of aggregate size (2.00, 1.00, 0.50, 0.25, 0.106, and 0.053 mm). The mean diameter of air-dried aggregates (AD) was determined following procedures described by Silva and Mielniczuc (1997) and the mean weight diameter of stable aggregates in water (AW) was determined by the method described by Tisdall et al. (1978) and adapted by Carpenedo and Mielniczuc (1990). Percentage macro- and micro-aggregates were estimated based on aggregates >0.25 mm and <0.25 mm, respectively. Soil aggregate stability index was obtained by the AW/AD ratio.

### Soil Fertility

Soil fertility was determined according to methodology proposed by EMBRAPA (1997). Seven replicates per split-plot were collected at the beginning of the experiment (January 2009) and at the end (December 2010) in five soil depths (0–20, 20–40, 40–60, 60–80, and 80–100 cm), with samples composited with approximately 300 g of soil within each depth.

### Root Measurements

Root length density (cm cm\(^{-1}\)), root mass (Mg C ha\(^{-1}\)), and root N mass (Mg N ha\(^{-1}\)) were determined in five depths (the same samples used for fertility analyzes) and only for the samples collected at the end of the experiment. In each plot, we used 50 g of soil to measure the roots. The soil samples were gently washed with running water to minimize the losses. Sieves with different mesh sizes were used (2.00 and 0.053 mm) grouped in this sequence to separate the roots in different particle sizes (Bohm, 1979). Roots were classified as thick (>2 mm) and fine (<2 mm). After washing, the roots were placed in a transparent acrylic tray with water and root length was analyzed using an HP scanner and the WinRHIZO Version 2009e software (Regent Instruments, 2009). After this procedure, root samples were dried at 65°C for 72 h, weighed, and milled using a mortar and pestle. Total C and N were determined using the Flash EA 1112 Series elemental analyzer.

### Statistical Analyses

Statistical analyses were performed using PROC MIX from SAS (SAS Institute, 1996). The experimental design was a split-plot in a randomized complete block design, with three replications. LSMEANS were compared using the PDIFF procedure from SAS adjusted by Tukey. Fixed effects included SR, N fertilization, and their interactions. Random effects were blocks and their interactions. For the soil fertility analysis at depths, data from 2009 was used as covariates. For the root analysis at depths, repeated measurements...
RESULTS AND DISCUSSION

Soil Bulk Density

Soil bulk density was not affected by N fertilization nor interaction between SR × N fertilization (P > 0.05). However, soil bulk density increased linearly with stocking rate (Table 2) at the 20-cm depth. The BD ranged from 1.42 to 1.58 g cm⁻³ for treatments subject to stocking rates from 2.0 to 5.8 AU ha⁻¹, respectively. Some studies have shown that greater stocking rates have led to serious problems with soil compaction and surface runoff (Steffens et al., 2008; du Toit et al., 2009; Fernández et al., 2010, 2015).

Soil bulk density was also different between soil layers of 0 to 10 and 10 to 20 cm (1.45 and 1.51 g cm⁻³, respectively) as shown in Fig. 2. Soil organic matter contributes to maintaining soil structure and, consequently, reducing soil bulk density (Zhao et al., 2007; Steffens et al., 2008; Celik et al., 2010).

Particle Density and Total Porosity

Particle density was not affected by stocking rate nor N fertilization or by their interaction. These values were within the expected range (2.71 ± 0.17 Mg m⁻³) reported by Brady and Weil (2002). Total soil porosity was not influenced by the different stocking rate (P = 0.174) and N fertilization (P = 0.390) or by their interaction (P > 0.05) despite the effect of stocking rates on soil bulk density (Table 2). However, changes in BD as the result of soil compaction altered the macropore and micropore distribution, but not enough to interfere with total porosity. Total porosity values were high for all treatments (45.12 ± 4.43%). These results are in accordance with the minimum total porosity for the root system to have efficient development and adequate soil aeration (Brady and Weil, 2002). Therefore, in the long term, the stocking rate may have a negative impact on the soil total porosity, particularly on the macro porosity, which is a sensitive indicator of soil physical quality, mainly due to its aeration and soil water infiltration (Bell et al., 2011).

Light Fraction of Soil Organic Matter

Total C concentration of LF-SOM was not affected by N fertilization, stocking rate, or their interaction. However, total C concentration of LF-SOM presented a quadratic effect for the different stocking rates (Table 3). The heavy stocking rate (5.8 AU ha⁻¹) promoted reduction of C on LF-SOM, whereas the light stocking rate (2.0 UA ha⁻¹) had an intermediate value between moderate and heavy stocking rates (3.9 and 5.8 AU ha⁻¹, respectively).

The balance between biomass production and its decomposition rate interferes with LF-SOM accumulation (Correia et al., 2015). The senescent material deposited aboveground under the light stocking rate (2.0 AU ha⁻¹) is more labile, because less recalcitrant plant compounds not consumed by the animals may still be lost due to trampling. In addition, greater soil moisture content observed in this stocking rate may have accelerated LF-SOM C decomposition. However, LF-SOM C increased under the moderate stocking rate (3.9 UA ha⁻¹). As there was an increase in the stocking rate, there was an increase of the BD in the 20-cm depth (Table 2) and, consequently, decreasing LF-SOM when compared with the light and heavy stocking rates (Table 3). Blanco Sepúlveda and Nieuwenhuyse (2011), working in areas with predominance of signal grass, located in the mountains of the humid tropics of northern Honduras, found a negative correlation between soil bulk density and organic matter content (r = −0.69, P < 0.01), and a positive one between soil bulk.

Table 2. Effect of stocking rate (UA ha⁻¹) on soil bulk density (g cm⁻³) in pastures of elephant grass in the 0- to 20-cm layer in Itambé–PE.

<table>
<thead>
<tr>
<th>Stocking rate</th>
<th>Soil bulk density</th>
</tr>
</thead>
<tbody>
<tr>
<td>UA ha⁻¹</td>
<td>g cm⁻³</td>
</tr>
<tr>
<td>2.0</td>
<td>1.42</td>
</tr>
<tr>
<td>3.9</td>
<td>1.44</td>
</tr>
<tr>
<td>5.8</td>
<td>1.58</td>
</tr>
</tbody>
</table>

† SE, standard error.
‡ Linear effect was considered significant if P ≤ 0.05.

Table 3. Light fraction of organic matter (mg C kg⁻¹) at soil surface (0–10 cm) in pastures of elephant grass managed under different stocking rates, Itambé–PE, Brazil.

<table>
<thead>
<tr>
<th>Stocking rate</th>
<th>Light fraction of the organic matter</th>
</tr>
</thead>
<tbody>
<tr>
<td>UA ha⁻¹</td>
<td>mg C kg⁻¹</td>
</tr>
<tr>
<td>2.0</td>
<td>263</td>
</tr>
<tr>
<td>3.9</td>
<td>383</td>
</tr>
<tr>
<td>5.8</td>
<td>174</td>
</tr>
</tbody>
</table>

† SE, standard error.
‡ Quadratic effect was considered significant if P ≤ 0.05.
density and stocking rate \(r = 0.44, P < 0.01\), Zhao et al. (2007) tested different levels of grazing intensity by sheep \(Ov\)is aries) and also found a negative correlation between soil bulk density and organic C content \(r = -0.94; P < 0.01\).

## Soil Aggregate Stability

Soil aggregate stability index was not affected by stocking rate, N fertilization, or their interaction, but a difference was detected among the depths studied (Table 4). However, this variable was influenced by water, which modified the macro and micro-aggregates determined at AW and AD conditions. Regardless of treatment, the AD macro-aggregates were above 90%. However, when the AW macro-aggregates were evaluated, this variable decreased to approximately 70%. Consequently, the AD micro-aggregates increased from 6 to 28%, depending on moisture conditions. Low proportion of clays dispersed in water show greater aggregate stability in areas with grasses (de Almeida et al., 2014). Argissoil typically presents low clay dispersed in water (Bronick and Lal, 2005). In addition, organic compounds (e.g., glucose, starch, and lignin) found in the soil (Abiven et al., 2009) are correlated to soil aggregate formation and stabilization. Enzymatic activity is likewise strongly correlated with soil structure (Cui and Holden, 2015).

The AD, AW, and aggregate stability index were affected by soil collection depth (Table 4). On the soil surface (0–2.5 cm), AD was greater when compared to the other two depths (2.5–7.5 and 7.5–15 cm). The opposite behavior was observed for AW, with the mean diameter of aggregates in water increasing with depth. This explains the increasing aggregate stability index with depth. Silva and Mielenzuc (1998), in a study with Dystrophic Red-Yellow Argissoil under perennial vegetation with signal grass, observed high values in ASI with 71.58, and 42% for depths of 10, 20, and 30 cm, respectively. These authors reported that the higher the aggregate stability index, the stronger the force that makes soil particles bonded. Several factors are related to stability of aggregates in soil: iron and aluminum oxides, fine roots, fungal hyphae, bacterial cells, clay and carbonate content, enzymatic activity, liming management, C, and N availability, and the effect of SOM play important roles in this process (Silva and Mielenzuc, 1998; Bronick and Lal, 2005; Abiven et al., 2009; de Almeida et al., 2014; Cui and Holden, 2015).

On the soil surface (0–2.5 cm), trampling may have influenced AD macro-aggregates, considering that this aggregation may occur through the compression action without stabilization (Silva and Mielenzuc, 1998). On the other hand, the wetting and drying cycles lead to soil clay dispersion and consequently the weakening of soil particulate bonds (Bronick and Lal, 2005), decreasing soil stabilization.

### Table 4. The mean diameter of air-dried aggregates (AD) and the mean weight diameter of stable aggregates in water (AW) and aggregate stability index \([AW/AD] \times 100\) in pastures of elephant grass at different depths, Itambé-PE.

<table>
<thead>
<tr>
<th>Depth</th>
<th>AD</th>
<th>AW</th>
<th>([AW/AD] \times 100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–2.5 cm</td>
<td>3.02</td>
<td>1.20</td>
<td>39.73</td>
</tr>
<tr>
<td>2.5–7.5 cm</td>
<td>2.86</td>
<td>1.26</td>
<td>44.05</td>
</tr>
<tr>
<td>7.5–15.0 cm</td>
<td>2.80</td>
<td>1.39</td>
<td>49.64</td>
</tr>
<tr>
<td>SE†</td>
<td>0.08</td>
<td>0.61</td>
<td>1.80</td>
</tr>
<tr>
<td>Linear effect†</td>
<td>0.0317</td>
<td>0.0163</td>
<td>0.0007</td>
</tr>
</tbody>
</table>

† SE, standard error.

‡ Linear effect was considered significant if \(P \leq 0.05\).

The lowest aggregate stability index found in the superficial layers (0–2.5 cm) compared with the deeper layer (7.5–15 cm) may be related to the inherent natural pedogenic processes. Clay, one of the factors affecting aggregate stability (Bronick and Lal, 2005), can be translocated to deeper layers in Argissoil, leaving the upper layers with a greater proportion of sand (Oliveira et al., 2010), increasing the binding among particles in the B horizon (Bronick and Lal, 2005).

## Water Infiltration Rate

Water infiltration rate was not affected by different stocking rates \((P = 0.4971)\) nor N fertilization \((P = 0.1098)\). The average WIR was 155.1 mm h\(^{-1}\). Compaction and total soil porosity modification by animal trampling may lead to lower water infiltration rate in the soil; however, litter accumulation and greater presence of macrofauna (e.g., termites and ants) may counteract the trampling effect and maintain soil macro porosity (Savadogo et al., 2007).

In our study, the absence of treatment effect on soil aggregate stability and total soil porosity—especially in the different stocking rates—and the contribution of labile material (Table 3), were sufficient to maintain the WIR unchanged, whereas there was a difference in soil bulk density (Table 2). Miguel et al. (2009), evaluating the WIR in an oxisol covered with palisadegrass pasture \(Urochloa brizantha\) (Stapf) Webster cv. Marandú under a rotational stocking rate of 6 AU ha\(^{-1}\), verified a reduction in the WIR of 73.3 and 64.6% in the 0- to 10- and 10- to 20-cm depths, respectively. In addition, du Toit et al. (2009) concluded that high stocking rates not only reduced water infiltration rate in the soil but also affected soil bulk density in an area dominated by mixed vegetation of grasses and shrubs in South Africa. Therefore, in many cases animal trampling is considered one of the main causes of the negative trends on soil water infiltration in pasture (Lima et al., 2018).

## Soil Fertility

Soil fertility variables were not influenced by the treatments applied; however, they differed as a function of soil depth. Soil organic matter content decreased with soil depth (Fig. 3A).

The highest levels of SOM found in the superficial layers are typically associated with greater concentration of roots, as well as the greater contribution of vegetal and animal residue deposited on the surface (Sarmento et al., 2008B) as well as fertilization and liming being more efficient on the soil surface (Silva et al., 2013).

In our study, surface soil had the greatest cation exchange capacity (CEC) values ranging from 35.85 to 68.45 mmol c dm\(^{-3}\) (Fig. 3B). This was evidenced by the greater SOM content found in this layer, generating negative charges and increasing CEC (Sarmento et al., 2008A). Base saturation was greater in the 20-cm depth compared with other depths (Fig. 3C). In the surface soil, base saturation was >50% (eutrophic character). On other hand, base saturation was <50% (dystrophic character) in deeper layers (>20 cm). This occurred due to greater soil nutrient content at shallower layers (Silva et al., 2013), especially K\(^+\), Ca\(^{2+}\), and Mg\(^{2+}\) (Fig. 3C).

Soil pH decreased with soil depth, ranging from 5.1 to 4.7 (Fig. 4A). These values are low and can have direct consequences in the unavailability of the essential elements to plant nutrition. Low pH values may indicate the presence of potentially toxic elements to plants caused by increased H\(^+\) and Al\(^{3+}\) activity (Mccauley et al., 2017). On the other hand, in pH 5 to 6, Al content in soil is not considered toxic to plants (Bojórquez-Quintal et al., 2017).
However, the process of acidification is associated with several factors, such as nitrate leaching (Bolan et al., 2003), nutrient uptake by the plant, release of root exudates, and mineralization of soil organic matter (Goulding, 2016). Nitrogen fertilization may also be one of the main causes of soil acidification (Bolan et al., 2003; Tian and Niu, 2015). In our study area, N fertilization has occurred for several years. The values of Al$^{3+}$ increased with depth, reaching 12.7 mmol dm$^{-3}$ (Fig. 4C). Part of this is related to the reduction in pH, also observed with depth. Costa et al. (2008) observed that pH reduction from 5.6 to 4.6 increased Al$^{3+}$ (0.05–0.41 cmol dm$^{-3}$) after 3 yr of continuous N fertilization. The application of N fertilizer has led to reduction of Ca$^{2+}$ and Mg$^{2+}$, besides increasing Al saturation (Tian and Niu, 2015).

Aluminum saturation (m) increased considerably in the deeper layers of the soil and ranged from 0.4 to 2.7%. The reduced value found in the superficial layer (20 cm) may be due to surface liming, leading to the reduction of Al$^{3+}$ (Silva et al., 2013). On the other hand, Al saturation values followed the same trend as Al$^{3+}$ in depth (Fig. 4A).

Greater Mg$^{2+}$ and K$^{+}$ content found in the 0- to 20-cm layer (Fig. 4C) may be related to the greater CEC of the soil (Fig. 3B). Greater CEC leads to greater cation retention capacity (Sarmento et al., 2008a), reducing the loss of nutrients by leaching.

Phosphorus content differed among soil depths and ranged from 6.10 to 1.39 mg dm$^{-3}$. Phosphorus content in the 0- to 20-cm depth was greater than that found in other layers (Fig. 4B); this result may be related to the deposition of organic waste (e.g., feces,
Root Distribution

Root length density was not affected by stocking rate, N fertilization, or their interaction, but differed among the depths (Table 5). In the 0- to 20-cm layer, root length density was greater than other depths for all root types (thin, thick, and total). A possible explanation for lack of response to SR and N fertilization was the presence of roots from other species, such as signal grass, which was present in greater proportion in the overgrazed paddocks.

Sarmento et al. (2008b) observed on pastures of Guinea grass (*Panicum maximum* Jacq. cv. IPR-86 Milênio), in the 0- to 40-cm depth profile, that approximately 85% of the root system was found in the 0- to 20-cm depth. Regardless of depth, there was predominance of thin-type roots (Table 5). Greater root length density increases the contact area between roots and soil. Greater absorptions of the less soluble nutrients are related to greater root density, especially the finer roots, which are the main root type responsible for nutrient and water uptake by plants (Gregory, 2007). This is fundamental for the plant to withstand stressful situations such as intense winters, dry summers, and grazing. It is possible that greater soil fertility in the superficial layer (0–20 cm) might have increased the root length density (Fig. 3 and 4). Thus, the decrease in fertility and increase in Al saturation, as the soil depth increased (Fig. 3 and 4), may explain the reduction of root length density in the layers below 0 to 20 cm.

Root C mass for thin, coarse, and total root types were different among soil depths (Table 6). There was no difference between 0 to 20 and 20 to 40 cm for all root types; however, they were different from other layers (40–60, 60–80, and 80–100 cm). Root biomass in the superficial layer (0–20 cm) was around 31.48 and 36% of the root biomass compared with the other depths for thin, coarse, and total root types, respectively. Greatest concentration of nutrients in the soil surface layer probably resulted in greater root biomass (Sarmento et al., 2008b).

The 20- to 40-cm soil layer had greater root biomass for all root types when compared with deeper layers. The low availability of nutrients in deeper soils (Fig. 3 and 4), considered common in tropical soils, especially for P, contributes to the increase in the length and mass of thin roots in depth. This behavior seems to be a strategy of the plant to assimilate nutrients, suggesting that soil P directly affects root depth distribution. According to Kergeruen et al. (2009), genotypes better adapted to growing in acid soils with low P concentration have increased the root mass and length compared with those less adapted in the same conditions.

The N stock within different root type (thin, coarse, and total) differed among depths (Table 7). There was no difference for root N stocks in the thin-type root between 0 and 20 and 20 to 40 cm. However, N stocks in thin roots in these two superficial depths were different compared with the root N stocks of thin roots found in the other layers (40–60, 60–80, and 80–100 cm).

For coarse and total-type roots, N stock in the 0–20 cm depth was different from the other layers (20–40, 40–60, 60–80, and 80–100 cm). Considering the whole soil profile (0–100 cm) on the total root (sum of thin and coarse roots), fine roots contributed 73% of the N stock. However, when considering only the 0- to 20-cm soils, the contribution of the N stock was 65%. This indicates that the largest contribution in the N stock was near the soil surface. Nitrogen from decaying roots is fundamental for maintaining soil fertility and for nutrient cycling processes, especially of fine roots. Soil organic matter is composed of living and non-living soil components (Ferreira et al., 2010), and the roots contribute 5 to 10% of the total. Therefore, the finer roots play an important role in the recycling of nutrients in pasture ecosystems.

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**Table 5. Root length density (cm cm⁻³) as a function of the soil depth in pastures of elephant grass, Itambé–PE.**

<table>
<thead>
<tr>
<th>Soil depth</th>
<th>Fine</th>
<th>Coarse</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>cm</td>
<td>cm⁻³</td>
<td>cm⁻³</td>
<td>cm⁻³</td>
</tr>
<tr>
<td>0–20</td>
<td>5.76</td>
<td>2.67</td>
<td>8.43</td>
</tr>
<tr>
<td>20–40</td>
<td>4.25</td>
<td>0.96</td>
<td>5.21</td>
</tr>
<tr>
<td>40–60</td>
<td>3.49</td>
<td>0.34</td>
<td>3.83</td>
</tr>
<tr>
<td>60–80</td>
<td>2.01</td>
<td>0.46</td>
<td>2.47</td>
</tr>
<tr>
<td>80–100</td>
<td>1.66</td>
<td>0.29</td>
<td>1.95</td>
</tr>
</tbody>
</table>

† SE, standard error.
‡ Linear effect was considered significant if *P* ≤ 0.05.
§ Quadratic effects was considered significant if *P* ≤ 0.05.

**Table 6. Root biomass (Mg C ha⁻¹) fine (<2 mm), coarse (>2 mm), and total as a function of the soil depth in pastures of elephant grass under different stocking rates (UA ha⁻¹) and N fertilization (kg ha⁻¹ N yr⁻¹), Itambé–PE Brazil.**

<table>
<thead>
<tr>
<th>Soil depth</th>
<th>Fine</th>
<th>Coarse</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>cm</td>
<td>Mg C ha⁻¹</td>
<td>Mg C ha⁻¹</td>
<td>Mg C ha⁻¹</td>
</tr>
<tr>
<td>0–20</td>
<td>2.78</td>
<td>1.53</td>
<td>4.31</td>
</tr>
<tr>
<td>20–40</td>
<td>2.68</td>
<td>0.78</td>
<td>3.46</td>
</tr>
<tr>
<td>40–60</td>
<td>1.60</td>
<td>0.35</td>
<td>1.95</td>
</tr>
<tr>
<td>60–80</td>
<td>0.82</td>
<td>0.30</td>
<td>1.12</td>
</tr>
<tr>
<td>80–100</td>
<td>0.95</td>
<td>0.22</td>
<td>1.17</td>
</tr>
</tbody>
</table>

† SE, standard error.
‡ Linear effect was considered significant if *P* ≤ 0.05.
§ Quadratic effect was considered significant if *P* ≤ 0.05.

**Table 7. Root N stocks (Mg N ha⁻¹) fine (<2 mm), coarse (>2 mm), and total as a function of the soil depth on pastures of elephant grass under different stocking rates (UA ha⁻¹) and N fertilization (kg N ha⁻¹ yr⁻¹), Itambé–PE Brazil.**

<table>
<thead>
<tr>
<th>Soil depth</th>
<th>Fine</th>
<th>Coarse</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>cm</td>
<td>Mg N ha⁻¹</td>
<td>Mg N ha⁻¹</td>
<td>Mg N ha⁻¹</td>
</tr>
<tr>
<td>0–20</td>
<td>0.132</td>
<td>0.070</td>
<td>0.202</td>
</tr>
<tr>
<td>20–40</td>
<td>0.129</td>
<td>0.035</td>
<td>0.164</td>
</tr>
<tr>
<td>40–60</td>
<td>0.072</td>
<td>0.029</td>
<td>0.101</td>
</tr>
<tr>
<td>60–80</td>
<td>0.057</td>
<td>0.015</td>
<td>0.072</td>
</tr>
<tr>
<td>80–100</td>
<td>0.049</td>
<td>0.011</td>
<td>0.060</td>
</tr>
</tbody>
</table>

† SE, standard error.
‡ Linear effect was considered significant if *P* ≤ 0.05.
§ Quadratic effect was considered significant if *P* ≤ 0.05.
SUMMARY AND CONCLUSIONS

At the end of 2 yr, stocking rate and N fertilization did not alter the total porosity, water infiltration rate, aggregation stability, and soil fertility parameters. Stocking rate, however, did modify soil bulk density and the light fraction of soil organic matter. These changes suggest a negative effect of overgrazing on soil physical quality, which, in the medium and/or long term, can cause soil degradation and negatively interfere in the sustainability of the system.

Environmentally negative implications can occur in areas with great bulk density, because it can change other physical and chemical parameters over time. In addition, the net primary productivity might be reduced by heavy stocking rate, leading to changes in plant C accumulation in the medium and/or long term. Therefore, recommendations for using intermediated stocking rate seem to be more advisable for seeking longevity of pasture ecosystems.


Regent Instruments. 2009. WinRHIZO V 2009c user’s guide. Regent Instruments, Quebec, QC.


