Root development and soil carbon stocks of tropical pastures managed under different grazing intensities

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Abstract

Grasslands may act as a carbon (C) sink or C source depending on how they are managed. Soil C stocks, root biomass, root length, root length density and soil organic C concentrations were assessed on pastures of elephant grass (*Pennisetum purpureum*) managed under different post-grazing stubble heights and signal grass (*Brachiaria decumbens*) managed under different stocking rates. Soil samples were collected in 20-cm layers down to 1-m soil depth. Neither stubble height nor stocking rate had any significant effects on root parameters. Both the root system and C stocks declined in both pastures with increasing soil depth. Root biomass in the 0–20 cm layer contained 2.84 and 2.04 t C/ha, declining to 0.39 and 0.64 t C/ha at 80–100 cm for elephant grass and signal grass, respectively. Signal grass had greater root development deeper in the soil than elephant grass pastures, possibly due to its greater tolerance of Al toxicity and acidity. Total soil C stocks were greater for signal grass than for elephant grass (358 vs. 214 t C/ha, respectively).

Resumen

Las pasturas pueden actuar como reservorio o fuente de carbono (C), dependiendo de la forma de manejo. En el trabajo se evaluaron las reservas de C y la concentración de C orgánico en el suelo, la biomasa y longitud radiculares y la densidad de la longitud de las raíces en pasturas de pasto elefante (*Pennisetum purpureum*) pastoreado a diferentes alturas y de pasto braquiaria (*Brachiaria decumbens*) manejado con diferentes cargas animal. Las muestras de suelo fueron tomadas cada 20 cm hasta 1 m de profundidad. La altura del pasto elefante ni la carga animal en braquiaria afectaron los parámetros de raíz y suelo evaluados. En ambas pasturas, tanto el sistema radicular como la reserva de C disminuyeron con el incremento de la profundidad en el suelo. En pasto elefante la biomasa radicular entre 0 y 20 cm contenía 2.84 t/ha de C y entre 80 y 100 cm contenía 0.39 t/ha. En pasto braquiaria estos contenidos eran, respectivamente, 2.04 t/ha y 0.64 t/ha. Este último pasto presentó un mayor desarrollo radicular a través del perfil del suelo que el pasto elefante, posiblemente por su mayor tolerancia a acidez del suelo y toxicidad por aluminio. La reserva total de C en el suelo fue mayor en pasto braquiaria (358 t C/ha) que en pasto elefante (214 t C/ha).

Introduction

Livestock production in South America occurs usually in low-input systems based on rangelands and sown pastures (Santos et al. 2002). Tropical grasses, such as signal grass (*Brachiaria decumbens*) and elephant grass (*Pennisetum purpureum*), are commonly found on farms throughout the region, despite the fact that poor soil fertility reduces their productivity, particularly that of elephant grass. In addition, soil acidity, Al and Mn toxicities, and N and P deficiencies limit grass yields in the tropics (Silva and Ranno 2005).

Plant growth is determined by 2 main processes: (1) synthesis of organic compounds by above-ground photosynthetic tissues; and (2) water and nutrient uptake by roots (Raven et al. 2001). Thus, the root system constantly interacts with the above-ground plant tissues,

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providing water, nutrients and other compounds to promote pasture regrowth after defoliation. A vigorous root system increases plant growth rate, tolerance of water deficit, and ability to compete for soil nutrients and, consequently, leads to an increase in pasture productivity.

Research on C stocks in tropical soils has increased in recent years owing to the increasing interest in quantifying carbon sequestration in agricultural systems (Zinn et al. 2005). The conversion of native forest into pasture may increase carbon stocks in soil, highlighting the importance of pastures in minimizing atmospheric CO_2 (Chapuis-Lardy et al. 2002). However, poor management of pastures could lead to a reduction in soil carbon (Silva et al. 2004).

There is currently limited information regarding the response by root systems of tropical grasses to grazing management strategies and how these strategies will affect soil properties and C sequestration. The present work aims to address these issues by quantifying the short-term impact of grazing intensities on the root systems and soil C stocks of elephant grass and signal grass pastures.

Materials and Methods

Two grazing experiments were carried out at the Agronomic Institute of Pernambuco (IPA) Experimental Station, located in Itambé, northern coastal region of Pernambuco State, Brazil (07º25' S, 35º06' W; 190 masl) on an Ultisol. Average annual rainfall is 1,200 mm, falling mostly from May to September, and average temperature is 25 ºC (ITEP 2010). Total rainfall during the experimental period was 1,311 mm (Figure 1).

The elephant grass stand (clone IRI 381) was established in July 2003, grazed from 2003 to 2005 (Freitas et al. 2004; Cunha et al. 2007) and used for a cutting experiment during 2006–2007. Grazing was re-established in October 2007 and lasted until December 2010. Soil samples and observations of the root system in the grazing study reported in this paper (Experiment 1) were collected from August 2007 to September 2008, comparing 3 post-grazing stubble heights (40, 80 and 120 cm) in a randomized complete block design with 3 blocks per treatment. Each paddock (experimental unit) measured 833 m^2. Response variables evaluated included soil C stocks and root system characteristics (root length, root length density and root biomass); the sampling occurred at the onset of the experimental period in August 2007 and again after the completion of 7 grazing cycles, in September 2008. Initial sampling occurred 70 days after the onset of grazing cycles. Pasture stubble heights at this initial evaluation were 48, 85 and 115 cm, corresponding with 40, 80 and 120 cm treatments, respectively. Soil texture and soil chemical characteristics for Experiment 1 are presented in Table 1.

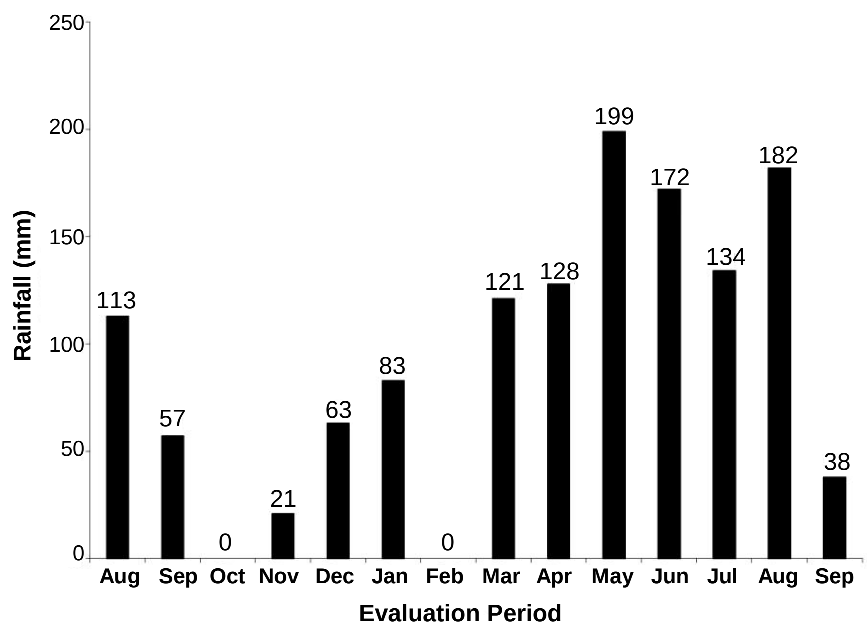

Figure 1. Rainfall at the experimental site from August 2007 to September 2008.

Table 1. Texture, density, pH and mineral concentrations of soil under elephant grass (IRI 381) pastures managed under different grazing intensities. Values are from samples taken at the completion of the study.

Soil layer (cm)	Soil texture (%)			Soil density (kg/dm^3)	pH (water 1:2.5)	Soil mineral concentration		
	Clay	Sand	Silt			P (mg/dm^3)	Ca ($cmol_c/dm^3$)	Al ($cmol_c/dm^3$)
0–20	29	58	13	1.21	5.41	12.2	2.12	0.31
20–40	35	55	10	1.18	5.48	6.1	2.82	0.62
40–60	36	53	11	1.19	5.05	6.3	1.63	0.82
60–80	38	52	10	1.18	5.02	2.7	1.51	0.84
80–100	41	46	13	1.24	4.99	3.1	1.33	0.77
s.e.	8.6	8.1	1.5	0.07	0.19	1.98	0.44	0.16

Table 2. Texture, density, pH and mineral concentrations of soil under signal grass pastures managed at different grazing intensities. Values are from samples taken at the completion of the study.

Soil layer (cm)	Soil texture (%)			Soil density (kg/dm^3)	pH (water 1:2.5)	Soil mineral concentration		
	Clay	Sand	Silt			P (mg/dm^3)	Ca ($cmol_c/dm^3$)	Al ($cmol_c/dm^3$)
0–20	27	60	13	1.24	5.66	18.9	2.92	0.09
20–40	35	54	11	1.29	5.33	8.7	1.92	0.64
40–60	39	52	9	1.34	5.23	3.3	1.38	0.83
60–80	40	51	9	1.35	5.11	2.5	1.22	0.73
80–100	43	44	13	1.30	4.92	2.5	1.11	0.68
s.e.	9.6	8.2	1.4	0.08	0.22	1.88	0.41	0.17

In Experiment 2, signal grass (*Brachiaria decumbens*) pastures were managed at 3 stocking rates: 2, 4 and 6 animal units (AU; 450 kg live weight) per ha. *Pennisetum* sp. hybrid HV-241 (elephant grass × pearl millet) had been planted and established at the same time as the elephant grass pastures (i.e. July 2003) but poor establishment of the hybrid led to signal grass spontaneously occupying the plots. Experimental design and experimental units were similar to those reported for Experiment 1. Evaluations for Experiment 2 occurred during the same period as for Experiment 1 (August 2007–September 2008). Soil texture and soil chemical characteristics for Experiment 2 are in Table 2.

For both experiments, a rotational stocking strategy was imposed. From January to May 2008, a grazing period of 3 days, followed by a rest period of 67 days (grazing occurred in January, March and May 2008), was employed. During the growing season (June to October 2008), the grazing period remained at 3 days, but the rest period was 32 days, resulting in a grazing cycle of 35 days (grazing occurred in June, August, September and October 2008). In Experiment 1, the number of animals varied in an endeavor to achieve target pre- and post-grazing stubble heights. Fertilizer (300 kg/ha of N:P:K 20:10:20, corresponding with 60 kg N, 13 kg P and 49.8 kg K) was applied after each grazing period during the growing season, resulting in 5 applications per year. Pasture fertilization (P and K) was based on soil testing prior to the beginning of the experiments. The high N fertilizer rate (300 kg N/ha/yr) was based on the higher stocking rate treatments in order to allow the comparison of a range of stocking rates and post-grazing stubble heights. While commercial farmers usually apply higher N fertilizer levels to elephant grass than to *Brachiaria* pastures, the same N rate was applied to both pastures.

In Experiment 1, 14 stratified soil samples were collected from each experimental unit (7 within rows and 7 between rows) across 5 layers (0–20, 20–40, 40–60, 60–80 and 80–100 cm) at the onset and completion of the study. In Experiment 2, only 7 samples per experimental unit were collected. Separate samples from grazed areas (833 m^2) and grazing exclusion areas (9 m^2) were collected to test the effects of grazing intensity on soil characteristics in the 2 pasture systems studied. Each paddock had an exclusion area, where 4 soil samples were collected (2 within rows and 2 between rows). Samples were combined to give composite samples for grazed and exclusion areas, row and inter-row and soil layer. Soil fertility analyses included pH (water), Mehlich-I P, Ca and Al levels. Soil organic carbon (SOC) was determined using the Walkley-Black modified method. Soil fertility analyses were performed according to EMBRAPA (1997).

Root biomass, root length and root length density were determined using a 200 g air-dried soil sample from each soil layer. Roots were separated from the soil using a group of sieves with 2.0, 1.0 and 0.5 mm mesh size. Root length was determined using the line intercept method (Bland and Mesarch 1990). Roots were oven-dried at 65 ºC and weighed. Root length density was determined by dividing root length by soil volume. Carbon stocks were calculated based on soil density, organic C concentration and depth of each layer (Veldkamp 1994).

Data were analyzed using the Proc MIXED procedure from the SAS statistical package (SAS 1996). Initial sampling data were used as a co-variable for the final sampling data to minimize possible initial differences at the experimental site. This was accomplished using the initial sampling as a fixed effect. Other fixed effects included post-grazing stubble height, grazed vs. non-grazed areas, soil layer and their interactions. Block and its interactions were designated as random effects. Data were analyzed in a strip-split-plot arrangement in a complete randomized block design. Means were compared using the LS-MEANS procedure from SAS and PDIFF adjusted by Tukey. Means were considered different using a 5% probability level.

Results

Post-grazing stubble height had no effects on soil C stocks, root length, root length density and root biomass for elephant grass pastures (P>0.05), and stocking rate did not affect these parameters for signal grass pastures (P>0.05). No difference between grazed areas and excluded areas was detected for soil and root characteristics in either pasture system (P>0.05) (data not presented). The absence of response to the treatments applied may be due to the short interval (13 months) between initial and final samplings.

Total root biomass from the 0–100 cm soil layer was 5.31 and 5.98 t/ha for signal grass and elephant grass, respectively (Figure 2). Root biomass was also greatest in the 0–20 cm soil layer, regardless of the forage species.

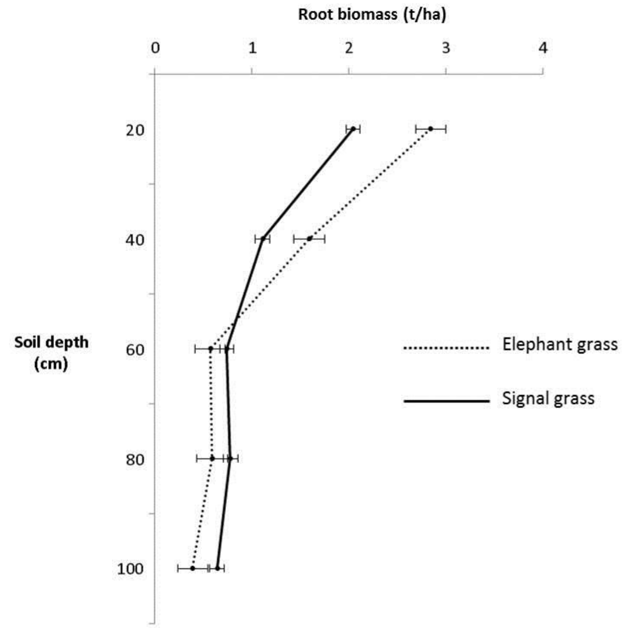

Figure 2. Root biomass of elephant grass (IRI 381) and signal grass pastures managed under different grazing intensities, which failed to significantly influence this parameter. Horizontal bars represent the standard error of the mean.

Although elephant grass had more roots than signal grass, soil C stocks to 1 m under elephant grass were lower than under signal grass (214 vs. 358 t/ha) (Figure 3).

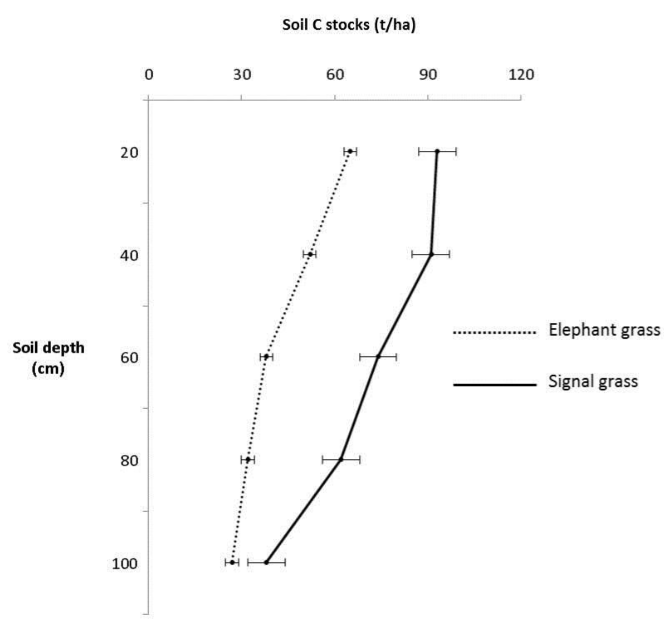

Figure 3. Soil C stocks of elephant grass (IRI 381) and signal grass pastures managed under different grazing intensities, which failed to influence this parameter. Horizontal bars represent the standard error of the mean.

Soil C stocks in signal grass pastures declined with soil depth, from 93 t C/ha in the 0–20 cm horizon to 38 t C/ha in the 80–100 cm horizon. Carbon stocks for elephant grass also declined with increasing soil depth, from 65 to 27 t/ha for the 0−20 cm and the 80−100 cm soil layers, respectively (Figure 3).

Root system variables varied (P≤0.05) with soil depth. Root length (Figure 4) and root length density (Figure 5) of elephant grass were greater at shallower depths, with approximately 38% of root length occurring in the 0–20 cm soil layer.

Soil organic C (SOC) did not vary among soil layers for signal grass pastures, ranging from 34.98 to 17.73 g/kg (Figure 6). The SOC concentrations in elephant grass pastures, however, were greater in shallower layers, with values of 25.36 and 21.15 g/kg for the 0–20 and 20–40 cm layers, respectively. In the other soil layers, the SOC concentration ranged from 13.62 to 16.14 g/kg.

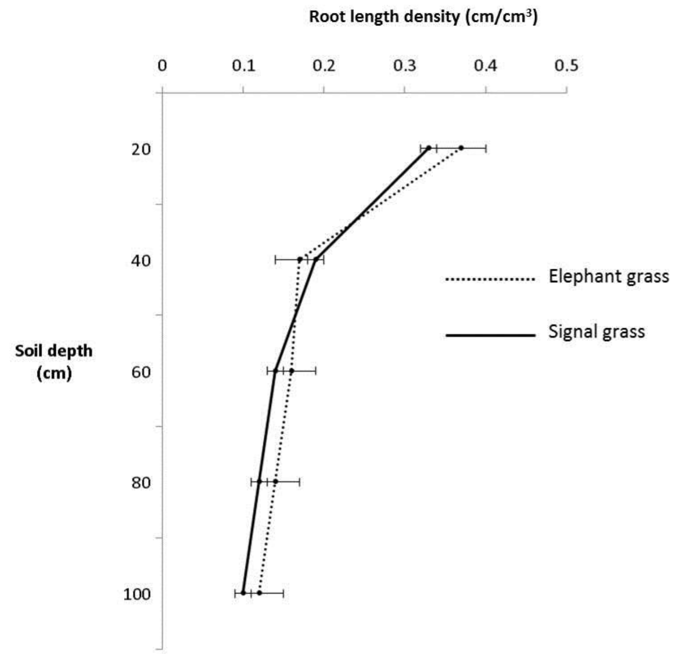

Figure 5. Root length density of elephant grass (IRI 381) and signal grass pastures managed under different grazing intensities, which failed to influence this parameter. Horizontal bars represent the standard error of the mean.

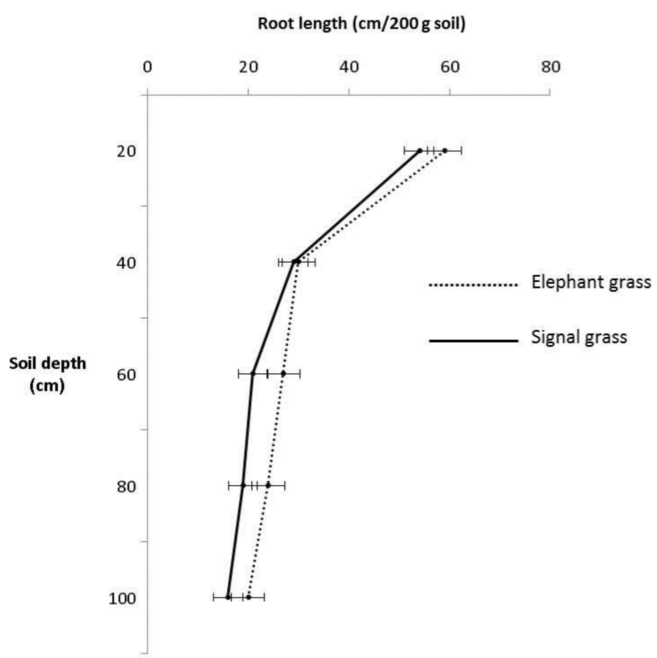

Figure 4. Root length of elephant grass (IRI 381) and signal grass pastures managed under different grazing intensities, which failed to influence this parameter. Horizontal bars represent the standard error of the mean.

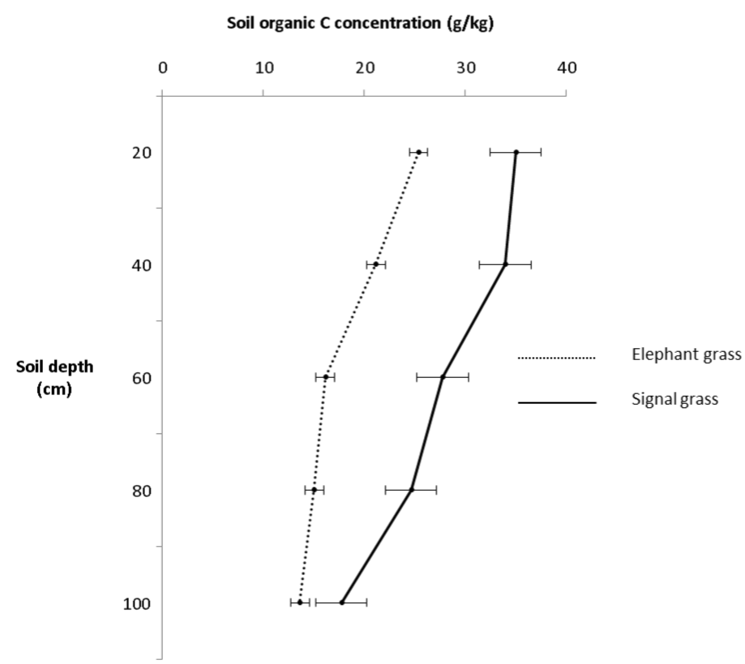

Figure 6. Soil organic carbon concentration of elephant grass (IRI 381) and signal grass pastures managed under different grazing intensities, which failed to influence this parameter. Horizontal bars represent the standard error of the mean.

Discussion

This study has provided valuable additional information on amounts of carbon in soils under tropical grass pastures, highlighting the role that tropical grass pastures can play in removing carbon from the atmosphere.

Marchão et al. (2009) compared crop and livestock systems and observed that pasture areas in Central Brazil contained 52.2 and 53.2 t C/ha in the 0–30 cm soil layer for rotational and continuous stocking, respectively. Other studies (D'Andréa et al. 2004; Silva et al. 2004; Bayer et al. 2006) reported values of 54, 31 and 41 t C/ha for the 0–20 cm soil layer, similar to the values observed for elephant grass in the current research. Soil C stocks to 40 cm of 117 t/ha (elephant grass) and 184 t/ha (signal grass) can be compared with a range of 69.6–81.9 t/ha quoted by Fisher et al. (2007) for a range of pastures in various stages of health.

Fisher et al. (1998) speculated that differences amongst species in soil C stocks might possibly be related to differences in the composition of litter, which in turn would affect their rates and patterns of decomposition. Greater above-ground litter biomass observed in signal grass pastures may have resulted in higher soil organic C concentration in our pastures. Additionally, the lower quality of signal grass litter reduces its decomposition, leading to higher soil carbon accumulation. Higher C concentration and content at shallower soil depths is directly linked to litter deposition on the soil surface and greater root biomass in the superficial layers (Figure 2). Costa et al. (2009a) observed greater C stocks in the 0–20 cm soil layer, with the best results for well-managed signal grass pastures compared with areas of native vegetation and degraded pastures. According to these authors, greater root biomass in signal grass pastures was the main reason for greater C stocks.

Short duration of the study would have been an important factor in the failure to show differences in C stocks on different treatments. For elephant grass pastures, the lack of response to grazing intensity may also be due to the small amplitude observed for the actual post-grazing stubble heights during the experimental period, which averaged 71.5 ± 18.1 cm, 98.7 ± 12.9 cm, and 117.0 ± 9.6 cm for the target heights of 40, 80 and 120 cm, respectively. A number of factors could have contributed to the failure to achieve the desired target heights, including the addition of insufficient animals during the adjustment of stocking rate, and low forage quality, because of lignified stems left after grazing. Large variation in tiller height within each elephant grass tussock may also have affected post-grazing stubble height measurements.

The values for total root biomass in the top 100 cm of soil in this study are similar to the 5.25 t/ha reported by Fisher et al. (2007) in a 1-year-old *Brachiaria brizantha* pasture, but much lower than the 10.38 t/ha for a 7-year-old pasture of the same species. Oliveira et al. (2004) recorded root biomass levels under *B. brizantha* pastures with varying histories and ages from 4.6 to 39.7 t/ha in the top 40 cm.

Signal grass and elephant grass pastures showed similar trends in root responses, but elephant grass had greater root development at shallower depths (Figure 2). Root length and root length density varied from 16 to 54 cm/200 g of soil and 0.10 to 0.33 cm/cm^3, respectively. Increased clay content with depth in the soil could have reduced root development, through increased soil resistance to penetration. Rosolem et al. (1999) showed that development of maize (*Zea mays*) roots was reduced when clay content exceeded 40% due to soil compaction. Other factors such as lower soil fertility, especially soil P concentration, higher soil density and less aeration in deeper soil layers also restrict root development in these layers. Studying crop rotation systems, De Maria et al. (1999) related higher levels of extractable P and soil moisture in topsoil layers to higher root length density. Costa et al. (2009b) linked greater maize root length density to higher soil P concentrations at shallower depths. At the experimental site, soil P was 12.2 mg/dm^3 for the 0–20 cm layer and ranged from 2.7 to 6.1 mg/dm^3 for the other layers (Tables 1 and 2).

Highest root concentrations in the top 20 cm of soil have also been reported for *Panicum maximum* (Sarmento et al. 2008), *B. brizantha* (Oliveira et al. 2004) and *B. decumbens* (Fisher et al. 2007). Sarmento et al. (2008) observed that 85% of the roots of *Panicum maximum* were found in the 0–20 cm soil layer, when it was managed under rotational stocking and N fertilization (0, 150, 300 and 450 kg N/ha/yr), regardless of the level of N applied. The reduction in root biomass with increasing soil depth was more evident for elephant grass, which is likely due to its lower Al tolerance. Signal grass tolerance of Al toxicity depends on mechanisms of Al elimination via the root system (Wenzl et al. 2002; Hartwig et al. 2007). Hydroponic studies revealed that signal grass has a higher tolerance for Al than the most tolerant genotypes of maize, wheat (*Triticum aestivum*) and triticale (*Triticosecale rimpaui*) (Wenzl et al. 2001).

Grazing systems are increasingly perceived as an alternative to mitigate major environmental impacts encountered in intensive livestock systems, but proper pasture and grazing management are required. Well-managed pastures with good soil cover reduce soil erosion and maintain or enhance soil fertility. In poorlymanaged pastures, however, pasture degradation may lead to negative environmental impacts. Dubeux et al. (2006a; 2006b) defined above-ground litter as the vegetal residue from plant senescence (shoot) deposited on the soil surface. This layer (litter) may immobilize and mineralize nutrients, acting as a buffering pool in intensive production systems.

Carbon sequestration from the atmosphere is currently considered a positive aspect that well-managed grasslands may provide. Fisher et al. (1994) reported that the global CO_2 balance from the atmosphere suggests a level of C retention of approximately 0.4 to 4.3 Gt per year through unidentified C sinks. A large part of this C, however, may be retained by deep-rooted grasses in pasture ecosystems. The same authors observed that C sequestration by such grasses in South America is of global importance owing to the extensive areas of pastures in this region.

Conclusion

While post-grazing stubble height and stocking rate did not affect soil C stocks and root systems during the evaluation period, the short duration of the study could have been a major factor. Studies over longer periods are needed to confirm these results. It is obvious that these pastures can store significant amounts of carbon below ground, which is an important attribute of tropical pastures located in more humid regions.

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