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PLANT SHOOTS AND ROOTS BIOMASS OF BRACHIARIA GRASSES AND THEIR EFFECTS ON SOIL CARBON IN THE SEMI-ARID TROPICS OF KENYA [1]

[BIOMASA DE BROTES Y RAÍCES DE PASTOS BRACHIARA Y SUS EFFECTOS EN EL CARBONO DEL SUELO EN LOS TRÓPICOS SEMI-ÁRIDOS DE KENIA]

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SUMMARY

Grassland management practices that improve carbon uptake by increasing productivity or reducing carbon losses can lead to net accumulation of carbon in soils. A study was conducted to quantify the amounts of shoots and roots biomass of Brachiaria grass cultivars and their effects on soil carbon in two sites, Ithookwe and Katumani in semi-arid tropical Kenya. The grass cultivars were *Brachiaria decumbens* cv. Basilisk, *B. brizantha* cvs. Marandu, MG4, Piatã and Xaraes, *B. humidicola* cv. Llanero and *B. hybrid* cv. Mulato II. These were compared with two locally cultivated grasses (*Chloris gayana* cv. KAT R3 and *Pennisetum purpureum* cv. Kakamega 1). The grass treatments were evaluated with fertilizer application (40 kg P applied at sowing and 50 kg N ha^{-1} in each wet season) and with no fertilizer application. Shoots biomass of the Brachiaria cultivars ranged from 3.0 to 11.3 t ha^{-1} and 5.5 to 8.3 t ha^{-1} at Ithookwe and Katumani sites respectively in year 1. The highest shoots biomass recorded at Ithookwe was from cv. Piata while cv. MG4 gave the highest biomass at Katumani. Similar trends were recorded in year 2 of growth though the shoots biomass was lower at Katumani. However, the yields were significantly lower than those recorded from control, Napier grass in both years. The cv. Marandu, Xaraes, Basilisk and Piata had higher roots biomass than the controls (Rhodes grass and Napier grass) indicating greater potential for the Brachiaria grasses to sequester more carbon in the soil. The results of this study indicate that introduction of Brachiaria grasses in the semi-arid tropics of Kenya and in other similar environments can help increase soil carbon stocks that would mitigate the adverse effects of climate change and have greater economic returns.

Key words: Brachiaria; roots biomass; semi-arid; shoots biomass; soil carbon

RESUMEN

Las prácticas de manejo de pastizales que mejoran la captación de carbono aumentando la productividad o reduciendo las pérdidas de carbono pueden conducir a la acumulación neta de carbono en los suelos. Se realizó un estudio para cuantificar las cantidades de biomasa de ramas y raíces de cultivares de pasto Brachiaria y sus efectos sobre el carbono del suelo en dos sitios, Ithookwe y Katumani en el trópicos semiárido de Kenia. Los cultivares de pasto fueron *Brachiaria decumbens* cv. Basilisco, *B. brizantha* cvs. Marandu, MG4, Piatã y Xaraes, *B. humidicola* cv. Llanero y *B. hybrid* cv. Mulato II. Estos fueron comparados con dos pastos cultivados localmente (*Chloris gayana* cv. KAT R3 y *Pennisetum purpureum* cv. Kakamega 1). Los pastos fueron evaluados con aplicación de fertilizantes (40 kg P aplicados en la siembra y 50 kg N ha-1 en cada estación húmeda) y sin aplicación de fertilizantes. La biomasa de brotes los cultivares de Brachiaria variaron de 3.0 a 11.3 t ha^{-1} y de 5.5 a 8.3 t ha^{-1} en los sitios de Ithookwe y Katumani, respectivamente, en el año 1. La mayor biomasa de los brotes registrada en Ithookwe fue para cv. Piata mientras cv. MG4 dio la mayor biomasa en Katumani. Tendencias similares se registraron en el año 2 de crecimiento aunque la biomasa de los brotes fue menor en Katumani. Sin embargo, los rendimientos fueron significativamente más bajos que los registrados en el pasto Napier (control) en ambos años. El cv. Marandu, Xaraes, Basilisk y Piata tuvieron mayor biomasa de raíces que los controles (pasto Rhodes y Napier) lo que indica un mayor potencial para las Brachiaria para secuestrar más carbono en el suelo. Los resultados de este estudio indican que la introducción de Brachiaria en los trópicos semiáridos de Kenia y en otros ambientes similares puede ayudar a aumentar las reservas de carbono del suelo que mitigarían los efectos adversos del cambio climático y generarían mayores retornos económicos.

Palabras clave: Brachiaria; Biomasa de raíces; Semiárido; Biomasa de brotes; Carbono del suelo

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INTRODUCTION

A large part of the world's grasslands is under pressure to produce more livestock by grazing more intensively, particularly in Africa's rangelands, which are vulnerable to climate change and are expected to supply most of the beef and milk requirements in Africa (Reid *et al.*, 2004). Previous research has documented that improved pasture management can lead to greater forage production, more efficient use of land resources and rehabilitation of degraded lands (Oldeman, 1994). Implementing grassland management practices that improve carbon uptake by increasing productivity or reducing carbon losses can lead to net accumulation of carbon in grassland soils sequestering atmospheric carbon dioxide (Lal, 2009).

Soil organic carbon (SOC), a key regulator of ecosystem processes plays an important role in soil fertility improvement and is critical in the reduction of soil erosion through aggregate stabilization (Gichangi, *et al*., 2016). Additionally, the preservation of SOC in soil mitigates greenhouse gas emissions (CO_2) into the atmosphere (Cole *et al*., 1996; Pan *et al.*, 2006). Atmospheric carbon can be sequestered in long-lived carbon pools of plant biomass both above and below ground or recalcitrant organic carbon in soils. Apart from offsetting CO_2 emissions and global warming, sequestration of carbon in soils also helps to improve soil quality by improving many physical, chemical and biological properties of soils such as infiltration rate, aeration, bulk density, nutrient availability, cation exchange capacity, buffer capacity, etc. Practices that sequester carbon in soils also tend to enhance resilience, and are thus likely to improve longer-term adaptation to changing climates more especially in the semi-arid environments where soils are inherently low in organic carbon content. Therefore, practices that sequester carbon should be promoted to provide near-term dividends in greater forage production for enhanced producer income and better environmental protection.

Perennial grasses hold promise for increasing belowground C storage, sequestering C in extensive roots structures (Norby and Jackson, 2000; Fornara and Tilman 2008) and accumulating SOC at rates averaging 40–100 g C m^{-2} y^{-1} (Chevallier *et al*., 2000; Anderson-Teixeira *et al*., 2009). Indeed, some pastures have higher soil C stocks than forests (Cole *et al*., 1996; Neill *et al*., 1996). Scharpenseel and Becker-Heidmann (1997) for example, reported that the mean residence time of C derived from pasture was longer than for C derived from forest in an Australian vertisols. Roots are the major C source in soil (Matamala 2008; Frank *et al*., 2004; Fornara and Tilman 2008), and can also stimulate SOM mineralization (Ladd *et al*., 1994; Bayer *et al*., 2006; Corbeels *et al*. 2006; Cerri *et al*., 2007). Brachiaria grasses are endaphytic and have a great ability to sequester and accumulate large amounts of SOC through their large shoots and roots biomass (Clapperton *et al*., 2003; Peters *et al.,* 2012) and thus important for livestock feed production and soil improvement. The grass is widely planted in the tropics of South America to sustain livestock production (Miles *et al*., 2004). About 55% of the total area of pastures is occupied by grasses of the genus *Brachiaria*. Brazil for example, has around 172 million hectares of grasslands that support a cattle herd of approximately 170 million heads (Jank et al., 2014). The objective of this study was therefore to quantify the amounts of plant shoots and roots biomass and their effects on soil organic carbon resulting from 2 years cultivation of Brachiaria grasses in the semi-arid tropical Kenya. We tested the hypothesis that Brachiaria grasses have higher shoots biomass and allocate more C to roots resulting in greater belowground biomass particularly when N and P fertilizers are applied compared with commonly cultivated local grasses, *Chloris gayana* and *Pennisetum purpureum*.

MATERIALS AND METHODS

Description of the study sites

The experiments were established in November during the short rains of 2013 at the Kenya Agricultural and Livestock Research Organization (KALRO) centres at Ithookwe (38º02'E, 1º37'S) and Katumani (37˚28'E, 1˚58'S). The elevations for Ithookwe and Katumani are 1150 m and 1600 m asl and the sites have a long term mean annual rainfall of 1010 and 717 mm, respectively in bimodal pattern with the long rains (LR) occurring from March to May and the short rains (SR) from October to December with peaks in April and November. Mean temperatures are 22.5 and 19.6˚C for Ithookwe and Katumani, respectively. The dominant soils in both sites are chromic Luvisols, which are low in organic C and highly deficient in N and P and generally have poor structure (NAAIAP, 2014).

Site characterization

Soil samples were collected in November 2013 before establishing the experiment at depths of 0–15 cm, 15–30 cm, 30–60 cm, and 60-100 cm using an auger for analysis. Plant litter on the soil surface was removed before collecting the samples. A composite soil sample, consisting of 12 cores, was collected in a grid pattern from within the 25 × 10 m blocks. Samples from each block were air-dried, visible plant roots removed, and the samples gently crushed to pass through a 2-mm sieve. The fractions sample <2 mm were used for subsequent chemical and physical

analyses. Total soil N, available P (Mehlick III), exchangeable K, Ca, and Mg were estimated following standard methods as described by Okalebo *et al.* (2002)**.** Cations Ca^{2+}, Mg^{2+}, and K^{+} were determined by atomic absorption spectrometry and soil P was measured as described by Murphy and Riley (1962).

Soil texture was determined by the hydrometer method. Soil pH was measured in water (soil: water ratio of 1: 2.5) using a pH meter and reference calomel electrode (Model pH 330 SET-1, 82362) after the suspensions were shaken for 30 minutes and allowed to stand for 1 hour. Organic carbon, was determined by the modified Walkley and Black procedure (Nelson and Sommers 1982). Cation exchange capacity (CEC) was based on the sum of exchangeable Ca, Mg, K, H + Al after extraction with ammonium acetate. Soil bulk density was determined according to Blake and Hartge (1986). Soils were vertically sampled using stainless steel rings (diameter 10 cm) at soil depths of: 0–15 cm, 15–30 cm, 30–60 cm, and 60-100 cm, resulting in undisturbed soil samples for bulk density determination. Soil samples were dried at 65ºC to a constant weight to allow soil bulk density calculation. All determinations were made in triplicate and expressed on a dry weight basis.

The soil characteristics are shown in Table 1. Mean surface (0-15cm) soil pH was moderately acidic and was 5.8 and 5.3 at Katumani and Ithookwe, respectively. The soil pH at Ithookwe was slightly below the range (pH 5.5–7.0) for good nutrient availability without toxicity problems (Landon, 1984). Organic carbon content was low in both sites and varied from 0.49 – 1.16% with depth for the Katumani and 0.52 – 0.83% for the Ithookwe (Table 1). Similarly nitrogen, phosphorus and zinc were low in both sites. Potassium levels were adequate at Katumani site but were generally low in soil samples collected from Ithookwe. According to Foster (1971), critical values for soil pH, organic matter, total N, P and K are 5.5, 3.0%, 0.18%, 5 mg kg^{-1} and 13.3 $cmolkg^{-1}$ respectively. Calcium and iron levels were adequate in both sites.

Results of the physical soil analysis of samples collected from the test sites at 0-15 cm indicated that the soils were sandy clay loam at Ithookwe and sandy clay in Katumani (Table 2). Cation exchange capacity ranged from 16.1 to 18.6 me% and 20.2 to 27.8 me% at Ithookwe and Katumani, respectively and tended to increase with depth. This would be expected as the clay content also increased with depth resulting to increased number of exchange sites. Bulk density ranged from 1.32 to 1.49 gcm^{-3} and the vales for both sites were greater than the ideal range of 1.1 - 1.3 g cm^{-3} for non-restricted plant roots growth (Landon, 1991). According to Landon (1991), soil bulk density exceeding 1.3 g cm^{-3} for clay soils could negatively interfere with soil aeration through reduced air-filled pore space. Silt and clay comprised over 50 % of the soil in both sites.

Treatments and experimental design

The treatments consisted of seven Brachiaria grass cultivars; *Brachiaria decumbens* cv. Basilisk, *B. humidicola* cv. Llanero, *B. brizantha* cvs. Marandu, MG4, Piatã, Xaraes and *B. hybrid* cv. Mulato II. Two commonly cultivated local grasses, [(*Chloris gayana* cv. KAT R3 and *Pennisetum purpureum cv*. Kakamega 1 (KK1)] were included as control. These treatments were evaluated in the plots measuring 4 m x 5 m with fertilizer (40 kg P ha^{-1} applied at sowing and 50 kg N top-dressed in each wet season) and without fertilizer application. The treatments were laid out in a randomized complete block design in a split plot arrangement (fertilizer treatments as main plots and the grass cultivars as sub plots) with three replications resulting to a total of 54 experimental units. The grasses were sown in November 2013 during the short rains. Broad leaf weeds in the experimental plots were removed by hand whenever necessary throughout the experimental period. The grasses were first harvested 16 weeks after establishment and later, harvesting was done on an 8 weeks interval during the wet seasons for a period of 2 years.

Shoots and roots biomass determination

Data for shoots biomass was collected eight times on an 8 weeks interval after plants were well established. The establishment period was considered as 16 weeks after seedling emergence. Harvesting of plant shoots was carried out from 2 m x 2 m net plots at a cutting height of 5 cm above ground. Total fresh weights of shoots from each plot were recorded, and approximately 500g subsamples were dried at 65°C to constant weight in forced-air drier for determination of dry matter. Roots were sampled using the soil-core method (Bohm, 1979). In each plot, four soil cores were randomly taken with a 6.5 cm diameter stainless steel auger to a depth of 0–15 and 15–30 cm from the inter-row and intra-row positions and composited into one sample per plot for each depth. The sampling was carried out at least 1m apart from the edge of the plot to avoid edge effects. Sampling was conducted 24 and 48 weeks of plants establishment. The roots from each soil layer were washed separately by hand with a 2.8 mm and a 2 mm soil sieve under running tap water. Root samples integrating both living and dead roots were then dried at 65°C to constant weight and roots dry weights were recorded. Total N and P in the plant samples were measured after digestion in a 1.2:1 H_2SO_4: H_2O_2 mixture at 360 ºC after which total N

and P were measured colorimetrically (Anderson and Ingram, 1993).

Soil samples for microbial biomass carbon (MBC) analysis were collected in November 2015, 24 months after the grasses had established. Four soil samples were carefully collected from a depth of 0-10 cm using an auger in each pasture plot. In this study, only the top 10 cm soil was sampled which was assumed to contain the highest biological activity and most likely exhibit short-term changes in response to Brachiaria grasses cultivation. Soils from the four sampling positions of a plot were pooled to one sample and used in the subsequent analysis as described below.

Microbial biomass carbon was determined on field moist soil (18-23% by weight) taken from a depth 10 cm in the rhizosphere by the chloroform fumigation-extraction technique as described by Brookes *et al*. (1984, 1985) and Gichangi *et al.* (2016). Briefly, 10 g dry weight equivalent of soil was fumigated with ethanol-free chloroform in a glass desiccator; and another 10g was incubated without fumigation at the same moisture content, time period and temperature for 24 h at 25°C. Both sets were extracted with 0.5 M K_2SO_4 and C in the extracts determined using the standard method as described by Okalebo *et al*. (2002). The Soil microbial biomass carbon was then calculated as the difference between the fumigated and un-fumigated samples and corrected for incomplete recovery using a conversion factor of 0.45 for C (Wu *et al*., 1990). All determinations were made in triplicate and expressed on a dry weight basis.

Statistical analysis

Treatment effects on shoots and roots biomass were tested using the analysis of variance (ANOVA) as a split-plot with fertilizers N and P as the main factor and grass type as the sub-plot factor using GENSTAT statistical software (GENSTAT Release 4.24DE, 2005). Differences at $p \leq 0.05$ were considered significant and means separation was done using Fischer's protected test (LSD). Regression analyses and Pearson correlation coefficient (r) were used to find models best describing the relationships between shoots and roots biomass with other soil and plant properties.

Table 1. Initial soil chemical properties at the experimental sites, Ithookwe and Katumani

Soil properties	Site							
	Ithookwe				Katumani			
Sampling depth (cm)	0-15	15-30	30-60	60-100	0-15	15-30	30-60	60-100
Soil pH	5.36	5.34	5.39	5.79	5.88	5.76	5.81	6.10
Total Nitrogen %	0.08	0.08	0.08	0.05	0.12	0.12	0.07	0.05
Org. Carbon %	0.83	0.78	0.77	0.52	1.16	1.15	0.65	0.49
Phosphorus ppm	13	10	15	12	10	12	10	15
Potassium me%	0.25	0.14	0.11	0.61	0.29	1.01	0.52	0.32
Calcium me%	1.9	1.7	1.8	1.3	3.1	3.4	2.2	2.4
Magnesium me%	3.62	4.11	3.75	3.59	5.72	5.99	5.96	6.31
Iron ppm	10.3	14.3	14.6	11.3	17.0	17.4	18.8	18.3
Zinc ppm	1.09	1.29	1.28	1.01	1.78	1.44	0.97	0.64

Table 2 Initial soil physical properties at the experimental sites, Ithookwe and Katumani

Soil properties	Site							
	Ithookwe				Katumani			
Sampling depth (cm)	0-15	15-30	30-60	60-100	0-15	15-30	30-60	60-100
Bulk density (g/cm^3)…..	1.59	1.48	1.49	1.39	1.32	1.41	1.35	1.45
Sand %	56.7	49.3	49.3	50.0	50.7	48.7	44.0	40.0
Silt %	12.7	8.7	8.0	18.0	6.0	8.0	5.3	7.3
Clay %	30.7	42.0	42.7	32.0	43.3	43.3	50.7	52.7
Cat. Exch. Cap. me%	16.1	14.2	18.6	11.9	20.2	21.3	20.9	27.8
Base saturation %	33.3	50.2	27.6	58.1	92.4	85.7	78.9	64.2

RESULTS AND DISCUSSION

Shoots biomass and N and P uptake

The shoots biomass differed significantly ($p \leq 0.05$) among Brachiaria grass cultivars and across experimental sites. The shoots biomass ranged from 3.0 to 11.3 t ha^{-1} and 5.5 to 8.3 t ha^{-1} at Ithookwe and Katumani, respectively in year 1 with the highest shoots biomass recorded from cv. Piata at Ithookwe and cv. MG4 at Katumani (Figure 1a). Similar trends were recorded in year 2 growth, but the shoots biomass was much lower at Katumani (Figure 1b) than in year 1 growth (Figure 1a). However the yields were significantly lower than those recorded from locally cultivated Napier grass (*Pennisetum purpureum* cv. Kakamega 1) for both periods. Generally, higher shoots biomass was recorded from Ithookwe site than that recorded from Katumani site (Figure 1) indicating that the Brachiaria cultivars are more suited to that site. The site has a higher annual rainfall with a long term mean of 1010 mm compared to 717 mm received at Katumani. There was a strong positive relationship between shoots biomass recorded with N and P uptake (Figure 2). Higher shoots biomass resulted to higher N and P uptake indicating better utilization of the fertilizer applied. Bonfim and Monteiro (2006) and Batista and Monteiro (2008) have previously reported that the combined application of nitrogen with phosphorus was more effective in maximizing the leaf area and the production of higher dry matter of grasses.

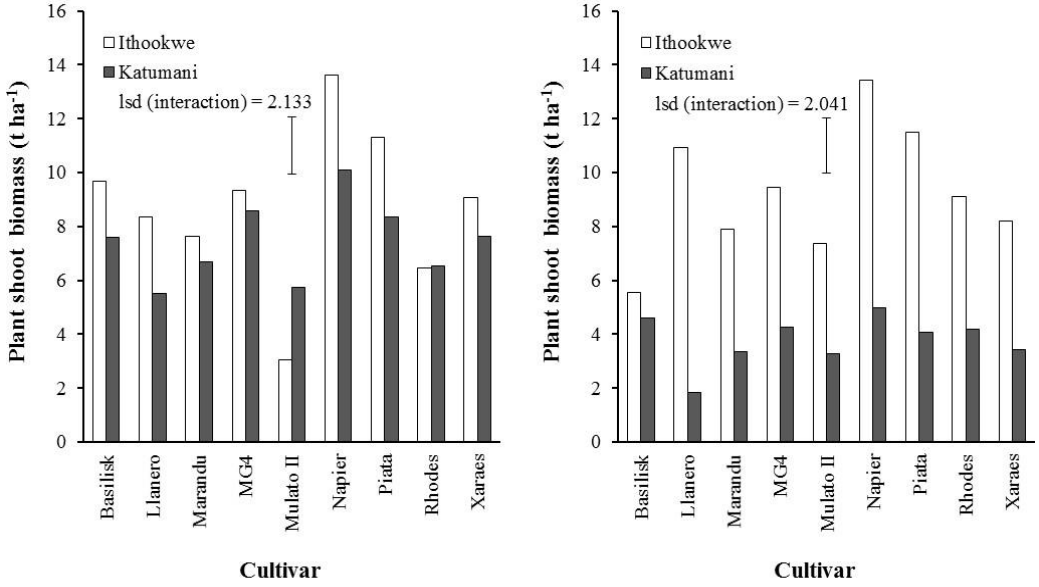

Figure 1 Effects of Brachiaria cultivars and local grasses Napier (*Pennisetum purpureum cv*. Kakamega 1) and Rhodes (*Chloris gayana*) and site on total shoots biomass a) Year 1 and b) Year 2

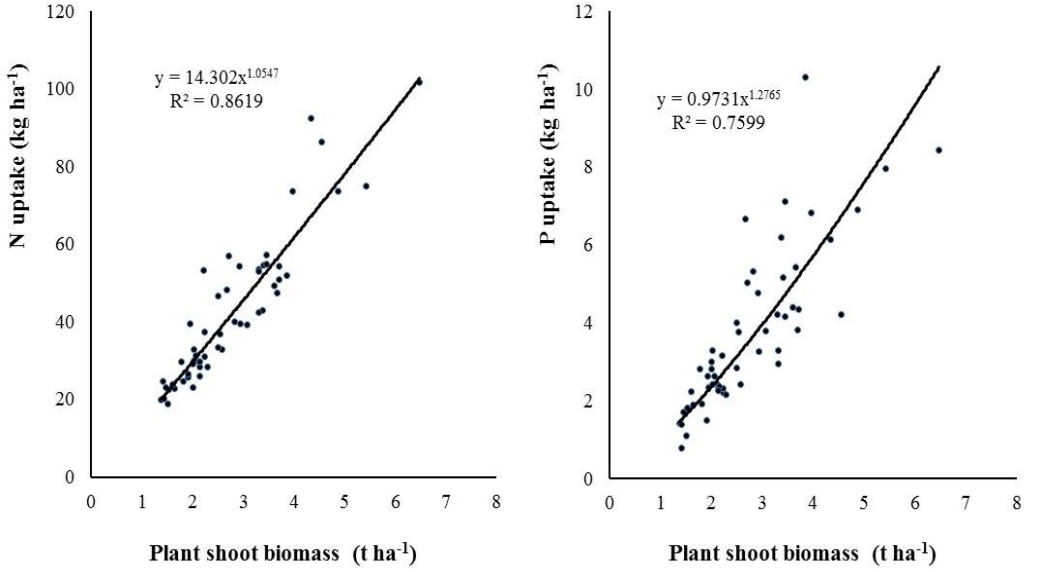

Figure 2 Relationships between shoots biomass with a) N and b) P uptake of Brachiaria grasses

Roots biomass

Brachiaria cultivars; Marandu, Xaraes, Basilisk and Piata had higher roots biomass than the controls, Rhodes grass and Napier grass indicating greater potential for the Brachiaria grasses to sequester more carbon in the soils. A vigorous roots system increases plant growth rate, tolerance to water deficit, and ability to compete for soil nutrients and consequently, leads to an increase in pasture productivity. These results are in agreement with observations made by Peters *et al.,* 2012 that Brachiaria grasses have greater ability to sequester and accumulate large amounts of organic carbon through their large roots biomass. Generally roots biomass was significantly higher from samples collected from Ithookwe than those obtained from Katumani (Figure 3). Grass type by sampling depth interaction was highly significant ($P<0.001$) for roots biomass with the highest roots concentration recorded in the upper (0 - 15 cm) soil layer regardless of the grass type and sampling period (Figure 4). There was approximately 79% of dry roots matter in the 0 - 15 cm soil layer and as expected, roots biomass, increased with age (Figure 4b). Among the Brachiaria cultivars, Mulato II hybrid had the lowest amount of roots; 242.3 g m^{-2} and 409.9 g m^{-2} in the 0-15 cm depth 24 and 48 weeks after plants had established, respectively. The trend was similar in the 15 – 30 cm depth (Figure 4).

Many management techniques intended to increase livestock forage production have the potential to augment soil carbon stocks, thus sequestering atmospheric carbon in soils. Grassland management that enhance production (through sowing improved species, irrigation or fertilization), minimizing the negative impacts of grazing or rehabilitating degraded lands can each lead to carbon sequestration (Follett, *et al*., 2001; Conant *et al*., 2001). In this study, fertilizer application significantly ($p<0.001$) increased roots dry matter of all grass types except cvs for Basilisk, MG4 and Mulato II, 24 weeks after plants had established (Figure 5a). However, the fertilizer effects were significant in all Brachiaria cultivars at 48 weeks (Figure 5b). The cultivar x fertilizer treatments interaction was also significant for roots biomass. This confirmed that low nutrient availability, especially phosphorus (P) and nitrogen (N) supply are a major limitation to forage production in infertile soils of the region. Our results are in agreement with those of Conant *et al*. (2001) who reported that intensively managed and fertilized grassland had higher roots biomass than less managed grasslands. As forage production increases with fertilizer application, an ancillary benefit may lie in increased sequestration of atmospheric carbon. Indeed, Gifford *et al*. (1992) noted that improved pasture management is an important consideration when computing a national carbon budget.

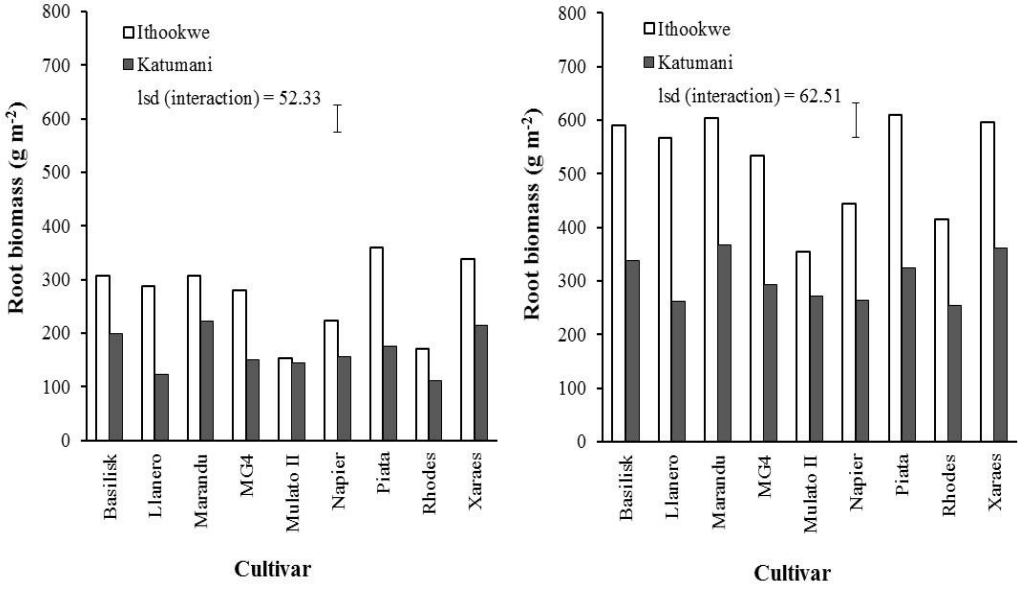

Figure 3 Effects of Brachiaria cultivars and local grasses Napier (*Pennisetum purpureum cv*. Kakamega 1) and Rhodes (*Chloris gayana*) and site on roots biomass a) 24 weeks and b) 48 weeks after grasses had established

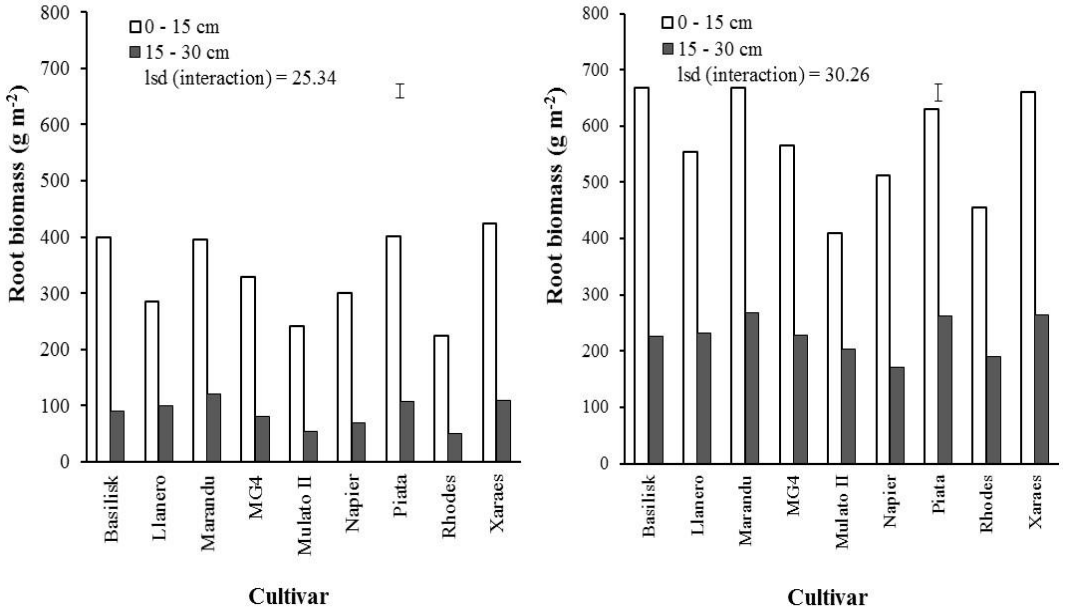

Figure 4 Effects of Brachiaria cultivars and local grasses Napier (*Pennisetum purpureum cv*. Kakamega 1) and Rhodes (*Chloris gayana*) and sampling depth on roots biomass across 2 sites (Ithookwe and Katumani) a) 24 weeks and b) 48 weeks after grasses had established.

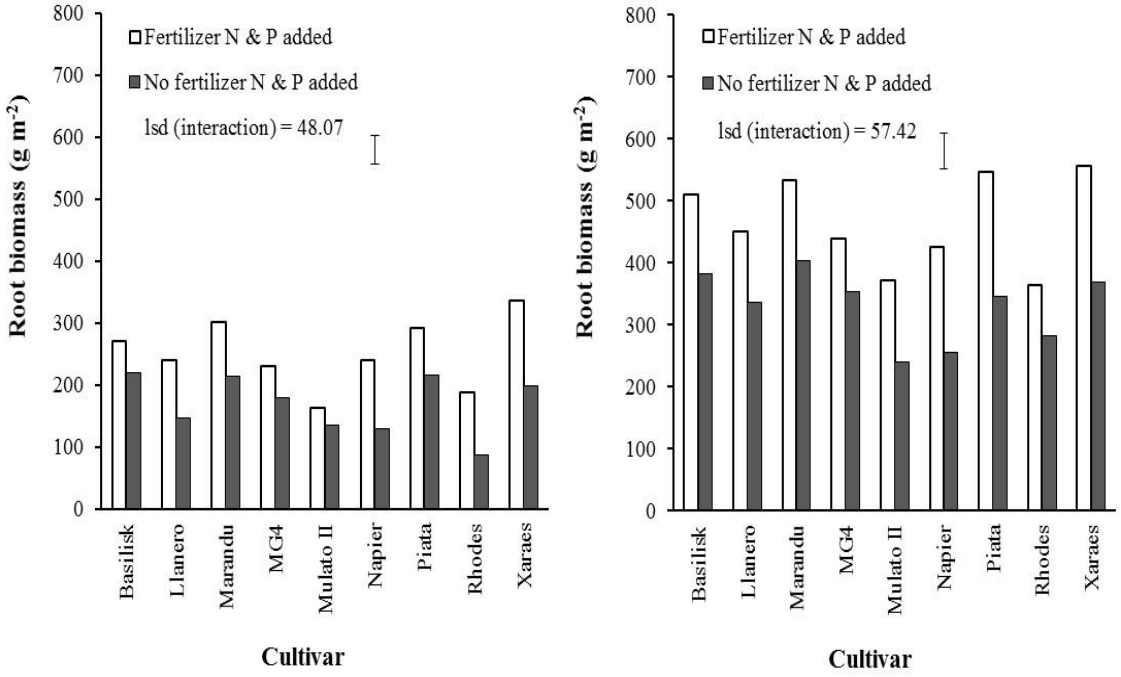

Figure 5 Effects of Brachiaria cultivars and local grasses Napier (*Pennisetum purpureum cv*. Kakamega 1) and Rhodes (*Chloris gayana*) and fertilizer application on roots biomass across 2 sites (Ithookwe and Katumani) a) 24 and b) 48 weeks after grasses had established

The synthesis by Smith *et al.* (2008) suggests that improvement of soil fertility could lead to C sequestration of between 0.42 and 0.76 t C ha^{-1} yr^{-1} depending on the region. Similar observations were also made by Follett *et al.* (2001) who reported that grassland management that enhances production

through sowing improved species, irrigation and fertilization can each increase carbon sequestration. The higher carbon allocation to the roots by the Brachiaria grasses in this study resulted in net belowground sequestration of carbon as indicated by the positive correlation between roots biomass with microbial biomass carbon (MBC) and soil organic carbon (SOC) (Table 3) even though the changes in SOC were very small and not significant among the Brachiaria grasses.

A prime underlying goal of sustainable management of grassland ecosystems is to maintain high levels of soil carbon stocks. An important argument in favour of grassland carbon sequestration is that implementation of practices to sequester carbon often lead to increased production and greater economic returns. Grazing or harvesting management can lead to decreased carbon removal if grazing or harvesting intensities are reduced or deferred while forage species are most actively growing (Kemp and Michalk, 2007). Sustainable grazing or harvesting management can thus increase carbon inputs and carbon stocks without necessarily reducing forage production. However in this study, frequent harvesting may have compromised roots growth. In addition removal of harvested herbage for livestock feed would result to reduced contribution of aboveground biomass to soil organic carbon. Therefore a trade-off between feeding livestock and improving soil carbon stocks by Brachiaria grasses introduced in the region should be investigated further particularly on the effects of harvesting frequency on roots development and herbage yield.

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Table 3. Relationships between roots biomass and soil and plant properties

Properties	MBC	Roots biomass Week 24	Roots biomass Week 48	SOC	Shoots biomass
MBC	1.0000				
Roots biomass-Week 24	0.7172**	1.0000			
Roots biomass-Week 48	0.6225**	0.8210**	1.0000		
SOC	0.3139*	0.4527**	0.4059**	1.0000	
Shoots biomass	0.6363**	0.6802**	0.6992**	0.4287**	1.0000

** $p < 0.01$ and *$p < 0.05$, MBC-microbial biomass carbon, SOC – Soil organic carbon

REFERENCES

Anderson, J. M., Ingram, J. S. I., 1993. Tropical Soil Biology and Fertility CAB International, Wallingford, UK

Anderson-Teixeira. K. J., Davis, S. C., Masters, M. D., DeLucia, E. H., 2009. Changes in soil organic carbon under biofuel crops. Bioenergy 1:75–96.

Batista, K., Monteiro, F. A. 2008 Nitrogen and sulphur on morphogenic characteristic of Marandu palisade grass replacing signal grass under degradation in a low organic matter soil. Brazilian Journal of Animal Science. 7: 1151-1160.

Bayer, C., Martin-Neto, L., Mielniczuk, J., Pavinato, A., Dieckow, J., 2006. Carbon sequestration in two Brazilian Cerrado soils under no-till. Soil Tillage Research, 86: 237-245

Blake, G. R., Hartge, K. H., 1986. Bulk density In: Methods of Soil Analysis. Part I, Vol 9 (Ed) A. Klute. American Society of Agronomy, Madison, WI. pp. 363-382.

Bohm, W., 1979. Methods of studying root systems. Ecological Studies, 33, Springer-Verlag, Berlin

Bonfim, E. M., Monteiro, F. A 2006 Nitrogen and sulphur for productive characteristics of signal grass from degrading pasture area.

Brazilian Journal of Animal Science, 4: 1289-1297.

Brookes, P. C., Landman, A., Pruden, G., Jenkinson, D. S. 1985 Chloroform fumigation and the release of soil nitrogen: a rapid direct extraction method to measure microbial biomass nitrogen in soil. Soil Biology and Biochemistry, 17: 837–842.

Brookes, P. C., Powlson, D, S., Jenkinson, D. S. 1984 Phosphorus in the soil microbial biomass. Soil Biology and Biochemistry, 16: 169–175.

Cerri, C. E. P., Sparovek, G., Bernoux, M., Easterling W. E., Melillo, J. M., Cerri, C. C., 2007. Tropical agriculture and global warming: impacts and mitigations options. Science and Agriculture, 64: 83-99.

Chevallier, T., Voltz, M., Blanchart, E., Chotte, J. L., Eschenbrenner, V., Mahieu, M., Albrecht, A., 2000. Spatial and temporal changes of soil C after establishment of a pasture on a long-term cultivated Vertisol (Martinique). Geoderma, 94: 43-58.

Clapperton, M. J., Chan, K. Y., Larney, F. J., 2003. Managing the soil habitat for enhanced biological fertility; Soil Biological Fertility – a key to sustainable land use in agriculture. L. K. Abbott and D. V. Murphy (Eds.); Dordrecht, Netherlands; Kluwer Academic; pp. 203-224.

Cole, V., Cem, C., Minami, K., Mosier, A., Rosenberg, N., Sauerbeck, D., 1996. Agricultural options for mitigations of greenhouse gas emissions. In. Watson, R.T., Zinyowera, M.C., Moss, R. H. (Ed.), Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of working group II to the second assessment report of the intergovernmental panel on climate change. Cambridge University Press, New York, pp. 745-771.

Conant, R. T., Paustian, K., & Elliott, E. T. 2001. Grassland management and conversion into grassland: effects on soil carbon. Ecology Applied. 11: 343–355.

Corbeels, M., Scopel, E., Cardoso, A., Bernoux, M., Douzets J. M., Siqueira-Neto, M., 2006. Soil carbon storage potential of direct seeding mulch-based cropping systems in the Cerrados of Brazil. Global Change Biology, 12: 1773-1787.

Follett, R. F., Kimble, J. M., Lal, R., eds. 2001. The potential of US grazing lands to sequester carbon and mitigate the greenhouse effect. Boca Raton, USA, CRC Press LLC

Fornara D. A., Tilman D., 2008. Plant functional composition influences rates of soil carbon and nitrogen accumulation. Journal of Ecology. 96:314–322.

Foster, H. L., 1971. Rapid soil and plant analysis without automatic equipment. Routine soil analysis. East African Agricultural and Forestry Journal. 37: 160–171.

Frank, A. B, Berdahl, J. D., Hanson, J. D., Liebig, M. A., Johnson, H. A., 2004. Biomass and carbon partitioning in switchgrass. Crop Science, 44: 1391-1398.

GENSTAT Release 4.24DE, 2005. Lawes Agricultural Trust (Rothamsted Experimental Station), U.K.

Gichangi, E. M., Njarui, D. M. G., Gatheru, M., Magiroi, K. W. N., Ghimire, S. R., 2016. Effects of Brachiaria grasses on soil microbial biomass carbon, nitrogen and phosphorus in soils of the semi-arid tropics of Kenya. Tropical and Subtropical Agroecosystems 19: 193-203.

Gichangi, E. M., Njarui, D. M. G., Ghimire, S. R., Gatheru, M., Magiroi, K. W. N., 2016. Effects of cultivated Brachiaria grasses on soil aggregation and stability in the semi-arid tropics of Kenya. Tropical and Subtropical Agroecosystems. 19: 205-217.

Gifford, R. M., Cheney, N. P., Noble, J. C.., Wellington, A. B., Zammit, C., 1992. Australia's renewable resources: sustainability and global change. In: R. M. Gifford, M. M. Barson, eds. pp. 151–188. Australian Government Publishing Service

Jank L., Barrios S. C., do Valle C. B., Simeão R. M., Alves G. F., 2014. The value of improved pastures to Brazilian beef production. Crop Pasture Science, 65: 1132-1137

Kemp, D. R., Michalk, D. L., 2007. Towards sustainable grassland and livestock management. Journal of Agricultural Science, 145: 543–564

Ladd, J. N., Amato, M., Zhou, L. K., Schultz, J. E., 1994 Differential effects of rotation, plant residue and nitrogen fertilizer on microbial biomass and organic matter in an Australian Alfisol. Soil Biology and Biochemistry. 26: 821-831

Lal, R., 2009. The plough and agricultural sustainability. Journal of Sustainable Agriculture. 33: 66–84.

Landon, J. R., 1991. Tropical Soil Manual: A Handbook of Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics; Longman Scientific Technical and Booker Tate Limited: London, U.K.

Matamala, R. N. L, Jastrow, J. D., Miller, R. M. N. L., Garten, C. T., 2008. Temporal changes in C and N stocks of restored prairie: implications for C sequestration strategies. Ecology Applied, 18:1470–88

Miles, J. W., Do Valle, C. B., Rao, I. M., Euclides, V. P. B. 2004 *Brachiaria* grasses In: Moser, L.E., Burson, B.L., Sollenberger, E.L. (Eds.). Warm-season (C4) grasses. The American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, WI. pp. 745-783

Murphy, J., Riley, J. P., 1962 A modified single solution method for determination of phosphate in natural waters. Analitica Chimica Acta, 27:31 – 36.

NAAIAP, 2014. Soil suitability evaluation for maize production in Kenya.A report by National Accelerated Agricultural Inputs Access Programme (NAAIAP) in collaboration with Kenya Agricultural Research Institute (KARI) Department of Kenya Soil Survey.Kilimo. Nairobi, Kenya.

Nelson, D. W., Sommer L. E., 1982, Total carbon, organic carbon, and organic matter. In A. L. Page (Ed.) Methods of Soil Analysis. 2nd Ed. ASA Monograph 9(2) American Society of Agronomy Madison, WI. p. 539-579

Norby, R. J. and Jackson, R. B., 2000. Root dynamics and global change: Seeking an ecosystem perspective New Phytosanitary, 147: 3–12.

Okalebo, J. R., Gathua, K. W., Woomer, P. L., 2002. Laboratory Methods of Soil and Plant Analysis: A Working Manual. TSBF-KARI, SSEA, SACRED Africa, Nairobi, Kenya, 2002 pp. 128.

Oldeman, L. R., 1994. Soil resilience and sustainable land use. In: soil resilience and sustainable land use. D.J. Greenland & I. Szabolcs, (eds.). Wallingford, UK CAB International. Pp: 99-118.

Peters, M., Rao, I., Fisher, M., Subbarao, G., Martens, S., Herrero, M., van der Hoek, R., Schultze, K.R., Miles, J., Castro, A., Graefe, S., Tiemann, T., Ayarza, M. and G. Hyman, G., 2012. Tropical forage-based systems to mitigate greenhouse gas emissions. In: Hershey, C. (Ed.) Issues in Tropical Agriculture I. Eco-Efficiency: From Vision to Reality.CIAT, Cali, Colombia. http://www.ciat.cgiar.org/publications/eco

Reid, R. Thornton, P. K., McCrabb, G. J., Kruska, R. L., Atieno, F., Jones P. G., 2004. Is it possible to mitigate greenhouse gas emissions in pastoral ecosystems of the tropics? Environment, Development and Sustainability, 6: 91–109.

Scharpenseel, H. W., Becker-Heidmann, P. 1997. Carbon sequestration by grassland and woodland soils of different climate zones as revealed by (thin) layer wise carbon-14 dating. Session 9 - Forage and grassland management. In: XVIII. International grassland congress Winnipeg and Saskatoon, Canada, pp. 3-4.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Wattenbach, M., Smith, J. 2008. Greenhouse gas mitigation in agriculture. Philosophical Transactions of the Royal Society Biological Sciences, 363: 789–813.

Vance, E. D., Brookes, P. C., Jenkinson, D. S., 1987 An extraction method for measuring soil microbial biomass C. Soil Biology and Biochemistry, 19: 703–707.

Wu, J., Joergensen, R. G., Pommerening, B., Chaussod, R., Brookes, P. C., 1990. Measurement of soil microbial biomass C by fumigation extraction an automated procedure. Soil Biology and Biochemistry, 22: 1167–1169.