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Climate smart *Urochloa* grasses improves soil health in the semi-arid tropics of Kenya

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Abstract

The measurement of soil aggregates stability and soil microbial biomass can be used as an early indicator of long-term changes in soil quality. A study was conducted to quantify the amounts of shoots and roots biomass of *Urochloa* grass cultivars (commonly known as Brachiaria) and their effects on changes in the size distribution and stability of soil aggregates and on microbial biomass carbon (C), nitrogen (N) and phosphorus (P) in a structurally unstable sandy loam soil at Ithookwe and Katumani in semi-arid tropical Kenya. The *Urochloa* grass cultivars included *Urochloa decumbens* cv. Basilisk, *U. brizantha* cvs Marandu, MG-4, Piatã and Xaraes, *U. humidicola* cv. Llanero and *U.* hybrid cv. Mulato II. Rhodes and Napier grass were included in the treatments as controls. Roots biomass was evaluated using the soil-coring method to depths of 0 – 15 and 15 – 30 cm. Four aggregates-size fractions (> 2000 µm, 250 – 2000 µm, 53 – 250 µm, and <53 µm) were isolated using the wet sieving method. Microbial biomass C, N and P were determined on field moist rhizosphere soil (18 - 23% by weight) from a depth of 10 cm using the chloroform fumigation-extraction technique. Shoots biomass of the *Urochloa* 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. Marandu, Xaraes, Basilisk and Piata had higher roots biomass than the controls (Rhodes grass and Napier grass). Aggregate stability differed among the grasses and was highest in soils under Mulato II and Marandu with mean weight diameters of 4.49 and 4.31 mm, respectively. Generally, microbial biomass N was higher in plots with grasses than in the bare plots. Among *Urochloa* cultivars, the highest microbial biomass C was recorded in plots with Mulato II and the lowest from the plots with MG-4.

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 (Reid et al. 2004). Previous research has documented that improved pasture management can lead to high forage production, efficient use of land resources and rehabilitation of degraded lands. 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 through sequestration of 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 and therefore tend to enhance resilience and 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. *Urochloa* grasses are endaphytic and have a great ability to sequester and accumulate large amounts of SOC through their large shoots and roots biomass (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. The objective of this study was therefore to quantify the amounts of plant shoots and roots biomass and their effects on soil aggregate stability and microbial biomass resulting from 2 years cultivation of *Urochloa* grasses in the semi-arid tropical Kenya.

Methods and study sites

The study was conducted at Ithookwe (1º37′S, 38º02′E) and Katumani (1º35′S, 37º14′E) in semi-arid tropical Kenya. The dominant soils are chromic Luvisols, which are low in organic C and highly deficient in N and P and to some extent Zinc (NAAIAP, 2014). The grass cultivars evaluated were *Urochloa decumbens* cv. Basilisk, *U. brizantha* cvs. Marandu, MG-4, Piatã and Xaraes, *U. humidicola* cv. Llanero and *U. hybrid* cv. Mulato II. These were compared with two locally cultivated grasses Rhodes grass (*Chloris gayana)* cv. KAT

R3 and Napier grass (*Pennisetum purpureum)* cv. KK1. The grass treatments were evaluated with fertilizer application (40 kg P ha^{-1} applied at sowing and 50 kg N ha^{-1} in each wet season) and with no fertilizer application.

Plant shoots biomass was evaluated eight times on an 8 weeks interval after plants were well established from 2 m x 2 m net plots at a cutting height of 5 cm above ground. Roots were sampled using the soil-core method (Bohm 1979) to depths of 0 – 15 and 15 – 30 cm using a 6.5 cm diameter stainless steel auger. The roots from each sampling depth 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. Soil samples for aggregate, POM and microbial biomass carbon, phosphorus and nitrogen analyses were collected 24 months after grass establishment. Four soil samples were carefully collected from a depth of 0 - 10 cm using a spade, so as to minimize aggregates disruption in each plot. Four aggregates-size fractions were isolated using triplicate 80 g of air-dry 8 mm sieved soil by the wet sieving method as described by Six et al. (1998), and the fractions named; large macro-aggregates (> 2000 µm), small macro-aggregates (250 – 2000 µm), micro-aggregates (53 – 250 µm), and silt + clay fraction (<53 µm). Microbial biomass 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 Vance et al. (1987). Soil microbial biomass element content was calculated as the difference between the fumigated and un-fumigated samples and using conversion factors of 0.45 for C (Wu et al. 1990), 0.45 for N (Jenkinson et al. 2004) and 0.40 for P (Hedley et al. 1982) for incomplete extraction. All determinations were made in triplicate and expressed on a dry weight basis. Treatment effects on shoots and roots biomass, aggregate stability and microbial 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). Where differences at $p \leq 0.05$ were significant the means separation was made 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, aggregate stability and microbial biomass with other soil and plant properties.

Results

Shoots biomass of the *Urochloa* 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. Marandu, Xaraes, Basilisk and Piata had higher roots biomass than the controls (Rhodes grass and Napier grass) indicating greater potential for the *Urochloa* grasses to sequester more carbon in the soil. Generally, roots biomass was significantly ($p \leq 0.05$) higher from samples collected at Ithookwe than those obtained at Katumani (Figure 1) with approximately 79% of dry roots matter in the 0 - 15 cm soil layer.

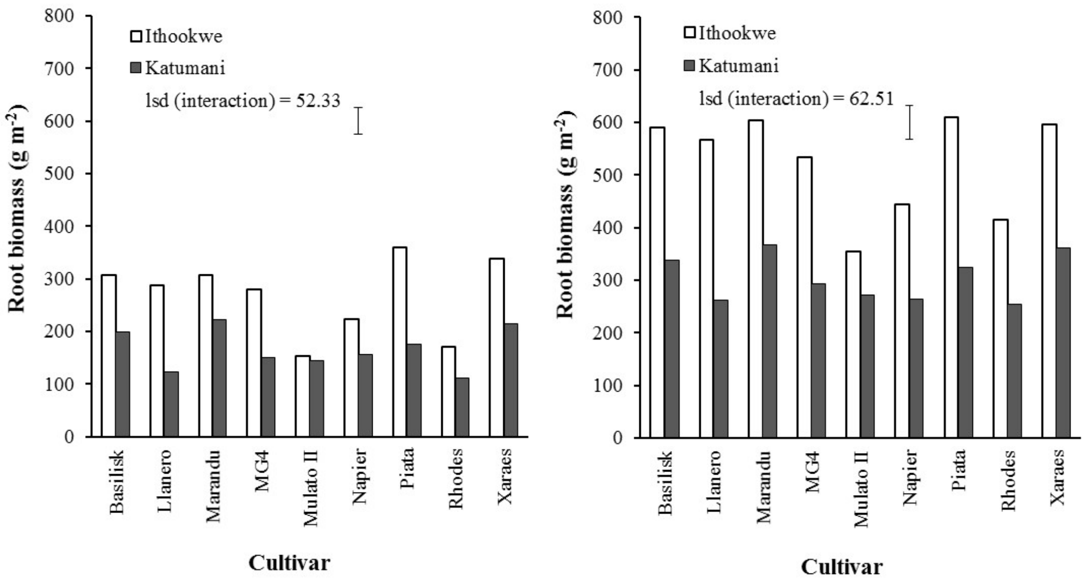
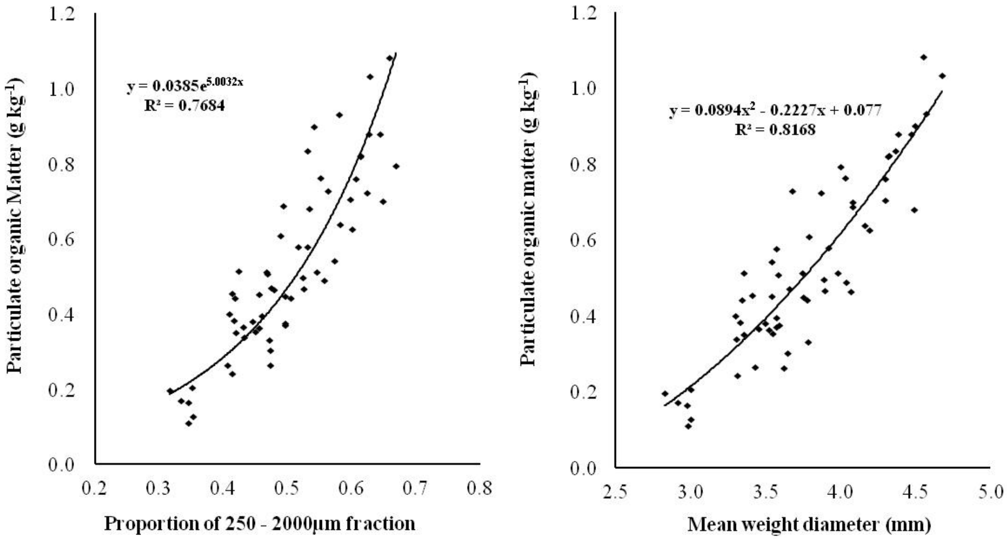


Figure 1. Effects of *Urochloa* cultivars and local grasses, Napier and Rhodes and site on roots biomass; a) 24 weeks and b) 48 weeks after grass establishment.

Aggregation based on the proportion of small macro-aggregates (250 – 2000 μm) increased in soils cultivated with all grass types compared to the bare plots control and was greatest in soils under Mulato II. Aggregate stability in terms of mean weight diameter (MWD) differed among the grasses and was highest in soils under Mulato II and Marandu with mean weight diameters of 4.49 and 4.31 mm, respectively. Changes in small macro-aggregates fraction was positively and significantly correlated with particulate organic matter (POM) ($r = 0.9104$, $p = 0.001$), microbial biomass carbon (MBC) ($r = 0.5474$, $p = 0.01$), soil organic carbon (SOC) ($r=0.3654$, $p = 0.05$) and root biomass ($r=0.4977$, $p = 0.01$). Overall, POM made the greatest direct contributions to aggregate stability (Figure 2), suggesting that greater POM in *Urochloa* cultivated soils enhanced aggregate stability



μm aggregates fraction and b) mean weight diameter (MWD)

Microbial biomass was significantly ($p < 0.01$) influenced by grass cultivars and N and P fertilizers. Generally, microbial biomass N was higher in plots with grasses than in the bare plots. Among *Urochloa* cultivars, the highest microbial biomass C was recorded in plots with Mulato II and the lowest in the plots with MG-4. *Urochloa* grasses with fertilizers application accumulated the highest microbial C and N compared to grasses without fertilizers, but no interaction was observed between fertilizer and grass cultivars. Marandu had the highest microbial biomass N (21.2 mg N kg^{-1}) in fertilizer treatments whereas cv. Mulato II hybrid had the highest microbial N (14.6 mg N kg^{-1}) in no fertilizer treatments.

Discussion and Conclusion

Generally, higher shoots biomass was recorded from Ithookwe site than at Katumani site implying that the *Urochloa* cultivars are more suited to that site. Ithookwe receive higher annual rainfall with a long-term mean of 1010 mm compared to 717 mm received at Katumani. The strong positive relationship between shoots biomass with N and P uptake shows that higher shoots biomass resulted to higher N and P uptake indicating better utilization of the fertilizer applied. Batista and Monteiro (2008) have previously reported that the combined application of nitrogen and phosphorus was more effective in maximizing the leaf area and the production of higher dry matter of grasses. The synthesis by Smith et al. (2008) suggested 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 region. The higher carbon allocation to the roots by the *Urochloa* 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. A vigorous roots system increases plant growth rate, tolerance to water deficit, and the 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 *Urochloa* grasses have greater ability to sequester and accumulate large amounts of organic carbon through their large roots biomass.

Higher soil aggregate stability recorded in the *Urochloa* planted soils could have resulted from the effects of soil cementing agents binding primary particles to micro-aggregates and macro-aggregates. Macro-aggregates (diameter >250 mm) are considered as a secondary soil structure associated with pores, microbial habitat, and physical protection of organic matter. The soil cementing agents bind micro-aggregates and primary particles to macro-aggregates, and minimize microbial decomposition by promoting physical protection through sorption to clay minerals and encapsulation within soil aggregates (Mikha and Rice, 2004). Consequently, macro-aggregates formation leads to longer mean residence time of SOC in soil over time through the formation of smaller, more stable soil fractions with increasingly intimate associations between organic matter and mineral surfaces. Similarly, higher C, N and P in the soil microbial biomass under *Urochloa* grasses in this study may be due to a higher capacity of nutrient immobilization by the microbes from the decomposing litter fall and root residues in addition to the root exudates released which serves as substrate for microbial growth in the soil. It has been reported that incorporation of P into the soil microbial biomass is a mechanism that significantly increases the availability of P to plants and forms a significant pool of plant nutrients. This pool play a key role in P dynamics in soils by immobilizing inorganic P which is later mineralized (Gichangi et al. 2010). Roots exudates and other by-products are also more readily absorbed and protected by soil aggregates and where concentrated are more likely to persist in the particulate organic matter and humus fractions than shoot-derived soil organic C (Zhang et al. 2005). The results of this study indicate that production of *Urochloa* grasses in the semi-arid tropics of Kenya and in other similar environments can help increase soil carbon stocks and improve soil structure that would mitigate the adverse effects of climate change and have greater economic returns.

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