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Effects of Cultivated Brachiaria Grasses on Soil Aggregation and Stability of a Chromic Luvisol in the Semi-arid Tropics of Kenya

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ABSTRACT

Soil aggregation is among the key short term indicators of soil quality attributed to changes in land management. A study was conducted to investigate the changes in the size distribution and stability of soil aggregates in a structurally unstable sandy loam soil following cultivation of Brachiaria grass in semi-arid region of Kenya. The Brachiaria grass cultivars included Brachiaria decumbens cv. Basilisk, B. brizantha cvs Marandu, MG4, Piata and Xaraes, B. humidicola cv. Llanero and B. hybrid cv. Mulato II which were compared with two locally cultivated forage grasses (Chloris gayana cv. KAT R3 and Pennisetum purpureum cv. Kakamega 1) and a bare plot (negative check). The grass treatments were evaluated with fertilizers application (40 kg P applied at sowing and 50 kg N ha^{-1} in each wet season) and with no fertilizer applications. Aggregate size fractions (>2000, 250–2000, 53–250 and 53 µm) were isolated using the wet sieving method. 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 B. hybrid cv. Mulato II. Aggregate stability in terms of mean weight diameter (MWD) differed among the grasses and was highest in soils under cv. Mulato II and cv. Marandu with mean weight diameters of 4.49 and 4.31 mm, respectively. Changes in small macro-aggregates fraction was positively 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 ($r=0.4977$, $p = 0.01$). This indicated that the binding agents were important in the aggregation of soils cultivated with Brachiaria grasses.

INTRODUCTION

The size of aggregates and aggregation state can be influenced by different agricultural activities that alter the content of SOC and the biological activity of the soil (Mills and Fey, 2003; Wick *et al*., 2009). Over short periods, the stability of soil aggregates is modified under the influence of different cropping practices, probably being more related to changes in the organic constituents than to the actual total organic matter content (Reid and Goss, 1980; Milne and Haynes, 2004). Reid and Goss (1980) for example, demonstrated that after only 4 weeks growth the living roots of perennial rye grass (*Lolium perenne*) increased the aggregate stability of a sandy loam as measured by turbidimetric and wet sieving analyses which was most strongly associated with the larger aggregates. This effect was probably caused by organic substances released from the roots which either stabilized the aggregates directly or indirectly after microbial colonization (Leifeld, *et al*., 2005; Franchini, *et al*., 2007). However, over long periods of time, the stability of soil aggregates diminishes as the SOC content declines as a result of it being used as an energy source by the microorganisms in the soil (Mills and Fey, 2003). Loss of SOC will therefore reduce soil fertility, degrade soil structure and water holding capacity and ultimately, leads to land degradation. Grasses, present the greatest effect on the aggregation and aggregate stability due to their extensive root system (Harris *et al*., 1996). Brachiaria grasses have the ability to sequester and accumulate large amounts of SOC through their large and extensive root biomass, reduce emissions of N_2O and CH_4

per unit of livestock production, and survive in dry areas of low soil fertility due to their deep and abundant root system (Fisher *et al*., 2007). This makes Brachiaria grasses to be drought tolerant and better adapt to poor soils and therefore can offer a better option for livestock feed production and soil improvement. The objective of this study was therefore, to investigate the short-term (2-years) changes in aggregate size distribution and the stability of soil aggregates following cultivation of Brachiaria grasses. We examined linkages between SOC and particulate organic matter (POM) with aggregation by comparing Brachiaria cultivated soils verses commonly grown Napier and Rhodes fodders and not cultivated weed free soils. We tested the hypothesis that, cultivation of Brachiaria grasses improves soil aggregation through increased SOC and aggregate associated C resulting from large root biomass. By studying aggregate stability it is possible to quantify whether or not the cultivation of Brachiaria grasses would ameliorate physical conditions of soils in semi-arid areas of Kenya and other areas with similar soil characteristic across the tropics.

MATERIALS AND METHODS

The experiment was conducted at the Kenya Agricultural and Livestock Research Organization (KALRO), Katumani farm. The site is located ($37^{\circ}28'0''$E, $1^{\circ}58'0''$S) 75 km southeast of Nairobi at an elevation of 1580 m above sea level. The dominant soils are chromic luvisols, which are low in organic C, highly deficient in N and P and to some extent Zinc and generally have poor structure. 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) as local check)] and a bare plot (as negative control). These treatments were evaluated in the plots with fertilizer (40 kg P ha^{-1} applied at sowing and 50 kg N ha^{-1} 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 treatments as sub plots) in three replications.

Soil sampling and determination water-stable aggregate distribution

Soil samples for aggregate and POM analysis were collected in November 2015 twenty four months after the grasses had established. Four soil samples were carefully collected from a depth of 0-10 cm using a spade, so as to minimize aggregates disruption in each pasture plot and from the bare plot controls. 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 grass cultivation. Soils from the four sampling positions of a plot were pooled to one sample. The soils were then dried at room temperature (21^{0} C) and sieved by gently breaking soil clods along natural planes of weakness, so that they passed through an 8 mm sieve. Soil sub-samples of approximately 400g were taken using the quartering method for further processing and analysis at International Center for Tropical Agriculture (CIAT, Nairobi). The soils were separated into aggregates to calculate aggregate size distribution, mean weight diameter (MWD) and aggregate associated carbon as described below.

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*. (2004), and each fraction was named as large macro-aggregates (> 2000 µm), small macro-aggregates (250–2000 µm), micro-aggregates (53–250 µm), and silt + clay fraction (<53 µm). The soil subsamples were spread evenly onto a 2000-µm sieve and slaked for 5 min in distilled water. The soil was then sieved for 2 min by oscillating the sieve 50 times up and down (approximately 3-cm amplitude). Large macro-aggregates retained on the 2000 µm sieve mesh were backwashed into pre-weighed pans for drying. Large (>2000 µm) floating litter was removed, while soil passing through the 2000 µm sieve was transferred to a 250 µm sieve and the process was repeated to obtain the small macro-aggregates fraction (250–2000 µm). The sieving process was repeated once more using a 53 µm sieve to separate micro-aggregates (53–250 µm) from the silt and clay fraction (<53 µm). All pans and soil solutions were placed in an oven at 65°C until dry and weighed in order to determine the mass of each aggregate size class. Aggregate fractions > 53 µm were corrected for sand prior to calculation of the proportional weight of aggregates and mean weight diameter (MWD) was determined. However, large macro aggregate > 2000 µm were not used in computing or calculating MWD, because the proportion of aggregates > 2000 µm recovered after the wet sieving were too small in weight to be corrected for sand (sand free fraction). Particulate organic matter was separated from water-stable aggregate fractions by floatation and decanting after mechanical dispersion of the soil by agitation in water with glass beads. The collected organic size fraction was oven dried at 65 ^{o}C for 24 h and their weight determined. The soil POM was expressed in g kg^{-1} after adjusting for soil moisture using the weight loss of sub-samples oven dried at 105 ^{o}C to a constant weight.

RESULTS AND DISCUSSION

The growth of perennial grasses enhances aggregate formation due to the production of large quantities of polysaccharide and phenolic binding agents by the large microbial biomass in the pasture rhizosphere. Additionally, the fine grass roots and associated fungal hyphae physically enmesh fine soil particles into aggregates (Milne and Haynes, 2004). The results of aggregate size distribution and stability determinations are presented in Table 1. The effects of grass types on the proportion of aggregate size fractions 250-2000, 53-250 and <53µm were significantly ($p<0.01$) different. The small macro-aggregates (250-2000 µm) comprised the largest proportion, which accounted for 34.1 – 64.2% of the total soil dry weight, and the fraction of micro-aggregates (53-250 µm) was the second largest, being 28.5–48.2% of whole soil dry weight. The effects of grass types on water stable aggregates revealed that soils under cv. Mulato II and cv. Marandu*,* significantly increased small macro aggregates (250-2000 µm) fraction. Macro-aggregates (diameter >250 mm) are considered as a secondary soil structure associated with pores, microbial habitat, and physical protection of organic matter. High macro-aggregates proportion favoured soil aggregate stability as indicated by high MWD values which might have resulted from increased soil cementing by organic compounds. The POM concentration in 0-10 cm depth ranged from the minimum of 0.16 g kg^{-1} in the bare soil plots to the maximum of 0.93 g kg^{-1} in soil under cv. Mulato II. The gains in POM within macro-aggregates concur with the results of others that suggest macro-aggregates may be good predictors of potential C responses to changes in agro-ecosystems management.

Table 1 Effects of grass types on soil aggregation, MWD, POM and SOC

Grass type	Proportion of aggregate size fraction				MWD (mm)	POM (gkg^{-1})	SOC (gkg^{-1})
	>2000 µm	250-2000 µm	53-250 µm	<53 µm			
cv. Basilisk	0.002	0.569	0.310	0.103	4.08	0.65	13.97
cv. Llanero	0.002	0.488	0.416	0.101	3.73	0.46	13.82
cv. Marandu	0.003	0.604	0.319	0.099	4.31	0.77	14.13
cv. MG4	0.001	0.432	0.441	0.120	3.43	0.37	13.87
cv. Xaraes	0.002	0.516	0.354	0.089	3.81	0.66	14.24
cv. Piatã	0.001	0.461	0.419	0.126	3.58	0.38	13.86
cv. Mulato II	0.001	0.642	0.285	0.090	4.49	0.93	13.99
cv. KK1	0.002	0.519	0.378	0.104	3.87	0.51	13.97
cv. KAT R3	0.002	0.422	0.440	0.140	3.38	0.35	14.07
Bare plot	0.002	0.341	0.482	0.176	2.95	0.16	12.09
Lsd ($p\leq0.05$)	NS	0.046	0.038	0.014	0.18	0.08	0.96
CV (%)	-	4.9	6.2	10.4	4.1	12.3	6.0

MWD= Mean weight diameter; POM= Particulate organic matter, SOC = Soil organic carbon; Lsd= Fischer's protected least significant difference; NS= Not significant, Cv = coefficient of variation

Particulate organic matter and MBC all act as important binding agents for aggregation (Six *et al*., 2004). Regression of the proportional weights of the 250-2000 µm aggregates fraction and MWD with POM showed that POM explained 79.4% and 81.7% of the variations of the aggregates fraction and MWD, respectively (Figure 1). Overall, POM made the greatest direct contributions to aggregate stability suggesting that greater POM in Brachiaria cultivated soils enhanced aggregate stability and by extension improved soil structure and was comparable to soils under *Pennisetum purpureum cv* KK1 a commonly cultivated fodder in the region.

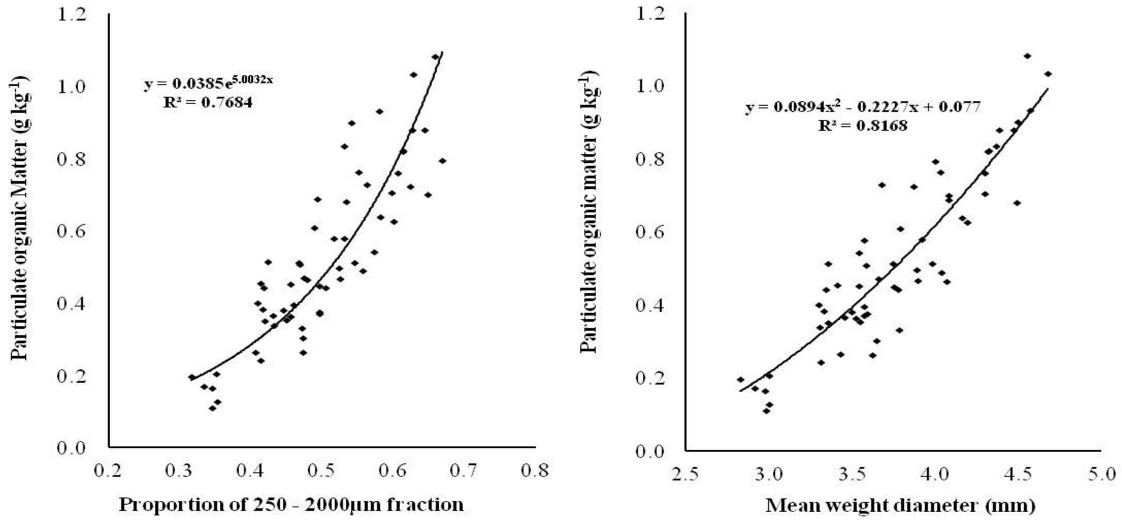

Figure 1 Relationships between particulate organic matter (POM) with a) proportional weights of 250-2000 µm aggregates fraction and b) mean weight diameter (MWD)

CONCLUSIONS AND OUTLOOK

Aggregate stability in terms of MWD differed among the Brachiaria grasses and was highest in soils under *Mulato II* hybrid and lowest under cv. MG4. This was attributed to the presence of higher POM in *Mulato II* hybrid cultivated soils. While we found that SOC did not vary among Brachiaria grasses, changes in below ground C cycling were apparent through effect on aggregate formation and higher POM in Brachiaria cultivated soils. By significantly improving soil aggregation and associated C content, the potential of Brachiaria grasses for enhancing C storage was noted.

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