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Soil Carbon Accumulation under Perennial Forage Grasses in the Southern Highlands of Tanzania

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Soil carbon accumulation under perennial forage grasses in the Southern Highlands of Tanzania

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Abstract
Land degradation caused by the loss of SOC in continuously cultivated agricultural systems is a major problem in many sub-Saharan Africa countries. The integration on perennial forage grasses in cropping systems has the potential to enhance SOC sequestration. The main objective of this study is to compare soil organic carbon (SOC) under perennial forages with SOC under annual food crops, specifically maize (*Zea mays)*. A survey was conducted in Njombe district in the Southern Highlands of Tanzania to identity farmers with planted forages that are more than five years old and with neighbouring maize plots. Survey results identified Rhodes grass (*Chloris gayana*) as the currently dominating forage in the district. Soils from 55 sets of paired sites, Rhodes versus adjacent maize plot, were sampled at depths of 0-20 and 20-50 cm. Total SOC and soil texture were determined for the two depths, while the aggregate fractions and their SOC content were determined only for the 0-20 cm. Average SOC content in Rhodes was higher than maize at both depths, but the differences in the paired plots was not significant. Across all sites, the SOC stocks in the 0-20 cm averaged 47.10 ±10.04 for Rhodes and 47.66±9.83 Mg C ha^{-1} for adjacent maize plots. The average SOC content in the large macroaggregate fractions was higher in the Rhodes plots, which indicates an increase in the physical carbon protection in soils under perennial forages. The results in this study suggest that there is a slight improvement in soil quality in soils under Rhodes grass, but further analysis on other soil organic matter indicators, e.g. particulate organic matter (POM) would be needed to understand the differences in the two land uses.

Introduction

Soil organic carbon (SOC) losses due poor management practices can cause a decline in soil quality and lead to carbon emissions into the atmosphere. Management strategies for sequestering SOC in agroecosystems have been widely documented (e.g., Lal, 2010; Paustian et al., 2016). Although practices such as reduced tillage, manure and residue application can enhance SOC sequestration, recent studies show that in humid tropical cropping systems, these practices only reduce the rate of SOC loss (Sommer et al., 2018). Converting degraded croplands to perennial grasses or introducing perennial grass into annual cropping systems can be a viable strategy for enhancing SOC sequestration. A recent global review indicates that improved grassland management can results in SOC sequestration of between 0.105 to more than 1 Mg C ha^{-1} yr^{-1} (Conant et al., 2017).

Forage grasses such as Napier grass (*Pennisetum purpureum*), Rhodes grass (*Chloris gayana)* and *Brachiaria* grasses are widely grown in dairy production systems in East Africa. Under proper management such grasses could play an important role in enhancing SOC accumulation in soils, through increased aboveground and belowground biomass inputs. Over the recent years, significant efforts have been made in assessing the impacts of these grasses on different soil properties, however studies from SSA are scarce (Korir et al., 2019). The objective of this study was to investigate the differences in SOC levels/accumulation between maize and the Rhodes grass, a common perennial forage in the southern highlands of Tanzania.

Methods
On-farm plot selection

The study area is located in Njombe district in the Southern Highlands of Tanzania, which lies at latitude 35.1269° E and longitude 9.2423°S Based on a survey and discussions with farmers we identified Rhodes grass as the most commonly cultivated grass among dairy farms in the district. A key condition for selecting the farms to include in our analysis was that selected Rhodes plots had to be under that land use for more three years and there had to be a neighbouring plot under maize (rotated or continuous) to allow for paired-plot approach of soil sampling. The Rhodes grass is grown in the cut and carry systems, which is typical for smallholder farming systems in sub-Saharan Africa. In the end, we identified a total of 55 paired sites in the different villages in the region. In addition, during the soil sampling exercise a survey was administered to farmers to gather information on the forage and crop plots, including the duration of time the crop had been on that specific land use, previous land use history and the types of management practices on the two farms.

Soil collection and analysis

10m by 10m sampling plots were marked and soil samples from 0-20 cm and 20-50 cm were collected using a soil auger on the Rhodes and maize plots in each farm. At each sampling plot, four subsamples were collected and mixed to create one composite sample of approximately 600g. of air dry soil. In addition, buk density (BD) samples were collected at one point within each of the plots with a cylindrical metal sampler with a volume of 100 ml. The BD samples consisted of soil collected with an auger between 0-20 cm from the top soil. The soils were then dried at room temperature and homogenized. A portion of the 600 g sample was taken to analyse for SOC, nitrogen, pH and soil texture at the IITA (International Institute for Tropical Agriculture) laboratory in Dar es Salaam. Total SOC was determined using Walkley–Black method (Anderson and Ingram 1993) , nitrogen was analysed using Kjeldahl method (Bremner and Mulvaney, 1982), while the texture was analysed using the hydrometer method.

In addition, sub-samples of 400 g for the 0-20 cm depth were set aside and air-dried for aggregate stability analysis. The samples were passed through an eight mm sieve and oven dried at 60 °C for 24 hours after which 32 g of sample was weighed into beakers. The samples were submerged in water in a Eijkelkamp wet sieving apparatus for five minutes to allow for slaking and sieved through a 2 mm sieve for 3 minutes to obtain large macro aggregates (LM; >2000 µm). The sample was again sieved through a 250 µm sieve for 3 minutes to obtain small macro aggregates (SM; 250-2000 µm). Soil not captured by 250 µm was sieved through 53 µm to obtain micro aggregates (Mi; 53-250 µm). The filtrate containing silt and clay (SC) fraction obtained after sieving with 53 µm sieve was collected. All the aggregate fractions obtained were oven dried at 60 ° C for 48 hours and weights recorded. Mean weight diameter (MWD)was calculated using equation (1) by (Cambardella & Elliott, 1993).

$$MWD = \sum X_i W_i \quad \text{(Equation 1)}$$

Where: X_i= diameter of the i^{th}sieve size and W_i= proportion of total aggregates in the i^{th}fraction

SOC stocks for the top soil (0 to 20 cm) was calculated from the SOC content using Eq. 3

$$SOC\left(\frac{Mg}{ha}\right) = SOC\left(\frac{g\,C}{kg}\right) \times Bulk\ density\left(\frac{kg}{m^3}\right) \times depth(m) \times 10000\,m^2 \times 10^{-6} \quad \text{(Eq.1)}$$

Statistical analyses were conducted using the R programming software. A paired t-test was used to test for significant differences in the analysed variables between the Rhodes and maize plots. In addition, we a linear regression analyses to assess the effect of soil texture and land use history on the differences in SOC between the paired plots.

Results

Soil texture, pH and bulk density

The soils at most of the selected plots were either pure clay or clay and sand mixtures, the average values of the pH and texture not differing much across the plots (Table 1). Across all sites and depths, the sand content ranged between 32 to 60%, clay ranged from 30 to 60% while the silt content ranged between 1 to 19%. The soil pH ranged between 3.94 and 6.58. The paired t-tests show no significant differences in the soil texture and pH between Rhodes and maize. This is expected as the plots were close to other and minimal variability in texture and pH is expected in soils. Bulk density for the maize plots ranged between 0.9 and 1.28 g cm^{-3} with a mean of 1.11±0.09 g cm^{-3}, while that in the Rhodes plots ranged between 0.85 and 1.22 g cm^{-3} with a mean of 1.08±0.09 g cm^{-3}. There were significant differences in the bulk density between the paired plots (p=0.0011).

SOC, SON concentrations and SOC stocks

SOC and SON concentrations in both land use systems for the top soils was higher than that in the subsoils, with the average values for Rhodes being higher than those of maize. The average SOC concentration was 22.4±4.8 g C kg^{-1} and 21.3±4.52 g C kg^{-1} in the Rhodes and maize plots respectively, while that for the subsoil was 15.7±3.5 g C kg^{-1}and 15.1±3.4 g C kg^{-1} (Table 1). Across the selected sites, the OC concentrations varied widely with values ranging between 14.8 and 39.5 g C kg^{-1} in the Rhodes plots and from 13.0 to 35.9 g C kg^{-1} in the adjacent maize plots (Fig. 1). Statistical analysis showed no significant differences in the SOC and SON in the paired Rhodes and maize plots at both the top and subsoils. In addition, there were no significant differences in the observed SOC stocks in the top soil between the Rhodes and maize plots, with the average stocks in the two land use systems being 47.10 ±10.04 and 47.66±9.83 Mg C ha^{-1}, respectively. The mean ON concentrations for Rhodes and maize plots in the top soil was 1.66±0.40 g N kg^{-1} and 1.61±0.26 g N kg^{-1}, respectively, while that in the subsoil was 1.10±0.26 g N kg^{-1}and 1.09±0.31 g N kg^{-1} (Table 1). The measured values across the sites for the top soil ranged between 1.0 and 2.9 g N kg^{-1} in the Rhodes plots and 0.8 and 3.4 g N kg^{-1} in the adjacent maize plots.

Table 1: Mean (±standard error) soil particle sizes (sand, silt and clay), pH, bulk density, SOC and SON concentrations and SOC stocks for cropland and Rhodes plots by soil depth.

Depth (cm)	Land use	Sand (%)	Silt (%)	Clay (%)	pH	Bulk density (g cm^{-3})	SOC (g C kg^{-1})	SON (g N kg^{-1})	SOC (Mg C ha^{-1})
0-20	Cropland	49.24 (4.73)	7.93 (3.56)	42.84 (3.56)	4.82 (0.38)	1.11 (0.09)	21.26 (4.52)	1.61 (0.44)	47.10 (10.04)
	Rhodes	49.50 (4.88)	8.45 (4.87)	42.05 (3.18)	4.83 (0.30)	1.08 (0.09)	22.43 (4.80)	1.66 (0.40)	47.66 (9.83)
20-50	Cropland	47 (5.2)	7.93 (3)	45 (5)	4.66 (0.30)	-	15.09 (3.38)	1.09 (0.31)	-
	Rhodes	48 (5.1)	8.45 (3)	46 (5)	4.77 (0.31)	-	15.65 (3.45)	1.10 (0.26)	-

Aggregate fractions and aggregate fraction SOC content

At 0–20 cm soil depth, the proportion of LM (> 2 mm) was slightly lower under Rhodes compared to maize, with the mean percentages being 3.04 g 100 g^{-1} in Rhodes vs. 3.34 g 100 g^{-1} in maize (Table 1). Differences in the amounts of SM were also small, with 61.59 g 100 g^{-1} vs. 60. 65 g 100 g^{-1}, while the amounts of Mi were slightly lower under Rhodes with 27.05 g 100 g^{-1} vs. 25.75 g 100 g^{-1}. The SC was slightly higher under Rhodes with 8.44 g 100 g^{-1} vs. 7.98 g 100 g^{-1}. Further analyses showed no significant difference between the Rhodes and cropland plots for LM, SM and Mi aggregate fractions, while the difference was significant for SC ($p = 0.0002$). The insignificant differences in aggregate size distribution were also reflected in the mean weight diameter (MWD), with means of 0.897±0.074 mm in Rhodes vs. 0.904±0.078 in the maize plots. The mean SOC content across the different aggregate fractions in the Rhodes plots were slightly higher than in the maize plots (Table 2). There significant differences in the carbon in the LM ($p<0.001$) and SC ($p<0.03$) aggregate fractions.

Table 2: Average aggregate fractions and aggregate fraction carbon content for Rhodes and maize for the 0-20 cm depth.

	Aggregate size (g 100 g^{-1} fraction)		Carbon content (g C kg^{-1} fraction)	
	Rhodes	Cropland	Rhodes	Cropland
Large Macroaggregates (LM)	3.04±1.60	3.34±1.53	34.6±10.6	28.71±6.45
Small Macroaggragates (SM)	61.6±3.35	60.6±5.80	15.8±4.31	15.38±3.81
Micro aggregates (Mi)	25.8±2.91	27.0±4.93	28.0±7.30	26.99±5.61
Silt and clay (SC)	8.44±1.26	7.68±1.24	43.9±8.37	42.14±8.10

Influence of land use and soil texture on SOC

Linear regression analyses indicate a significant relationship between the land use history in the Rhodes and maize plots and the differences in SOC between the paired plots (p == XX). In addition, there was a significant relationship between the differences in SOC and the time the Rhodes plot under been under the land use, and the clay content in the plots. However, none of the considered models could explain the variation in the differences in SOC with the adjusted R^2 values being low.

Discussion and conclusion

Forage grasses could potentially play an important role to mitigate climate change through enhanced SOC sequestration. Our results from on-farm pairwise evaluations how that, although soils under Rhodes have a higher SOC (0-20 cm depth) compared to soils under maize, the difference is relatively small (~1%). The survey on the land management practices in the paired plots revealed that in most of the plots manure was added in both plots, while fertilizer was applied only in the maize plots. In addition, there was rotation of maize with other crops, i.e. beans and potatoes. The constant annual carbon inputs from manure, increased maize productivity from fertilizer application, and rotation are likely to be the main reason for the lack of significant differences in SOC between the paired plots. In addition, most of the selected Rhodes plots had been under the land use for 3 years, because there were very few plots with a higher number of years under this land use. Thus, more time would be needed to have differences in SOC. Despite the Rhodes plots having zero tillage, our results show a smaller percentage of large macro aggregates in these plots compared to paired maize plots. Nevertheless, the results show a higher OC in the LM in Rhodes compare do maize. This indicates that there is physical protection of carbon in the perennial forages compared to continuously tilled cropland systems. A recent study suggests that particulate and mineral-associated components of soil organic matter provide much more meaningful information when quantifying changes in SOC associated land-use and other global changes (Lavallee et al., 2020). Therefore, further laboratory analyses with these components are likely to be useful in understanding the differences in SOC in the paired-plots considered in this study.

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