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Amendment of Soil Water Retention and Nutrients Holding Capacity by using Sugar Cane Bagasse

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Abstract

Sugarcane bagasse (SCB) is byproduct of sugarcane industry can be used as soil amendments to improve soil hydro, physical-chemical characteristics. It also provides reasonable economic means to recycle these in an environmentally friendly manner. The soil samples were studied for different soil characteristics collected from different sites of Dodoma city, Tanzania. Soil sample with poor water holding capacity selected and made into six treatments by different percentages of sugarcane bagasse 0, 2, 5, 10, 20 and 100% in triplicates for each treatment. The result showed that water holding capacity of the soil increased from 26.85 to 84.08 % representing 3.16 times. The soil of Dodoma have low organic matter (438.6 - 1126.6 mg/kg), and deficient in K^+ (0.5 cmol/kg), Ca^{2+} (2.8 cmol/kg), Mg^{2+} (1.3 mg /kg), Na^+ (1.03 cmol/kg) and cation exchange capacity (5 cmol/kg). The available K^+ , Ca^{2+}, Mg^{2+} contents of soil increased by 13.87, 22.79, 33.13 and 43.61% with the application of 2, 5, 10 and 20 % of sugarcane bagasse, respectively. Different levels of SCB positively influence the hydro, physico-chemical properties of soil. Utilization of SCB as organic fertilizer was found to save the water cost and chemical fertilizer along with minimizing environmental pollution. Application of 10% of sugarcane bagasse was found to be the standard dose to achieve important hydo, physico-chemical properties of soil to a required level.

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Sugarcane Bagasse.

Introduction

The success or failure of agricultural projects and arable farming is often based on the physical properties of the soil which are more complicated to change than chemical properties.[1] Sandy soils are practically important economic resource for agricultural production in many parts of the world. Although sandy soils differ in their origin, formation

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and properties, they may be considered as one group having common problems.[2,3,4] Dodoma soil is sandy with low water holding capacity and low nutrient retention. In addition the climate of Dodoma city is semi-arid with an average rainfall of 567 mm per year with almost five months no rain. The maximum temperature is 26°C, which occur in February while the minimum temperature is 21°C, which occur in July. Due to this climate condition there is high demand of water for both domestic and agriculture use. Although Dodoma Urban Water and Sanitation Authority (DUWASA) supplies 23,491.92 m^3/day of water, one solution that can reduce water used for irrigation is by amending the sandy soil of Dodoma which containing a low average Organic Carbon (OC) of about 0.68 %.[5] Amending the soil by using sugarcane bagasse (SCB) with organic carbon of 45.35 % was achieved to reduce water loss through leaching thus, improving absorption and retention of water as well as supporting micro-organism that improve soil fertility.[6] SCB is a major lignocellulosic, inexpensive byproduct of the sugarcane industry.[7] SCB is quantitatively composed of 38.8- 45.5% cellulose, 22.7-27.0%, hemicellulose and 19.1-32.4% lignin.[8] The ashes range from 1.0 - 2.8% and extractives from 4.6 - 9.1%.[8] In addition to this SCB contain different minerals. Moreover, application of sugar industries by-products reduces the recommended dose of fertilizers and improves organic matter of soil during the crop production.

A soil amendment is any material added to a soil to improve its physical properties, such as water retention, permeability, water infiltration, drainage, aeration and structure. The purpose is to provide a healthier environment for plant roots.[9] On the whole; there are two types of soil amendments, organic and inorganic. Organic matter refers to anything that comes from something that is alive such as peat, grass clippings, straw, manure, wood chips, compost, bonemeal, bat guano, and earthworm castings. Organic amendments act as an energy source for bacteria, fungi and earthworms that live in the soil. Inorganic amendments can be obtained through mined or manufactured; examples are lime, vermiculite, and perlite. Both organic and inorganic materials were used for soil amendment. How long the amendment will last in the soil depends on soil texture, soil salinity, plant sensitivities to salts, salt content and pH of the amendment.[9] Some of organic amendments are used direct but others processed before use. In the literature it is found that different researchers used different inorganic and organic materials for soil amendment. The researchers Hidalgo & Harkess (2002) used vermi compost produced from sheep, cattle, and horse manures mixed at different ratios with 70% peat moss, 30% perlite (v/v) substrates.[10] According Ansari & Jaikishun (2010), the vermi compost produced from bagasse and rice straw showed the highest percentage of production of *Pheseolus vulgaris* and showed better productivity than cow dung and chemical fertilizer.[11] Babaei *et al*., (2016) reported an increase in phosphorus content and total Kjeldahl nitrogen from vermi-compost prepared by mixing bagasse as bulking agent with cow dung, sewage sludge and kitchen waste.[12] Hossain *et al*., (2016) reported on the use of plant origin wastes as soil conditioner and organic fertilizer, in soil amendment.[13] Also addition of organic wastes such as filter cake have the best potential for improving soil organic carbon retention and cation exchange capacity.[14,15]

Humus, produced after decomposition of SCB, functions as to improve the soil's water holding capacity by increase larger surface area of soil hence the easier for the soil to hold the water as a result a higher water holding capacity. Humic substances help in the spatial arrangement of individual particles, their aggregates, and of pores that facilitates water infiltration and helps hold water within the root zone. Because of their large surface area and internal electrical charges, humic substances function as water sponges. These sponges like substances have the ability to hold seven times their volume in water.[16] According to El halim (2016), the increase of water holding capacity attributed by the nature of SCB as organic matter. SCB was helped to change the soil matrix by facilitating the coherent interaction of soil/bagasse or bagasse/bagasse particles as result increase the soil aggregation together with its angular pores which are responsible for holding more water by adhesive and cohesive forces.[17] SCB as by product of sugar production has always made it an attractive for soil amendment.[18] One of the promising approaches to use SCB waste is as a low-cost soils amendment. An amendment with SCB was able to improve the physical characteristics of the soils, including the ventilation, humidity, and nutrient support for the growth of microorganisms.[19] Therefore in this research, soil water retention and nutrients holding capacity studied by amending the soil of Dodoma city using sugar cane bagasse.

Materials and Methods

Study Site

Dodoma city is a part of Dodoma region which is located at 6°10′23″S 35°44′31″E lies in the Eastern-central part of Tanzania (Figure 1).

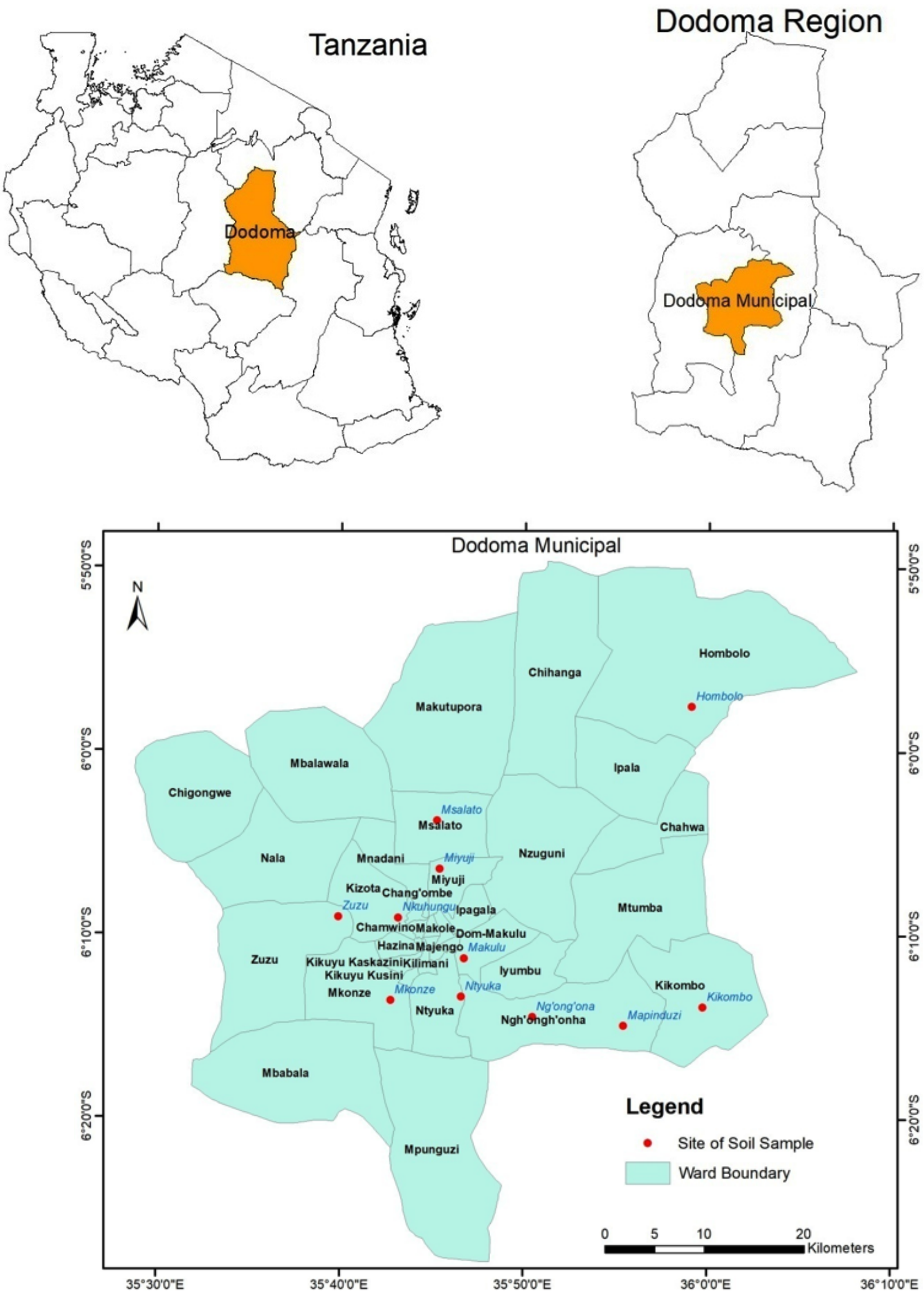

Fig. 1: Map of Dodoma city showing soil sampling sites.

Soil Sample Collection and Preparation

The first and most critical step in soil testing is collecting a soil sample. Eleven samples of soils were collected from different locations Hombolo, Kikombo, Makuru, Mapinduzi, Miyuji, Mkonze, Msalato, Ngongona, Nkurungu, Ntyuka and Zuzu found in Dodoma municipal as shown in Figure 1, which have high population. The composite sampling method was used for sampling, where about 1kg of sub-samples (15 to 25 sub samples) were collected with the help of an auger from 10 cm depth and filled in plastic bags and label for easy identification of the sample. The entire packed samples were kept in a bucket.[20] Soil samples were air dried on dry wood which act as drying surface after transporting the samples to laboratory. Care was taken to maintain the identity of each sample at all stages of preparation. Finally, the portion of the solid soil sample was used for analysis of water retention, and other portion of the solid soil sample was crushed and screened through a 2-mm sieve repetitively until fine particles were obtained ready for analysis of organic carbon, exchangeable bases, and cations exchange capacity.

Sampling and Preparation of Sugarcane Bagasse

20 kg of sugarcane bagasse was collected from local sugarcane juice vendors (Ngongona sugarcane juice extract) manually by using hands processed before use [Figure 2(A)]. The sample was air dried for four days and then in the oven at 70°C for two consecutive days. Finally grounded by using blender and sieved (2 mm mesh) to make fine powder [Figure 2(B)].[18]

SCB powder was kept in desiccators until the further experiments for soil studies.[21,22] Different test samples were prepared by mixing SCB and soil in different ratios like B_1-2%, B_2-5%, B_3-10%, B_4-20%, B_5-100% and C-0% was kept as control. Water content and ion exchange capacity of the soil samples were determined before and after mixing with SCB.

Water holding capacity

Water holding capacity was determined by using gravimetric method where the weight of moisten soil (WMS) and weight loss (WLS) of amended and non-amended soil were determined. For the study of weight loss, an oven is used at 32°C. The WMS was determined by measuring the weight of non-amended and amended soil before and after wetting the soil with water. The water weight was the difference between the weight of wet soil sample and dry soil sample. The weight gain of soil due to water absorption (WMS) was calculated by using equation below.[23]

% WMS =(Wet weight-dry weight / Wet weight) X 100

The weight loss of amended and non-amended soil (WLS) after placing the sample in the oven at 32°C was obtained by gravimetric method.[19] In this study, the behavior of water holding capacity with modified and unmodified soils also studied with respect to the wetting capacity, means gain in weight of moisten soil (WMS) after 24 h of wetting and weight loss of soil per day for three days. The weight loss after keeping in the oven is calculated by the following formula.[24]

% WLS = (Wet weight - Wet weight after time / wet weight) X 100

Organic Carbon

Organic carbon and organic matter were determined by using method described by Walkley & Black (1934).[25] Calculations were made based on

(a) (b)

Fig. 2: (A) SCB collected from local sugarcane juice vendors. (B) SCB powder after processing.

stoichiometric chemical equation. The percentage carbon is determined from the following formula:

% OC = 0.003 × N × 10mL × 100 × (1-T/S) / ODW = 3N(1-T/S) / ODW

Where N is Normality of $K_2Cr_2O_7$ solution, T is volume of ammonium ferrous sulphate used in sample titration (mL), S is volume of ammonium ferrous sulphate used in blank titration (mL) and ODW is Oven-dry sample weight (g). Soil organic Matter (SOM) was calculated as 1.72 x % OC.[25]

Exchangeable Bases

Exchangeable bases such as total sodium, potassium, magnesium and calcium were determined by using Flame Atomic Absorption Spectrometer (FAAS) as per the procedure described by Bansal & Kapoor (2000).[26] The concentrations of potassium, sodium, magnesium and calcium were determined by using FAAS after adjusting the flame photometer by the standard solution.

The extractable sodium, potassium, magnesium and calcium were obtained by using a known volume of 1 N ammonium acetate and the exchangeable contents of these elements were obtained as difference between the extractable and soluble quantities.

Exchangeable bases (cmol/kg) = (mg / L) × (Vol.of exctract (mL) / w(g)) × DF × (100g/Eq.)

Where DF is dilution factors, Eq is equivalent weight (atomic weight / valence), mg/L is concentration of elements and W is the weight of oven dried soil sample in grams. Exchangeable sodium percentage (ESP) was calculated, using results from exchangeable sodium and cation exchange capacity (CEC) while sodium absorption ratio (SAR) was calculated from the result of Mg^{2+} and Ca^{2+} ions.[27]

ESP = (Exch. Na / CEC) × 100
SAR = (Na /√ Ca + Mg / 2)

Calibration of FAAS

Calibration of the instruments used for measuring exchangeable bases (Na^+, K^+, Mg^{2+} and Ca^{2+}) was done by preparing five standard solutions. The FAAS was calibrated with known concentrations of analyte (Table 1). A blank solution having 0.0 mg/L of the analyte was used to correct background signal for the matrix. The calibration curves (Figure 3) were drawn and equations from them were used to get the concentration of each element (mg/L) which was used to obtain the exchangeable bases of each element in the solution.

Cation Exchange Capacity

The cations exchange capacity (CEC) of the soil was determined by using the ammonium acetate saturation method as described by Chapman (1965) & Ross (1995).[28,29] The soil (5g) was saturated with neutral NH_4OAC, shaken for 30 minutes and filtered by using Buchner funnel. The filtrate was used to determine exchangeable K^+, Na^+, Ca^{2+} and Mg^{2+} using flame atomic adsorption spectrophotometer (Shimadzu, AA-840-01). Excess NH_4OAC was removed by washing twice with 95% ethanol. The residue of NH_4^+. Saturated soil was equilibrated

Table 1: The data for calibration of FAAS for different elements.

K^+		Na^+		Ca^{2+}		Mg^{2+}	
Std. conc. (mg/L)	Absor-bance	Std. conc. (mg/L)	Absor-bance	Std. conc. (mg/L)	Absor-bance	Std. conc. (mg/L)	Absor-bance
0	0	0	0	0	0	0	0
2	1.9	2	2.5	2.5	0.036	0.5	0.202
5	5.4	5	5.8	10	0.177	1	0.384
10	10.3	10	10.9	15	0.268	1.5	0.585
15	15.2	15	15.8	20	0.36	2	0.742
20	20.2	20	20.5	-	-	-	-

with 4% KCl, shaken for 30 minutes and filtered. The filtrate was used for the determination of NH_4^+ by micro kjeldahl distillation in the presence of 40% NaOH and the NH_3 liberated was collected in 4% boric acid (with mixed indicator) and titrated with standard 0.1N H_2SO_4. The titre values were used for the calculation of the CEC.

CEC = (Tv - Bl × N × Vex) / W

Where T_v is the titre values, Bl is blank volume, N is normality of sulphuric acid and Vex is volume of extraction.

Results and Discussion

Water Holding Capacity of Soil

Table 2 contains the detailed laboratory analysis of soil mixed with different doses of SCB. The analysis reveals that like other organic wastes, SCB affects the hydro physical properties of soil positively. The water holding capacity of the soil increased from 26.85 % for control with 0 % SCB to 84.08% B5 that is 100% SCB representing 3.16 x more water absorption. The results show that there is significance effect of SCB on water holding capacity. The results proved that it is beneficial to mix SCB with soils to increase water holding capacity of soil. These results are consistent with the literature. Organic carbon in these soils acted as a fine medium of sorption to hold water as well improved the soil aggregation.[30] The addition of SCB increases inter-particle bond strength, which could be due to enhanced inter-particular aggregate cohesion due to inward diffusion of binding organic substances within the aggregates hence reduce water loss. Also other researcher were reported that, addition of materials rich in organic

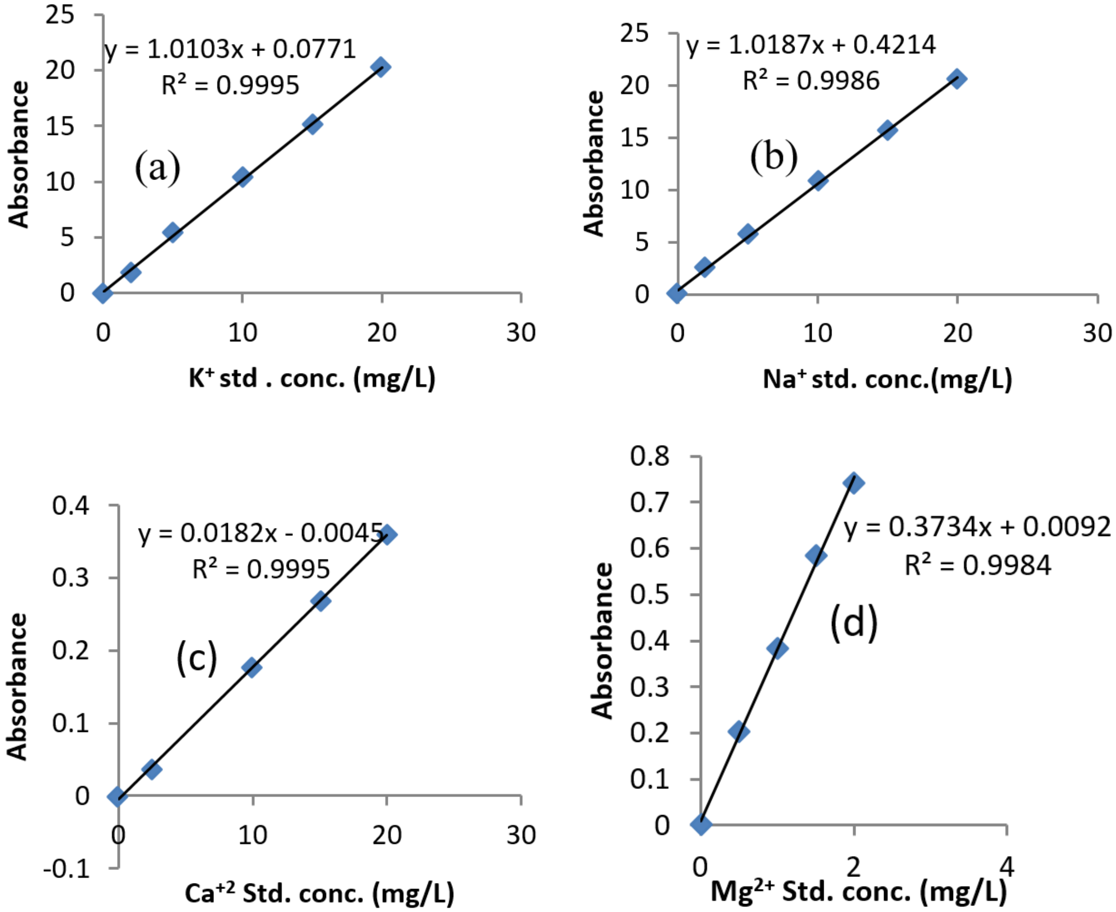

Fig. 3: Calibration curves of (a) Potassium (b) Sodium (c) Calcium and (d) Magnesium.

carbon leads to an improvement of the aggregation status of the soil which had a positive effect on hydro¬physical properties of soil, i.e. decreasing soil bulk density as well as macroporosity (drainage pores) at the expense of ones. The moisture content was increased due to the increase of water holding pores as well as decreases the mean diameter of soil pores and turns its water transmitting properties namely hydraulic conductivity.[6] According to Yadav (2015) long term application of organic materials increase the water holding capacity.[31] SCB increases water retention due to the decrease of dry bulk density and improve soil porosity positively that make moisture availability in the root zone.[18] Hudson (1994) and Kern (1995) found an increase in water content with increasing soil organic contents (SOC).[32,33] Garambois and his co-workers (2002) showed that per gram of additional carbon at -10 kPa suction, a 50 % increase in water content was achieved.[34] The results were similar with that reported by Hueso *et al.*, (2011), organic amendment increased the soil WHC, which reflected that the rate of moisture loss during the dry period was lower in amended than in un-amended soil.[35]

In this study, the behavior of water holding capacity with modified soils also studied with respect to the wetting capacity, means gain in weight of moisten soil (WMS) after 24 h of wetting and weight loss of soil per day for three days and the results were showed in the Figure 4. According to these results it is clearly visible that with the increase in the percentage of SCB in soil, water absorption capacity increased. The amount of water loss per day from the soil decreases with the increase in the percentage of SCB in soil.

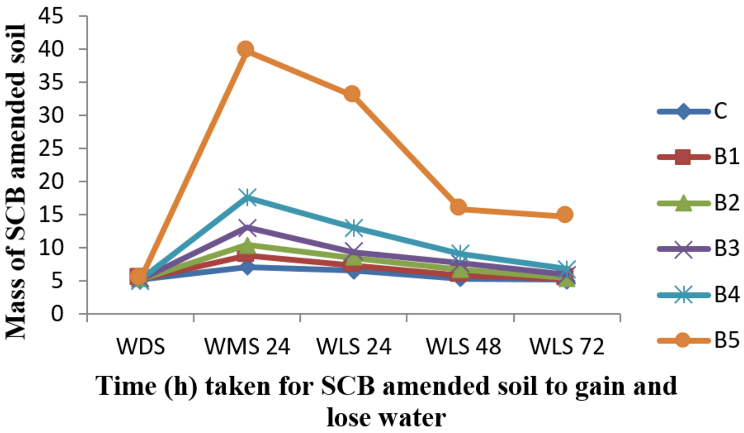

Fig. 4: Effect of SCB on amended soil water gain and loss per hour. WDS = Weight of dry soil, WMS = Weight of moisture soil after water absorption and WLS = Weight of soil after placing in oven at 32°C.

Table 2: Effect of sugarcane bagasse on soil water holding capacity.

Treatment	% of SCB mixed	Mass of dry soil	Mass of wet soil	%WHC
C	0	5.18	7.09	26.85
B1	2	5.2	8.79	40.72
B2	5	5.22	10.43	49.64
B3	10	5.23	13.07	59.98
B4	20	5.18	17.55	70.46
B5	100	5.20	32.99	84.08

Initial Soil Organic Carbon and Organic Matter Properties of Dodoma

The results of percentage of organic carbon (% OC) and percentage of organic matter (% OM) contents in different sites of Dodoma are presented in Table 3. This shows that the values are high in the soils of sites Miyuji and Mkonze. These contents are less in the site Nkuhungu. The values are ranged between 0.28 and 1.31 for % OC and 0.48 upto 2.26 for % OM. Organic carbon contents was categorized as < 0.60% as very low, 0.60 – 1.25 % as low and 1.26 – 2.50 % as medium. Based on these categories, soils in this study ranged from very low to medium organic carbon content. These levels are similar to those from other studies done by Budotela (1995) in selected grape producing areas of Dodoma region (0.68% OC).[5] Letayo (2001) reported 0.65 % OC in the study of millet and groundnut soils of some areas from Dodoma region.[36] Sanga (2013) reported the range of organic carbon from low to medium (0.64 to 1.96 OC %) in the study of evaluation of soil fertility status and optimization of its management in sesame (*Sesamum indicum*) growing areas of Dodoma district.[37] Thus many soils of Dodoma seem to be low in organic carbon. This is due to the management practices used in crop production that do not promote increase in soil organic matter. Although various organic amendments were used but the quantity applied is either insufficient to build up and maintain soil organic matter for sustainable crop production.[38] Soil organic matter (SOM) contents in Dodoma are very low (Table 3) due to poor structural properties, vegetative cover is very poor, soil aggregates tend to be unstable and the soils are susceptible to top soil erosion and surface sealing.

Table 3: Percentage of Organic carbon (% OC) and percentage of organic matter (% OM) in the soils of Dodoma.

Soil site	% OC	% OM
Hombolo	0.51	0.88
Kikombo	0.89	1.53
Makuru	0.63	1.09
Mapinduzi	0.71	1.22
Mbalawata	0.66	1.14
Miyuji	1.31	2.26
Mkonze	1.31	2.26
Msalato	0.65	1.12
Ng'ong'ona	0.48	0.81
Nkuhungu	0.28	0.48
Ntyuka	0.79	1.36
Zuzu	1.23	2.12

Effect of SCB on Soil Chemical Properties

The organic carbon of SCB was 45.57% (Table 4). This value is slightly similar to 43.56% reported by Ricard, (2015) on the study of effect of adding bulking materials over the composting process of municipal solid biowastes.[39]

The statistical test ANOVA used to check the significance of the variation in the chemical properties of soil with increase in percentage of SCB in the soil. The results showed that there is significant increase of organic carbon in amended soil as the concentration SCB treatment increase ($F_{calculated}$ = 2.9973 > $F_{critical}$ = 2.6684, null hypothesis rejected at probability 0.05) (Table 4). This result is in agreement with the results of Ricardo, 2015 and Shehzadi

Table 4: Chemical properties of soil before and after amending with SCB.

Treatment (%SCB)	K^+ (cmol/kg)	Na^+ (cmol/kg)	Ca^{2+} (cmol/kg)	Mg^{2+} (cmol/kg)	CEC* (cmol/kg)	% OC (SOC)	% OM (SOM)	SAR*	% ESP*
C (0)	0.5	1.03	2.8	1.3	5	0.53	0.91	0.72	20.1
B1 (2)	0.52	0.55	2.98	1.51	5.75	1.09	1.87	0.36	9.55
B2 (5)	0.64	0.47	3.24	1.85	6.21	2.3	3.95	0.29	7.56
B3 (10)	0.65	0.31	3.44	1.86	6.83	5.1	8.77	0.19	4.53
B4 (20)	0.67	0.21	3.83	2.71	7.94	9.11	15.66	0.12	2.64
B5 (100)	1.25	0.08	8.61	5.47	24.84	45.57	78.38	0.02	0.32

*CEC = cations exchange capacity, SAR = Sodium Adsorption Ratio and ESP = exchange sodium percentage.

et al., 2017. According to their study the addition of organic wastes increases OC.[14,39] According to Dotaniya *et al.*, 2013, addition of organic residue enhanced the soil organic carbon in soil and accelerated the microbial activities in soil.[40]

Since SOM content was calculated from soil organic carbon these parameters had the same trend.[25] It is generally accepted that a threshold for SOM in most soils is 34 g/kg below (treatment C to B_4 in table 4) which decline in soil quality is expected to occur.[41] Soil organic matter was below the proposed threshold values in all the sites under study, suggesting a decline in soil quality. This result is in agreement with the studies of Makoi, (2014) in the selected soil chemical properties and fertility assessment in some traditional irrigation schemes of the Mpwapwa district in Dodoma region that was 2.3 to 11.7 g/kg SOM.[42] Dodoma is semi-arid with high soil erosion which may lead to a decline in soil productivity since the finest and most fertile soil particles are generally removed. It is therefore apparent that there is a need to replenish the SOM using resources such as SCB for maximum crop yields. Understanding the SOM status before any development interventions are undertaken is of vital importance and it plays a key role in the improvement of soil physical and chemical properties. These properties include structural stability, porosity, mineral elements availability (i.e. N, P and S), cation exchange capacity, soil moisture and nutrient holding capacity. SOM has also been reported to have great impact on improving irrigation efficiency for sustainable land productivity to enhance productivity and environmental quality, to reduce the severity and costs of natural phenomena such as drought, floods, disease and to reduce atmospheric CO_2 levels that contribute to climate change.[3]

Exchangeable Bases

Analysis showed that exchangeable calcium, magnesium and potassium concentration in soil slightly varies due to application of organic matter. Slightly high calcium (8.61cmol/kg) was detected from 100 % SCB (B5) treated soil while the lowest exchangeable calcium (2.8 cmol/kg) was obtained from untreated soil. This result is in agreement with Sarwar *et al.*, (2010) who reported that the exchangeable Ca^{2+} increases with application of organic matter (sugarcane by product).[43] Unlike the other exchangeable cations sodium concentration in the soil was reduced by SCB treatment (Table 4). The highest exchangeable sodium 1.03 cmol/kg was recorded from untreated soil, while the lowest exchangeable sodium (0.08 cmol/kg) was obtained from the application of 100 % (B5) SCB to the soil. This result is in agreement with findings of Qadir *et al.*, (2007) who reported that exchangeable sodium decreased with increase of organic matter treatment. This might be due to the replacement of exchangeable sodium by Ca^{2+} that released from dissolution of the native calcium carbonate that works on the same principle of native calcite dissolution to supply soluble calcium by facilitating changes in root zone partial pressure of CO_2 by plants and thus helps to remediate soils.

Cation Exchange Capacity (CEC)

The lowest CEC was 5.0 cmol /kg for untreated soil and it increases with the increase in percentage of SCB from 2% (B1) to 100% (B5) in the soil (Table 4). This result is in agreement with findings of Ricardo, (2015) who reported that the raise of CEC is due to the increase soil organic matter and improve its quality. The charges resulting from isormorphous substitution and its large number of negatively charged functional groups also causes higher CEC.[39]

Sodium Adsorption Ratio (SAR) and Exchangeable Sodium Percentage (ESP)

The highest SAR (0.72) was found in untreated soil, whereas the trend is decreasing as percent SCB increases in the soil (Table 4). The lowest sodium adsorption ratio (0.03) was observed in the soil with 100% SCB (B5). Shaaban *et al.,* (2013) also reported declining in SAR after application of organic matter.[45]

The highest ESP (20.1 %) was recorded in untreated soil (Table 4). However, the lowest ESP (0.32 %) was recorded from application of 100 % SCB (B5). The decrease of ESP in the soil might be due to replacement of exchangeable sodium by Ca^{2+} in exchange site. Ca^{2+} releases from $CaCO_3$ due to its dissociation caused by lower soil pH of the soil with higher organic matter. The same result was reported by Wang *et al.*, (2014) who found that a mixture of organic wastes decreased ESP by 71%.[46]

Conclusion and Recommendation

Sugarcane bagasse is generally considered a waste product; however, the present findings show that it contains sufficient amounts of K^+, Ca^{2+}, Mg^{2+} and CEC. Different levels of sugarcane bagasse positively influence the hydophysico-chemical properties of soil. Utilization of sugarcane bagasse as organic fertilizer leads to improve soil water holding capacity and cation exchange capacity. It can also save the water cost and chemical fertilizer along with minimizing environmental pollution. This study concluded that application of 10% SCB is optimal to improve its quality to the required level. Further research should be conducted in order to increase knowledge on interactions between SCB and soil.

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Conflict of Interest

Authors declare no conflict of interest.

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