



Carbon Sequestration Potential of Cropland at Different Doses of Composts in Southern Togo

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Authors' contributions

This work was carried out in collaboration among all authors in its research conceptualization, conducting experiments, data recording and manuscript preparation. The final manuscript was read and approved by all authors for its submission.

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ABSTRACT

The objective of this study was to assess the carbon sequestration potential of cropland amended at different doses of solid household waste compost. Field experiments were conducted during four cropping seasons alternating maize and tomato. Soil samples were collected on experimental plots in 20 cm depth for soil organic carbon content determination using wet oxidation method while bulk density was measured by the core method (volumetric cylinder method) with undisturbed soil samples taken in 0 - 20 cm with steel cylinder of 100 cm³. Carbon sequestration potential varied with carbon content, bulk density and soil depth. The results shown that amount of carbon sequestered under maize cultivation (0.035±0.03 to 0.191±0.03 t C ha⁻¹) was higher than those recorded under tomato growing areas (0.016±0.03 to 0.164±0.02 t C ha⁻¹). Carbon sequestration rates ranged from 0.105±0.01 to 0.573±0.01 t C ha⁻¹ yr⁻¹ under maize cultivation and from 0.048±0.02 to 0.492±0.03 t C ha⁻¹ yr⁻¹ under tomato growing. It is able to conclude that household waste compost application contributes to increase carbon accumulation in soil.

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1. INTRODUCTION

The ferrallisols in coastal zone of Togo constitute the main part of cropland. These soils formed on sedimentary deposit [1] are frequently cultivated without fallow and no organic restitution for the following two reasons. First, the land preparation is mainly provided by human energy; and second, the incorporation of crop residues (leaves, straw, stubble and various stems) into soil is not ease with the rudimentary agricultural tools (hoe, daba). Due to these limitations, Togolese smallholders, usually adopt the use of fire to clean their plots, burning plant materials that cannot be gathered and buried. Burning is generally practiced after a clearing land where decomposition of crop residues is very slow. The vegetal biomass parched in the field are heaped or swathed and incinerated. Crop residues (mainly maize straw, cassava stalks and sorghum stubble) are burnt before land preparation for sowing or installation of next culture. Furthermore, farmers remove crop residues from the field and use them for feeding their livestock or as fuel to cook their food. As a result, crops like maize and tomato are cultivated on poor agricultural soils and the continuous mono-cropping still enhanced the problem. This conducted to soil organic carbon stock decreasing, soil surface horizons destructuring and decline in agricultural production essentially food. The organic amendment such as compost use, an eco-friendly technology for enhancing agricultural production, is one possibility to restore them [2, 3].

Sub Saharan African countries are facing a problem of the management of wild dumping grounds of household urban wastes. The composting is more suitable technology to valorise these municipal wastes and to resolve the unsanitary problem [4,5]. Organic amendments have been known as a means to enhance carbon stock in soils [6]. Others researchers reported that utilization of organic fertilizer such as compost in agriculture helps in increase the amount of carbon stock in soils [7]. Despite efforts of various studies worldwide to increase the amount of carbon stock in soil, a few studies have been undertaken in Togo to identify the options that may enhance the amount of carbon stock in cropland.

The aim of the present study is to assess the carbon sequestration potential of cropland amended at different doses of compost produced

using solid household waste under maize and tomato cropping.

2. MATERIALS AND METHODS

2.1 Field Experiments

Field experiments were conducted in coastal zone of Togo at the Teaching Research and Demonstration Farm of Agronomic School at University of Lomé located in 6°10'N, 1°10'E; altitude: 19 - 60 m, which is known as Equatorial Guinean climate [8]. The soil type was a ferrallisol locally called "Terre de barre" that developed from sedimentary deposit [1]. This soil is red, deep and suitable for almost all crops. Among two composts used, one was produced with 100% of household urban solid wastes collected from Agbalepedogan district in Lomé and another with 70% of household wastes mixed with 30% of poultry manure [4]. The field experiments were conducted during four cropping seasons alternating tomato-maize-tomato-maize. The composts were applied at the beginning of each crop season. It was spread on the soil surface after ploughing and mixed with the topsoil at about 15 cm depth. The manually ploughed land was divided into plots with plot area of 3.84 m² (2.4 m × 1.6 m). Each plot was separated from the adjacent by 1 m interval while the replicates were separated by 1.5 m interval. The treatments were arranged in a randomized complete block design. Each treatment was replicated three times. There were ten treatments per block where T0 refers to control plots without compost while T1, T2, T3 and T4 refer to plots treated with compost elaborated with 100% of household waste applied at doses of 10 t ha⁻¹, 20 t ha⁻¹, 30 t ha⁻¹ and 40 t ha⁻¹ respectively while T5, T6, T7 and T8 refer to plots treated with compost elaborated with 70% of household wastes mixed with 30% of poultry manure applied at doses of 10 t ha⁻¹, 20 t ha⁻¹, 30 t ha⁻¹ and 40 t ha⁻¹ respectively and T_{MF} refers to mineral fertilizers such as NPK 15-15-15 and Urea (46% N) applied at 0.2 t ha⁻¹ and 0.1 t ha⁻¹ respectively as a national fertilizers recommendation for maize [9].

Soil sampling, organic carbon content analysis and bulk density determination:

Prior to the start of the experiment, soil samples were collected from the 0-20 cm soil layer in the experimental site with an auger for the analysis

of particle size distribution [10] and organic carbon content. At the end of harvest of each crop season, the soil samples were taken randomly at the same depth of 0 - 20 cm in each plot for estimation of organic carbon content and bulk density. The organic carbon content was determined following the wet oxidation method [4]. The bulk density was determined from undisturbed soil samples that were taken in top 20 cm soil horizon with a steel cylinder of volume 100 cm³ using the core method or volumetric cylinder method [11]. It was measured after undisturbed soil samples drying at 105°C during two days i.e. 48 hours. Soil samples were composite samples and each composite sample was generated by five simple samples.

2.2 Soil Organic Carbon Stock and Sequestration Rate

According to Boulmane *et al.* [12], the soil organic carbon stock (SOC_{stock}: t ha⁻¹) is a function of the soil's organic carbon content (SOC_{conc}: g kg⁻¹), the bulk density (BD: g cm⁻³), the investigated soil depth (d: cm) and the conversion factor between the units: 0.1 which is a factor for converting mg C cm⁻² to t C ha⁻¹. In this study, soil organic carbon stock within the top 20 cm was calculated by multiplying soil's carbon content concentrations by bulk density, investigated soil depth and conversion factor. The amount of soil organic carbon was calculated according to the following formula:

$$\text{SOC}_{\text{stock}} = \text{SOC}_{\text{conc}} \times \text{BD} \times d \times 0.1 \quad (1)$$

The amount of sequestered organic carbon in top soil up to 20 cm of depth in every treatment was estimated after subtracting the initial value of organic carbon stock [13]. The annual carbon sequestration rate depends on organic carbon stock captured in four months of experimentation. Thus, it was calculated by dividing the organic carbon stock obtained by four and multiplying this by 12 (12 months of year).

3. RESULTS AND DISCUSSION

3.1 Soil Characteristics before Agronomic Trials

The characteristics of top 20 cm soil horizon of experimentation site were presented in Table 1. They were related to invariable parameters (clay, silt and sand content) and variable parameters (bulk density and organic carbon content) of soil before agronomic trials installation.

The particle size distribution analysis shown that top soil 0 - 20 cm of experimental site was loamy sand according to USDA Soil Texture Triangle [14] where the clay content hardly exceeds 5.5% and the organic carbon content does not reach 0.055 g kg⁻¹ i.e. 0.055‰. This indicates that the surface horizon of this soil was devoid of the organic and mineral colloidal fraction by the phenomena of leaching and selective erosion causing his depletion in clay and organic matter. Similar observations were reported by Brabant *et al.* [15] who signalized that essential symptoms of soil degradation are, among others, the loss of clay and organic matter of soil surface horizon.

3.2 Soil Characteristics during Trials

The soil bulk density values, the amount of organic carbon sequestered in cropland and the sequestration rates during four months of experimentation are presented in Tables 2, 3, 4 & 5. The soil bulk density values ranged from 1.21 to 1.64 g cm⁻³. The amount of organic carbon sequestered ranged from 0.009 to 0.164 t C ha⁻¹ under tomato growing and from 0.030 to 0.191 t C ha⁻¹ under maize cultivation while the carbon sequestration rates ranged from 0.027 to 0.492 t C ha⁻¹ y⁻¹ under tomato growing and from 0.090 to 0.573 t C ha⁻¹ y⁻¹ under maize growing season.

3.3 Soil Bulk Density

It was observed in Fig. 1, a regular trend decreasing of soil bulk density average from the first growing season to the fourth on plots treated with compost. This reflected both the increase of compost levels, nature of compost and the cumulative effect of compost in amended soil. On the contrary, the control plots shown a gradually increasing trend of bulk density from the first growing season to the fourth. As could be seen in Fig. 1, soil bulk density decreased with level and nature of compost applied. The bulk density values are inversely proportional to soil organic carbon concentration following the trend line $y = -0.056x + 1.44$; $r^2 = 0.9561$. The control treatments presented the highest bulk density values (1.59 - 1.64 g cm⁻³) while the plots treated with composts shown the lowest bulk density (1.21 - 1.57 g cm⁻³). These results are in line with the findings of Bazzoffi *et al.* [16] who demonstrated that soil bulk density decreases under plots received a compost amendment. The authors [16] revealed that application of 60 t ha⁻¹ of household waste compost induced soil bulk density reduction. Authors attributed the soil bulk

density reduction to the presence of stable compounds (humus) within the compost. Similarly, Agbede *et al.* [17] found a decrease in soil bulk density by applying chicken manure in a field experiment. Overall, many previous studies established the link between compost application levels and soil bulk density reduction. The

explanation given in literature was that the organic matter increased the void spaces leading to a decrease in the bulk density. These phenomena have been described by Layman *et al.* [18] as fluff effect on soil bulk density as soil organic fraction has a lower density than that of soil mineral fraction.

Table 1. Initial values of organic carbon content and particle size distribution in soil (0 - 20 cm)

Bulk density (g cm ⁻³)	Soil organic carbon content concentration (g kg ⁻¹)	Sand (%)	Silt (%)	Clay (%)	Textural class
1.60	0.0529	79.39	14.82	5.57	loamy sand

Table 2. Soil organic carbon (SOC) stock and sequestration rates after first cropping season (culture of tomato)

Treatments	SOC conc. (g C kg ⁻¹)	Bulk density (g cm ⁻³)	SOC stock (t C ha ⁻¹)	SOC stock captured in four months (t C ha ⁻¹)	SOC stock sequestration rate (t C ha ⁻¹ yr ⁻¹)
Initial value	0.053±0.02	1.60±0.01	0.169±0.01	-	-
T0	0.056±0.01	1.59±0.01	0.178±0.01	0.009±0.01	0.027±0.03
T1	0.059±0.01	1.57±0.01	0.185±0.03	0.016±0.03	0.048±0.02
T2	0.066±0.03	1.54±0.03	0.203±0.01	0.034±0.01	0.102±0.01
T3	0.079±0.01	1.48±0.02	0.234±0.02	0.065±0.02	0.195±0.01
T4	0.089±0.03	1.41±0.03	0.251±0.02	0.082±0.02	0.246±0.03
T5	0.061±0.02	1.55±0.03	0.189±0.01	0.020±0.01	0.060±0.01
T6	0.069±0.02	1.52±0.02	0.209±0.01	0.040±0.02	0.120±0.02
T7	0.083±0.03	1.46±0.03	0.242±0.03	0.073±0.02	0.219±0.01
T8	0.096±0.02	1.39±0.02	0.266±0.03	0.097±0.01	0.291±0.03
T _{MF}	0.070±0.01	1.49±0.02	0.208±0.01	0.039±0.03	0.117±0.01

In Tables 2 to 5, T0 refers to control plot without any compost use while T1, T2, T3 and T4 refer to 100% household waste compost applied at 10 t ha⁻¹, 20 t ha⁻¹, 30 t ha⁻¹ and 40 t ha⁻¹ doses respectively; T5, T6, T7 and T8 refer to compost elaborated with 70% of household wastes mixed with 30% of poultry manure applied at doses of 10 t ha⁻¹, 20 t ha⁻¹, 30 t ha⁻¹ and 40 t ha⁻¹ respectively. T_{MF} refers to mineral fertilizers NPK 15-15-15 and Urea (46% N) applied at 0.2 t ha⁻¹ and 0.1 t ha⁻¹ respectively

Table 3. Soil organic carbon (SOC) stock and sequestration rates after second cropping season (culture of maize)

Treatments	SOC conc. (g C kg ⁻¹)	Bulk density (g cm ⁻³)	SOC stock (t C ha ⁻¹)	SOC stock captured in four months (t C ha ⁻¹)	SOC stock sequestration rate (t C ha ⁻¹ yr ⁻¹)
Initial value	0.053±0.01	1.60±0.01	0.169±0.01	-	-
T0	0.062±0.01	1.61±0.01	0.199±0.02	0.030±0.03	0.090±0.02
T1	0.066±0.02	1.55±0.01	0.204±0.02	0.035±0.03	0.105±0.01
T2	0.080±0.03	1.52±0.03	0.243±0.01	0.074±0.01	0.222±0.03
T3	0.086±0.01	1.45±0.02	0.249±0.03	0.080±0.02	0.240±0.03
T4	0.101±0.03	1.38±0.03	0.278±0.03	0.109±0.01	0.327±0.02
T5	0.070±0.02	1.50±0.03	0.210±0.01	0.041±0.02	0.123±0.02
T6	0.074±0.02	1.47±0.02	0.217±0.02	0.048±0.01	0.144±0.01
T7	0.090±0.03	1.40±0.03	0.252±0.03	0.083±0.03	0.249±0.02
T8	0.112±0.02	1.31±0.02	0.293±0.02	0.124±0.03	0.372±0.01
T _{MF}	0.072±0.01	1.48±0.02	0.213±0.01	0.044±0.02	0.132±0.01

Table 4. Soil organic carbon (SOC) stock and sequestration rates after third cropping season (culture of tomato)

Treatments	SOC conc. (g C kg ⁻¹)	Bulk density (g cm ⁻³)	SOC stock (t C ha ⁻¹)	SOC stock captured in four months (t C ha ⁻¹)	SOC stock sequestration rate (t ha ⁻¹ yr ⁻¹)
Initial value	0.053±0.01	1.60±0.01	0.169±0.01	-	-
T0	0.062±0.01	1.62±0.01	0.201±0.01	0.032±0.02	0.096±0.03
T1	0.068±0.02	1.53±0.02	0.208±0.02	0.039±0.02	0.117±0.03
T2	0.083±0.03	1.49±0.03	0.247±0.02	0.078±0.01	0.234±0.01
T3	0.094±0.01	1.41±0.02	0.265±0.01	0.096±0.03	0.288±0.02
T4	0.113±0.03	1.36±0.03	0.307±0.03	0.138±0.01	0.414±0.02
T5	0.070±0.02	1.50±0.03	0.210±0.01	0.041±0.02	0.123±0.01
T6	0.075±0.02	1.46±0.02	0.219±0.03	0.050±0.02	0.150±0.01
T7	0.094±0.03	1.37±0.03	0.257±0.02	0.088±0.03	0.264±0.03
T8	0.129±0.02	1.29±0.02	0.333±0.01	0.164±0.02	0.492±0.02
T _{MF}	0.079±0.01	1.41±0.02	0.223±0.01	0.054±0.01	0.162±0.03

Table 5. Soil organic carbon (SOC) stock and sequestration rate after fourth cropping season (culture of maize)

Treatments	SOC conc. (g C kg ⁻¹)	Bulk density (g cm ⁻³)	SOC stock (t C ha ⁻¹)	SOC stock captured in four months (t C ha ⁻¹)	SOC stock sequestration rate (t C ha ⁻¹ yr ⁻¹)
Initial value	0.053±0.01	1.60±0.01	0.169±0.02	-	-
T0	0.064±0.01	1.64±0.02	0.210±0.03	0.041±0.03	0.123±0.02
T1	0.074±0.03	1.50±0.03	0.222±0.01	0.053±0.01	0.159±0.01
T2	0.092±0.03	1.41±0.01	0.259±0.02	0.090±0.03	0.270±0.01
T3	0.104±0.01	1.35±0.03	0.281±0.03	0.112±0.02	0.336±0.02
T4	0.127±0.03	1.28±0.02	0.325±0.03	0.156±0.03	0.468±0.03
T5	0.078±0.02	1.45±0.01	0.226±0.01	0.057±0.01	0.171±0.02
T6	0.094±0.02	1.39±0.01	0.261±0.01	0.092±0.02	0.276±0.02
T7	0.108±0.03	1.31±0.02	0.283±0.02	0.114±0.02	0.342±0.01
T8	0.149±0.02	1.21±0.03	0.360±0.02	0.191±0.03	0.573±0.01
T _{MF}	0.084±0.01	1.40±0.02	0.235±0.03	0.066±0.03	0.198±0.01

3.4 Estimation of Carbon Sequestration Potential

A regular trend increasing of carbon stock sequestered was ($y = 0.0313x + 0.222$; $r^2 = 0.8762$). It ranged from 0.016 to 0.097 t C ha⁻¹ in first growing season to 0.053 to 0.191 t C ha⁻¹ in fourth growing season on plots treated with compost (Fig. 2). This reflected the nature and application dose of composts then the cumulative effect in amended soil.

The results shown that the plots treated with compost recorded highest carbon stock (0.016 to 0.191 t C ha⁻¹) compared to those of mineral fertilizer treatments (0.039 to 0.066 t C ha⁻¹) and control treatments (0.027 to 0.041 t C ha⁻¹). The amount of carbon sequestered under maize cultivation (0.035 to 0.191 t C ha⁻¹) were higher than those recorded under tomato growing (0.016 to 0.164 t C ha⁻¹). The compost made with

100% of solid household waste provided the lowest amount of carbon sequestered (0.016 to 0.156 t C ha⁻¹) while the highest amount (0.020 to 0.191 t C ha⁻¹) were provided by compost elaborated with 70% of solid household waste mixed with 30% of poultry manure. In fact, the production and accumulation of maize root biomass may explain the variations of carbon stock linked to the crops and the nature of compost since the highest carbon stocks were recorded under maize cropping and plots treated with compost elaborated with 70% of household waste mixed with 30% of poultry manure. These results were lower than those reported in literature [13,19-21]. From the studies carried out in six East African countries (Burundi, Ethiopia, Kenya, Rwanda, Tanzania and Uganda), Tessema *et al.* [19] reported that soil organic carbon stocks in grasslands ranged from 3 to 93 t C ha⁻¹ in the upper 0.3 m of the soil profile. Hunziker *et al.* [20] reported that the severely

degraded soils can potentially sequester an additional carbon of 20 t ha^{-1} in top soil 0 - 30 cm beyond 50 years to reach the soil organic carbon stock of naturally growing birch woodlands. Hu *et al.* [13] demonstrated that application of compost in period of 11 years could increase soil organic carbon stock with average increased by 9.98 t ha^{-1} in top 20 cm soil horizon. Quattara *et al.* [21]

reported that the average carbon stock in continuous cultivation system was $10.05 \text{ t C ha}^{-1}$ in Burkina Faso in West Africa. The difference between the results of this present study and those of previous studies may be explained by the duration of the field experimental tests, the soil depth investigated, the nature of the organic manure and the annual dose applied.

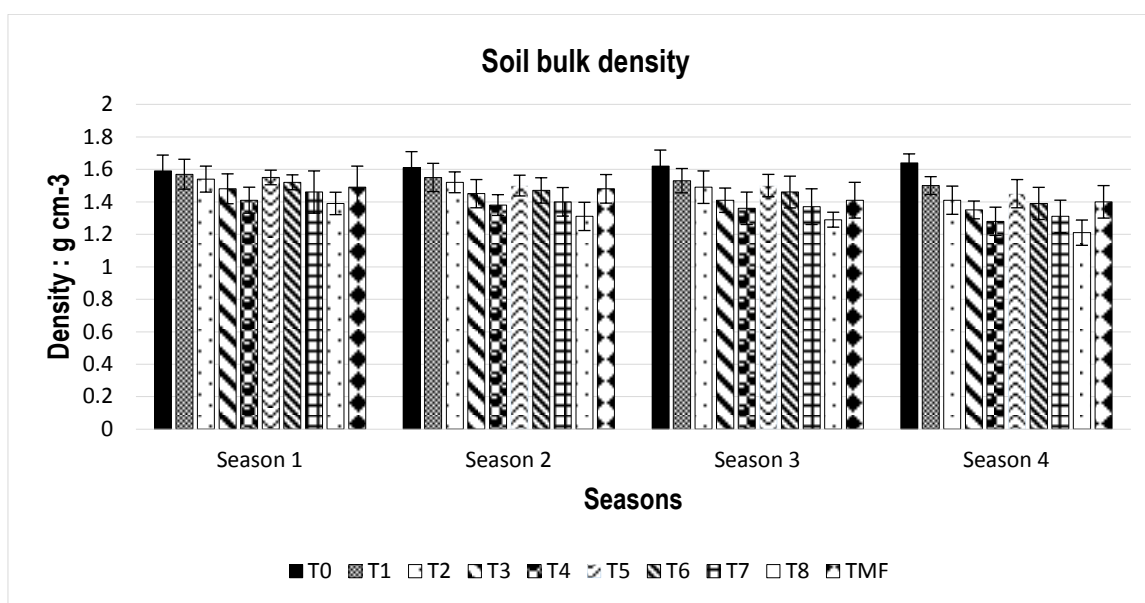


Fig. 1. Soil bulk density during the trials (g cm^{-3})

In Figures 1 to 3, T0 refers to control plot without any compost use while T1, T2, T3 and T4 refer to 100% household waste compost applied at 10 t ha^{-1} , 20 t ha^{-1} , 30 t ha^{-1} and 40 t ha^{-1} doses respectively; T5, T6, T7 and T8 refer to compost elaborated with 70% of household wastes mixed with 30% of poultry manure applied at doses of 10 t ha^{-1} , 20 t ha^{-1} , 30 t ha^{-1} and 40 t ha^{-1} respectively. T_{MF} refers to mineral fertilizers NPK 15-15-15 and Urea (46% N) applied at 0.2 t ha^{-1} and 0.1 t ha^{-1} respectively

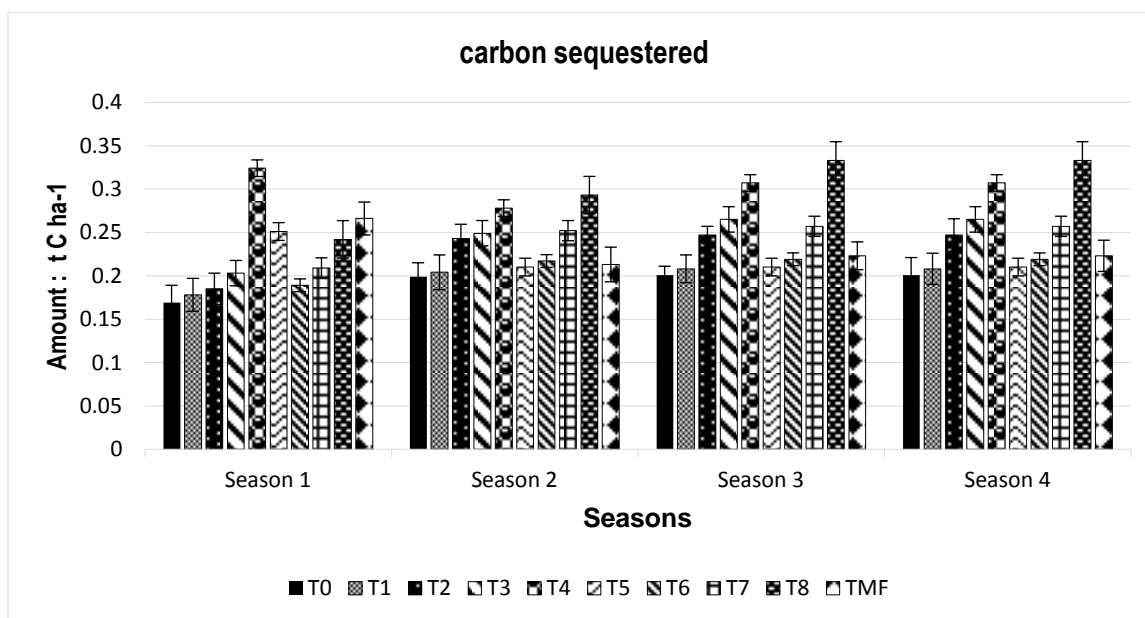


Fig. 2. Amount of carbon sequestered (t C ha^{-1})

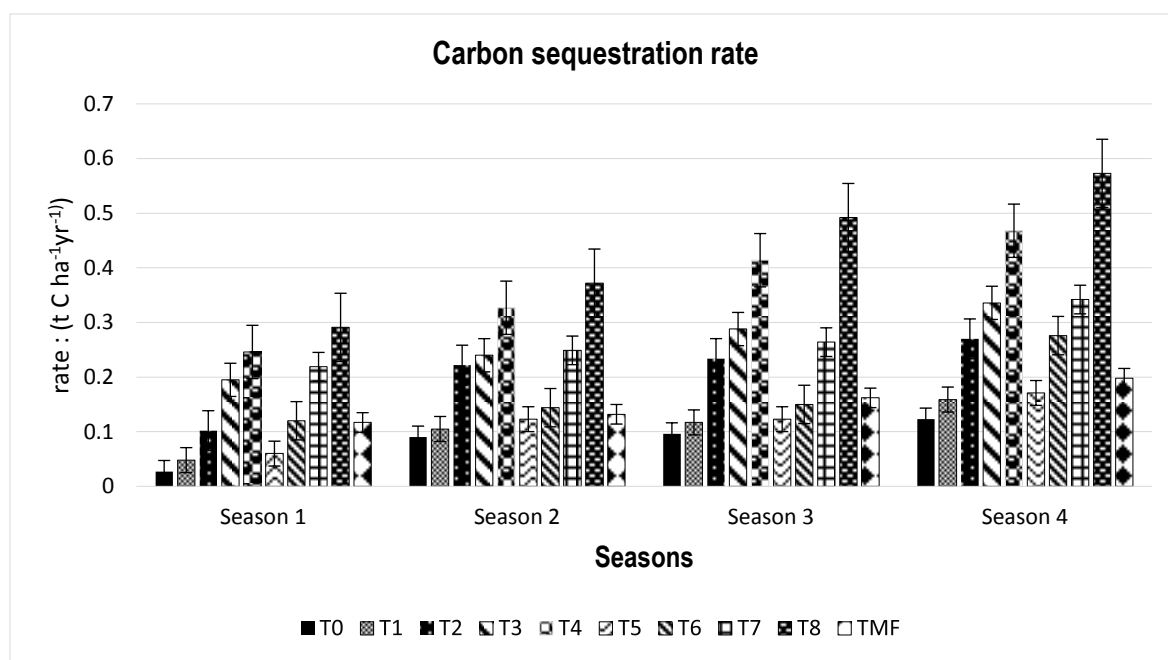


Fig 3. Carbon sequestration rate (t C ha⁻¹yr⁻¹)

The carbon sequestration rates recorded on plots treated with compost were higher than those obtained from mineral fertilizer and control treatments (Fig. 3) following the trend line $y = 0.0966x + 0.1905$; $r^2 = 0.9935$.

It was observed that the carbon sequestration rates under maize cultivation were higher than those recorded under tomato growing. The carbon sequestration rates on plots treated with compost ranged from 0.105 t to 0.573 t C ha⁻¹ yr⁻¹ under maize cultivation and from 0.048 t to 0.492 t C ha⁻¹ yr⁻¹ under tomato growing. Overall, the results of this study were comparable with those of previous studies. Similar results were reported in others countries of sub-Saharan Africa by [19,22-24]. From the studies performed in six East African countries, Tessema *et al.* [19] reported that soil organic carbon sequestration rates ranged from 0.1 to 3.1 t C ha⁻¹ yr⁻¹ in upper soil 0 - 30 cm under different management strategies. Gonzalez-Sanchez *et al.* [22] claim that the soil organic carbon sequestration potential of cropland through conservation agriculture for the African continent is about 0.90 t ha⁻¹ yr⁻¹ (including perennial woody crops). They reported that in four climatic zones of Africa (Mediterranean, Sahelian, Tropical and Equatorial) the soil organic carbon sequestration rates ranged from 0.44 t C ha⁻¹ yr⁻¹ (Mediterranean climatic zone) to 1.56 t C ha⁻¹ yr⁻¹ (Equatorial climatic zone) for annual crops, and

from 0.12 t C ha⁻¹ yr⁻¹ (Sahelian climatic zone) to 1.29 t C ha⁻¹ yr⁻¹ (Mediterranean climatic zone) for woody perennial crops. Liniger *et al.* [23] estimated to 0.57±0.14 t C ha⁻¹ yr⁻¹ the soil potential carbon sequestration rate in East Africa. Vågen *et al.* [24] pointed out that in cultivated areas in sub-Saharan Africa, the addition of manure in combination with crop residues and no-till, the rates of attainable carbon sequestration ranged from 0 to 0.36 t C ha⁻¹ yr⁻¹. In addition, the results of this study are in agreement with those found by Zhang *et al.* [25] in Tai-Lake paddy soils of China. These authors reported that the sequestration potential in Tai-Lake paddy soils of China increased with increasing application of N-fertilizer, manure, conservation tillage, and crop residues, with an annual average soil organic carbon changes ranged from 0.107 to 0.121 t C ha⁻¹ yr⁻¹, 0.159 to 0.326 t C ha⁻¹ yr⁻¹, 0.078 to 0.128 t C ha⁻¹ yr⁻¹, and 0.489 to 1.005 t C ha⁻¹ yr⁻¹, respectively. Jonard *et al.* [26] found an average annual increase in carbon stock of 0.34 t C ha⁻¹ yr⁻¹ in the top 40 cm soil horizon of forest soils in France.

On the contrary, the findings of this present study were lowest compared to those of others studies. Namirembe *et al.* [27] reported that the short-term soil organic carbon sequestration rates in the 0-30 cm horizon as a result of agronomic best management practices in East Africa was 19.7±3.9 t C ha⁻¹ yr⁻¹ from crop residues,

14.8±8.7 t C ha⁻¹yr⁻¹ from farmyard manure, 3.5±4.5 t C ha⁻¹ yr⁻¹ from inorganic fertilizers, 2.7 t C ha⁻¹ yr⁻¹ from agroforestry, and 2.5 t C ha⁻¹ yr⁻¹ from improved fallow. Follett *et al.* [28] reported soil organic carbon sequestration rates of 1.0 to 1.9 t C ha⁻¹yr⁻¹ in an irrigated vertisol in Central Mexico. Smiley and Kroschel [29] found that C stocks of cocoa agroforests in Central Sulawesi in Indonesia increased after 9-15 years plantation age at a rate of 5.3 t C ha⁻¹yr⁻¹. The difference between the findings of this study and those of others researchers may be attributed to local conditions, soil nature, topographic scape and land use.

4. CONCLUSION

This study investigated the possibilities of municipal waste compost use as an environment friendly technology for enhancing cropland carbon sequestration. Thus, soil organic carbon sequestration rates were assessed under maize and tomato growing. The results indicated that carbon sequestration rates were higher under maize cultivation than that recorded under tomato growing. It was noted that carbon sequestration rates varied according to compost nature, application dose, supply frequency and culture.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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