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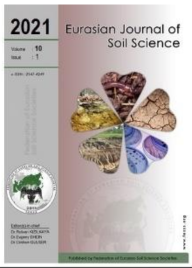

Variations in soil heat transfer under different land use types in Abia State, South eastern Nigeria

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Abstract

An in-depth knowledge on variations in soil heat transfer under different land uses is essential for proper understanding of the variations in thermal energy transfer under different human activities and modifications on land. This paper presents an investigation on the variations in soil heat transfer under different land use types in Abia State. This study evaluates three land use types: forest land (FL), continuously cultivated land (CC) and excavation site (EX). The parameters investigated in this study include; particle size distribution, bulk density, volumetric moisture content, atmospheric temperature, soil temperature, soil thermal conductivity, soil heat flux, soil volumetric heat capacity and soil thermal diffusivity. The results show that the different land use types studied influenced the soil heat energy transfer and had a significant effect on soil thermal properties. The results revealed that excavation site recorded the highest soil bulk density (1.70 Mg m^{-3}) and soil temperature (42.6^{o}C) while forest land recorded the lowest bulk density (1.36 Mg m^{-3}) and soil temperature (30.3^{o}C). The transmission of heat through a unit length of soil per unit cross-sectional area (2.476 W mk^{-1}) was higher in forest land than the other land use types studied. Soil under continuously cultivated land recorded the highest volumetric heat capacity (1.407 J $(m^3K)^{-1}$). This study will help farmers and land owners in terms of choice and management of different land use types for agricultural and industrial purposes.

Keywords: Soil heat energy transfer, bulk density, soil temperature, soil thermal conductivity, volumetric heat capacity, soil thermal diffusivity.

Introduction

Variations in soil temperature and related soil heat transfer processes are influenced by different land use types and soil management practices (Wang et al., 2018). As a result, it may be able to transform the processes of volumetric heat capacity, thermal conductivity and diffusivity of heat from soil to the surrounding. The knowledge of land use types and soil heat transfer is important for effective soil energy balance at different land uses. The soil thermal properties play a major role in governing the exchange of energy between the soil and atmosphere (Alrtimi et al., 2016). Some land use types in Nigeria include; arable land (Ogeh and Ogwuruike, 2006), excavation and refuse dump sites (Oguike and Onwuka, 2017), oil palm, secondary forest and building sites (Senjobi and Ogunkunle, 2011). Forest land use type allows only about 5 to 20% of the shortwave solar radiation to the surface of the soil (Beltrami, 2001). However, changing forest land use to arable land or excavation sites extensively increases the measure of solar radiation that touches the soil surface, which causes significant modifications in the soil thermal process and energy transfer in soil (Geiger et al., 1995). The presence of leaves from litter fall, tree cover and crop residues reduce the effect of solar radiation impact on the soil thermal properties and heat energy transfer in the soil, thereby reducing

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soil biological and chemical processes (Onwuka, 2016). The transformation of pasture and forest lands into crop lands is known to cause the increase in soil thermal properties and heat energy transfer (Beltrami, 2001) and such soils may become more susceptible to increased oxidation of organic materials and other soil biochemical processes (Fierrer et al., 2005). Excavation sites increases soil temperature and heat transfer in soils which may cause the depletion of organic matter through faster decomposition of organic materials (Broadbent, 2015). Continuous tillage alters soil structure, pore size distribution and break the continuity of macropores in the soil thereby resulting to high soil heat energy transfer. This may cause heat-induced cracks in the sand-sized particles that will consequently result to disintegration and reduced amount of sand-sized particles in the soil (Onwuka, 2016).

Knowledge of the variations in soil heat transfer under different land uses is imperative in the determination of soil heat energy balance for a particular land use as well as the management strategies to be adopted to maintain such energy balance. Therefore, the objectives of the study were to investigate the variations in soil thermal properties under different land use types.

Material and Methods

Study area

The study was executed in three locations in Abia state, South-eastern Nigeria (Figure 1). The locations are characterized by a mean annual rainfall of 2201.92mm (Nigeria Meteorological Agency, 2015). The rainfall of the study area is bimodal, which starts in April and ends in October with peaks observed in June and September (Nigeria Meteorological Agency, 2015). The mean annual temperature of the area ranges from 25 – 27°C. The soil is identified by changes in topography and parent materials as a result of uplands and inland valleys within the rural landscape underlain by coastal plain sands and shale (Chukwu et al., 2014). Due to the changes in topography and parent materials, there is an increased potential for different land uses ranging from arable crop and tree crop production to forestry, animal husbandry and fishery.

Within the study area continuously cultivated land, forestland and excavation site were investigated. The continuously cultivated land was studied in Ikwuano local government area, while forestland and excavation sites were studied in Umuahia south and Ohafia local government areas, respectively. The forestland had stayed for almost 60 years with trees such as Miliciaexcelsa (iroko), Swieteniamahagoni (mahogany) and Gamelinaarborea (gmelina) whereas the continuously cultivated land has been under continuous cultivation of crops such as sweet potato, maize, cassava and fluted pumpkin for about 8 years. The excavation site has been used for mining of laterites (for road construction and housing) for more than 7 years.

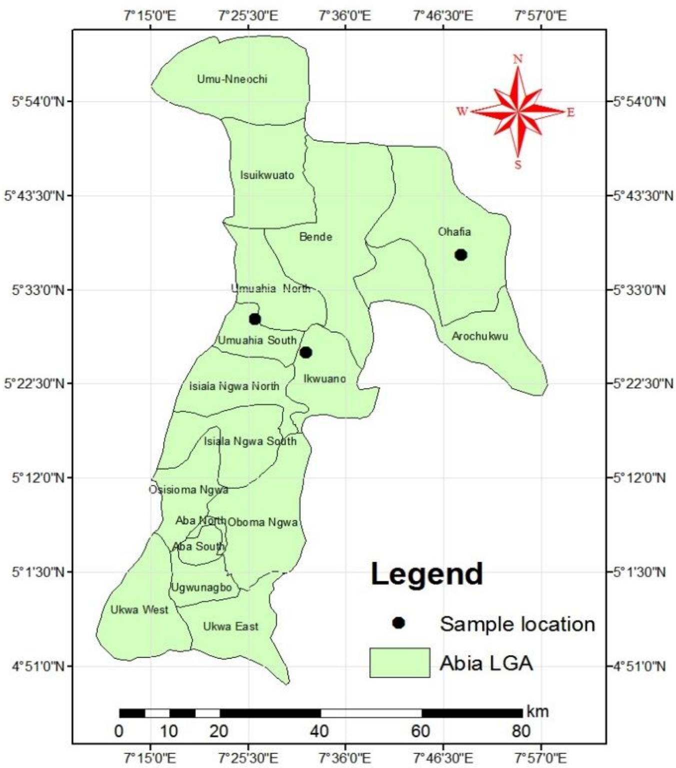

Figure 1. Map of the study area

Field method

Under each of the land use systems, three sampling points were randomly located. In each of the 3 sampling points within a land use, field measurements of soil temperature and volumetric moisture content in 0–5 and 5–10 cm depth were taken daily for a period of 24 weeks (6 months). Soil core samples for bulk density determination were also collected in 0 – 10 cm depth from the designated sampling points within each land use type.

Determination and calculation of soil properties studied

Particle size analysis was determined in the laboratory using Bouyoucos hydrometer procedure as defined by Kettler et al. (2001).

Soil bulk density (Bd) was determined in the laboratory by the method described by Blake (2003) using the equation.

$$\text{Bulk density (Bd)} = \frac{mass\ of\ dry\ soil\,(Mg)}{volume\ of\ the\ soil\ sample} \tag{1}$$

The volumetric moisture content (VMC) was calculated by gravimetric methods of field soil at a depth of 0 – 20 cm as described by Smith (2000) using the equation:

$$\text{Volumetric moisture content (VMC)} = \frac{mc \times Bds}{Bdw} \tag{2}$$

Where mc = moisture content in percentage; Bds = soil bulk density (Mg m^{-3}); Bdw = water density (Mg m^{-3}).

Soil temperature (T) was determined in the field in 0 – 5 and 5 – 10 cm depths using soil mercury-in-glass thermometer as described by Nwankwo and Ogagarue (2012).

Thermal conductivity (K) was determined using Stefan's Boltzmann equation (Gwani et al., 2013).

$$\text{Rt} = K\frac{\Delta T}{\Delta D} \tag{3}$$

Where, Rt = rate of conduction of heat per unit area.

$$\text{Rt} = \delta(\text{TA})^4 \tag{4}$$

(Stefan's Boltzmann equation)

δ = 5.67×10^{-8} $MW^{-2}K^{-4}$
TA = Temperature of soil at 0 – 5 cm depth
Ts = Temperature of soil at 0 – 10 cm depth
ΔT = Difference between the temperature at 0–5 cm depth (TA) and temperature at 5–10 cm depth (TS)

$$\Delta T = TS - TA \tag{5}$$

ΔD = Depth of the soil
K = Thermal conductivity of the soil

Volumetric heat capacity (CV) was calculated from the volumetric water content (VMC) and soil bulk density (Bd) as described by Evett et al. (2012).

$$\text{Volumetric heat capacity (CV)} = \frac{2.02 \times 10\,Bd}{.65 + 4.19 \times 10\,VMC} \tag{6}$$

Thermal diffusivity (D) was calculated from thermal conductivity (K) and volumetric heat capacity (CV);

$$\text{Thermal diffusivity (D)} = \frac{k}{cv} \tag{7}$$

Soil heat flux (Q) was calculated from thermal conductivity (K) and temperature (T).

$$\text{Heat flux (Q)} = K\frac{\Delta T}{\Delta Z} \tag{8}$$

Statistical analysis

The data generated under soil heat transfer were subjected to time series analysis which was used to determine the effects of different land use types on the measured soil thermal properties over a period of time. The data generated for the selected soil physical properties was subjected to analysis of variance and the means separated using Fisher's least significant difference (FLSD).

Results and Discussion

Particle size distribution and bulk density

The texture of soils was observed to be loamy sand in continuously cultivated land (CC), sandy loam in forest land (FL) and sandy clay in excavation site (EX) (Table 1). The particle sizes of forest land were significantly (P≤0.05) different from CC and EX. The Table 1 also showed the variations in bulk density under different land use types. Excavation site recorded the highest bulk density (1.70 Mg m^{-3}), while forest land with a bulk density of 1.36 Mg m^{-3} had the lowest.

Table 1. Particle size distribution and bulk density of the soils studied

Land use	Sand (%)	Silt (%)	Clay (%)	Textural class	Bd (Mg m^{-3})
CC	763.00	160.40	76.60	Loamy sand	1.70
FL	721.00	110.00	169.00	Sandy loam	1.36
EX	539.00	20.00	441.00	Sandy clay	1.88
LSD	20.15	11.20	15.60		

CC = continuously cultivated land; FL = forest land; EX = excavation site

The higher sand contents of the soils could be as a result of their being produced from unconsolidated deposits of sand formed over coastal plain sand (Asawalam et al., 2009; Chukwu, 2013). The removal of vegetative cover and top soil in continuously cultivated land due to severe cultivation may have exposed the soil thereby contributing to the high sand content resulting to its loamy sand texture (Jaiyeoba, 2003). The sandy loam texture in forest land, corroborated the observation of Ufot et al. (2016), who recorded sandy loam texture for a tree crop plantation and forest land in Alokwa, Imo State. The higher clay contents observed in excavation site could be due to increased mining activities (Oguike and Onwuka, 2017). This may be as a result of either increase in translocation of clay from the surface to belowground horizons or clay removal from the surface by runoff (Jaiyeoba, 2003). However, Shepherd et al. (2001) reported that changes in particle sizes as a result of land use do not show easily. The variation in bulk density observed under continuously cultivated land and excavation site may be attributed to the mechanical disruption of the pore arrangements by tillage and excavation activities, respectively (Celik, 2005). The lower bulk density of forest land may be due to the minimal soil disturbance and the presence of soil organisms in the forest (Cerdà and Jurgensen, 2008).

Atmospheric temperature

The temperature trend of the location under study over a period of 24 weeks is shown in Figure 2. The graph shows that the mean temperature was highest (28.4^{0}C) in week 14, whereas the 20th week had the lowest (25.2 ^{0}C) mean temperature. However, from 2nd week to the 7th week and from 16th week to 19th week the mean temperature was fairly constant. The location under study had experienced more 25.2 ^{0}C temperature per day. The figure shows an increasing trend in the temperature of the area. The average annual temperature increased in the range of 25.2 – 28.4 ^{0}C per week amid the study period. Erstwhile studies also indicate that warming has occurred across Nigeria (Ogolo and Adeyemi, 2009), at fluctuating rates but largely constant with global and African trends. The increasing temperature trend imposes its impact on crop production and industrial purposes by increasing the evaporative demand especially in regions where rainfall is scarce. Reduced seasonal precipitation with high evaporative demand may enhance the risks of low yields in rainfed crop production.

Soil temperature

The data of soil temperature under different land use types are shown in Figure 3. The result showed that the mean weekly soil temperature under continuously cultivated land (CC) ranged from 35.3^{o}C – 38.5^{o}C. Under forest land (FL) the mean weekly temperature of the soil was observed to fall within 30.3^{o}C – 33.5^{o}C while for excavation site (EX) the mean weekly temperature ranged from 40.0 ^{0}C – 42.6 ^{0}C. In Figure 1, it was observed that soil under excavation site had the highest mean temperature (42.6^{o}C), while forest land had the lowest (30.3 ^{o}C).

The higher soil temperature recorded in excavation site may be as a result of the greater net radiation that passes through the exposed soil surface (Ramakrishna et al., 2006). Savva et al. (2009) observed that the exposed soil surfaces (excavation site) have 10 to 20% lower albedo and higher thermal admittance, thus absorb more energy than that of continuously cultivated and forest land. The lower soil temperature under forest land may be as a result of little soil surface warming due to the dense leaf cover (Lim et al., 2008). Soil surface cooling by transpiration, evaporation and soil moisture associated with surface vegetative cover and tropical humid climate could have contributed to the lower soil temperature of the forest land (Xue and Shukla, 1993).

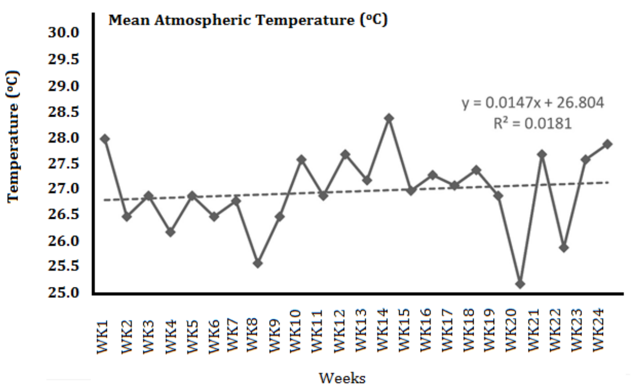

Figure 2. Mean weekly atmospheric temperature of the study area

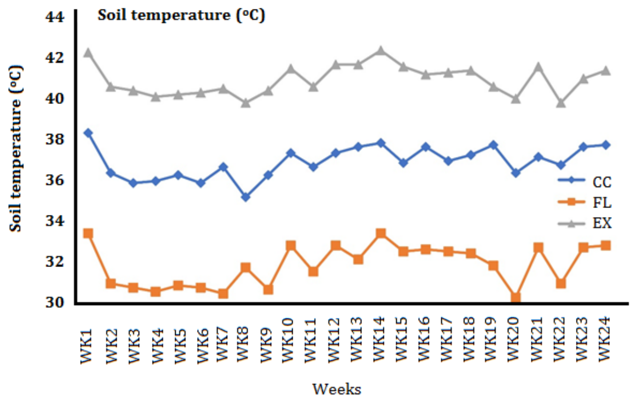

Figure 3. Mean weekly soil temperature studied

Volumetric moisture content

Figure 4 indicates the changes in volumetric moisture content in soil under different land use types. The result showed that the forest land had the highest volumetric moisture content ranging from 43.05 – 43.80 $m^3 m^{-3}$ while excavation site had the lowest of 28.97 to 29.92 $m^3 m^{-3}$. However, the soil volumetric moisture content under continuously cultivated land varied from 35.71 – 36.22 $m^3 m^{-3}$. The higher volumetric moisture content recorded under forest and continuously cultivated land than in excavation site could have been caused by the presence of soil organisms which helped in producing high organic matter content which provided a larger surface area needed for the absorption and retention of water molecules (Oguike and Onwuka, 2018). The lower volumetric water content of soils under excavation site may be due to their higher capillary rise (as a result of the high clay content) which may have stimulated the evaporation of soil moisture (Nugraha et al., 2016). Uzoma and Onwuka (2018), reported that continuous evaporation of soil moisture reduced the volumetric moisture content of soil.

Thermal conductivity

The variations in thermal conductivity under different land use types is shown in Figure 5. According to the result, the thermal conductivity was higher in the soil under forest land than that of continuously cultivated land and excavation site. The result showed that the quantity of heat transmitted through a unit length of soil per unit cross-sectional area under continuously cultivated soil ranged from 0.741 – 1.080 W mk^{-1}. Under forest land, the thermal conductivity varied between 1.640 – 2.476 W mk^{-1} while for excavation site the thermal conductivity falls between 0.598 – 0.681 W mk^{-1}. The thermal conductivities were moderate as it falls within the standard range of measurement of 0.02 – 4.00 W mk^{-1} (Oladunjoye et al., 2013).

The higher quantity of heat transmitted through the soil under forest land may be as a result of increase in soil volumetric moisture content (Figure 3). Roxy et al., (2014) observed that the presence of moisture in the soil resulted to the development of a thin water film which bridges the gaps between the soil particles thereby improving the thermal contact between soil particles. O'Donnell et al. (2009) reported that the higher soil moisture content could have enhanced the effective contact area between the soil particles and also replaced the air in the soil pores, resulting to higher heat flow thereby resulting to increased thermal conductivity. The resulting increase in soil volume probably may have provided a larger heat flow and possibly increased the soil thermal conductivity.

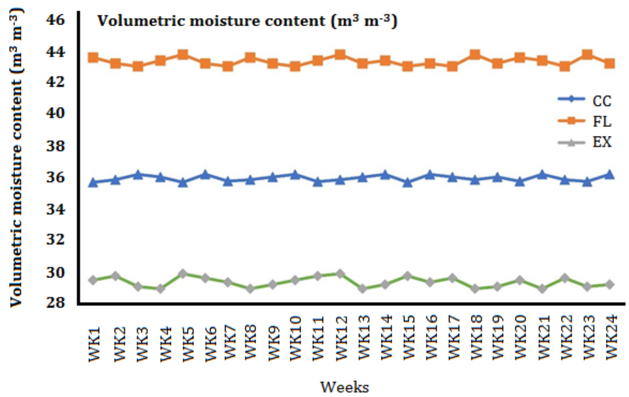

Figure 4. Volumetric moisture content of the soils studied

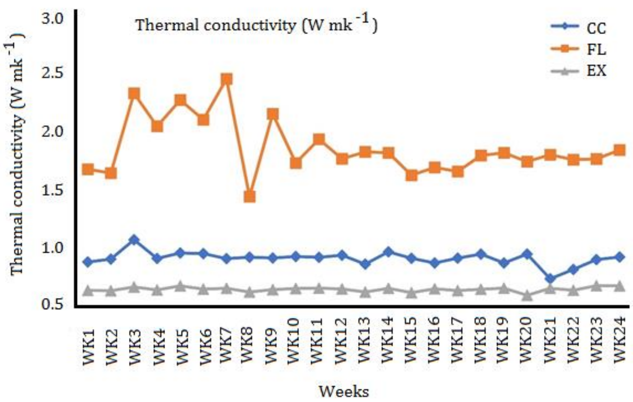

Figure 5. Thermal conductivity of the soils studied

Volumetric heat capacity

Figure 6 indicates the changes in volumetric heat capacity of the soil at different land use types. The result showed that the soil volumetric heat capacity under continuously cultivated land (CC) ranged from 1.386 – 1.407 J $(m^3K)^{-1}$. Under forest land (FL) the volumetric heat capacity of the soil was observed to fall within 1.342 – 1.386 J $(m^3K)^{-1}$ while for excavation site (EX) the soil volumetric heat capacity ranged from 1.267 – 1.290 J $(m^3K)^{-1}$. In Figure 5 it was observed that soil under continuously cultivated land had the highest volumetric heat capacity (1.407 J $(m^3K)^{-1}$), while excavation site had the lowest (1.267 J $(m^3K)^{-1}$). The changes in the volumetric heat capacity varied between the different land use types but it was highly noted in continuously cultivated land and forest land. The implications of increasing volumetric heat capacity in the soils under different land use types showed there is a positive correlation between volumetric water content and volumetric heat capacity. Gülser et al. (2019) showed that volumetric heat capacity increased from 0.497 cal cm^{-3} °C to 0.541 cal cm^{-3} °C by increasing volumetric water content from 0.286 cm^3 cm^{-3} to 0.330 cm^3 cm^{-3}. The higher volumetric heat capacity of the soil under continuously cultivated soil and forest land is probably due to adsorption of water (from soil moisture content) forming thick hulls around the soil particles, which greatly enhanced its effective heat capacity (Abu-Hamdeh, 2003).

Thermal diffusivity

Figure 7 shows the influence of different land use types on thermal diffusivity. According to the result, the soil thermal diffusivity of forest land was higher than that of continuously cultivated land and excavation site. The result showed that thermal diffusivity ranged from (0.534 – 0.779 m^2s^{-1}) under continuously cultivated land, (1.049 – 1.811 m^2s^{-1}) under forest land and (0.469 – 0.538 m^2s^{-1}) in excavation site. From the result, it was observed that the soil under excavation site had the lowest thermal diffusivity (0.469 m^2s^{-1}), while the soil of forest land under study had the highest (1.811 m^2s^{-1}).

The higher soil thermal diffusivity under forest land as compared with that of continuously cultivated land and excavation site agree with the findings of Beltrami (2001). The higher thermal diffusivity of the forest land may be attributed its higher volumetric moisture content (Figure 4) and lower bulk density (Table 1). Roxy et al. (2014) observed that as the soil moisture content increases, the thermal conductivity rises (Figure 5), because water is a good conductor of heat. Furthermore, since thermal diffusivity is directly proportional to thermal conductivity (equation VII), so when the soil moisture content increases, the thermal diffusivity also increases (Arkhangel'skaya, 2009). The soil with higher thermal diffusivity adjust quickly to their temperature to suit that of the environment because they tend to conduct heat quickly when compared to their volumetric heat capacity and they generally do not require much energy from their surroundings to reach thermal equilibrium (Oladunjoye and Sanuade, 2012).

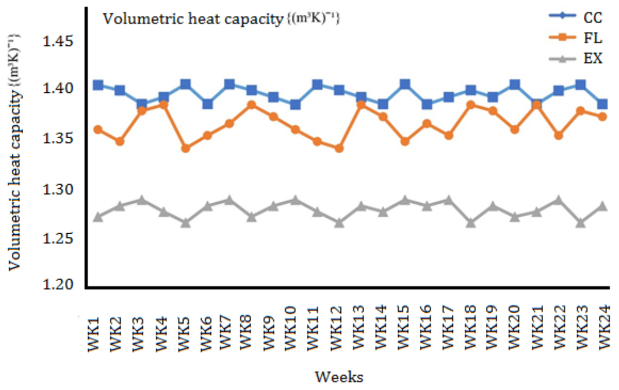

Figure. 6. Volumetric heat capacity of the soils studied

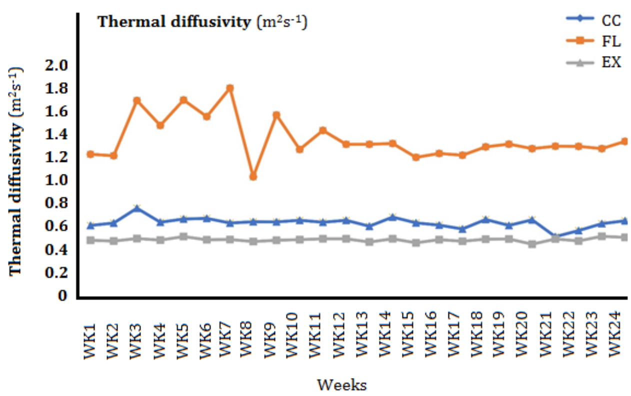

Figure 7. Thermal diffusivity of the soils studied

Heat flux

The data of soil heat flux under different land use types are shown in Figure 8. The result showed that the rate of soil heat transfer per unit area ranged from 27.64 – 38.88 $W.m^{-2}$ under continuously cultivated land, while under forest land the soil heat flux varied from 46.24 – 75.52 $W.m^{-2}$. However, the rate of soil heat transfer per unit area under excavation site ranged from 24.04 – 28.07 $W.m^{-2}$. From the results, it was observed that forest land had the highest soil heat flux followed by continuously cultivated land and excavation site. The higher soil heat transfer recorded in forest and continuously cultivated land may be as a result of the higher soil moisture content of the soil (Figure 4). Abu-Hamdeh (2003) observed that rate of heat transmissivity is faster in the soil with higher moisture content. O'Donnell et al. (2009) observed that changes in soil moisture content largely determine the variability in soil heat flux.

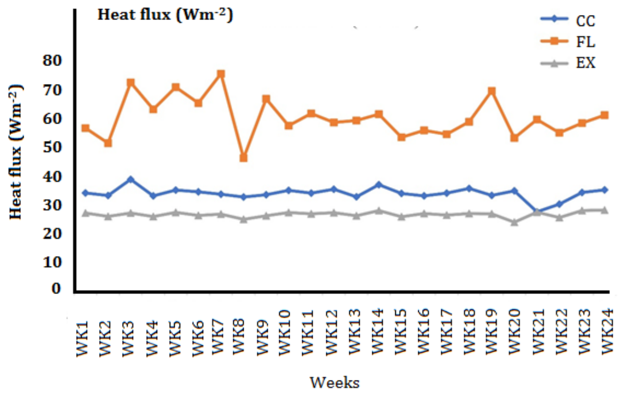

Figure 8. Heat flux of the soils studied

Conclusion

Variations in soil heat transfer under different land use types were studied in Abia state, Southeastern, Nigeria. The principal objective was to study the effects of different land use types on soil heat transfer. The result showed that the soil thermal properties varied among the different land use types. Excavation site had the highest soil temperature while forest land recorded the lowest. Higher soil bulk density and lower volumetric moisture content were observed in excavation site than in other land use types. The higher volumetric moisture content of forest land could have enhanced the increase in the amount of heat transferred and transmitted into the soil. This study suggests that the relationship between soil moisture content and heat transfer is of great importance to agriculture since it directly affects crop production. However, additional studies on the response of soil thermal properties to variations in soil moisture content are recommended.

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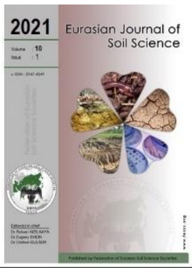

Short-term effect of rice straw application on soil fertility and rice yield

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Abstract

The study was conducted at the experimental field of the Department of Soil Science of Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Gazipur, Bangladesh during July to November 2015 in transplanted aman (T. aman) season to evaluate the influence of rice straw application on growth and yield of rice (BINA dhan7) and soil fertility. The experimentation was established following a randomized complete block design (RCBD) using 3 treatments (T1= Inorganic fertilizer dose as per STB, T2= rice straw + inorganic fertilizer as IPNS basis and T3= Farmer's practice). Results of the experiment showed that application of rice straw along with inorganic fertilizers as IPNS basis did not produce any significant ($p<0.05$) variation in yield and yield regulating parameters of T. aman rice but ensured higher filled grains panicle-1 (96.68), 1000- grain weight (23.23g), straw (6.97 t/ha) and grain yield (6.32 t/ha) as compared to other treatments. Short term addition of rice straw in soil did not create any significant influence on post harvest soil nutrient status except K which was found high. Significantly highest N contents in grain and straw were observed in straw added plots, which further contributed to higher nutrient uptake by grain and straw.

Keywords: Rice Straw, soil fertility, rice yield.

Introduction

As an agricultural country, farmers of Bangladesh grow various crops but rice cultivation is very popular throughout the country having the common cropping pattern of Boro rice- Fallow- T.aman rice (BBS, 2008). Declining soil fertility is one of the important limitations for better crop production all over the world including Bangladesh. Higher dependency on synthetic chemical fertilizers and improper nutrient management without replenishment of organic matter for intensive crop cultivation (about 200%), use of modern HYVs & hybrids varieties, cultivation of high biomass potential crops, removal of crop residues from crop fields, use of less or no organic fertilizers, lack of crop rotation, nutrient leaching have resulted in a remarkable nutrient mining from Bangladesh soils has lead to deterioration of soil health and fertility and impaired the productivity of soils in Bangladesh (Rijpma and Jahiruddin, 2004; Islam et al., 2008; Rahman, 2013). Crop residues, poultry litter, animal dung and any other natural manure available in farm household could be considered as a good source of organic fertilizer to be applied to soils (Channabasavanna, 2003).
For agricultural sustainability, nutrient recycling from different sources is very important (King, 1990). From various organic materials, it is possible to use the poultry manure as organic material in some parts of

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Bangladesh due to rapid expansion of poultry farms, while there is still inadequate availability of poultry manure in most part of the country. Moreover, some reports demonstrated the presence of heavy metals in poultry manure; therefore we have to be cautious in using poultry manure. On the other hand, number of cattle is decreasing in our country day by day due to rapid mechanization in agricultural sector. Therefore, availability of cowdung is decreasing day by day and most of the available cowdung is used as fuel. But among the organic materials, the availability of rice straw is comparatively higher all over the country as most of the farmers grow rice in their wetland fields which could easily be incorporated into the soil as a source of plant nutrients. Rice straw contains about 0.5-.8 %N, 0.16-.27% P_2O_5, 1.4-2.0% K_2O, 0.05-0.1% S and 4-7% Si (Dobermann and Fairhurst, 2002). Addition of unnecessary crop residues and straw materials to the field ensure the return of considerable amount of nutrients to the soil as well as facilitate to build nutrient reserves for a longer period of time. So it is revealed that rice straw is the best alternative to maintain organic matter status in soil as well as to sustain soil fertility. In view of the present discussion, the experiment was conducted with the aim of evaluating the influence of rice straw addition on yield regulating parameters as well as yield of rice without deteriorating soil fertility status.

Material and Methods

A study was carried out at the experimental field (Block- 9) of the Department of Soil Science of BSMRAU, Gazipur, Bangladesh from July 2015 to November 2015 to evaluate the performance of rice straw as organic manures on yield regulating parameters as well as and yield of T.aman rice. Nutrient uptake by rice as well as post harvest soil fertility status was also assessed as influenced by rice straw incorporation. The Shallow Red Brown Terrace soil of the experimental field belongs to Salna series and according to USDA classification system, soils of the study site fall under the order Inceptisol having the pH value around 5.8 (FAO, 1988). The experimental area has subtropical humid climate distinguished by intensive rain for the duration of April to September and inadequate rainfall from the period of October to March.

Before starting the field experiment, initial soil samples were collected from a depth of 0-15 cm from the experimental field. Collected samples were analyzed for pH, organic carbon (OC in %), total N (%), available P (mg/kg), exchangeable K, Ca, Mg (cmol(+)/kg) and available S (mg/kg) by the standard methods. The initial soil sample had pH of 5.7, OC 0.72%, total N 0.09 %, available P 8.59 mg/kg, exchangeable K 0.14, Ca 1.4 cmol (+)/kg, Mg 1.6 cmol (+)/kg and available S 25.93 mg/kg. Post harvest soil samples were also collected from every replicated plot (0-15 cm depth) and analyzed for different chemical properties. The field study was established following Randomized Complete Block Design (RCBD) having six replications for each treatment. The experiment had 18 unit plots where the dimension of each individual plot was 5m × 4m = 20 m^2. The spacing was 25cm × 20cm. Thirty days old seedlings of the rice variety BINA dhan 7 was transplanted in the field during T-aman rice growing season. The Cropping pattern of the field was Aus- T. aman- Boro.

The experiment was comprised of three treatments which are as follows:

T_1: Soil test based (STB) Inorganic fertilizer dose,

T_2: Rice straw + inorganic fertilizer as IPNS basis and

T_3: Farmer's practice.

Rice straw of the previous aus rice was incorporated into the wet soil (15kg straw/ plot) followed by ploughing so that the rice straw mixes well with the soil. Transplanting of the T-aman rice was carried out three weeks after rice straw incorporation. The full dose of triple super phosphate (TSP), muriate of potash (MoP) and gypsum fertilizer were added during the final land preparation, whereas urea fertilizer was applied as 3 equal installments. Firstly, it was applied at 20 days of transplanting (DOT), second installment of urea was applied at 40 DOT (maximum tillering stage) and the final split of the fertilizer was applied at 60 DOT (panicle initiation stage). Necessary amount of urea, TSP, MoP and gypsum as the source of N, P, K and S respectively were calculated using the following equation as mentioned in FRG (2012). $F_r = U_f – C_i / C_s \times (S_t - L_s)$ Based on this calculation, necessary amount of fertilizers were as follows: T1: N-P-K-S-Zn @ 65-7-28-8-1 kg/ha, T2: N-P-K-S-Zn @ 55-6-25-7-1 kg/ha and T3: N-P-K @ 69-23-38 kg/ha.

Required intercultural operations were carried out during the whole crop growing season as and when required. After harvest, data were recorded for different parameters including plant height (cm), number of tillers per hill, number of panicles per hill, number of grains per panicles, thousand grain weight (g), grain yield (t/ha) and straw yield (t/ha). Plant samples were analyzed to determine nitrogen, phosphorus and potassium using standard protocols (Jackson, 1973). Statistical analysis of the experimental data was done using the STATISTIX 10 software for windows. For the better understanding of the obtained results, mean differences of the treatments for each parameter were taken from LSD test considering 5% level of probability (Gomez and Gomez, 1984).

Results and Discussion

Yield contributing characters of rice (BINA dhan7) as influenced by rice straw management in combination with inorganic fertilizers

Plant height

Plant height of BINA dhan7 was significantly affected by different treatment combinations (Table 1). Plant height ranged from 101.2 cm in treatment T_2 (Rice straw residues + Inorganic fertilizer as IPNS basis) to 103.42 cm in treatment T_3 (Farmer's practice). The tallest plant was recorded in T_3 treatment but it was statistically comparable with T_1 treatment (Fertilizer dose as per STB). Nitrogen is the most important plant nutrients responsible for the vegetative growth of the plants. In case of T_3 treatment (Farmer's practice) highest plant height was recorded, which might be resulted because of the application of higher amounts of nitrogenous fertilizers in this treatment. Lowest plant height in rice straw + IPNS based NPK treatment might be as a result of the immobilization of nitrogen due to the addition of rice straw having higher C: N ratio (Kumar and Goh, 2000).

Table 1. Yield contributing characters of rice (BINA dhan7) as influenced by rice straw management in combination with inorganic fertilizers

Treatment	Plant height (cm)	Number of tillers hill^{-1}	Number of Panicles hill^{-1}	Panicle Length (cm)	Number of filled grains panicle^{-1}	No. unfilled grains panicle^{-1}
T1	101.80ab	14.81	14.24	23.86	95.66	21.18
T2	101.20b	14.39	13.51	23.20	96.68	17.03
T3	103.42a	15.53	14.96	23.76	93.81	21.63
S.E.(±)	0.69	0.53	0.63	0.39	3.53	2.03
CV%	0.96	5.04	6.29	2.39	5.25	14.44

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter (s) differ significantly as per LSD at 5% level of significant. Legends, CV= Co-efficient of Variation, T_1: Inorganic fertilizer dose as per STB, T_2: Rice straw residues + Inorganic fertilizer as IPNS basis, T_3: Farmer's practice

Number of effective tillers per hill

There was no significant effect of rice straw and other fertilizer treatments on the number of effective tillers hill^{-1} of BINA dhan7 (Table 1). Results of the present study illustrated that number of tillers hill^{-1} due to different treatments varied from 14.39 to 15.53. The maximum number of effective tillers hill^{-1} (15.33) was obtained from the treatment T_3 (Farmer's practice) and the minimum number of effective tillers hill^{-1} (14.39) was recorded in T_2 (Rice straw + inorganic fertilizer as IPNS basis) treatment. Our experimental findings are in line with other research result as reported by Surekha et al. (2003) where non- significant influence of rice straw on number of tillers in the first season of residue application was observed. Slow decomposition rate of rice straw in the initial stage of application might led to the lower release of plant nutrients which trigger less nutrient use efficiency and thus effective tiller became lower in rice straw applied plots than other treatments.

Number of panicles per hill

Panicle number per hill was not significantly influenced by different treatments (Table 1). Experimental results demonstrated maximum number of panicles per hill in the treatment T_3 (Farmer's practice) with a value of 14.96. In contrast, the minimum number of panicles per hill was recorded in the treatment T_2 (Rice straw + inorganic fertilizer as IPNS basis) having a value of 13.51. Our results corroborate the findings reported by Surekha et al. (2003) who observed non significant influence of rice straw incorporation on number of panicles per hills in the first season of residue application.

Panicle length

Experimental findings presented in Table 1 show that panicle length of BINA dhan 7 was affected non-significantly by different treatment combinations. It is noteworthy that variation of panicle length under different treatments was very close which ranges from 23.86 cm to 23.20 cm. Considering different treatments, the longer panicle was recorded in treatment T_1 (Fertilizer dose as per STB). On the other hand, the shorter panicle length was recorded from the treatment T_2 (Rice straw + inorganic fertilizer as IPNS basis) treatment. The longer panicle length in T_1 treatment might be attributed due to the balanced fertilization, whereas due to slow decomposition of the added straw in first season cause lower availability of plant nutrients resulting shorter panicle in T_2 treatment.

Number of filled grains per panicle

Filled grains panicle^{-1} was not significantly affected by various treatments (Table 1). Number of filled grains panicle^{-1} regarding various treatments varied between 93.81 and 96.68. Among different treatments, though there is no significant differences but the higher filled grains panicle^{-1} (96.68) was recorded in T_2 (Rice straw + inorganic fertilizer as IPNS basis) treatment and the lower number was recorded in T_3 (Farmer's practice) treatment. Our findings are in accordance with the findings presented by El-Refaee (2012) that reported the maximum number of grains/panicle in plants treated with NPK + rice straw compost and no significant differences were observed from that of recommended NPK fertilizers. Similarly, none of the yield components including number of grains per panicle were affected by the first season of residue incorporation in rice (Surekha et al., 2003).

Number of unfilled grains per panicle

Findings of the present study illustrated that unfilled grains panicle^{-1} was non-significantly influenced due to the treatments (Table 1). Study results indicated that the number of unfilled grains panicle^{-1}varied from 17.03 to 21.63. The higher number of unfilled grains panicle^{-1} was produced by the treatment T_3 (Farmer's practice). It is noteworthy that comparatively higher amounts of NPK fertilizers were applied in this treatment as compared to other treatments. This finding clearly demonstrated that grain formation is highly dependent on the applied nutrient status and higher doses of inorganic fertilizers adversely influence the grain formation in rice. Study results further revealed that lower number of unfilled grains were obtained in T_2 (Rice straw + inorganic fertilizer as IPNS basis) treatment. Suitable combination of organic and inorganic fertilizers in T_2 treatment may trigger the lower number of unfilled grains per panicle.

Thousand grain weight

The 1000–grain weight of BINA dhan7 was non-significantly affected by various treatments under the present experiment which is shown in Table 2. The 1000–grain weight was very close for different treatments and ranged from 22.47 to 23.30 g. However, there is no significant variation among the treatments but higher thousand grain weight was documented in T_1 (Fertilizer dose as per STB) treatment and the lower value was obtained from the T_3 (Farmer's practice) treatment. Our findings are well supported by the results of Surekha et al. (2003) and Ranamukhaarachchi and Ratnayake (2006) who demonstrated non-significant influence of rice straw application over inorganic fertilizers alone on thousand grain weight of rice crop.

Table 2. Grain and straw yield of rice (BINA dhan7) as influenced by rice straw management in combination with inorganic fertilizers

Treatment	Thousand grain wt (g)	Yield (t/ha)	
		Straw	Grain
T_1	23.30	6.88	6.05
T_2	23.23	6.97	6.32
T_3	22.47	6.88	6.28
S.E.(±)	0.34	0.35	0.42
CV%	2.11	12.66	16.67

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter (s) differ significantly as per LSD at 5% level of significant. Legends, CV= Co-efficient of Variation, T_1: Inorganic fertilizer dose as per STB, T_2: Rice straw residues + Inorganic fertilizer as IPNS basis, T_3: Farmer's practice.

Grain yield (t/ha)

Rice straw management practices did not demonstrate any significant influence on grain yield of BINA dhan7 (Table 2).Grain yield of rice under the present study varied from 6.05 to 6.32 t ha^{-1}. Among the treatments, higher grain yield (6.32 t ha^{-1}) was obtained in the treatment T_2 (Rice straw + inorganic fertilizer as IPNS basis). On the other hand, the lower grain yield (6.05 t ha^{-1}) was obtained in the T_1 (Fertilizer dose as per STB) treatment. These findings imply that application of rice straw for a single season could substitute some portion of synthetic inorganic fertilizers which will not affect the grain yield of rice as compared to the recommended inorganic fertilizers. Moreover, application of higher doses of inorganic fertilizers by the farmers (Treatment 3: Farmer's Practice) could easily be reduced through the application of rice straw along with inorganic fertilizers as IPNS basis without affecting the rice grain yield.

Addition of the crop residues along with straw into the soil replenish the nutrients which facilitate to create nutrient reserves in soil for a considerable period of time for sustainable production systems (Tuyen and Tan, 2001). As compared to other crop residues, availability of rice straw is comparatively higher throughout the country which could incorporate into the soil of wetland rice field very easily. Research findings often demonstrated negligible effect on rice grain yield due to the short term incorporation of crop residues, while in the long run it might benefits considerably. Tuyen and Tan (2001) observed that incorporation of rice straw may increase rice yield about 0.4 t ha^{-1} per season. Polthanee et al. (2008) and El-Refaee (2012) reported that incorporation of rice straw into soil did not increase rice yield in the immediate season, however long term effect of straw addition would increase crop yield. Our results supported the finding reported by Man et al. (2003) who observed that rice grain yield, in treatment of rice straw after decomposition combined with recommended rate of inorganic fertilizer (NPK), was not significantly different from treatment of 100% recommended rate of inorganic fertilizer application. Verma and Bhagat (1992) demonstrated that straw incorporation produced wheat yield even less than the control treatment during the first two crops. Prasert and Vitaya (1993) reported significant increase of grain yield after 3 years of rice straw incorporation into the soil.

Straw yield (t/ha)

Straw yield of rice varied non-significantly due to various fertilizer treatments and rice straw management practices (Table 2). Results displayed in table 3 indicate that the straw yield of BINA dhan 7 varied from 6.88 to 6.97 t ha^{-1}. The higher straw yield of 6.97 t ha^{-1} was obtained in T_2 (Rice straw + inorganic fertilizer as IPNS basis) treatment and the lower straw yield (6.88 t ha^{-1}) was found in T_1 (Fertilizer dose as per STB) and T_3 (Farmer's practice) treatments. Our findings are in harmony with the research results of Surekha et al. (2003) who described non-significant influence of rice straw application over inorganic fertilizers alone on the yield of rice straw during dry season of 1999 and 2000. Similar findings were also reported by El-Refaee (2012) during 2011 rice growing season in Egypt. Normally it is assumed that application of rice straw along with inorganic fertilizers would increase the grain as well as straw yield of rice over the application of recommendation doses of inorganic fertilizers. But available literature suggests that significant positive influence of rice straw application might be obtained after few years of rice straw application (Prasert and Vitaya, 1993; El-Refaee, 2012). Non significant influence of rice straw application at the initial seasons might be due to the immobilization of N resulting from incorporation of rice straw containing higher C:N (60–70) ratio, causing nitrogen deficiency to the subsequent crop (Singh et al., 2001).

Table 3. Chemical properties of postharvest soil (0-15 cm) as influenced by rice straw management in combination with inorganic fertilizers

Treatment	pH	OC	N	K	Ca	Mg	P	S
			Nutrient content in soil					
		%		cmol (+)/kg			mg/kg	
T_1	5.68	0.74	0.11ab	0.16ab	1.57	1.68	7.61	26.18
T_2	5.63	0.76	0.10b	0.20a	1.62	1.63	7.29	24.28
T_3	5.68	0.74	0.12a	0.14b	1.57	1.68	7.29	24.45
S.E.(±)	0.08	0.02	0.002	0.021	0.04	0.04	0.61	1.19
% CV	2.02	5.12	3.30	18.34	4.17	3.47	11.69	6.74

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter (s) differ significantly as per LSD at 5% level of significant. Legends, CV= Co-efficient of Variation, T1: Inorganic fertilizer dose as per STB, T2: Rice straw residues + Inorganic fertilizer as IPNS basis, T3: Farmer's practice.

Nutrient uptake by rice grain

Nitrogen uptake by grain was significantly affected by various treatments (Figure 1). Results presented in figure 1reveal that the N uptake by rice grain ranged from 75.41 to 66.20 kg ha^{-1}. Significantly highest N uptake (75.41 kg ha^{-1}) by rice grain was estimated in T_2 (Rice straw + inorganic fertilizer as IPNS basis) treatment which was statistically identical with T_3 (Farmer's practice) treatment having a value of 70.75 kg ha^{-1}. In contrast, significantly lowest N uptake (66.20 kg ha^{-1}) by grain was obtained from the T_1 (Fertilizer dose as per STB) treatment. Among the treatments, the highest N uptake in T_2 treatment might be due to higher dry matter production and nutrient concentration following straw incorporation. Kumar and Goh (2000) showed similar findings and proved that application nutrients from both organic and inorganic sources remarkably enhanced N uptake.

Phosphorus uptake by rice grain also differed significantly with various treatments (Figure 2). Study results demonstrated in Figure 2 indicate that P uptake ranged from 11.19 to 13.58 kg ha^{-1}. Significantly highest P uptake (13.58 kg ha^{-1}) was calculated in T_2 (Rice straw + inorganic fertilizer as IPNS basis) treatment which was statistically alike with T_3 (Farmer's practice) treatment. Significantly lowest P uptake (11.19 kg ha^{-1}) by grain was estimated in T_1 (Fertilizer dose as per STB) treatment which was statistically identical with T_3 treatment. Study results imply that rice straw addition in soil had profound influence on P uptake by rice grain. Straw incorporation might have enhanced the availability of both native and applied P throughout the rice growing season under submerged condition which ultimately resulted in the enhanced P uptake. The increase in available P due to incorporation of straw might be due to inactivation of Fe and Al as well as hydroxyl Al ions, which reduced the fixation of P (Subehia et al., 2005).

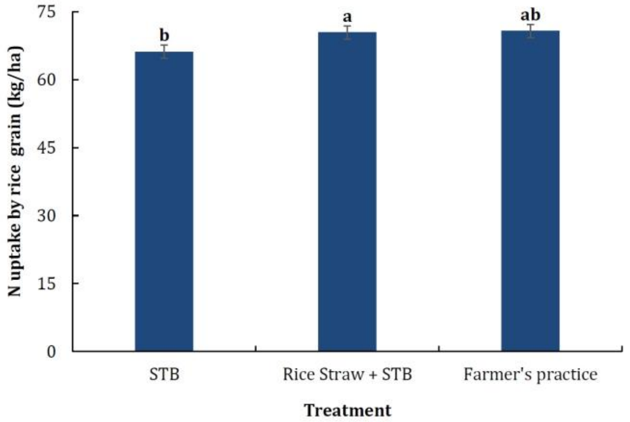

Figure 1. Nitrogen uptake by grain as influenced by rice straw management in combination with inorganic fertilizers

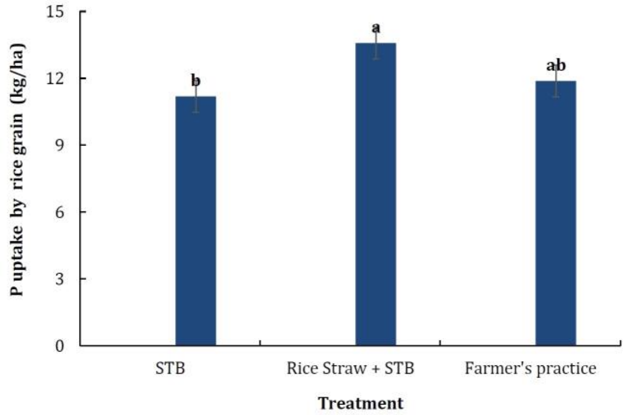

Figure 2. Phosphorus uptake by grain as influenced by rice straw management in combination with inorganic fertilizers

The potassium uptake by grain (BINA dhan7) was also significantly affected by experimental treatments (Figure 3). Potassium uptake under different treatments ranged from a value of 26.40 to 30.43 kg ha^{-1}. Statistically highest K uptake (30.43 kg ha^{-1}) by rice grain was found in T2 (Rice straw + inorganic fertilizer as IPNS basis) treatment which was statistically identical with treatment T3 (Farmer's practice) having a value of 27.40 kg ha^{-1}. On the contrary, significantly lowest K uptake (26.40 kg ha^{-1}) by grain was recorded in the treatment T1 (Fertilizer dose as per STB) which was statistically identical with T3 treatment. It was observed that straw incorporation significantly increased the nutrient uptake along with K than control where straw was not incorporated (Kumar and Goh, 2000; Rajkhowa, 2012).

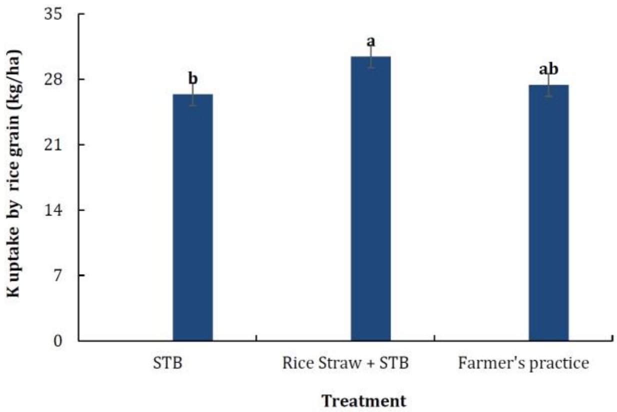

Figure 3. Potassium uptake by grain as influenced by rice straw management in combination with inorganic fertilizers

Post harvest soil properties as influenced by rice straw management in combination with inorganic fertilizers

Soil pH

There was no significant influence of rice straw management practices in combination with synthetic fertilizers on the soil pH of post-harvest soil samples (Table 3). However, considering the treatments of the study, higher pH (5.68) was estimated in T_1 (Fertilizer dose as per STB) and T_3 (Farmer's practice) treatments and lower pH in the treatment T_2 (Rice straw + inorganic fertilizer as IPNS basis) with a value of 5.63 at 0-15 cm depth. However, rice straw applied treatment showed slight decrease of soil pH which is in accordance with the research results of Sarwar et al. (2008) who noticed that addition of higher level of compost alone and in combination with inorganic fertilizer in the same level reduced the soil pH. This result is very likely as the rice straw was applied only for a single season which is not enough to influence the soil pH value.

Soil organic carbon

No significant differences were observed in the organic carbon status of the postharvest soil samples as influenced by the experimental treatments (Table 3). At 0-15 cm depth, soil organic carbon ranged from 0.74 to 0.76%. Among the different treatments, T_2 (Rice straw + inorganic fertilizer as IPNS basis) treatment showed the highest organic carbon content (0.76%). Though there is no significant variation among the treatments but rice straw treated plots demonstrated higher organic carbon content as compared to other treatments. This is possibly due to the addition of organic matter upon decomposition of rice straw residues in soil. Similar findings were achieved by Saothongnoi et al. (2014) and Pathak et al. (2006) who explained that soil organic carbon increased in rice straw applied treatment in comparison with the control treatment.

Total nitrogen content in soil

Total nitrogen content of the postharvest soil samples was significantly influenced by the experimental treatments (Table 3). Significantly highest nitrogen (0.12%) content was illustrated in T_3 (Farmer's practice) treatment which was statistically identical with T_1 (Fertilizer dose as per STB) treatment. The lowest N (0.10%) was recorded in treatment T_2 (Rice straw + inorganic fertilizer as IPNS basis) treatment. This result might be attributed due to lower mineralization of rice straw residues in the first season of application, whereas, comparatively higher doses of application of synthetic inorganic fertilizer in Farmer's practice treatment led to attribute higher total N in soil.

Available phosphorous in soil

Available P content of postharvest soil samples demonstrated no significant differences due to various treatment combinations (Table 3). Available P content varies from 7.29 mg/kg to 7.61 mg/kg. According to the fertilizer recommendation guide FRG (2012) phosphorus status ranges from low to medium. This is very common phenomena for acidic soil as their might be fixation of P in acidic soil. Considering the treatments, comparatively higher P (7.61 mg/kg) was found in T_1 (Fertilizer dose as per STB) treatment and lower available P both at T_2 (Rice straw + inorganic fertilizer as IPNS basis) and T_3 (Farmer's practice) treatment with a value of 7.29 mg/kg.

Exchangeable Potassium content in soil

Experimental results demonstrated a significant variation in exchangeable K content of the post harvest soil samples collected from a depth of 0-15 cm (Table 3). Exchangeable K content varied from 0.14 -0.20 cmol (+)/kg. The highest K (0.20 cmol (+)/kg) content was calculated in T_2 (Rice straw + inorganic fertilizer as IPNS basis) treatment but statistically comparable with T_1 (Fertilizer dose as per STB) treatment with a value of 0.16 (cmol (+)/kg). On the other hand, significantly lowest exchangeable K (0.14 cmol (+)/kg) was found in T_3 (Farmer's practice) treatment but statistically identical with T_1 treatment. Our findings are in line with the results of Gui-mei et al. (2015) and Wen-Wei et al. (2011), where it was showed increased K content in soil due to rice straw addition over control. This might be attributed due to the higher K content in rice straw which ultimate increase soil K content upon decomposition

Available Sulphur in soil

Results of the present study reveal that available S content of the postharvest soil sample was influenced non-significantly due to different treatments as shown in the Table 3. Sulphur contents ranged from 24.28 mg/kg to 26.18 mg/kg where the higher sulphur was estimated in treatment T_1 (Fertilizer dose as per STB) and the lower value was recorded in T_2 (Rice straw + inorganic fertilizer as IPNS basis) treatment.

Other nutrient status in soil

Post harvest soil samples from a depth of 0-15 cm were also analyzed to estimate Ca and Mg contents and showed no statistical differences among the treatments for both parameters (3). At 0-15 cm soil depth Ca and Mg contents ranges from 1.57-1.62 mg/kg and 1.63-1.68 mg/kg respectively. Study results demonstrated that one season addition of rice straw in crop field had no pronounced effect on most of the soil properties however it can reduce the application of synthetic inorganic fertilizers in agriculture and it is assumed that consecutive addition of rice straw for several years would increase the soil fertility as well as crop production.

Conclusion

Findings of the present experiment revealed that short term effect of rice straw application on yield attributing parameters and yield of rice (BINA dhan 7) was slight however rice straw added treatment produced higher straw and grain yield in comparison with recommended dose as well as farmers practice. Experimental results further reveal that addition of rice straw in one season in the crop field had no pronounced effect on most of the soil properties, except K content was significantly highest. However, straw addition could reduce the application of inorganic fertilizers in agriculture without affecting the crop yields and it is assumed that consecutive addition of rice straw for several years would increase the soil fertility as well as crop production.

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Changes in chemical and biological properties during co-composting of swine dung and different plant materials

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Abstract

Plant residues and animal manures have been reported to have high nutritive value. This study was carried out to evaluate different plant materials in combination with swine dung for their chemical and biological properties. Eight (8) different plant materials namely banana leaves, cassava peels, *Giliricidia sepium*, *Leuceana*, Maize stover, Neem, *Panicum maximum* and saw dust was combined with swine dung in a ratio 1:1 and composted for a period of eight weeks using the enclosed heap method. Chemical and biological parameters were monitored at a two (2) week interval. Analysis of the plant materials before composting showed that *Giliricidia sepium* was the richest in N (3.63%), P (0.14%), K (2.59%), Mg (1.07%). Banana leaves was rich in Ca (4.75%) while saw dust was rich in Cu (45.36 mg/kg) and Zn (502.85 mg/kg). At the final week, the pH of most of the swine based compost was near neutral. The combination of *Giliricidia sepium* and swine dung had the highest N (4.68 %), Zn (804.3 mg/kg) and Cu (75.44 mg/kg). *Leuceana* in combination with swine dung had the highest total P value of 0.26 % while total K was high (1.44 %) in *Panicum maximum* at the final week. However, Ca and Mg decreased at the final week. Conclusively, it can be stated that *Giliricidia sepium, Leuceana* as well as *Panicum maximum* are potential sources of both the macro and micro nutrients when combined with swine dung for compost production.

Keywords: Plant residues, Animal manure, compost production, Macro and micro nutrients.

Introduction

A good source of organic matter is decomposed compost, which is a recycled fertilizer and good as a soil amendment. Increased productivity and sustainable agriculture has been linked to the use of compost in times past, with its ability to solve the declining trend in soil fertility.

Compost although effective in increasing most of the soil physical properties such as improving the aggregate stability, increasing the water holding capacity among other properties has its limitation in supplying all the nutrients needed in the soil for plant growth. Although compost is rich in the micronutrients, it has been observed to supply less of N and moderately supply P and K. Biologically treating wastes whether from animal or plant source is co-composting and this is done towards achieving a sustainable process and zero waste. It has the ability to supply nutrients. Organic matter, total N and C:N ratio contents suitable for soil amendments have been reported with a co-composted cattle manure with rice straw (Qian et al., 2014). Stable organic matter in a matured co-composted pig manure with saw dust was reported in a study by Huang et al. (2006), using chemical and spectroscopic methods. N loss with an initial C/N ratio of 40 was observed with an amended dairy manure of 83% of moisture with either straw dust or

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straw (Michel Jr. et al., 2004). Essential plant nutrients needed by crops such cereals, legumes, vegetables and pastures has been found in swine manure (Choudhary et al., 1996). Also, swine manure has been reported to have an average of 67 % of total N as ammonium-N (Chantigny et al., 2008). Crop residues on the other hand have also been reported to have the potential to enhance soil fertility (Anguria et al., 2017). Also it has also been reported that crop residues have a significant amount of organic matter (Surekha et al., 2003). However, Auguria et al. (2017) also reported that at the initial stage of decomposition of plant residues, N and P are not usually readily available. Combining various crop residues with swine manure will make available most macronutrients for plant uptake. Therefore, this study was carried out to determine the chemical changes that occur during co-composting of swine manure with various plant residues.

Material and Methods

Preparation of the Plant based Compost

The heap method was used. Different plant materials namely cassava peels, Leuceana, saw dust, maize stover, neem clippings, *Panicum maximum, Gliricidia sepium* and banana leaves were composted with swine dung in a ratio 1:1. Composting was done for eight (8) weeks and sampling done at two (2) weeks intervals.

Chemical analysis

The modified Micro-Kjeldahl method was used for total N determination (AOAC, 1980). Total P, K, Ca and Mg was estimated in Aqua Regia digested samples and read on the atomic absorption spectrophotometer (AAS) (Chen and Ma, 2001). The aqua regia method as described by Hseu et al. (2002) was used for the determination of Cu and Zn and also read on the atomic absorption spectrophotometer (AAS). Total P was determined by the method of Jackson (1973). Potassium was measured by flame meter. Compost pH were measured as described by Rhoades (1996) and Blakemore et al. (1981) respectively.

Microbiological analysis

Determination of CO_2 evolution

The incubation-alkaline absorption method (Coleman et al., 1978) was used for the determination of microbial activity. Measurement of the moisture adjusted sub-samples was done according to the method described by Forster (1995). It was then placed in a suspended beaker containing 10 ml of 0.05 M NaOH. Incubation of the jars were done at 25 °C for 3 days in the dark immediately after sealing. The CO_2 trapped in NaOH was titrated with 0.05 M HCl at the completion of the incubation period. Respiration rate was calculated using the method of Eze et al. (2013). The amount of CO_2evolved from microbes present per gm of soil per hour (μg CO_2 g^{-1} soil h^{-1}) was used to express the final value.

Determination of bacterial and fungal abundance

At a weekly interval, 1.0 g of compost collected from each compost heap and diluted ten-folds using sterile normal saline. Inoculation of 0.1 ml aliquots from the 10^{-8} dilution onto nutrient agar and potato dextrose agar respectively by the pour plating technique was used to determine the population of viable bacterial and fungal cells in each sample. Incorporation of 50 μg of chloramphenicol/ml (v/v) was used to further make potato Dextrose agar selective for fungi. For bacteria and fungi respectively, incubation was done at 30°C for 24 h and 30°C for 5 days.

Statistical analysis

A 5 x 5 factorial experiment design, replicated three times was used for studies. Data collected were subjected to analysis of variance (ANOVA) using GenStat Discovery Edition 4,10.3D Estatistical software, and where the F-value was significant, treatment means were separated at $P \leq 0.05$ level of significance using Fisher least significant differences (LSD) (Genstat, 2011).

Results and Discussion

Chemical properties of the materials used for the composts

The materials used for the different swine based composts ranged between slightly acidic and moderately alkaline (Table 1). The least pH value was observed for *Giliricidia sepium* (6.50) while the highest value was observed for maize stover. The highest percentage total N was observed for *Giliricidia sepium* (3.63%) while swine dung had the least percentage of N (0.22%). *Giliricidia sepium* also had the highest percentage of P (0.14 %) while banana leaves had the least P value (0.05%). The highest percentage of K was also observed for *Giliricidia sepium* (2.59%) while banana leaves had the least value (0.24 %). Banana leaves was however high in percentage Ca (4.75%), followed by *Giliricidia sepium* (3.76 %) while *Panicum maximum* had the least percentage of Ca (1.57%). The percentage Mg in the materials used was not as high as Ca, however, *Giliricidia sepium* had the highest percentage Mg (1.07%) while banana leaves had the least value (0.30%). Saw dust was rich in both Cu (45.36 mg/kg) and Zn (502.85 mg/kg) while the least values for these two ions i.e Cu and Zn was observed in *Panicum maximum* with 8.97 mg/kg and 177.51 mg/kg values respectively.

Table 1. Chemical properties of the materials used for the composts

Different Composting Materials	pH	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Cu (mg/kg)	Zn (mg/kg)
BL	7.74	2.17	0.05	0.24	4.75	0.30	31.24	203.65
CP	6.92	1.02	0.13	1.30	2.68	0.60	18.54	405.18
GL	6.50	3.63	0.14	2.59	3.76	1.07	20.18	293.42
L	7.59	3.49	0.08	0.48	1.89	1.02	19.11	261.28
MS	8.32	2.22	0.11	0.42	2.17	0.74	16.98	234.58
N	7.54	2.70	0.11	0.45	2.37	0.89	14.85	308.12
PM	7.60	1.72	0.07	1.44	1.57	0.68	8.97	177.51
SW	7.69	1.98	0.13	0.33	2.01	1.01	45.36	502.85
SD	6.80	0.22	0.10	0.35	2.09	0.95	19.07	321.01

Banana leaves- BL, Cassava peel - CP, Gliricida - GL, Leuceana - L, Maize Stover - MS, Neem - N, Panicum maximum - PM, Saw dust - SW, SD- Swine dung

pH of the different swine based composts during the composting period

The pH showed significant differences among the different heaps of the swine based composts during the composting period (Table 2). The pH of the different heaps ranged between slightly acidic and moderately alkaline with combination of *Giliricidia sepium* and swine dung having the lowest pH of 6.5 and the combination of maize residue and swine dung been observed to have the highest pH of 8.32 at the start of the period. Increase in compost pH was observed at the 2nd week for most swine based composts. However, a decrease and later an increase was later observed from the 4th week to the last week of composting. At the completion of the period, pH values was between been near neutral and moderately alkaline. The combination of cassava peels and swine dung had the least pH value of 7.14 while *Panicum maximum* in combination with swine dung had the highest pH value of 8.72 at the 8th week.

Table 2. pH during composting of different feed stock

Different Swine based Composts	Initial	2nd Week	4th Week	6th Week	8th Week
BL + SD	7.74ab	8.81a	8.14a	7.77ab	8.08ab
CP + SD	6.92bc	6.92cd	6.95bc	7.07bc	7.14b
GL + SD	6.50c	6.76d	6.79c	6.85bc	7.35b
L + SD	7.59ab	7.11cd	6.80c	6.43c	7.15b
MS + SD	8.32a	7.81bc	7.75ab	7.53ab	7.72b
N + SD	7.54ab	7.82bc	7.89a	7.35abc	7.76b
PM + SD	7.60ab	8.13ab	8.51a	8.23a	8.72a
SW + SD	7.69ab	7.49bcd	7.73ab	7.64ab	7.56b
FPr	*	*	**	*	*

Letters followed by the same letters are not significantly different from each other *=($p<0.05$); **=($p<0.01$); ***=($p<0.001$); NS= Not Significant. Banana leaves + Swine Dung- BL + SD, Cassava peel + Swine Dung- CP + SD, Gliricida + Swine Dung- GL + SD, Leuceana + Swine Dung- L + SD, Maize Stover + Swine Dung- MS + SD, Neem + Swine Dung- N + SD, Panicum maximum + Swine Dung- PM + SD, Saw dust + Swine Dung- SW + SD

Population of fungi in the different swine based composts during the composting period

There were significant differences among the values obtained for the fungal population in the different swine based composts during the composting period (Table 3). The results obtained the combination of *Leuceana* and swine dung had the largest population of fungi (17 x 10^{-7}cfu/ml) while the least population of 4 x 10^{-7}cfu/ml was observed for the combination of neem and swine dung. The fungal population increased at the second week while intermittent decrease and increase was later observed in most heaps till the last week of composting. As compared to the 6th week, the population of fungi decreased at the 8th week.

Table 3. Fungal count (10^{-7}cfu/ml) during composting of different feed stock

Different Swine based Composts	Initial	2nd Week	4th Week	6th Week	8th Week
BL + SD	10 c	16 c	27 b	17 b	10 b
CP + SD	11 b	13 d	8 e	10 e	8 c
GL + SD	2 f	5 h	5 g	3 g	5 e
L + SD	17 a	24 a	69 a	12 d	11 a
MS + SD	1 g	8 f	7 f	7 f	6 d
N + SD	4 e	10 e	12 c	14 c	5 e
PM + SD	11 b	22 b	5 g	7 f	2 f
SW + SD	5 d	7 g	9 d	18 a	11 a
FPr	***	***	***	***	***

Letters followed by the same letters are not significantly different from each other *$p<0.05$; **$p<0.01$; ***$p<0.001$; NS= Not Significant. Banana leaves + Swine Dung- BL + SD, Cassava peel + Swine Dung- CP + SD, Gliricida + Swine Dung- GL + SD, Leuceana + Swine Dung- L + SD, Maize Stover + Swine Dung- MS + SD, Neem + Swine Dung- N + SD, Panicum maximum + Swine Dung- PM + SD, Saw dust + Swine Dung- SW + SD

Population of bacterial in the different swine based composts during the composting period

As observed for the fungal population in the different heaps, there were significant differences among the bacterial count obtained for the different swine based composts (Table 4). The combination of saw dust and swine dung had the largest population of bacteria (6 x 10^{-7}cfu/ml) while the least population (1.1 x 10^{-7}cfu/ml) was observed in the heap that had the combination of neem and swine dung. The bacterial population increased as observed at the 2nd week, while a decrease and later an increase was observed from the 4th week till the end of period. At the 8th week of the period, the bacterial population then decreased was observed across the different swine based composts.

Table 4. Bacterial count (10^{-7}cfu/ml) during composting of different feed stock

Different Swine based Composts	Initial	2nd Week	4th Week	6th Week	8th Week
BL + SD	1.7bc	6.0d	5.6d	10.4b	3.0d
CP + SD	1.5bc	1.6e	7.2bc	6.8d	7.6a
GL + SD	1.9bc	6.8d	10.8a	19.2a	4.0c
L + SD	1.5bc	2.3e	8.0b	3.1f	4.8c
MS + SD	1.9bc	9.2b	10.8a	2.6f	4.0c
N + SD	1.1c	9.8b	3.0e	5.8e	4.8c
PM + SD	2.1b	12.4a	7.0c	10.2b	4.6c
SW + SD	6.0a	8.0c	7.5bc	7.8c	6.3b
FPr	***	***	***	***	***

Letters followed by the same letters are not significantly different from each other *p<0.05; **p<0.01; ***p<0.001; NS= Not Significant. Banana leaves + Swine Dung- BL + SD, Cassava peel + Swine Dung- CP + SD, Gliricida + Swine Dung- GL + SD, Leuceana + Swine Dung- L + SD, Maize Stover + Swine Dung- MS + SD, Neem + Swine Dung- N + SD, Panicum maximum + Swine Dung- PM + SD, Saw dust + Swine Dung- SW + SD

CO_2 evolution of the different swine based composts during the composting period

The results obtained for the CO_2 evolution in the swine based composts showed significant differences among the different heaps (Table 5). The activities of the microorganisms were more in the heap that had a combination of *Leuceana* and swine dung while the least activity was observed for the heap that had a combination of saw dust and swine dung. The activities of the microorganisms increased from the 2nd week to the 4th week and later decreased at the six (6) weeks of composting, which continued till the 8th week.

Table 5. CO_2 evolution (mg CO_2–C kg^{-1}.) during composting of different feed stock

Different Swine based Composts	Initial	2nd Week	4th Week	6th Week	8th Week
BL + SD	2.93b	19.07ab	16.59ab	16.83a	5.39e
CP + SD	2.81bc	15.46c	16.32b	14.46b	7.03b
GL + SD	2.50bc	19.07ab	16.91ab	15.64ab	5.81de
L + SD	4.03a	17.17bc	17.48ab	15.08b	6.46c
MS + SD	1.96cd	15.89c	16.89ab	16.05ab	6.42c
N + SD	2.08bcd	17.96ab	16.80ab	10.94c	4.8 f
PM + SD	2.72bc	18.03ab	18.00a	11.4c	9.84a
SW + SD	1.22d	19.50a	17.84ab	15.64ab	6.16cd
FPr	***	**	*	***	***

Letters followed by the same letters are not significantly different from each other *p<0.05; **p<0.01; ***p<0.001; NS= Not Significant. Banana leaves + Swine Dung- BL + SD, Cassava peel + Swine Dung- CP + SD, Gliricida + Swine Dung- GL + SD, Leuceana + Swine Dung- L + SD, Maize Stover + Swine Dung- MS + SD, Neem + Swine Dung- N + SD, Panicum maximum + Swine Dung- PM + SD, Saw dust + Swine Dung- SW + SD

Nitrogen content of the different swine based composts during the composting period

Total nitrogen (N) content obtained for the different swine based composts showed significant differences (Table 6). The highest total N content was observed in the combination of *Giliricidia sepium* with swine dung (4.56%) while the least value was obtained in the combination of saw dust with swine dung. Increase in the total N content occurred at the 2nd week, with a decrease at the 4th week for most swine based compost. The total N content later increased at the 6th week and decreased at the 8th week for most of the swine based composts.

Table 6. Nitrogen (%) content during composting of different feed stock

Different Swine based Composts	Initial	2nd Week	4th Week	6th Week	8th Week
BL + SD	2.830c	2.845c	2.904c	2.904c	2.877c
CP + SD	2.264e	2.382ef	2.443d	2.434d	2.342e
GL + SD	4.558a	4.667a	4.414a	4.603a	4.678a
L + SD	4.189b	4.218b	3.611b	4.109b	4.126b
MS + SD	2.461d	2.525e	2.578d	2.555d	2.571d
N + SD	2.914c	3.086c	2.941c	3.037c	2.990c
PM + SD	2.222e	2.318f	2.264e	2.222e	2.251ef
SW + SD	1.979f	1.998g	1.914f	2.013f	2.125f
FPr	***	***	***	***	***

Letters followed by the same letters are not significantly different from each other *p<0.05; **p<0.01; ***p<0.001; NS= Not Significant. Banana leaves + Swine Dung- BL + SD, Cassava peel + Swine Dung- CP + SD, Gliricida + Swine Dung- GL + SD, Leuceana + Swine Dung- L + SD, Maize Stover + Swine Dung- MS + SD, Neem + Swine Dung- N + SD, Panicum maximum + Swine Dung- PM + SD, Saw dust + Swine Dung- SW + SD

Phosphorus content of the different swine based composts during the composting period

Significant differences were observed in the phosphorus (P) content of the different swine based composts (Table 7). The percentage P content ranged between 0.12 and 0.3 % at the start of the period and decreased at the 2nd week of the period. The P content increased at the 4th week for most of the swine based compost, decreased at the 6th week and finally increased at the 8th week. The final week of composting, combination of *Leuceana* and swine dung had the highest P content of 0.26% while the least value of 0.14% was observed for the combination of saw dust and swine dung.

Table 7. Phosphorus (%) content during composting of different feed stock

Different Swine based Composts	Initial	2nd Week	4th Week	6th Week	8th Week
BL + SD	0.30a	0.07b	0.19a	0.14a	0.24a
CP + SD	0.13ab	0.22ab	0.16a	0.20a	0.17a
GL + SD	0.15ab	0.13ab	0.18a	0.19a	0.22a
L + SD	0.17ab	0.15ab	0.21a	0.12a	0.26a
MS + SD	0.12b	0.20ab	0.21a	0.18a	0.21a
N + SD	0.12b	0.26a	0.17a	0.15a	0.19a
PM + SD	0.16ab	0.13ab	0.18a	0.17a	0.17a
SW + SD	0.12b	0.09ab	0.13a	0.14a	0.14a
FPr	*	*	ns	ns	ns

Letters followed by the same letters are not significantly different from each other *p<0.05; **p<0.01; ***p<0.001; NS= Not Significant. Banana leaves + Swine Dung- BL + SD, Cassava peel + Swine Dung- CP + SD, Gliricida + Swine Dung- GL + SD, Leuceana + Swine Dung- L + SD, Maize Stover + Swine Dung- MS + SD, Neem + Swine Dung- N + SD, Panicum maximum + Swine Dung- PM + SD, Saw dust + Swine Dung- SW + SD

Potassium content of the different swine based composts during the composting period

At the start of the preparation, there were observed differences in the potassium (K) content of the different swine based composts (Table 8). The combination of banana leaves and swine dung had the highest K content at the start of the preparation while the least value was observed for the combination of saw dust and swine dung. Increase in K content was observed for some of the swine based composts while K decreased in others at the 2nd week. However, generally, the K content increased at the 4th week of composting and later decreased in most heaps at the 6th week. At the completion of the period, increases in K content was observed across the compost heaps. The highest value was observed for the combination of *Panicum maximum* and swine dung (1.44%) which was not significantly different from the value obtained for the combination of *Leuceana* and swine dung (1.41%). The least value in the K content was observed for the combination of saw dust and swine dung.

Magnesium content of the different swine based composts during the composting period

There were observed differences in the magnesium (Mg) content at different stages of the composting period (Table 9). The combination of banana leaves and swine dung had the highest Mg content (1.33%) while the least value (0.62%) was observed for the combination of *Leuceana* and swine dung. Increases in the Mg content occurred at the 2nd week and then decreased at the 4th week. Increase in the Mg content occurred six (6) weeks after the start of the period and then decreased at the 8th week of the composting period.

Table 8. Potassium (%) content during composting of different feed stock

Different Swine based Composts	Initial	2nd Week	4th Week	6th Week	8th Week
BL + SD	0.74a	0.5bc	0.56de	1.22a	1.35a
CP + SD	0.58b	0.3d	0.26f	0.3c	1.16bc
GL + SD	0.38c	0.73a	1.37a	0.49b	1.34a
L + SD	0.56b	0.46bcd	0.93b	1.37a	1.41a
MS + SD	0.47bc	0.48bc	0.73c	0.42bc	1.32ab
N + SD	0.38c	0.72a	0.52de	0.38bc	1.28abc
PM + SD	0.49bc	0.56b	0.68cd	0.53b	1.44a
SW + SD	0.37c	0.37cd	0.42e	0.28c	1.14c
FPr	***	***	***	***	**

Letters followed by the same letters are not significantly different from each other *p<0.05; **p<0.01; ***p<0.001; NS= Not Significant. Banana leaves + Swine Dung- BL + SD, Cassava peel + Swine Dung- CP + SD, Gliricida + Swine Dung- GL + SD, Leuceana + Swine Dung- L + SD, Maize Stover + Swine Dung- MS + SD, Neem + Swine Dung- N + SD, Panicum maximum + Swine Dung- PM + SD, Saw dust + Swine Dung- SW + SD

Table 9. Magnesium (%) content during composting of different feed stock

Different Swine based Composts	Initial	2nd Week	4th Week	6th Week	8th Week
BL + SD	1.333a	0.829d	1.037a	0.854b	0.6225ab
CP + SD	1.1155b	1.203b	0.81b	1.1145a	0.7855a
GL + SD	0.859cde	1.195b	0.666bc	0.918b	0.5555bcd
L + SD	0.6235f	0.99c	1.09a	0.8985b	0.684ab
MS + SD	0.7095ef	1.278b	1.192a	0.87b	0.52bcd
N + SD	0.93cd	1.037c	0.73bc	0.88b	0.6bc
PM + SD	1.02bc	1.994a	0.591c	0.993ab	0.4285d
SW + SD	0.829de	1.21b	0.687bc	0.972ab	0.442cd
FPr	***	***	***	*	**

Letters followed by the same letters are not significantly different from each other *p<0.05; **p<0.01; ***p<0.001; NS= Not Significant.
Banana leaves + Swine Dung- BL + SD, Cassava peel + Swine Dung- CP + SD, Gliricida + Swine Dung- GL + SD, Leuceana + Swine Dung- L + SD, Maize Stover + Swine Dung- MS + SD, Neem + Swine Dung- N + SD, Panicum maximum + Swine Dung- PM + SD, Saw dust + Swine Dung- SW + SD

Calcium content of the different swine based composts during the composting period

Significant differences were observed across the weeks of composting for the different swine based composts (Table 10). At the start of the period, the highest value for Ca (3.69%) was observed in the combination of maize residue and swine dung while the least value (2.02%) occurred in the combination of *Giliricidia sepium* and swine dung. The Ca content increased as observed at the 2nd week and then started decreasing in most compost heap to the 8th week of composting.

Table 10. Calcium (%) content during composting of different feed stock

Different Swine based Composts	Initial	2nd Week	4th Week	6th Week	8th Week
BL + SD	2.675c	1.570g	2.515c	1.995e	1.845b
CP + SD	3.315b	2.490f	2.030d	3.110a	1.585c
GL + SD	2.015e	5.635a	1.950d	2.270d	1.855b
L + SD	2.770c	3.720c	3.480b	2.930b	2.335a
MS + SD	3.690a	2.955e	4.620a	2.810bc	1.660c
N + SD	2.460d	4.035b	2.390c	2.190d	1.290d
PM + SD	2.390d	3.025e	1.700e	2.710c	1.395d
SW + SD	2.445d	3.280d	1.885d	1.525f	0.930e
FPr	***	***	***	***	******

Letters followed by the same letters are not significantly different from each other *p<0.05; **p<0.01; ***p<0.001; NS= Not Significant. Banana leaves + Swine Dung- BL + SD, Cassava peel + Swine Dung- CP + SD, Gliricida + Swine Dung- GL + SD, Leuceana + Swine Dung- L + SD, Maize Stover + Swine Dung- MS + SD, Neem + Swine Dung- N + SD, Panicum maximum + Swine Dung- PM + SD, Saw dust + Swine Dung- SW + SD

Zinc content of the different swine based composts during the composting period

There were observed differences across weeks of composting as regards the zinc (Zn) content in the different swine based composts (Table 11). At the start of the composting period, the highest value for the Zn content was observed for the combination of cassava peels and swine (485.5 mg/kg) dung while the least value (342.2 mg/kg) was observed for the combination of *Giliricidia sepium* and swine dung. The Zn content decreased as observed in most compost heap at the 2nd week and later increased four (4) weeks after the composting started. At the 6th week, the Zn content increased in some heaps and decreased in others. However, at the 8th week, increase in Zn was observed for some compost heap while a decrease occurred in others. The combination of *Giliricidia sepium* and swine dung had the highest Zn content (804.3 %) while the least value (322.7 mg/kg) was observed for the combination of banana leaves and swine dung.

Table 11. Zinc (mg/kg) content during composting of different feed stock

Different Swine based Composts	Initial	2nd Week	4th Week	6th Week	8th Week
BL + SD	355.1g	290.5f	434.7c	482.5a	322.7h
CP + SD	485.5a	415.8c	304.1h	481.7b	436.3d
GL + SD	342.2h	405.5d	330.8f	417.4d	804.3a
L + SD	442.6d	288.2g	586.2b	248.7g	323.7g
MS + SD	467.3c	524.3a	305.4g	326.7f	461.2c
N + SD	367.5f	512.3b	367.8e	341.3e	501.4b
PM + SD	431.7e	196.8h	621.2a	445.1c	388.2e
SW + SD	477.6b	383.2e	432.4d	241.2h	326.9f
FPr	***	***	***	***	***

Letters followed by the same letters are not significantly different from each other *p<0.05; **p<0.01; ***p<0.001; NS= Not Significant. Banana leaves + Swine Dung- BL + SD, Cassava peel + Swine Dung- CP + SD, Gliricida + Swine Dung- GL + SD, Leuceana + Swine Dung- L + SD, Maize Stover + Swine Dung- MS + SD, Neem + Swine Dung- N + SD, Panicum maximum + Swine Dung- PM + SD, Saw dust + Swine Dung- SW + SD

Copper content of the different swine based composts during the composting period

Significant differences were observed in the different swine based composts across the different weeks of composting (Table 12). At the start of the composting period, the combination of maize stover and swine dung had the highest value (46.86 mg/kg) for the copper (Cu) content while the combination of saw dust and swine dung had the least value (23.31 mg/kg). The level of Cu increased as observed at the 2nd week for most swine based composts. However, a decrease and later an increase was observed form the 4th week to the 8th week of the composting period. At the 8th week, the combination of *Giliricidia sepium* and swine dung had the highest level of Cu (75.44 mg/kg) while the value was obtained in the heap that had a combination of saw dust and swine dung.

Table 12. Copper (mg/kg) content during composting of different feed stock

Different Swine based Composts	Initial	2nd Week	4th Week	6th Week	8th Week
BL + SD	36.65b	43.54a	29.06d	68.45a	32.33f
CP + SD	34.46c	40.17d	27.88e	23.44h	35.47e
GL + SD	25.16g	29.55f	19.87h	54.27b	75.44a
L + SD	32.28e	33.46e	38.61b	28.17g	29.44g
MS + SD	46.86a	40.55c	21.67g	34.28e	38.22d
N + SD	32.88d	11.45h	23.14f	47.46c	51.31b
PM + SD	29.84f	28.19g	30.09c	29.16f	48.05c
SW + SD	23.31h	41.02b	41.27a	46.67d	29.18h
FPr	***	***	***	***	***

Letters followed by the same letters are not significantly different from each other *p<0.05; **p<0.01; ***p<0.001; NS= Not Significant. Banana leaves + Swine Dung- BL + SD, Cassava peel + Swine Dung- CP + SD, Gliricida + Swine Dung- GL + SD, Leuceana + Swine Dung- L + SD, Maize Stover + Swine Dung- MS + SD, Neem + Swine Dung- N + SD, Panicum maximum + Swine Dung- PM + SD, Saw dust + Swine Dung- SW + SD

Discussion

The initial chemical analysis carried out on the plant materials used for the different swine based composts showed that *Giliricidia sepium* had higher levels of N, P, K and Mg followed closely by *Leuceana* while the micronutrients studied notably Cu and Zn was high in saw dust. *Giliricidia sepium* has been observed to contain appreciable levels of N, P and K (Gaisie et al., 2016).

The pH of the different swine based composts increased as compared to the initial values obtained for the chemical properties of both the plant and animal source. The liming ability must have been due to the effect of the swine dung present (Adeniyan et al., 2011). However, at the final week of composting the cassava based compost had a near neutral pH, which might be due to the release of acids from the cassava peels and swine dung.

As the decomposition process continued, increase in total N was observed, signifying release of more N into the heaps and this was evident in the heap that had a combination of *Giliricidia sepium* and swine dung. Although total N decreased at the 8th week for most of the swine based composts, increases in N was observed in some heaps and this could probably be due to effect of some of the plant materials which are rich in N (Jeschke and Heggenstaller, 2012). At the 8th week, the combination of *Giliricidia sepium* and swine dung had the highest total N and the contributory material would probably be from *Giliricidia sepium*.

The percentage total P was higher than what was observed for total K in the heaps. However, variability occurred across the weeks of composting as regards the percentage total P in the heaps but at the final week, the combination of *Leuceana* and swine dung had the highest percentage P. *Leuceana* among other green manures have been reported to be rich in P.

The initial high level of K in the combination of banana leaves and swine dung would have been due to richness of banana leaves in K (Mayadevi, 2016). However, variability occurred across the weeks of composting as regards K but the final composts was rich in K. Combining either *Panicum maximum* or *Leuceana* with swine dung had relatively higher total K value than other swine based composts. *Leuceana* and *Panicum maximum* have been identified as potential source of organic matter among other nutrients (Asaolu et al., 2014).

The secondary nutrients notably Ca and Mg, although present at the initial starting material was not highly available at the completion of the period. However, the combination of *Leuceana* and swine dung showed a potential of making Mg available over time while this observation was observed in the combination of *Giliricidia sepium* and swine dung for Ca.

For the micronutrients at the start of the period, the high level of Zn observed in the combination of cassava peels and swine dung. This could have been due to the reports of presence of Zn in cassava peels (Otache et al., 2017) coupled with the contributory factor from swine dung, which has also been reported to be rich in the micronutrients (Eteng, 2015). However, at the final week, the combination of *Giliricidia sepium* and swine dung had the highest Zn content and this could have been due to initial high levels of Zn in *Giliricidia sepium* and swine dung, which would have jointly contributed to the final high value.

For Cu, the initial high level observed in the combination of maize stover and swine dung could have been due to a quick release of Cu into the heaps. Variability occurred across the composting period but at the 8th week, the high level of Cu in the combination of *Giliricidia sepium* and swine dung could be attributed to the initial high Cu content of *Giliricidia sepium* which was then released over time coupled with the contributory richness of swine dung in Cu (Eteng, 2015).

As regards the microbial population, there were more of fungi in the compost heaps than bacteria, probably because of the lignin content in the plant materials (Varma et al., 2017). This was evident in neem with a low population of both fungi and bacteria while a high microbial population was evident in the plant materials used. However, at 8 weeks, a decrease in the microbial population occurred, signifying compost maturity and invariably stability.

The CO_2 evolution signifying activities of the microorganisms was low at the start of the period probably due to limited supply of factors such as aeration and temperature (Varma, 2015) among other factors that lead to increase in the activities of the microbes. The activities of the microorganisms started increasing at the 2nd week probably due to increase in the compost temperature from the 2nd to the 6th week (Ribeiro et al., 2017). However, at the 8th week, there was less activity of the microorganisms signifying a reduction in the decomposition process and invariably stability.

Conclusion

It was evident that there were more of fungi than bacteria in the compost heaps probably due to the lignin content in the different plant materials and their activities was more between the 2nd and 6th week signifying the period when rapid decomposition took place. However, the nutritive value of the plant materials especially *Giliricidia sepium*, *Leuceana* and *Panicum maximum* was established in terms of the high N, P, K, Cu and Zn at the end of the eight week.

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Phosphorus mineralization in response to organic and inorganic amendment in a semi-arid pasture soil

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Abstract

Phosphorus deficient soil was amended with compost (C) (organic source of phosphorus) and inorganic P (KH_2PO_4 as inorganic phosphorus) at different rates and incubated for 28 days. Six treatments were used including i) Control ii) Inorganic P (0.79 mg per 30 g of soil sample) iii) 100 % C (0.13 g) iv) 75% C (0.1 g) + 25% P (0.2 mg) v) 50% C (0.065 g) + 50% P (0.4 mg) vi) 25% C (0.03 g) + 75% P (0.6 mg). Soil respiration was recorded using Infra-red CO_2 gas analyzer. MBC was determined by using fumigation extraction method. Resin P and MBP extraction was carried out by anion exchange membranes and was determined colorimetrically. P pools were determined by using DeLuca method. Cumulative respiration microbial biomass significantly increased in organic amended soil with higher increase in soil emended with 75% C +25% P rate followed by 50% C and 50% P rate. It was concluded that compost amended with high inorganic P stimulated the formation of P labile pools which supply long term slow release of P for plants and microbes.

Keywords: Compost, microbial dynamic, phosphorus pools, pasture soil.

Introduction

Phosphorus is one of the essential nutrients which directly affect crop production and crop quality (Maranguit et al., 2016) also phosphorus is non-renewable resource which highlights the importance of phosphorus for sustainable agriculture (Horta et al. 2018). Only 10-20% of applied P is taken up by the plants because majority of applied P is quickly fixed or precipitated as poorly available P resulting in the formation of large unavailable P bank (Khan et al., 2016). Organic amendments increase soil fertility by increasing organic matter contents and supply of essential crop nutrients (Partey et al., 2014). Incorporation of organic materials to soil cause rapid increase in microbial activity and growth (Schneider et al., 2016). Organic amendments are considered to mobilize P in the soil by releasing organic acids which replace P from the fixation sites in the soil complex. Increase in P availability depends upon the type of organic amendments added to soil and their C:P ratio. Soil microbes play key role in transformation of P by decomposing and providing P back in the soil system in the form of microbial biomass (Brennan et al., 2013). Moreover, microbes can also stimulate and enhance P availability by releasing organic molecules during the decomposition of organic materials which ultimately block the sorption sites for P (Damon et al., 2014). Combined application of inorganic P fertilizer and organic sources such as crop residues, organic manure and organic wastes have the potential to stimulate soil microbial biomass synthesis and labile microbial metabolites which is labile P pool and this pool is protected in soil against fixation (Mackay et al., 2017). A better understanding of the relationship between type of organic amendment, microbial activity and changes in soil P pools is important for a better management of soil P. Present study was conducted to

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determine the effect of organic and inorganic P sources on P pools and microbial activity in a pasture soil with low P availability. Here, we tested whether the changes in P pools induced by organic amendment is applicable or not. Compost was used as organic source. Compost was used as amendment because of nutrients they have for soil, microbes and plants. Compost have high Organic C which increase soil organic matter and stimulate soil microbial biomass and other crop nutrients necessary for soil fertility and crop productivity (Sun et al., 2014).

Material and Methods

Experimental Setup

Silt loam soil was collected from 0 to 15 cm depth in Urrbrae, South Australia (Longitude 138°38′3.2″ E, Latitude 34°58′0.2″S). This site is in a semi-arid area and has a Mediterranean climate with cool, wet winters. The hot, dry summers can be interrupted by short, heavy rainfall events. Soil was collected along a transect in three 2 x 2 m plots which were at least 10 m apart. In each sampling plot, after removal of plants and surface litter, five samples of topsoil (0–15 cm) were taken and sieved to less than 2 mm followed by air-drying in a fan-forced oven at 40°C. Soil had following properties: 22% sand, 60% silt, 18% clay, maximum water holding capacity (WHC) 371 g kg^{-1}, pH (1:5) 6.3, electrical conductivity (EC) (1:5) 143 µS cm^{-1}, total organic C 17 g kg^{-1}, total organic N 1.5 g kg^{-1}, bulk density 1.3 g cm^{-1}, available P 10 mg P kg^{-1} and available N 15 mg N kg^{-1} (Table 1).

Table 1. Physico-chemical properties of semi-arid pasture soil

Property	Soil
Texture	Silt loam
Sand (%)	22
Silt (%)	60
Clay (%)	18
Bulk Density (g/cm^{-3})	1.3
Water Holding Capacity (g/kg)	378
$pH_{1:5}$	6.3
$EC_{1:5}$ µS/cm	143
Organic Carbon (g/kg)	17
Available N (mg/kg)	15
Total N (g/kg)	1.5
Available P (mg/kg)	10
Total P (mg/kg)	371

Soil was incubated prior to experiment for seven days to avoid the flush of microbial activity and water holding capacity was adjusted at 50%. After pre-incubation of unamended soil six treatment were added i) Control ii) P fertilizer in KH_2PO_4 form at the rate of 0.79 mg for 30 g soil iii) 100% compost (0.13 g for 30 g soil) iv) 75% compost (0.1 g for 30 g soil) and 25% P (0.2 mg) v) 50% compost (0.065 g for 30 g soil) and 50% P (0.4 mg) vi) 25% compost (0.03 g for 30 g soil) and 75% P (0.6 mg) (Table 2).

Table 2. Concentration of Compost, Inorganic phosphorus (P) and Nitrogen (N) added in 30 g of soil

Treatments	Organic Addition	Inorganic P	N
Control			
Inorganic P		0.790 mg	1.300 mg
100% C	0.130 g	0.200 mg	1.300 mg
75%C+25%P	0.100 g	0.400 mg	1.300 mg
50%C+50%P	0.065 g	0.600 mg	1.300 mg
25%C+75%P	0.030 g		1.300 mg

(C= Compost) (Inorganic P in the form of KH_2PO_4) (N in the form of KNO_3)

Nitrogen was added with each treatment (1.3 mg N for 30 g soil) in the form of KNO_3. Soil was sampled at day 0 (taken approximately 3 hours after amendments addition), 14 and 28 after amending the soil. Each treatment was replicated four time and sampling time was arranged in completely randomized design. After thoroughly mixing the amendments and adjusting the water holding capacity up to 50%, 30 g soil was filled in PVC cores having diameter of 3.7 cm and 5 cm long with the net bottom having mesh size of 0.75 µm (Australian filter specialist) and bulk density was adjusted to 1.4 g cm^{-3}. Cores to be sampled were placed in 1 liter jar with air tight lids and equipped with septum for respiration measurement. Centrifuge tubes containing 10 ml RO water were placed along with each core inside the jar to maintain the humidity. Jars and remaining cores were incubated at 25±1 for 28 days. On day 14, samples were collected for determination of chemical and biological properties. Then the cores to be sampled on 28th day were placed in the jar for measurement of respiration. Soil respiration was measured on days 1, 2, 3, 5, 8, 11, 14, 17, 20 and day 23 by using Infra-red CO_2 gas analyzer. After each measurement lids were open and headspace was refreshed by using a fan. The CO_2 evolved from each sample was calculated as difference between the initial and the final CO_2 concentrations for each measurement period. Infra-red gas analyzer was calibrated by using known amount of CO_2 injected to the glass jars same to the samples used. Soil samples were stored in the cold room at 4°C before determining chemical and biological analysis. P pools were measured in samples from day 0, 14 and 28 days. Compost was analyzed for pH total organic carbon (TOC), Total P and Total N (Table 3).

Table 3. Chemical composition of Compost used as organic source of phosphorus

Compost	Sample Reading
Total C (g/kg)	213.48
Total N (g/kg)	6.63
Total P (g/kg)	4.51
C/N	32.49
C/P	44.74

Analysis of organic material

Walkley-Black method was used to determine the total organic C in the compost (Nelson and Sommers, 1996). Total P was determined colorimetrically after the digestion of 0.5 g compost and cow manure in 6:1 HNO_3:$HClO_4$ mixture (Westerman, 1990).

Soil Analysis

Hydrometer method was used to determine the particle size distribution (Gee and Bauder, 1986). Soil saturated paste was prepared to determine water holding capacity (Anderson and Ingram, 1993). Soil water content was measured by 24 h drying at 105 °C. Soil pH was measured by 1:5 soil:water suspension. Total organic carbon was determined by using Walkley-Black method (Nelson and Sommers, 1996). Microbial biomass carbon was determined by using fumigation extraction of Vance et al. (1997). Available P (Resin P) and microbial biomass phosphorus extraction was carried out by anion exchange membranes following Kouno et al. (1995) and was determined colorimetrically described by Murphy and Riley (1962). P pools were determined by using DeLuca method (Biologically-Based Phosphorus Extraction Method) (DeLuca et al., 2015). $CaCl_2$-extractable P was measured by dissolving 1.11 g $CaCl_2$ in 800 ml DI water. To extract Citric acid associated P, 2.1 g citric acid was dissolved in 600 ml DI water. Enzyme solution was prepared for extrcting phophatase associated P. Reagent A and reagent B were prepared for extracting HCL associated P.

Statistical Analysis

For each sampling time there were four replications of each treatment. Cumulative respiration was analyzed by one-way ANOVA and rest of the data was analyzed by one-way ANOVA. Means were compared by Tukey Test at 5% level of significance.

Results

Cumulative Respiration

Compared to un-amended control all the treatments increased the cumulative respiration with the greatest increase in 75% C+25% P amended soil unlikely in soil amended with 100% C. Possible reason behind this is that compost was already degraded and soil was also P deficient that's why maximum respiration was recorded from soil amended with 75% C+25% P (Figure 1). In comparison to organic P sources, cumulative respiration was lower under inorganic P. Overall, organic amendment increased the soil respiration compared to un-amended control and soil treated with inorganic fertilizer. Maximum cumulative respiration was observed under the treatments where more organic C was added in the soil.

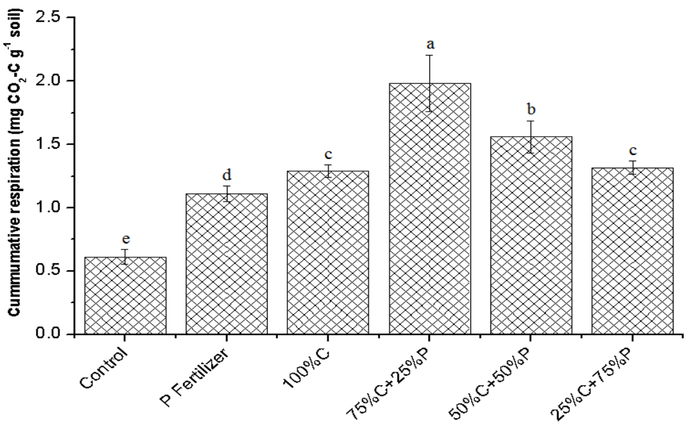

Figure 1. Cumulative respiration in response to inorganic P and compost amendments during 28 days of incubation period

Microbial biomass

Microbial biomass C (MBC) was higher in all soils amended with organic and inorganic fertilizer compared to un-amended control. Under all the treatments of compost, microbial biomass C was higher at day 0 with maximum increase in soil amended with75% P+25% C followed by 100% C (Figure 2). MBC changed over time, in P inorganic fertilizer MBC increased up to day 14. Under, 75% C+25% P amended soil MBC significantly increased after day 14. In microbial biomass carbon soil amended with 100% and 75% Compost performed better than other treatments because of the maximum concentration of organic C present in compost. Microbial biomass P (MBP) was higher in all compost amended soils compared to P fertilizer alone and un-amended soil with the highest increase in 75% C+25% P amended soil (Figure 3). Microbial biomass P significantly changed with time, it was higher at 0 and significantly decreased up to day 14 in all the compost amended soils. In P fertilizer alone and un-amended control MBP remained same at day 0, 14 and 28 also there was no significant difference between P fertilizer alone and un-amended control.

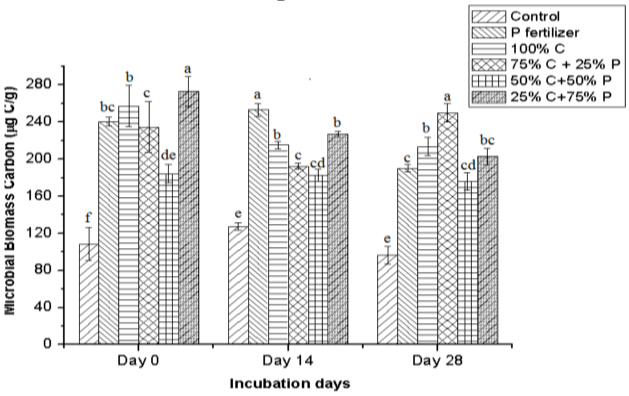

Figure 2. Microbial biomass carbon in response to inorganic P and compost amendments during 28 days of incubation period

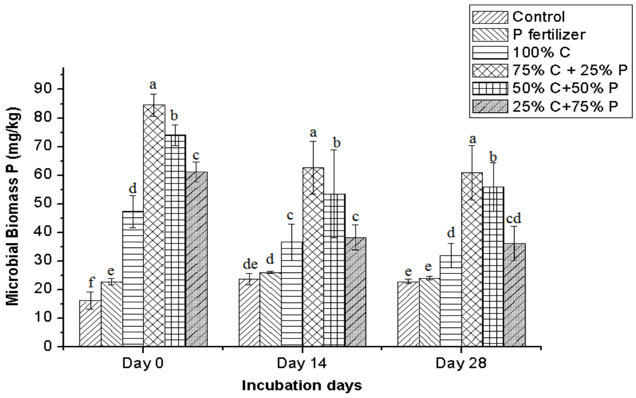

Figure 3. Microbial biomass phosphorus in response to inorganic P and compost amendment during 28 days of incubation period

Available N

Available N was significantly higher in all the amended soils compared to un-amended control with maximum increase in 75% C+25% P followed by 50% C + 50% P amended soil (Table 4). All the organic and inorganic amendments were significantly higher than un-amended control. There was no significant difference in available N between these 75% C+25% P and 50% C + 50% P soils throughout the experiment. Little change was observed in available N throughout the experiment as available N was observed higher throughout the experiment days and it was higher at day 0 and decreased a bit at day 14 and 28.

Table 4. Available N in response to inorganic P and compost amendment

Treatment	Available N (mg/kg)		
	Day 0	Day 14	Day 28
Control	0.27F	0.38F	0.31F
Inorganic P	4.52C	4.34CD	3.93D
100 % Compost	5.84BC	5.21BC	4.87BC
75% C + 25% P	7.44A	6.96A	6.83A
50% C + 50% P	7.13A	6.82B	6.74B
25% C + 75% P	6.97B	6.88A	6.81A

Available P

Resin (Available) P was significantly higher throughout the incubation time in soils amended with compost compared to P fertilizer alone and un-amended control with maximum in soil amended with 50% C+50% P followed by 75% compost + 25% P (Figure 4). Available P changed significantly throughout the study period from day 0 to day 28. Available P was highest at day 0 and decreased up to day 28 in all the treatments. There was significant difference in all sampling dates under P fertilizer alone amended soil. Organic P mixed with inorganic P had significant effect on P availability under all application rates.

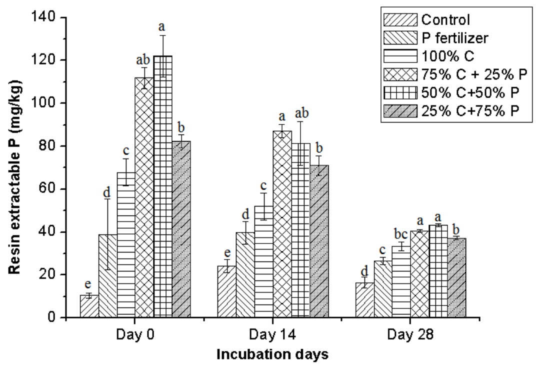

Figure 4. Available / Resin phosphorus in response to inorganic P and compost amendments during 28 days of incubation period

P pools

In the un-amended soil P pools increased in the order Citrate-extractable P (46.8%)> HCL-extractable P_i (38.8%) > $CaCl_2$-extraxtable P (7.3%) Phosphatase-extractable P (6.9%). Under all the amended treatments concentrations of Citrate-extractable P, HCL-extractable P_i, $CaCl_2$-extraxtable P_i, Phosphatase-extractable P increased by 2-3 folds compared to un-amended control. Maximum P pools were recorded in soil treated with inorganic P fertilizer which may have through mineralization (Table 5). Among all the amended treatments concentration of P pools were higher in soil amended with 75% organic and 25 inorganic P application rate. Maximum percentage of P pools was in order HCL-extractable P_i (40.4%), Citrate-extractable P (29.24%), Phosphatase-extractable P (18.35%), $CaCl_2$-extraxtable P (11.92%). Concentrations of P pools significantly decreased from day 0 to day 28 under all the treatments.

Table 5. Effect of inorganic P and compost on phosphorus pools in semi-arid pasture soil

Treatments	Citric acid-extractable P (µg/g)	HCL-extractable P (µg/g)	Phosphatase-extractable P (µg/g)	$CaCl_2$-extractable P (µg/g)
Control	125 B	106 E	23 E	17 D
P fertilizer	130 A	216 A	78 A	63 A
100% C	80 E	125 D	42 C	15 D
75% C + 25% P	114 C	141 C	35 D	37 C
50% C + 50% P	128 A	163 BC	61 B	43 B
25% C + 75% P	102 D	175 B	59 B	44 B
P-value	< 0.05	< 0.05	< 0.05	< 0.05

Discussion

Results of this study showed that inorganic P and application of P with organic amendment like compost resulted in immediate increase in labile P pools compared to un-amended soil. Generally, compost where applied at the rate of 75% C+25% P and 50% C+50% P greatly stimulated the microbial activity and growth also production of P pools and maximum microbial activity was observed under soil amended within organic P and 75% C and 25% P and 50% C and 50% P. Results and findings are being discussed based on amendment composition, forms and percentage of P added with organic amendment. Organic amendment i.e. compost significantly increased soil respiration, microbial biomass C and microbial biomass P which can be explained by the addition of high amount of C and P in the form of compost (Malik et al., 2013). Application of amendment also resulted in significant increased concentrations of both labile and non-labile P pools at day 0 which can be explained by the presence of soluble P in organic amendment. In this short period of experiment time increase in non-labile P pool (HCL-extractable P_i) can be due to immediate sorption or precipitation but there could be other possible reason that this non-labile P forms can also come from organic amendments (Schmidt et al., 2011). Different amount of inorganic P was added in compost, compost resulted in smaller increased concentrations of P pools compared to where inorganic P alone was applied, this smaller increase compared to inorganic P can be explained by the strong decomposition of compost and compost may contain complex substances and compounds like lignin and other macromolecules (Zameer et al., 2010). After the addition of compost formation of labile P pools were increased and this P pools formation was stronger with time. This formation of P pools can be explained that microbial activity and growth was higher and it increased over time and organic P pools can also be formed even when the microbial activity and growth is not increased (Malik et al., 2013). Microbial biomass C was highest at day 0 and decreased gradually over time which indicated decline in the presence of easily available decomposable organic C and this can be correlated with soil respiration in which amendments immediately increased the CO_2 evolution and after that gradually decreased and at certain point soil respiration was stable and did not changed based on the daily recorded measurement which was also due to not presence of easily decomposable organic C.

By comparing the treatments having low organic P concentration with treatments having high organic P concentration treatments it was observed that having low amount of organic P amendments significantly increased the soil respiration but that increase was lower than the increase induced by treatments having higher amount of organic P added concentrations. Similarly, microbial biomass C was enhanced by treatments having high amount of organic P and this can be explained by the addition of high amount of organic P in the form of compost resulted in high soluble P and easily decomposable organic C. Though, inorganic P addition maintained the available P. A great difference was observed in the formation of P pools between inorganic P treated soil and high P treatments with organic amendments which was clearly due to the low amount of presence of soluble P in inorganic P treatments compared with organic additions.

Conclusion

Results confirmed that organic amendment (compost) applied with inorganic P enhanced the soil respiration, microbial biomass C, Resin P and available P compared to inorganic P applied alone (due to presence of more decomposable organic C and microbial activity). Organic amendment was found less prone to sorption and precipitation compared to inorganic P because all the labile P forms were higher on all sampling days compared to un-amended soil and P fertilizer alone. P pools were also enhanced by both organic and inorganic amendments compared to un-amended control. Under compost amendment soil especially amended with high organic C concentrations along with inorganic fertilizer concentrations stimulated more microbial activity and growth and P pools formation which was due to addition of large amount of water soluble and easily decomposable C and P. Results confirmed that addition of organic P sources in the form of compost in addition to inorganic source can behave as a constant source of nutrients to microbes and plants and enhance the bioavailability of P to plants and microbes.

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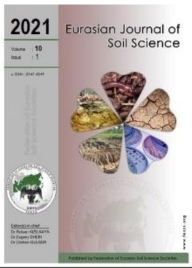

Effect of polyvinyl alcohol on the physico-chemical properties of soil and soil-amino acid interaction

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Abstract

Thin layer chromatography (TLC) is considered as an efficient analytical technique used for the monitoring and identification of the adsorption behaviour of different amino acids through soil as a stationary phase amended with polyvinyl acetate at different concentration. The study gives complete idea about the mobility of four different uncharged amino acids namely glycine, alanine, tryptophan and glutamine in terms of retention factor by thin layer chromatography. Among four amino acids, highest mobility was found in case of glycine. The order of mobility was found to be in order of glycine > alanine > tryptophan > glutamine in which distilled water has been used as a mobile phase. It has been observed from the results that pH and electrical conductivity also influence mobility of amino acids. The influence of activation temperature and particle size of soil on the mobility of amino acids was also studied.

Keywords: Soil, amino acids, electrical conductivity, pH, poly-vinyl acetate, retention factor, TLC.

Introduction

Soil thin layer chromatography is one of the most versatile techniques used for the separation and identification of some of the important organic and inorganic compounds through soil bed (Khan et al., 2000a,b). Few researchers have studied mobility of amino acids on soil bed by used soil chromatographic technique (Swarnakumari et al., 2019).

In soil, nitrogen occurs in organic and inorganic forms. Most surface soils account for greater than 95% of the total nitrogen (Ros et al., 2011). It has been found from literature that about 40% of total nitrogen exists in soils in the form of amino acids. These amino acids are divided into three different categories.

(i) They are present in dissolved form in the soil solution. They are considered as free amino acids (FAA) and freely available for plants (Jones et al., 2005a).

(ii) They are present in the form of exchangeable amino acids which are attached to charged surfaces on soil organic matter and clay particles of soil (Jones et al., 2005a).

(iii) The large fractions of amino acids are generally present in the form of proteinaceous amino acids which are present in proteins and peptides. They are called Bound amino acids (BAA) (Schulten and Schnitzer, 1997).

Bound amino acids (BAA) are mostly available indirectly to the plants and considered as reservoir. However, the concentration of FAA in soil is found to be in the range of 0-158 μM (Jones et al., 2005b).

In the present study, interaction of soil with amino acid was done by soil thin layer chromatographic technique. It was done with four different amino acids viz; glycine, alanine, glutamine and tryptophan. All

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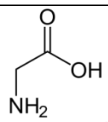
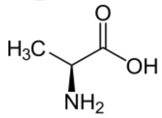
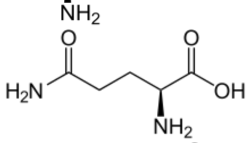
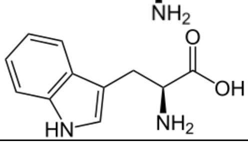
four amino acids are uncharged in nature. The different properties of glycine, alanine, glutamine and tryptophan have been tabulated in Table 1.

Table 1. Properties of glycine, alanine, glutamine and trytophan

Amino Acids	Molecular Masses (gm per mol)	Structures	Solubility (in gm per 100 ml water at 25°C)	Nature	Acidity (pKa)
Glycine	75.07		24.99	Non-Polar, uncharged	2.34 (carboxyl), 9.6 (amino)
Alanine	89.09		16.7	Non-Polar, uncharged	2.34 (carboxyl) 9.87 (amino)
Glutamine	146.14		4.13	Polar but uncharged	2.2 (carboxyl), 9.1 (amino)
Tryptophan	204.23		11.4	Non-Polar, uncharged	2.38 (carboxyl), 9.39 (amino)

Many organic waste chemicals like organic acids, alcohols, dyes, polymers, etc., enter into the soil which can affect soil properties and composition of many useful compounds and micro-organisms present in soil (Tian et al., 2020). Organic acids, alcohols, dyes and polymers come in the soil from different sources which may include plant roots and microorganisms. These compounds affect the soil quality and soil structure and part of wastewater containing dyes, polymers and alcohol can also leach in underlying ground water and affects its soil quality.

Polyvinyl alcohol (PVA) is an environment-friendly, water soluble and degradable polymer. PVA is also called as soil stabilizer (Liu et al., 2017). Its main composition is acetic-ethylene-ester polymer (Ding et al., 2002). It contains $OOCCH_3$ functional groups in large amount. PVA has a solid content of 41%, a pH of around 7, a specific gravity of 1.05 gm per cm^3 and a viscosity of 400 mPas (Aslam et al., 2018). PVA can form a viscous and elastic membrane on soil surface. The study is focused on the effect of PVA on the physico-chemical properties of soils and amino acids-soil interaction. Soil thin layer chromatography has been studied successfully by soil scientists for determination of amino acids mobility through soil bed (Khan and Moheman, 2005, Tian and Xie, 2008, Mohammad et al., 2012). Clay composition of the soil has a direct relation to mobility of amino acids in soil (Khan et al., 2012). Perhaps soil TLC could not been be used till date in the identification and separation of amino acids with soil amended with poly vinyl acetate.

Material and Methods

Four amino acids glycine, alanine, glutamine and tryptophan and ninhydrine have been purchased from CDH (India) and 0.01 M amino acid solution was prepared in distilled water. Poly vinyl acetate has been purchased from Sigma Aldrich.

Determination of physico-chemical properties of soil

For the investigation, soil sample was collected from Aligarh district (27.89° N, 78.08°E), state Uttar Pradesh, India. The sample was first dried at room temperature in tray of non-rusting material and then it was crushed in a mortar. Further it was passed through 150 µl size sieve so that uniformity in particle size can be maintained. Physico-chemical properties of soil were determined.

- The mechanical composition of soil was analyzed by standard method of 'International pipette" (Mitchell and Kenichi, 2005). The pH of soil was measured by pH meter (Elico model L1-10T).
- The soil electrical conductivity was calculated by conductivity cell by measuring the electrical cell resistance of 1:5 soil suspensions (Hanna HI 8314, USA).
- The moisture content and moisture percentage (both wet and dry) in soil has been calculated and the result obtained for the moisture content is recorded in Table 2.
- The organic matter of the soil sample was measured by Walkley and Black method (Souza et al., 2016).
- Cation exchange capacity was estimated by the Jackson method (Aprile and Lorandi, 2012). Physico-Chemical properties of soil are tabulated in table 2.

Table 2. Pyhsico-chemical properties of stationary soil phase

Parameters		Values
Mechanical composition (%)		
(i)	Sand	71.08
(ii)	Silt	19.72
(iii)	Clay	09.20
pH (1:5, soil:water)		6.73
Electrical conductivity (dSm^{-1})		0.37
Determination of moisture content		
(i)	Moisture content	10.50
(ii)	Moisture percentage (wet soil basis)	21.00
(iii)	Moisture percentage (oven-dry basis)	26.58
Exchangable cations ($Cmol(p^+)Kg^{-1}$ soil)		
(i)	Na^+	0.52
(ii)	K^+	0.82
(iii)	Ca^{2+}	5.50
(iv)	Mg^{2+}	1.50

Preparation of glass plates

To determine the R_f values of four amino acids, the soil sample were dried at room temperature, and then crushed in a mortar. It was then passed through a 150 µl size sieve so that uniform particle size can be obtained. The soil slurry was prepared in distilled water with different concentration of PVA. The resultant consistent slurry was spread onto glass plate of 200x35x 0.25 mm size. The coated plates were air dried and then it was kept in an air-tight chamber further used.

Loading of amino acids and development of plates

A 15 µl amount of the 0.01 M amino acid solution was smeared on the base line of soil coated TLC plate using micropipette. Micropipette was obtained from Abdos Labtech, India. Glass plates were developed into glass chamber by using distilled water as a developer up to a distance of 10 cm as shown by the upper line on TLC plates. Glass chamber was obtained in the laboratory from Sisco, India.

Detection of chromatograms

The developed plates were air dried at room temperature and amino acids were marked by spraying 0.2% alcoholic solution of ninhydrin (weight divided by volume). All of them were kept in an oven (Labline equipment) at temperature range of 70-80^{0}C for 20 min till appearance of pink coloured spots. Further, R_f values of amino acids was determined after the spots were stable for several days.

Results and Discussion

The separation and identification of amino acids are important because of their increasing pharmaceutical, industrial, pesticidal and toxicological applications. Figure 1 to Figure 5 illustrate R_f values of different amino acids such as glycine, alanine, glutamine and tryptophan through stationary soil phase with and without PVA at different concentration. The R_f values of glycine > alanine > glutamine > tryptophan through pure soil as a stationary phase (without PVA) and it is found to be 0.72, 0.70, 0.69 and 0.66 respectively (as shown in Figure 1). The same trend is observed in soil amended with different concentration of PVA. The trend is negatively correlated with the size and molecular weight of different amino acids. The molecular weight are 75.07 gm per mol, 89.09 gm per mol, 146.14 gm per mol and 204.22 gm per mol for glycine, alanine. tryptophan and glutamin respectively. The size of amino acid molecules is found to be affecting their diffusion rate through soil TLC. The mobility decreases with increasing order of size and molecular masses of amino acids.

The R_f values of amino acids decreases with increasing PVA concentration in soil. The impact of individual parameters is highly dependent on the characteristics of different amino acids. The mobility of amino acids is found to decrease with higher dosages of PVA in soil bed. It may be due to high adsorption capacity of PVA for amino acids. The data proves that highest mobility was observed in case of glycine in pure soil as well as in soil amended with PVA. At the different concentration of PVA viz; 0.0001, 0.001, 0.01 and 0.1 (0.001%, 0.1%, 1%, 10% respectively) amended with soil, R_f values of glycine were found to be 0.79, 0.77, 0.76 and 0.74 respectively. However, in case of alanine, tryptophan and glutamine, the same trend was observed with same concentration of PVA amended with soil. However, minimum R_f values were obtained in case of glutamine. The reduction in R_f values may be reported due to high adsorption capacity of the soil for glutamine as a result of the increased surface area of the particles. As the process of adsorption progress, equilibrium exists between adsorbate and adsorbent. The adsorbate and adsorbent combine together by the phenomenon of chemisorption. However, it is interesting to note that R_f values of all amino acids were found to be minimum in pure soil as stationary phase as compared to soil amended with PVA. It may be because of strong electrostatic force of attraction between pure soil and different amino acids. Pure soil provides a surface on which amino acids can be adsorbed easily due to its highly porous nature. On the other hand, soil amended with PVA is having poor porosity due to the already adsorbed PVA on the surface of soil.

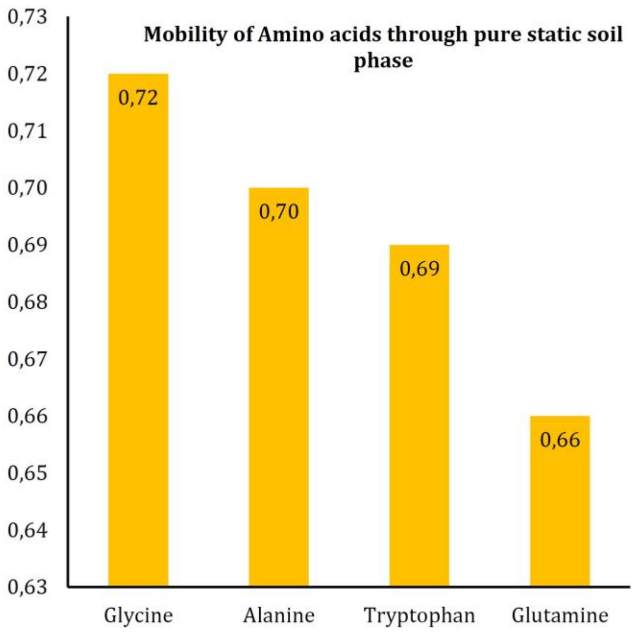


Figure 1. Mobility of amino acids through statinary soil phase

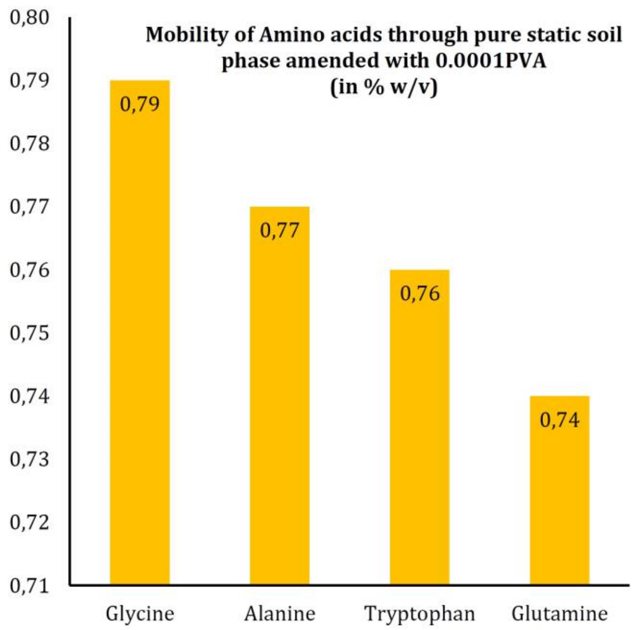


Figure 2. Mobility of amino acids through stationay soil phase amended with 0.0001PVA (in % weight divided by volume)

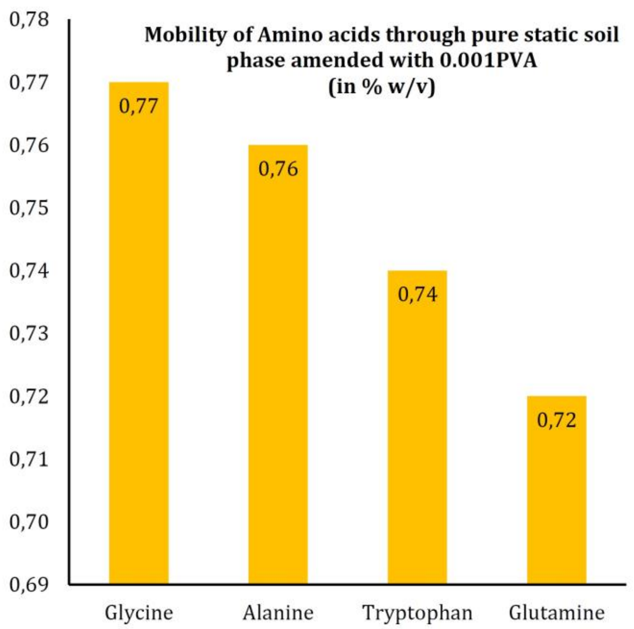


Figure 3. Mobility of amino acids through stationary soil phase amended with 0.001PVA (in % weight divided by volume)

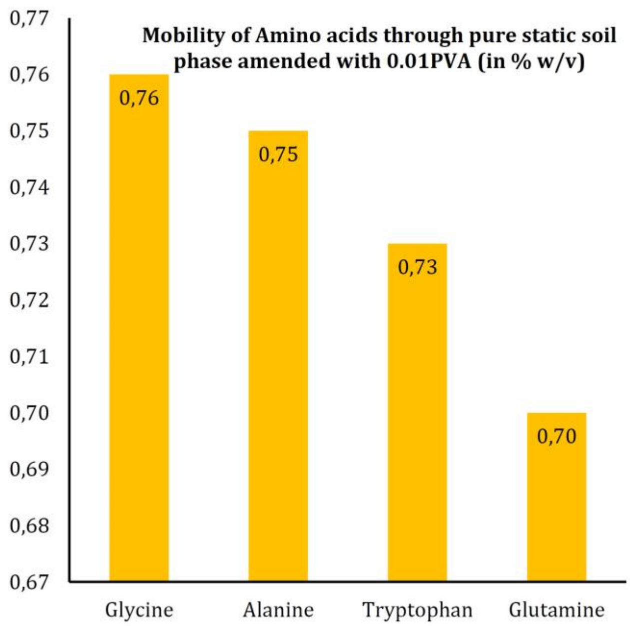


Figure 4. Mobility of amino acids through stationary soil phase amended with 0.01PVA (in % weight divided by volume)

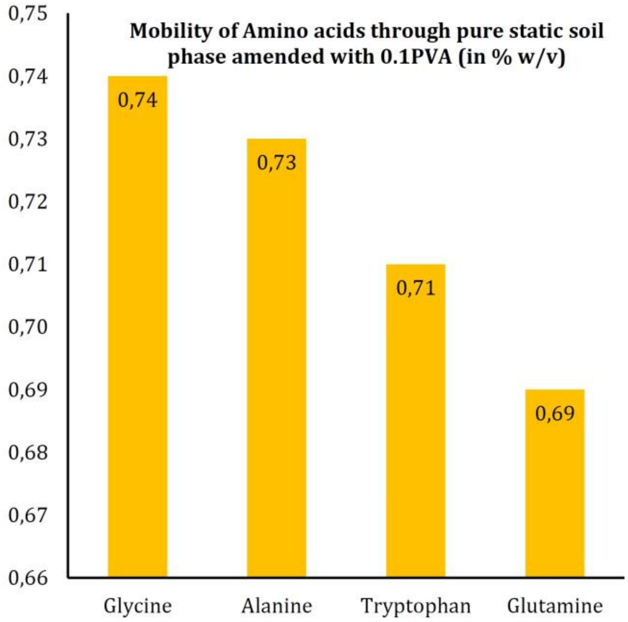


Figure 5. Mobility of amino acids through stationary soil phase amended with 0.1 PVA (in % weight divided by volume)

Effect of pH and Electrical Conductivity

The pH and EC of soil bed with different concentration of PVA have been studied and results have been indicated in figure 6. It has been observed from the results that as the concentration of PVA increases, the value of pH also increases. However, pH and EC are negatively correlated as per results. It has also been observed from the result that as the concentration of PVA increases in soil bed, EC went on decreasing. This may be due to the change in the physical structure of the soil. Soil pH also affects physical and chemical behaviour of soil. Soil electrical conductivity is directly related to salinity. Salinity generally refers to the presence of soluble salt in the soil. Soil pH may probably affect the solubility of salts. More alkaline soil is having lower values of soluble salt. Hence low value of soil pH will have high soluble salt and therefore high electrical conductivity.

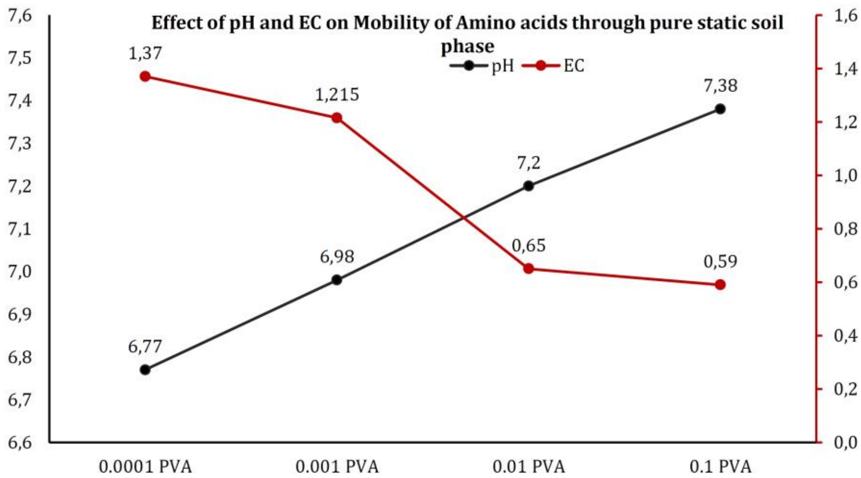


Figure 6. Effect of pH and EC on Mobility of Amino acids amended with various concentration of PVA (0.001%, 0.1%, 1%, 10% respectively)

Effect of thermal activation of plate

Soil TLC plates which dried at room temperature have been thermally activated by heating at temperature of 55-60°C for 30 min in an oven. The study was repeated using the thermally activated plates and results have been compared. It was observed that mobility of amino acids was found to be same with plates dried at room temperature as well as with thermally activated plates.

Influence of particle size of soil

Effect of soil particle size on the mobility of different amino acids was done by taking two different soil size viz; 100 mesh and 200 mesh size. The study was done under identical conditions. However, with increasing soil particle size from 100 to 200 mesh, development time for travelling of mobile phase also increases by 10 to 15 min in each case. Minor reduction in R_f values of amino acids were also observed. Although no significant changes were observed in R_f values of amino acids. Maximum reduction was only 3% from average R_f values. It may be because of an increase in the holding capacity of the soil and soil amended with PVA for amino acids as a result of the increased surface area of the particles.

Conclusion

The present work deals with physico-chemical properties of Aligarh soil and effectiveness of stationery soil phase and soil amended with PVA as an analytical tool to study the mobility of different amino acids. Results shows trend of transportation of amino acids through soil and soil amended with PVA. Results indicate that among the four amino acids, R_f values were found to be maximum in case of glycine and minimum in case of glutamine through pure soil and soil amended with PVA. All amino acids namely glycine, alanine, tryptophane and glutamine are uncharged in nature but their interaction with PVA increases the adsorption site and promotes adsorption of soil particles (clay) and soil organic matter. The mobility of different amino acids decreases with high molecular masses of amino acids. It has also been concluded from the study that as the concentration of PVA increases in soil, value of pH also increases. However, electrical conductivity is found to be decreasing with increasing concentration of PVA. It was also observed from the study that particle size of soil does not have any significance effects on the mobility of amino acids through pure soil and soil amended with PVA. It is, therefore, understood from the results that this study will provide direction for further application in the field of Soil Thin Layer Chromatography.

Acknowledgment

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Vermicomposting of anaerobically digested sewage sludge with hazelnut husk and cow manure by earthworm *Eisenia foetida*

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Abstract

Vermicomposting of organic waste has an important part to play in an integrated waste management strategy. The aim of the present study was to investigate the ability of an epigeic earthworm *Eisenia foetida* to transform anaerobically digested sewage sludge (SS) amended with hazelnut husk (HH) and cow manure (CM) in different proportions under laboratory condition (in darkness at 25°C±0,5 ^{0}C). Two approaches investigated in the study were: (1) to find the best medium for growth and reproduction of *E. foetida* in different feed mixtures, (2) to analyze the heavy metal concentrations in different feed mixtures of SS-HH-CM before and after vermicomposting, and (3) to explore heavy metals accumulation of earthworms in sewage sludge with different feed mixtures. Number and biomass of earthworms and heavy metal contents in feed mixtures and earthworms were periodically monitored. The results indicated that maximum earthworm biomass was attained in feed mixture of 20% SS + 40% CM + 40% HH while the earthworm number was highest in feed mixture of 30% SS + 35% CM + 35% HH during the vermicomposting period. Heavy metals concentration (Zn, Cu, Cd, Pb, Ni and Cr) in all feed mixtures decreased associated with the increasing vermicomposting time. The heavy metals' content in the feed mixtures was lower than that of initial mixtures. Metal analysis of earthworms revealed considerable bioaccumulation of heavy metals in their bodies' tissue. Heavy metal analysis of earthworm body showed that increasing proportion of SS in the feed mixtures promoted the heavy metal content of earthworm body.

Keywords: Vermicompost, *Eisenia feotida*, sewage sludge, heavy metal, bioaccumulation.

Introduction

It is well established that a large number of organic wastes can be ingested by earthworms and egested as stabilized humus-like product termed as vermicompost. It is much more fragmented, porous and microbially active than parent material due to humification and increased decomposition (Edwards, 1988; Garg and Kaushik, 2005; Kızılkaya, 2008). Use of earthworms in waste management, organic matter stabilization, soil detoxification and vermicompost production has been reported by Bansal and Kapoor (2000), Kaushik and Garg (2003), Garg and Kaushik (2005), Gupta and Garg (2008). The epigeic forms of earthworms can hasten

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the composting process to a significant extent with production of a better quality of compost as compared with those prepared through traditional composting methods (Ndegwa and Thompson, 2001).

The use of earthworm in sludge management has been termed as vermistabilization (Neuhauser et al., 1988). During this process, important plant nutrients such as N, P, K etc. present in the waste are converted through microbial action into forms that are much more soluble and available to plants than those in the parent substrate (Ndegwa and Thompson, 2001; Kızılkaya and Hepşen 2004, 2007). The end product, namely vermicompost is considered as an excellent product, since it is stable and homogenous, has desirable aesthetics, has reduced levels of contaminants and furthermore, is a valuable, marketable and superior plant growth medium (Aranda et al., 1999).

Sewage sludge, the solid portion that remains after waste water treatment, may be high content of nutrients (N, P, K, etc.) essential trace elements, and organic matter, which improves soil physico-chemical properties and plant nutrient status, thus rendering sewage sludge an effective and cheap alternative to commercial fertilizers. Besides the beneficial effects, potential risks to environmental health associated with either non-essential in living organisms such as Cd, Cr, Ni, Pb and essential in only trace quantities such as Cu, Fe, and Zn have received increasing attention (Mench et al., 1994; McBride, 1995; Kızılkaya and Bayraklı, 2005). For this reason, sewage sludges, including high content of potentially toxic metals, must be stabilized and/or composted with different methods and reduce toxic metal concentrations. Composting and/or stabilizing of sewage sludge is therefore recommended as a method not only to avoid plant growth inhibition but also to facilitate the handling of the dewatered sewage sludge cake where it is mixed with soil.In addition, composting and/or stabilizing offers a minimum risk for the environment or public health, especially in relation to epidemiological aspects and odors (Katayama et al., 1987).

In recent years, earthworms have been widely used in the breakdown of sewage sludge and other organic wastes in producing vermicomposts (Jain et al., 2003). Some species of earthworms are known to be potential accumulators of heavy metals and therefore they have been successfully demonstrated in mitigating the toxicity of industrial and municipal waste by vermicomposting technology (Gupta et al., 2005). This simple and low-cost technique can be used in the removal of toxic metals and the breakdown of complex chemicals to non-toxic forms (Jain and Singh 2004). Substantial evidence indicates that earthworms accumulate heavy metals from polluted soils and other media (Ireland, 1983; Goats and Edwards, 1988; Neuhauser et al., 1985; Edwards, 1996; Kızılkaya 2004, 2005). The most common earthworm used for vermicomposting is *Eisenia feotida*, commonly well known as red wigglers. Advantages of *E.feotida* are that it grows rapidly, and uses almost any organic matter as feeds. It has also wide temperate tolerance a high reproductive rate and has the capability of accumulate heavy metal accumulation in the sewage sludge vermicompost (Hartenstein, 1983; Edwards and Bater, 1992).

This study attempted vermicomposting of sewage sludge with hazelnut husk and cow manure attempted. The advantages of this utilization option are (a) it is capable of handling very low to very high quantities of sewage sludge vermicompost, (b) it is simple and cost-effective, thus appropriate for small scale as well as for large scale utilization and (c) the vermicasts have a very popular and ready markets as enrichers of soil (Abbasi and Ramasamy, 1999; Ismail, 1997). Vermicasts are believed to have several components, which improve the soil, where they are applied. Vermicasts are also believed to contain enzymes and hormones that stimulate plant growth and discourage pathogens (Abbasi and Ramasamy, 1999; Szczeck, 1999; Gupta et al., 2005). So, the main objectives of the present study were (i) to find out the appropriate proportion of sewage sludge – hazelnut husk – cow manure for sustainable and the best medium for growth of *E. feotida*, (ii) to analyze the heavy metal content in sewage sludge mixtures before and after vermicomposting, and (iii) to determine the concentration of heavy metals accumulated in earthworm tissues.

Material and Methods

Organic wastes and earthworm

Sewage sludge (pH 7.35, conductivity 1.82 dS m^{-1}, C:N ratio 9) was obtained from the wastewater facility set up by the Ankara Wastewater Treatment Plants, Ankara, Turkey. The sludge was anaerobically digested with a mixture of primary and waste activated sludge typically entering the digester. Hazelnut husk (pH 5.81, conductivity 1.93 dS m^{-1}, C:N ratio 47) collected from hazelnut trees in the Eastern Black Sea Region, Turkey. Hazelnut is one of the major cash crops in Turkey with a yield of 650 000 tons per year; it is basically produced in the Black Sea Region. Cow manure (pH 8.46, conductivity 2.35 dS m^{-1}, C:N ratio 12) mixed with minor amounts of bedding and feed refusals from different cows in Tokat, Turkey mixed within faeces type and dried in the sun. The sewage sludge (SS), hazelnut husk (HH) and cow manure (CM) on an average contained 22.9%, 53.9%, and 20.7% organic C; 2.54%, 1.14%, and 1.70% total N; 2184 μg.g^{-1}, 379 μg.g^{-1}, and

189 μg.g-1 NH_4^+-N; 1873 μg.g-1, 2490 μg.g-1, and 2294 μg.g-1 NO_3-N; 2.43%, 0.34%, and 2.66% total P; 1.14%, 2.19%, and 3.94% total K, respectively. The organic wastes (SS, HH and CM) in this experiment was digested and air dried and sieved to less than 0.5 mm and stored in polyethylene bags at 5 ^{0}C until used. The content of the some heavy metal of interest in the organic wastes are given in Table 1. The *Eisenia feotida* were collected from the same CM. Earthworms were washed with distilled water and kept for 2 weeks before starting the experiment in containers with CM at 25 ± 0.5 0C.

Table 1. Heavy metal concentrations (μg.g-1) in SS, HH and CM used in this study

Heavy metal	SS	HH	CM
Zn	15961,7	120,6	559,1
Cu	392,4	18,9	135,9
Cd	10,34	1,37	3,29
Pb	119,8	8,3	38,3
Ni	111,1	35,7	60,9
Cr	718,1	28,6	105,1

Experimental design

A randomized complete plot design with five replicates per treatment and organic wastes were used. The experiment was performed with the following 11 treatment and given in Table 2.

Table 2. Composition of treatments used for experimentation

Mixture number	Mixture Description	SS		HH		CM	
		(g)	(%)	(g)	(%)	(g)	(%)
1	0% SS + 50% HH + 50% CM	0	0	250	50	250	50
2	10% SS + 45% HH + 45% CM	50	10	225	45	225	45
3	20% SS + 40% HH + 40% CM	100	20	200	40	200	40
4	30% SS + 35% HH + 35% CM	150	30	175	35	175	35
5	40% SS + 30% HH + 30% CM	200	40	150	30	150	30
6	50% SS + 25% HH + 25% CM	250	50	125	25	125	25
7	60% SS + 20% HH + 20% CM	300	60	100	20	100	20
8	70% SS + 15% HH + 15% CM	350	70	75	15	75	15
9	80% SS + 10% HH + 10% CM	400	80	50	10	50	10
10	90% SS + 5% HH + 5% CM	450	90	25	5	25	5
11	100% SS + 0% HH + 0% CM	500	100	0	0	0	0

The organic wastes (SS, HH and CM) were thoroughly mixed (Table 2) on air-dried weight basis by a mixer. These mixtures (500 g dry weight) were placed in a 1-L cylindrical plastic container. Then, three clitellated earthworm Eisenia foetida each weighing between 0.6 and 0.7 g, were placed in the mixed material. Each treatment was replicated three times. The samples were first adjusted to 50% of the soil water holding capacity by adding distilled water and then pre-incubated at 25 ^{0}C for one day (conditioning period). After conditioning, the moisture content of the mixture was maintained at 70% throughout the vermicomposting period and the containers were maintained in darkness at 25°C ± 0,5 ^{0}C. Because, optimal environmental conditions for the growth and reproduction of *E.foetida* fed on wastes are a temperate range of 15-25 °C, moisture content of 43-90% and pH of 5-9 (Kaplan et al., 1980; Edwards, 1988; Neuhauser et al., 1988; Edwards and Bater, 1992). Substrate samples collected every 15 days during vermicomposting period (90 days) to determine the heavy metal distribution, and were stored in plastic vials at 4°C until analysis. Earthworm numbers and biomass gain were recorded for every vermicomposting period.

Changes in the total earthworm mass and the number within each maturity category were determined 15 days. All worms and vermicompost were taken from the core and placed onto a tray. Under red light (to minimise stress) the worms were separated from the vermicompost. Worms separated from the vermicompost were washed thoroughly under slow running water. Most vermicompost separated from the worms freely and was easily removed; however some vermicompost clung to the worms and required further washing. The worms were classified by maturity category into adults, subadults and juveniles. Adults were classified by the presence of a large and clearly visible clitellum. Subadults had no clitellum and tended to be smaller than the adults. Juveniles were very small and transparent. Each category was counted, weighted and immediately stored at -80 ^{o}C to use during the heavy metal analysis.

Total heavy metal contents in vermicompost

The total heavy metal contents of the vermicomposts were determined by atomic absorption spectrophotometry (Perkin Elmer A400) following a digestion with a mixture of Aqua Regia-HNO_3 and HCI.

Heavy metal contents in earthworms body

Earthworms were oven-dried in glass flask at 105^{0}C. The dried earthworms were digested overnight in nitric acid at a rate of 1 ml HNO_3 per mg dry weight of earthworm. After heating at 120^{0}C and evaporation, 1 ml $HNO_3/H_2SO_4/HCI$ (10/2/3; v/v/v) was added. The solution was heated at 180^{0}C; after cooling, samples were diluted with deionized water up to 25 ml. The concentrations of copper and zinc in earthworms were determined by flame atomic absorption spectrophotometry using and air-acetylene-flame device (Perkin Elmer A400) (Scaps et al., 1997).

Bioaccumulation Factors (BAF)

BAF for earthworm E.feotida were estimated based on the heavy metals in earthworm tissues and substrate materials using the method described by Pearson et al. (2000). The BAF is defined as follows: BAF=Cbiota/Csubstrate, where Cbiota and Csubstrate were the total heavy metal concentrations (in μg.g^{-1}) in taxa (earthworm) and substrate (used for vermicomposting experiment), respectively. It was possible to obtain BAF estimates for heavy metals since the earthworm concentrations for these metals reached steady state levels during the testing period.

Statistical analysis

All data were analyzed using SPSS 11.0 (Statistical Package for Social Science) statistical software. Analysis of variance (two-way ANOVA) was carried out using two factors randomized plot design (mixture ratio and vermicomposting period). The means were compared using by the LSD (Least Significant Difference) test, with a significance level of $P < 0.01$. All the figures presented include standard deviation of the data. The asterisks, *, ** and *** indicate significance level at $P<0.05$, 0.01 and 0.001 respectively.

Results and Discussion

Earthworm production and reproduction

Figure 1 and 2 show the values obtained from the experiments for production and reproduction in *Eisenia foetida* in different feed mixtures. Increasing proportion of SS in the feed mixtures caused the decrease in survival and growth of *E.foetida*. Mortality was recorded in ≥ 60% SS feed mixtures (mixture no 7, 8, 9, 10, 11) at all vermicomposting period. This indicated that a greater percentage of SS in the feed mixture was significantly toxic for the production and reproduction of *E.foetida*. This situation may be related high NH_4-N and Zn concentrations of anaerobically digested SS. Similarly, Elvira et al. (1997) showed worms were unable to survive in paper-pulp mill sludge; however, feed mixtures of paper-pulp mill sludge with pig and poultry slurry were suitable materials for vermicomposting. They attributed this mortality to degradation processes, resulting in changes of the environmental characteristics. Masciandaro et al. (2002) have also reported the some results for vermicomposting of anaerobic and aerobic sludges using *E.foetida*. In this study, feeds having higher percentage of anaerobic sludge were not accepted by the worms. The other study conducted by Harstenstein and Mitchell (1978) determined that anaerobically digested sludge was found to be acutely toxic to *E.feotida* but this toxicity a disappeared when the sludge was allowed to age for 2 months as thin layers exposed to air. On the other hand, Edwards (1988) indicated that organic wastes containing much ammonia (> 500 μg.g^{-1}) or large amounts of inorganic salts are toxic to *E.feotida*. In addition, Harstenstein and Mitchell (1978) suggested that various sludge treatments with salts of heavy metal at these concentrations were not toxic to *E.feotida* over a six week period: Cd at 100 μg.g^{-1}, Ni at 1000 μg.g^{-1}, and Pb at 5000 μg.g^{-1}. The same sludge treated with Cu at 2500 μg.g^{-1} or with Zn at 10000 μg.g^{-1} was toxic.

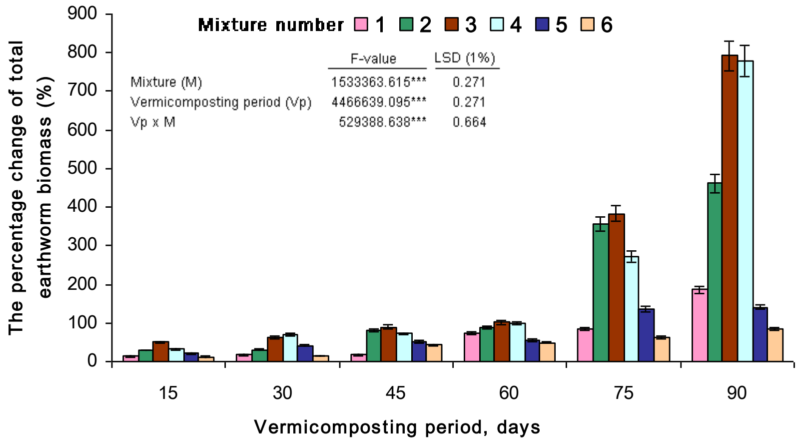

Figure 1. The percentage change of total earthworm biomass in experimental units obtaining different feed mixtures treatments (n=5).

During the vermicomposting period, the percentage changes of total earthworm biomass production by E. foetida in different feed mixtures were given in Figure 1. The numbers of *E. foetida* in the studied feed mixtures associated with observation period were given in Figure 2. In all feed mixtures, significant differences in the total earthworm biomass were recorded. The percentage change of total earthworm biomass was similar in all vermicomposting periods. Feed mixtures no.3 (20% SS + 40% CM + 40% HH) had the highest worm masses while the lowest was observed in the 50% SS + 25% CM + 25 HH feed mixture (no.6) at *P*<0.001.

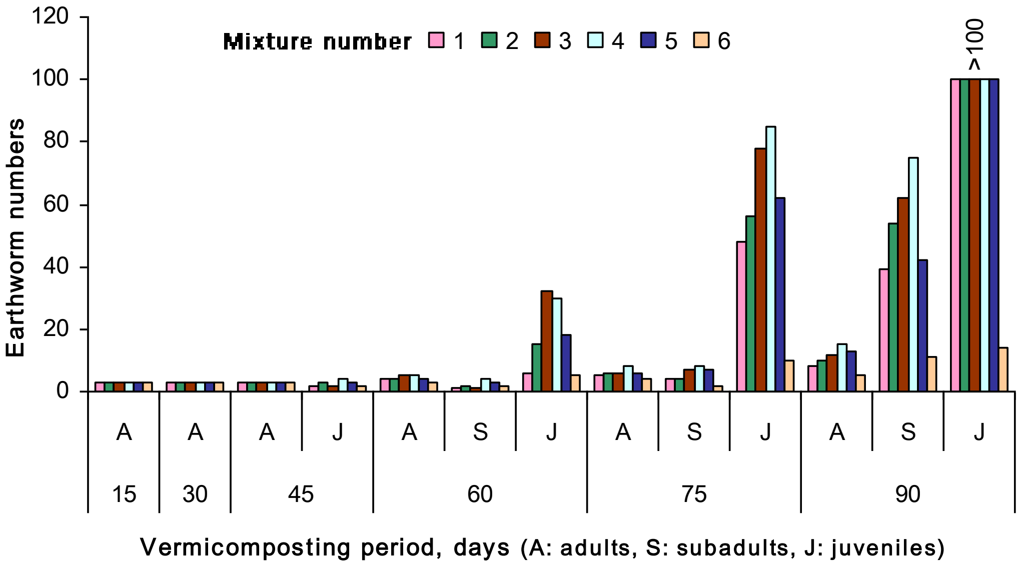

Figure 2. Population dynamics of earthworm *E.feotida* in experimental units obtaining different feed mixtures treatments (n=5).

Increasing percentage of SS in the feed mixtures led to decrease in the number of earthworm *E.feotida*. The net number gain by *E.foetida* was higher in feed mixtures no. 3 and 4 compared to other feed mixtures. The maximum earthworm biomass and number were observed in the 75th or 90th day in all the feed mixtures. Based on the results of six sampling dates for each class of worms, there was interaction between sampling time and feed mixture. However, the population dynamics within mixture feeds tended to be cyclical; for example, mixture feeds had high numbers of adults at three sampling time and low adult numbers, then at the next sampling time, the reverse was recorded. To account for this cyclical shift in populations were depicted in Figure 2.

Total heavy metal contents in vermicompost

Heavy metals appear in the sewage sludge from a variety of sources like batteries, consumer electronics, ceramics, light bulbs, plastics, house dust and paint chips, etc. So, the vermicompost made from sewage sludge may have higher heavy metal concentrations (Gupta and Garg, 2008). In small amounts, many of these elements may be essential for plant growth, however, in higher concentrations they are likely to have detrimental effects upon plant growth (Whittle and Dyson, 2002). So, prior to vermicompost application to the soils, there is in need of determining the heavy metal concentrations in final vermicomposts. The results indicated that initial heavy metal contents of SS were higher than HH and CM (Table 1), resulting in higher heavy metal concentrations in SS containing initial feed mixtures. Table 3 presents the heavy metal status in different mixtures of SS, HH and CM before vermicomposting.

Table 3. Heavy metal concentrations ($\mu g.g^{-1}$) in mixture feeds before vermicomposting

Heavy Metal	Mixture number					
	1	2	3	4	5	6
Zn	339,89	1902,07	3464,26	5026,44	6588,62	8150,81
Cu	77,40	108,90	140,40	171,90	203,40	234,90
Cd	2,33	3,13	3,93	4,73	5,53	6,34
Pb	66,87	132,00	197,12	262,25	327,37	392,50
Ni	23,28	32,92	42,57	52,22	61,87	71,52
Cr	48,32	54,60	60,88	67,17	73,45	79,73

The results of comparisons revealed that heavy metal concentrations in final vermicompost in the feed mixtures no. 1–6 were lower than that of the initial feed mixtures (Figure 3) and these heavy metal concentrations increased from the feed mixtures no 1 to 6. Feed mixtures no 4–6 contained more SS than that of feed mixtures no 1–3. Heavy metal concentrations in the vermicompost decreased associated with time increasing (Figure 3).

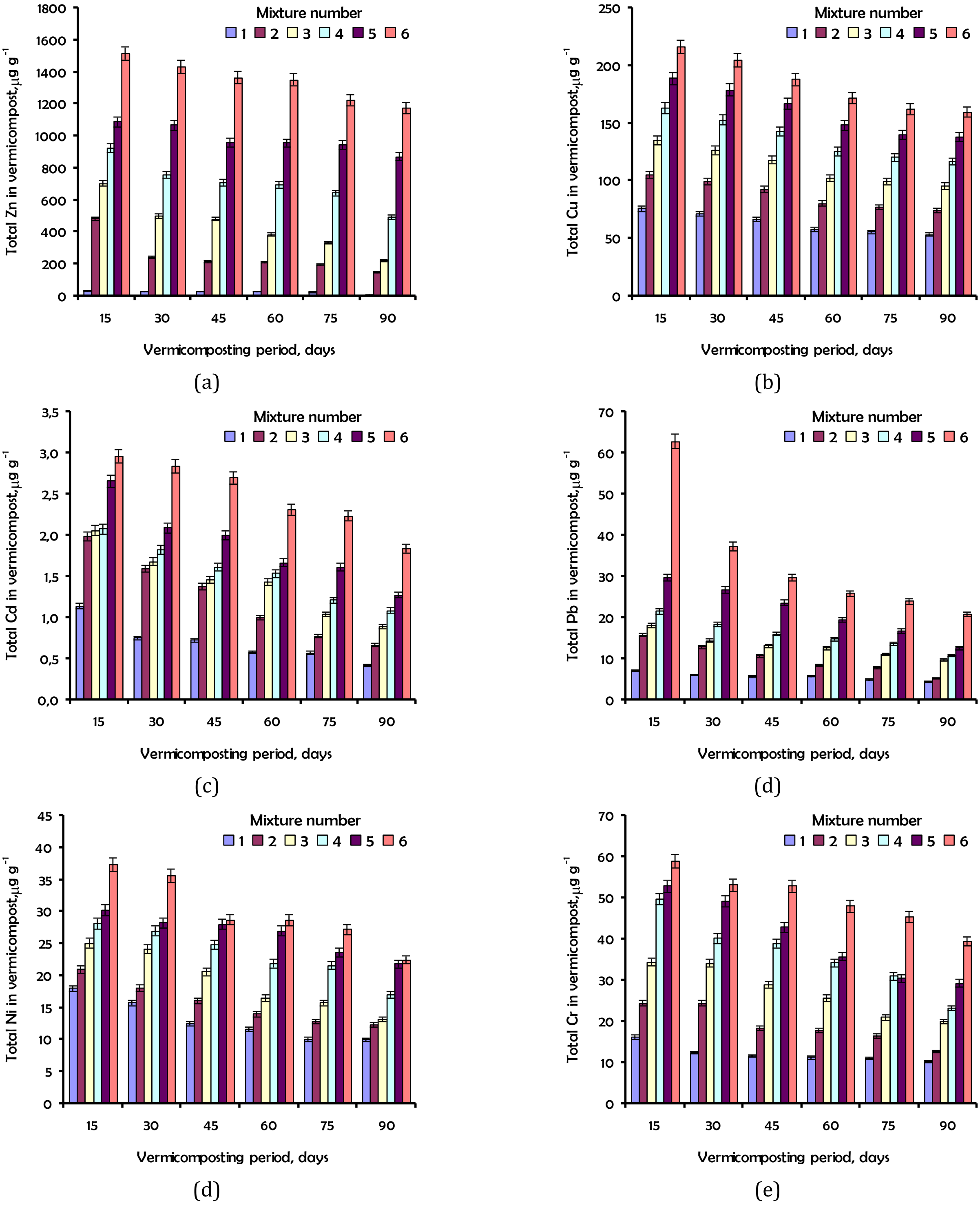

Figure 3. Changes in heavy metal concentrations (μg.g-1) in vermicomposting of different feed mixtures associated with time during vermicomposting process. Vertical bars indicate standard error of mean of three replicates at 95% confidence level. a) Zn b) Cu c) Cd d) Pb e) Ni f) Cr

Zn was the highest concentrations in all mixture feeds and followed by Cu, Cr, Pb, Ni and Cd. The analysis of postvermicomposted samples revealed considerable decline in metal concentrations in all mixture feeds. The results of ANOVA (Table 4) indicated that there were significant differences among feed mixtures for the contents of Zn, Cu, Cd, Pb, Ni and Cr at different vermicomposting period.

Table 4. Results of ANOVA

		Mixture (M)		Vermicomposting period (VP)		M x VP	
		F-value	$LSD_{\alpha=0.01}$	*F*-value	$LSD_{\alpha=0.01}$	*F*-value	$LSD_{\alpha=0.01}$
Metals in vermicompost	Zn	16540,184***	14,583	751,316***	14,583	46,145***	35,721
	Cu	15211,053***	1,045	2132,948***	1,045	36,015***	3,440
	Cd	11854,068***	0,021	5271,295***	0,021	86,898***	0,052
	Pb	11285,000***	0,355	3434,383***	0,355	561,634***	0,870
	Ni	12515,521***	0,224	4535,933***	0,224	95,949***	0,548
	Cr	14032,726***	0,452	2844,023***	0,452	128,698***	1,108
Metals in Earthworm body	Zn	16650,914***	68,047	648,531***	68,047	44,540***	166,681
	Cu	6058,989***	0,501	4714,220***	0,501	1348,415***	1,227
	Cd	14797,186***	0,036	2502,279***	0,036	34,193***	0,088
	Pb	15248,899***	0,430	2097,935***	0,430	36,192***	1,053
	Ni	10417,604***	0,321	7020,564***	0,321	18,785***	0,786
	Cr	16215,307***	2,852	1100,241***	2,852	41,510***	6,987
Bioaccumulation factor	Zn	6273,274***	0,188	2916,186***	0,188	1667,778***	0,461
	Cu	2516,827***	0,002	7206,373***	0,002	1641,486***	0,004
	Cd	5323,754***	0,015	9396,826***	0,015	591,053***	0,038
	Pb	9617,526***	0,020	5594,875***	0,020	482,634***	0,049
	Ni	12995,577***	0,013	2334,413***	0,013	402,773***	0,033
	Cr	9122,221***	0,028	4789,747***	0,028	724,567***	0,069

*** $P<0.001$

Based on the chemical analysis of vermicomposted samples, considerable reduction in heavy metals concentrations was observed for all feed mixtures (Figure 4). Vermicomposted material had reduced heavy metal content at the end of the experiment. The reductions ranged between 74.6 and 98.3% for Zn, 2.1 and 32.0% for Cu, 36.6 and 81.8% for Cd, 12.2 and 84.3% for Pb, 53.2 and 79.2% for Ni and between 75.8 and 91.1% for Cr (Figure 4).

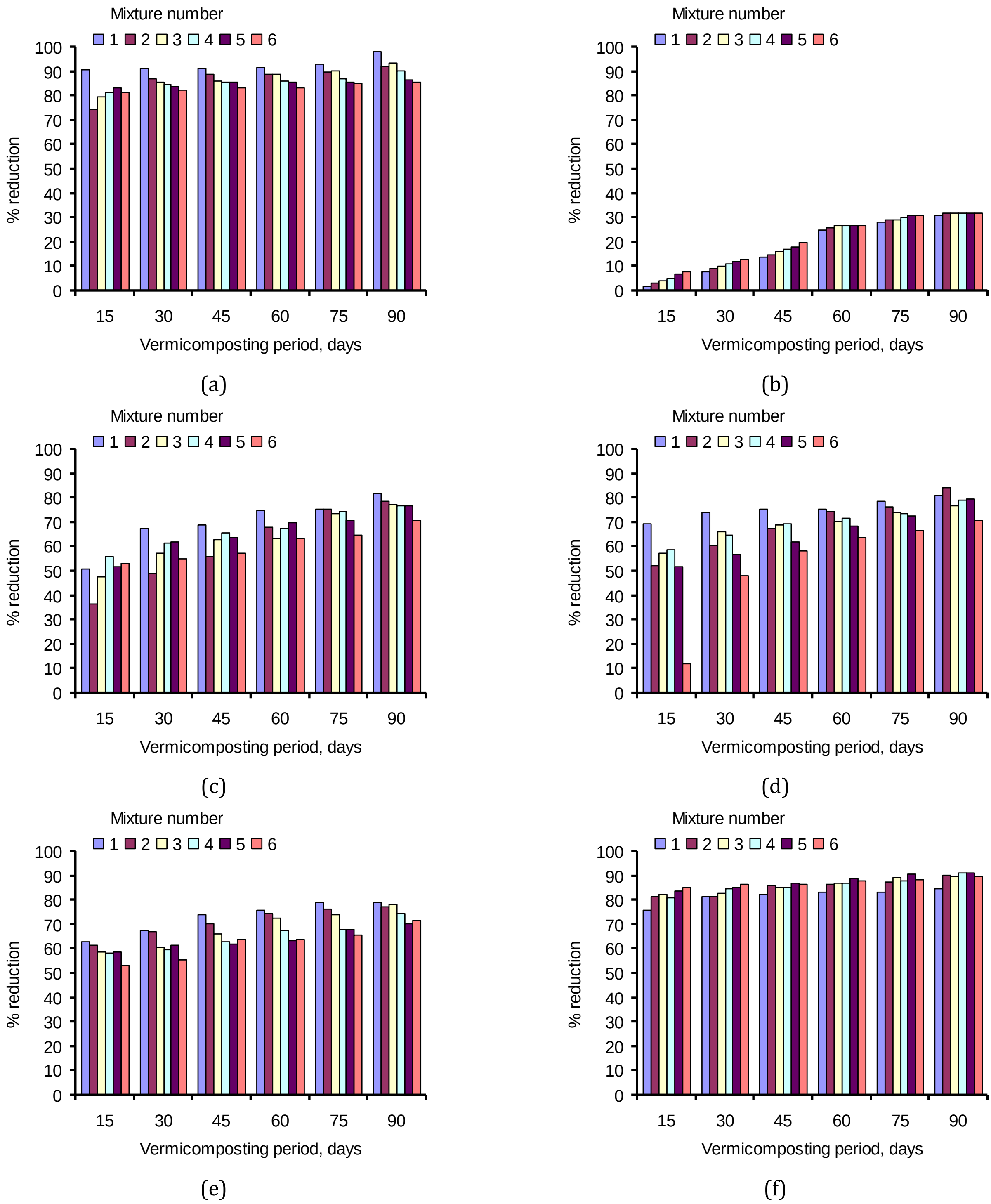

Figure 4. % reduction of heavy metals of different feed mixtures with time during vermicomposting process
a) Zn b) Cu c) Cd d) Pb e) Ni f) Cr

The heavy metal reduction increased associated with vermicomposting period depending upon earthworm growth activities. Therefore, it was attributed to the earthworm activity and/or vermicomposting time in the waste decomposition system. Some of the metals were accumulated in body tissues. Similarly, previous studies have revealed that earthworms can accumulate heavy metals in their tissues during the process of vermicomposting (Hartenstein and Hartenstein 1981; Graff 1982; Garg and Kaushik 2005; Gupta et al.

2005). Garg and Kaushik (2005) reported a considerable loss in heavy metal contents from solid textile mill sludge mixed with poultry droppings. They attributed the heavy metal loss from substrate to accumulation by earthworm body tissues. Also, Gupta et al. (2005) studied the vermicomposting of fly ash by mixing it with cow dung in different ratios and reported 30–50% loss in heavy metal content in different combination, at the end. They reported that heavy metals bioaccumulated in earthworm tissues. This study confirmed that earthworms could efficiently reduce the metal content in substrate.

Heavy metals in Earthworm body

The earthworm *E.feotida* collected at the end from different feed mixtures showed considerable concentrations of metals in their bodies (Figure 5). The difference among feed mixtures in terms of contents of metals in earthworms was statistically significant (Table 4).

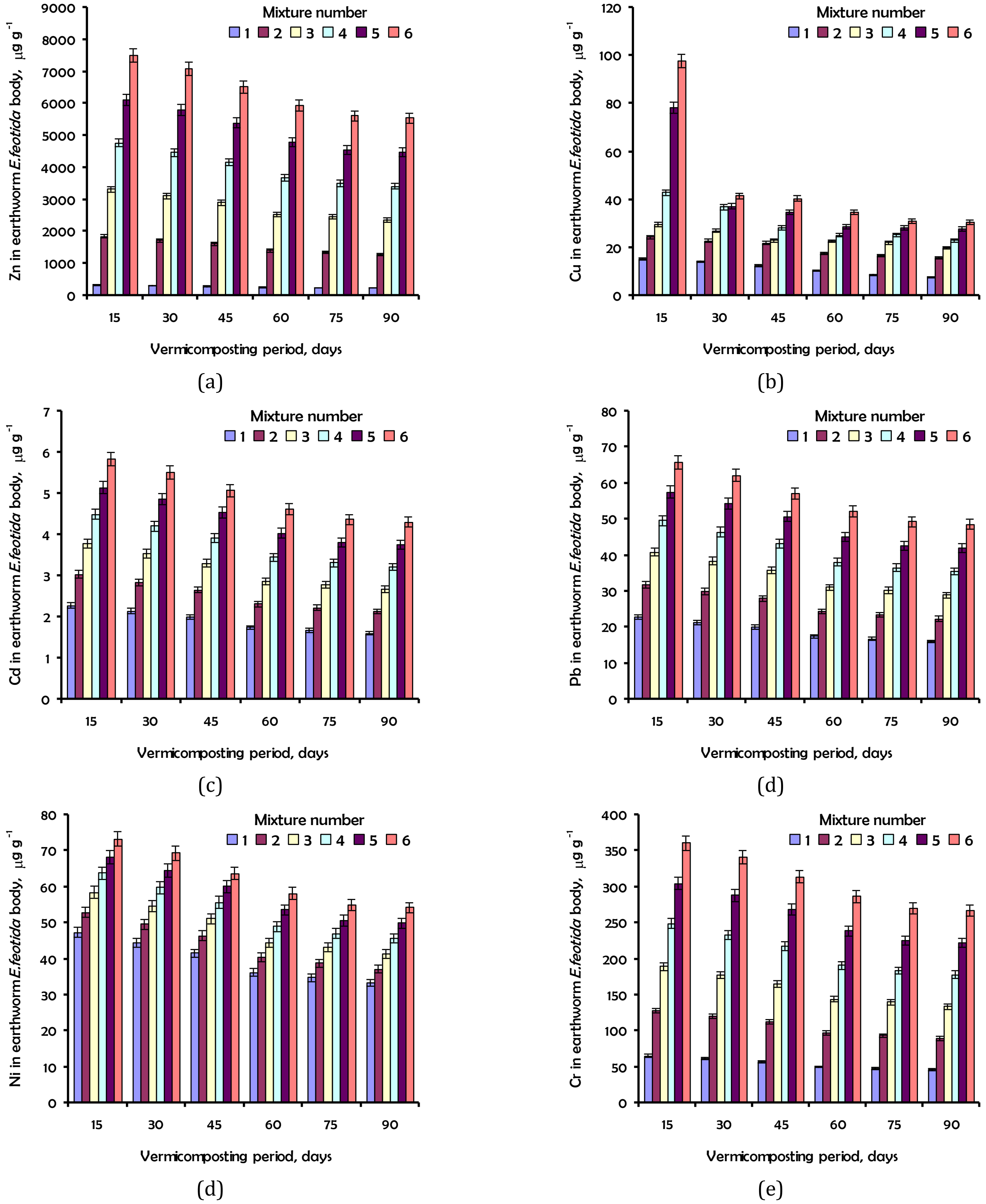

Figure 5. Changes in heavy metal content in earthworm *E.feotida* body with time during vermicomposting process. Vertical bars indicate standard error of mean of three replicates at 95% confidence level.
a) Zn b) Cu c) Cd d) Pb e) Ni f) Cr

The heavy metal concentrations in earthworm body tissues decreeased associated with time, and at all vermicomposting period of the experiment, heavy metal content of earthworm body in the feed mixture no. 6 (50% SS + 25% HH + 25% CM) was significantly higher (P<0.01) than that of other feed mixtures. The observed difference in heavy metal contents in vermicomposted material for different feed mixtures may be related to the different rates of SS for heavy metals. It meant that the heavy metal level in earthworm was directly related to the contents of metals in feed mixtures. Our finding, first two treatments supported the above statement (Figure 5).

Bioaccumulation of high concentration of metals is well documented (Hsu et al., 2006). According to Kızılkaya (2004, 2005) and Suthar (2008), earthworms accumulate a considerable content of metal in their tissues and can serve as useful biological indicator of contamination due to the fairly consistent relationships among the concentrations of certain contaminants in earthworms. In this study, SS proportion in feed mixtures seemed to be of primary importance. Finding on concentration of heavy metals in earthworm *E. feotida* collected from vermibeds with higher proportion of SS e.g., feed mixture no 5 and 6, further supported the above hypothesis. Zn and Cu concentration was greater in tissues of inhabiting earthworms than other studied heavy metals. It may be attributed that these metals could be a part of different metabolic requirements of earthworms for Zn and Cu. Ireland (1983) stated that Cd did not appear in earthworm tissues indefinetely and the BAF ratio decreases with increasing Cd concentration, unlike Pb that appears in tissues continously. Carter et al. (1983) found some regulation of Zn and Cu, but not of Cd which reached a maximum in earthworm tissue of about 34 $\mu g.g^{-1}$. Graff (1982) examined the accumulation of heavy metals in *E.feotida* before and after feeding on compost made from municipal garbage. The heavy metal contents ($\mu g.g^{-1}$) before and after feeding were: Cu 4 to 29, Zn 140 to 640, Pb 3 to 14, Cd 2 to 9. These data indicated that earthworm *E.feotida* was extracting the heavy metals from the compost and accumulating them in their tissues. Previous reports on the metal accumulation ability of earthworms stated that the metals like Cu and Ni are not bioaccumulated by the earthworms (Barerra, 2001), but results of the present study explored considerable bioaccumulation of these metals in earthworms. This study confirmed and extended the earlier studies that earthworms can accumulate a considerable amount of metals in their tissues when inoculated in SS. In general, the content of metals in earthworms depends on inhabiting substrate metal contents (Lukkari et al., 2006).

Bioaccumulation factors (BAF)

The bioacumulation factors (BAF) for the different heavy metals in the earthworm *E.feotida* body tissues during the 90 day vermicomposting period are depicted in Figure 5. BAF varied associated with the different feed mixtures in this study (Table 4). When the BAF were calculated in relation to the total metal concentrations in different mixture feeds, the highest value came from Zn. The BAF were higher than 3 for Zn, Cr and Pb but lower than 3 for Cd, Ni and Cu in mixture feeds. In addition, the results showed that elevation of BAF increased with in SS proportions for all metals except Cu and Cr (Figure 6). BAF of the six heavy metals in vermicomposting for 90 d by the earthworm *E.feotida* was ranked as: Zn> Cr> Pb> Cd>Ni>Cu.

Composting earthworm *E.feotida* showed relatively greater values of BAF for Zn and Cu than compared to heavy metals. The difference among different metals for BAF may be related to the difference in specific metal regulating mechanism in earthworms. Recent studies have revealed that accumulation of metals, especially Cd, Cu and Zn, in earthworms is mainly due to the binding of metals by metallothioneins (Kagi and Kojima, 1987). The BAF ranges calculated in this study, however, were higher than those of reported by earlier researchers (Dia et al., 2004; Hsu et al., 2006; Suthar and Singh 2008; Kızılkaya 2004, 2005). The observed difference for BAF in present and past studies could be related with the level of metals contamination and exposure duration or earthworm species type (Suthar and Singh, 2008). According to Morgan and Morgan (1992), difference species can show a considerable difference for tissue's metal contents mainly due to difference in their food selectivity and metabolic physiology. Similarly, Hopkin (1989) suggested that earthworms have specific capacity to regulate metals, particularly trace metals, such as Cu and Zn, in their bodies, and accumulation and regulation mechanisms could be species-specific. It was also suggested here that exposure duration could be main determinant for observed differences in BAF; although the exposure duration was relatively longer in this study (i.e., 90 days) compared to previous studies (Kizilkaya 2004, 2005). Few past studies reported considerable ranges of BAF for metals in earthworms (Dia et al., 2004; Hsu et al., 2006). The higher BAF ranges for metals suggested that vermicomposting could be a risky technology if applied to stabilize SS. There is great possibility of entering of toxicants via earthworms to organisms occupying different trophic levels, if proper management of inoculated worms is not made (Suthar and Singh, 2008).

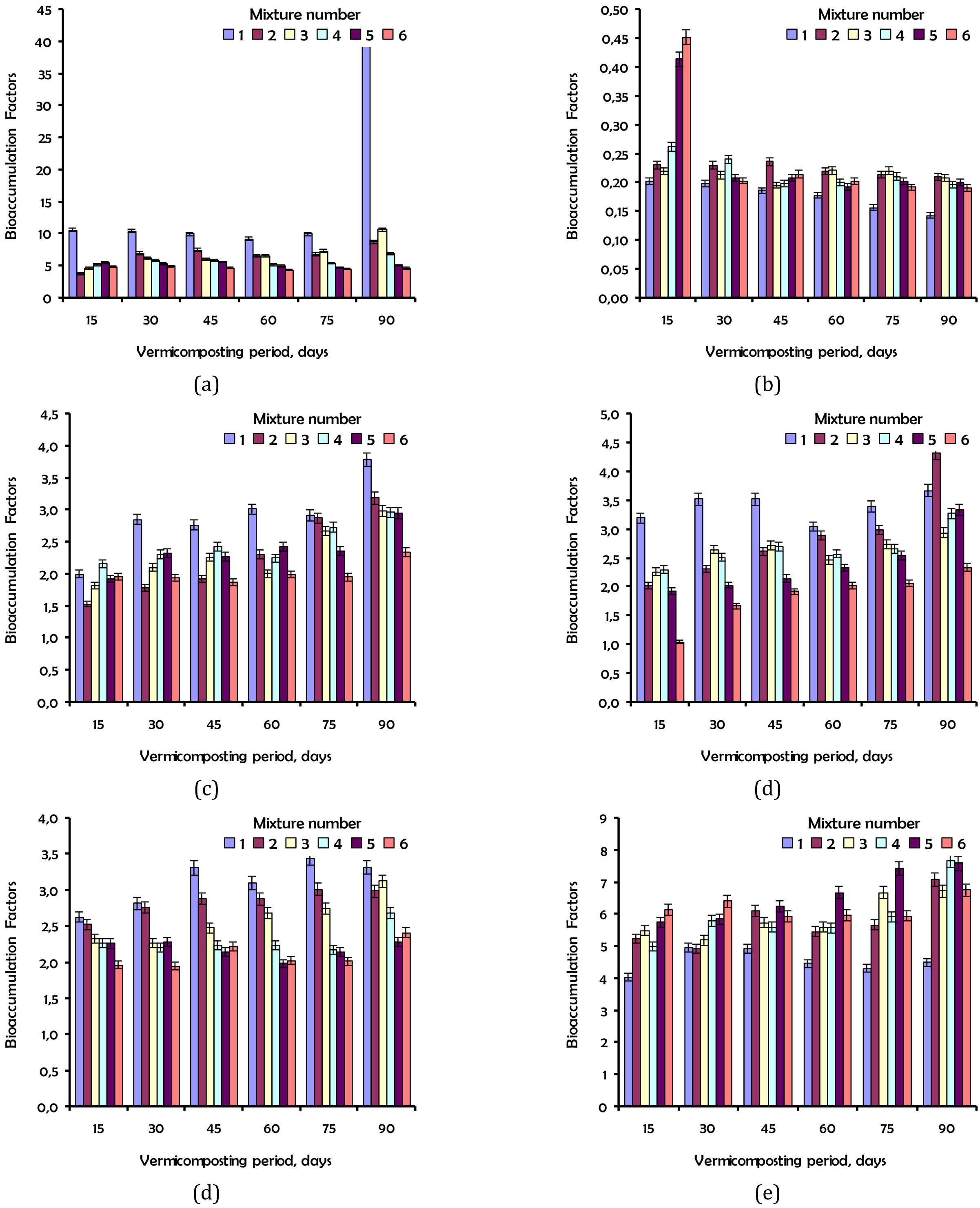

Figure 6. Bioaccumulation factors of heavy metals accumulated in earthworm *Eisenia feotida* body in relation with metal concentrations in different feed mixtures. Vertical bars indicate standard error of mean of three replicates at 95% confidence level. a) Zn b) Cu c) Cd d) Pb e) Ni f) Cr

Conclusion

Disposal of SS by environmentally acceptable means is a serious problem. Our trials demonstrated that vermicomposting could be an alternate technology for the management of primary SS mixed with HH and CM. Vermicomposting of SS, after mixing it with a HH and CM reduced in the concentration of heavy metals. However, in both feed mixture no. 3 (20% SS + 40% HH + 40% CM) and feed mixture no. 4 (30% SS + 35% HH + 35% CM) maximum increase in numbers and biomass production rates of earthworms as well as decrease in heavy metal concentrations was recorded during the vermicomposting period. The decrease in metal concentrations in the vermicompost indicated the capability of *E. feotida* in accumulating heavy metals in their body tissues. Although, earthworm *E.feotida* could efficiently reduce the contents of heavy metals in sludge, which could be further used for sustainable land restoration practices, but greater level of bioconcentrated metals in earthworm tissues could not be ignored due to high level of mortality was recorded in ≥ 60% SS feed mixtures. The results indicated that after the addition of primary SS in appropriate quantities (20–30%) to the HH and CM, it may be used as a raw material in the vermicomposting.

Heavy metals can be accumulated in earthworm tissues to reduce of heavy metal level in during the vermicomposting process. The metal contamination is a major problem during direct field application of such SS. Earthworm biomass production and reproduction performance was found

excellent in bedding those contained lower proportions of distillery sludge i.e. feed mixture no. 3 and 4. It is suggested that the numbers and biomass production rates of earthworms were significantly affected by the proportion of SS of their feed mixtures. Results indicated that SS mixed with HH and CM could be utilized as an efficient soil conditioner for sustainable land restoration practices, at low-input basis, after processed by epigeic earthworms *E.feotida*. The study also inferred that the application of SS-based vermicompost in the agricultural fields as a soil conditioner, would not have any adverse effect.

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Dynamics of soil organic carbon stock under different types of savannah agrosystems in the Sudano-Sahelian zone of Cameroon

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Abstract

The aim of this study was to quantify the current soil organic carbon stock under different types of savannah agrosystems in the Sudano-Sahelian zone of Cameroon in the context of greenhouse gas emissions and land degradation. It is so crucial for combating climate change and improving ecological restoration. Random field sampling was carried out on 0-10, 10-20 and 20-30 cm depth, then were collected in four types of savannah agrosystems. Soil bulk density, pH, moisture content, CEC, exchangeable bases, particle size distribution and soil organic carbon were determined using standard laboratory procedures and calculations. The results of the study did not reveal a significant difference in soil organic carbon stock between different types of savannah agrosystems (P>0.05). Soils of Tamarindus indica savannah agrosystems in recorded higher values SCOS (36.03 ± 3.31 tC/ha), Prosopis africana (33.40 ± 3.27 tC/ha), Haematostaphis barterii (31.83 ± 3.21 tC/ha) and Detarium microcarpum (31.19 ± 3.19 tC/ha) savannah agrosystems. Similarly, SCOS decreased with soil depth in all types of savannah agrosystems. Results showed a positive and significant (P<0.05) correlation between soil organic carbon stock with basal area, biovolume, bulk density, moisture content, C/N ratio, Ca^{2+}, Mg^{2+}, OM; negative and significant (P<0.05) with Soil pH, Total Nitrogen, Na^{+} but negative and non-significant (P>0.05) with Density, K^{+}, CEC, Sand %, Silt %, Clay %, Silt + Clay %. The results show the potential contribution of savannah agrosystems to improve soil organic carbon sequestration and environmental protection.

Keywords: Organic carbon, soil organic carbon stock, carbon sequestration, Savannah agrosystems, Cameroon, climate change.

Introduction

Soil is the loose surface layer of the earth's crust. It is also defined as a natural environment with essentially dynamic properties, differentiated into horizons with mineral and/or organic constituents that are generally loose, resulting from the transformation of an underlying parent rock, under the influence of various chemical, physical and biological processes (FAO, 2017). It is the place where plant roots develop. The increase in population around the world is accompanied by an increase in agricultural production needs,

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leading to ever-increasing pressure on impoverishing soils, particularly agricultural soils (FAO, 2017). Today, nearly 40 % of the world's agricultural land has lost its functions such as biological, physical and chemical functions (FAO, 2017). Soil provides physical, chemical and biological habitat for living organisms ; since it regulates water flows, storage and recycling of nutrient cycles and other elements, maintains biological activities and diversity to support plant growth and animal productivity through filtering, buffering, transformation, immobilization and detoxification of organic and inorganic substances it also provides mechanical support to living organisms and their structures (Schmidt et al., 2011; Nibéron, 2016). Ecosystem services include supporting, provisioning, cultural and regulation services (FAO, 2015). For example, those that affect climate, biodiversity, disease, water purification (FAO, 2017). Increasing carbon storage in the form of soil organic matter plays an important role in combating the increase of greenhouse gases in the atmosphere (FAO, 2017). Carbon exists as inseparable components of biomass and soil organic matter (Awé et al., 2020). Its storage in soil organic matter is important in mitigating global climate change and improves the livelihood of resource poor farmers (Moore et al., 2018). It increases land productivity through improved soil properties such as nutrient supply and moisture retention (Bessah et al., 2016). Degradation and deforestation have impacted negatively on both vegetation and soil carbon stock (Bessah et al., 2016). SOC is a vital component of soil with important effects on the functioning of terrestrial ecosystems (Mazarrasa et al., 2018; Rovai et al., 2018). Storage of SOC results from interactions among the dynamic ecological processes of photosynthesis, decomposition, and soil respiration (Spohn, 2020). Soil organic carbon (SOC) is the largest carbon (C) stock in most terrestrial ecosystems, containing approximately 2344 Gt of organic C globally (Stahr et al., 2018). The amount of organic C contained in soils is estimated to be about 1500 billion tones, about twice as much as in the atmosphere and three times as much as in terrestrial vegetation (Stockmann et al., 2013). This carbon mineralizes and returns to the atmosphere with highly variable lifetimes (or storage times), depending on many factors like land use and agricultural practices (FAO, 2015). It is therefore important to know the potential offered by this C reservoir according to practices and uses (FAO, 2017; Lui et al., 2017). Soil carbon sequestration is one way to reduce GHG emissions from agriculture, and the establishment of a market for carbon reduction would allow farmers to gain economic benefit from this process (Hoffmann et al., 2012). Soil organic carbon (SOC) stock has a great importance component in any terrestrial ecosystem, and is any variation in its abundance and composition has important effects on many of the processes that occur within this system (İmamoğlu and Dengiz, 2016; Dengiz et al., 2019). This organic matter generally comes from dead, mainly plant organs and organisms, animal excreta, root exudates and living organisms (Gorham et al., 2020). The organic matter (OM) then undergoes biotransformation in the soil : biodegradation and finally mineralization, which returns the Carbon to the atmosphere in the form of CO_2 (Awé et al., 2019a). Carbon exchanges between the atmosphere and terrestrial ecosystems are about ten times greater than the emissions caused by the use of fossil fuels (FAO, 2017). The biosphere plays an important role in the cycle since a small change in emission or sequestration rates can lead to a major change in the carbon balance. In order to be able to predict climate change and to discover solutions to mitigate or mitigate the problems predicted by experts, it is important to quantify and better understand the GHG dynamics of compartments. Savannah agrosystems represent an important part of the plant community in the Sudano-Sahelian zone of Cameroon. They occupy a very important place in view of their ecological, economic and social values. They play several roles for the user populations, such as feeding the livestock at all times, particularly during periods of food shortage and providing timber and fuelwood. According to our bibliographical investigations, no other work has so far targeted the quantification of soil carbon stock in savannah agrosystems in the Sudano-Sahelian zone of Cameroon. The objective of this study is to assess the soil organic carbon stock in the different savannah agrosystems in the Sudano-Sahelian zone of Cameroon.

Material and Methods

Field Description of the Study area

The study was carried out in the north region (Cameroon). The zone extends between 8° and 10° North latitude and between 12° and 16° East longitude, and is bounded to the North by the Far North region, to the South by the Adamawa region, to the East by the Republics of Chad and Central African Republic and to the West by the Federal Republic of Nigeria (Awé et al., 2019c). The north Cameroon region has a tropical climate of the Sudano-Sahelian type. Average monthly temperatures are between 25.4 and 32.5 °C. Each year, precipitation averages 1003 mm. The relief is a vast pediatric plain between the Mandara Mountains (1,442 m) in the North and the Adamawa Plateau in the South. The soil is of ferruginous type formed by degradation of sandstone from the Middle Cretaceous (Awé et al., 2020). The vegetation encountered is a shrubby Sudanian savannah with a clear and degraded savannah appearance (Awé et al., 2020). The fauna is rich and very diverse (Awé et al., 2019b). Economic activities concern: agriculture, animal husbandry, fishing, social economy and handicrafts, transport and trade. Agriculture is the main activity of the populations of the North region (Cameroon) (Figure 1).

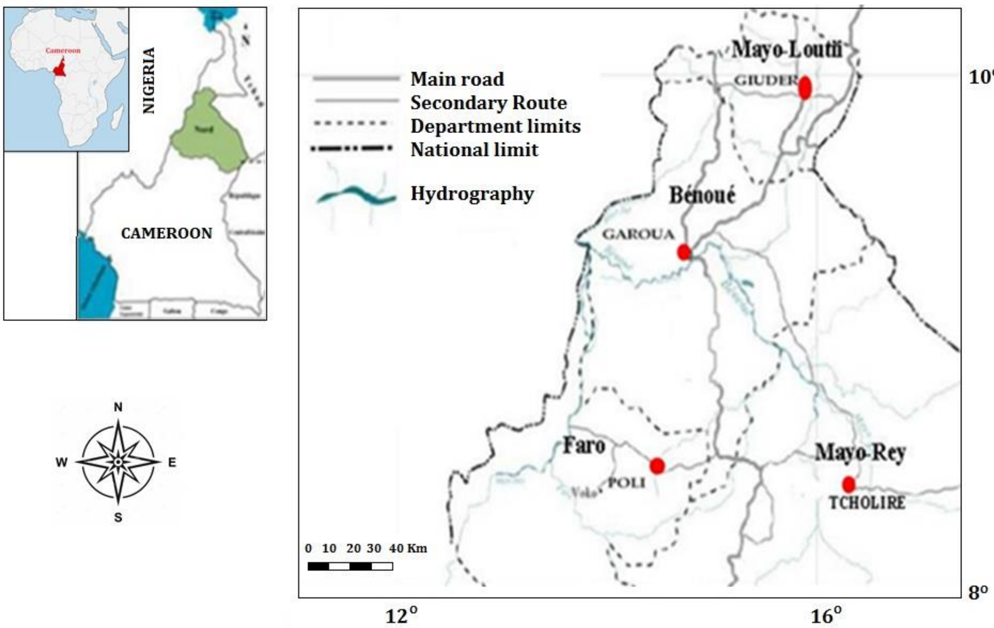

Figure 1. Geographic location of the study area in North Cameroon Region

Data collection

Transects 80 m long by 25 m wide were installed at each site and each transect is spaced 10 m apart. A total of 4 transects were installed for a total sampling area of 1 ha per site. Sampling strips were established using compass, tape measure, GPS and twine. At the ends of each strip, stakes were planted equidistantly 20 m apart. Along the transect, all woody trees of Dbh ≥ 10 cm were surveyed in the four selected savannah agrosystems (*Detarium microcarpum*, *Haematostaphis barterii*, *Prosopis africana* and *Tamarindus indica*). For the calculation of vegetation structure two parameters were taken into account: tree density, basal area and biovolume. For the density of woody plants, we applied the formula below: D= n/S with D: density (trees/ha), n: number of trees present on the area considered and S: area considered (ha). For the basal area, we applied the formulas below: $S = \pi\ (Di^2/4)$ with S: basal area (m^2/ha) and Di: diameter (m). The biovolume is given by the formula of Dawkins (1959): Bv= 0,53 agi x hi x ni with gi: basal area (m^2/ha); Hi: height of trees (m); ni: number of trees; Bv: biovolume (m^3/ha). According to (Roger and Rabarison, 2000 in Awé et al., 2019c), the biovolume is high when it is above 250 m^3/ha, medium when it is between 50 and 250 m^3/ha, and low when it is below 50 m^3/ha.

Soil samples are taken from January to March. In each 2000 m^2 survey, soil samples were taken in 0.25 m x 0.25 m frames. These samples are taken at 0-10 cm, 10-20 cm, 20-30 cm depth on the four elementary plots. Each level of soil depth was sampled using a machete and trowel and then immediately put in a closed bag in a cooler, in the shade to avoid evaporation. A total of 3 samples were taken per drilling unit, which corresponds to a total of 12 samples per site and then homogenized to obtain an aggregate sample. A total of 48 samples (4 sites x 3 depths x 4 replicates x 1 area) for all four sites were dug into the ground to a depth of 30 cm. Once all samples were collected, they were taken for laboratory analysis. The laboratory method consists of determining, evaluating or measuring the physico-chemical parameters of the soils:

Bulk density

The determination of the bulk density was carried out by sampling a defined volume of soil using a cylinder driven into the ground. After drying the sample in an oven at 105°C for 48 hours, it was weighed again. The dry weight of the sample P divided by the sample volume (V) gave the bulk density (Da) in g/cm^3. It is calculated using the following formula Da=P/V; was done according to the NF ISO 11464 Standard (AFNOR, 2006).

Determination of pH

The pH measurement was carried out on a sol-water solution for the pH water and a sol-KCL solution for the pH in a ratio of 1/2.5 using a PH-meter with a glass electrode. The pH meter was previously calibrated using the standard solutions according to the NF ISO 10390 standard (AFNOR, 2005).

Determination of the moisture content at 105°C

The moisture content at 105°C which allows to estimate the water content was done according to the NF X15-110 standard (AFNOR, 1994). It consists in introducing 5 g of the fresh sample into a previously tared flask, then let the soil sample dry in the oven at 105°C for 24 h; then let it cool in a desiccator and weigh. The equivalent moisture is thus determined by the following formula: H= (P gross air-dried) - (P gross air-dried at 105°C) / (P net air-dried) x 100.

Soil texture analysis

Soil texture analysis was determined by the Robinson's pipette method on air-dried soil samples sieved at 2mm. The organic matter was previously destroyed by attack with hydrogen peroxide. The sol was then dispersed by rotary shaking in flasks after addition of sodium hexa-metaphosphate $(NaPO_3)_6$. The different particle size fractions were determined by pipetting for the clayey and silty fractions and by sieving for the sand (AFNOR, 2003).

Determination of Total Nitrogen

The total Nitrogen was obtained through the (Kjeldahl, 1883) method after heat treatment of the sample with a mixture of sulphuric acid (H_2SO_4) and salicylic acid ($C_6H_4(COOH)(OH)$. The nitrates present in the sample were first fixed by the salicylic acid and then reduced to ammonia by the use of a catalyst consisting of copper sulphate ($CuSO_4$). The distillate was captured in boric acid (H_3BO_3) and then titrated with sulphuric acid (H_2SO_4) according to the NF EN ISO 23470 Standard (AFNOR, 2011).

Determination of Exchangeable Bases

Exchangeable bases were extracted from the soil with a solution of Ammonium Acetate ($C_2H_3O_2NH_4$) at pH7. The concentrations were made by atomic absorption spectrometry (Magnesium) and by flame emission (Calcium, Potassium, Sodium) according to the NF X31-108 standard (AFNOR, 2002). The K, Mg, Na and Ca contents are converted into kg/ha.

Cationic exchange capacity (CEC): This was done with ammonium acetate at pH7 and notably in three phases: saturation of the absorbent complex by NH_4^+ ions and extraction of the exchangeable bases; washing of the soil with alcohol in order to eliminate excess NH_4^+ ions; determination of NH_4^+ by Kjéldahl distillation after desorption from a KCL solution according to the NF EN ISO 23470 standards (AFNOR, 2011).

Soil organic carbon was determined by (Walkley and Black, 1934) method, which is an oxidation with potassium bicarbonate ($K_2Cr_2O_7$) in an acid medium (H_2SO_4) according to the NF ISO 14235 standard (AFNOR, 1998). The dosage was done by calorimetry. The organic matter content was obtained by multiplying the organic carbon rate by the Sprengel factor which is 1.724 for cultivated soils and 2 for uncultivated soils. Soil carbon (SCOS) (tC/ha) = Da. (% COS). S. P (Awé et al., 2020) with Da: bulk density in tones /m^3; COS%, organic carbon content of the soil; S: area in m^2; p: depth m.

Data analysis

The data were encoded in EXCEL software and then analyzed using STATGRAPHICS plus 5.0 and R software. Correlation and significance tests were performed using ANOVA and Duncan's 5 % test.

Results and Discussion

Soil physical characteristics

The highest density was recorded in Detarium microcarpum (310 ± 10.10 stems/ha) savannah agrosystems (Table 1). This high density means that the stems used to reconstitute the environment are shrubs. This result lies in the range 208 ± 8.57 - 408 ± 11.12 individuals/ha found by (Awé et al., 2019c) in savannah agrosystems in the Sudano-Sahelian zone of Cameroon. The highest values of basal area (11.50 ± 1.65 m^2/ha) and biovolume (48.65 ± 3.95 m^3/ha) were recorded in the Tamarindus indica savannah agrosystems (Table 1). This indicates the existence of large specimen trees on the one hand and a significant timber potential due to their large diameters on the other. The basal area and biovolume values obtained in this work are respectively in the range, 2.94 ± 0.13 - 11.56 ± 0.57 m^2/ha and 32.94 ± 3.03 - 116.78 ± 16.57 m^3/ha found by (Awé et al., 2019c) in savannah agrosystems in the Sudano-Sahelian zone of Cameroon. The analysis of variance shows that there is no significant difference in density (P=0.321), basal area (P=0.123) and biovolume (P=0.532) between the different types of savannah agrosystems studied (Table 1).

Table 1. Structural characterization of the different savannah agrosystems

Savannah agrosystems	Density (stems/ha)	Basal area (m^2/ha)	Biovolume (m^3/ha)
Detarium microcarpum	310 ± 10.10a	8.33 ± 1.01a	33.43 ± 2.05a
Haematostaphis barterii	278 ± 8.98a	10.42 ± 1.35a	36.53 ± 3.15a
Prosopis africana	202 ± 8.14a	10.55 ± 1.42a	37.65 ± 3.63a
Tamarindus indica	138 ± 5.93a	11.50 ± 1.65a	48.65 ± 3.95a

Values assigned the same letter are not statistically different (p > 0.05; Duncan's test)

The granulometric distribution made it possible to distinguish 4 textural classes including clay- sandy, fine silt, clayey and clay-silt soils. The analysis of variance relating to soil textural fractions (Clay: P = 0.0268; Silt: P = 0.0000 and sand: P = 0.0004) show that there is a variation in soil textural composition according to the different savannah agrosystems studied (Table 2). In fact, clay soils have a more acidic pH than sandy soils (Carrier, 2003).

Table 2. Soil texture under the different savannah agrosystems

Textural fractions	*Detarium microcarpum*	*Haematostaphis barterii*	*Prosopis africana*	*Tamarindus indica*
Sand, %	12 ± 1.50a	18 ± 2.88b	38.43 ± 6.35d	31 ± 4.95c
Silt, %	42 ± 8.54b	63 ± 15.03c	15.89 ± 2.38a	37 ± 8.80b
Clay, %	46 ± 5.46c	19 ± 2.92a	45.68 ± 5.44c	32 ± 3.04b
Textural classes	Sandy clay	Fine silt	Clayey	Clay loam

Values assigned the same letter are not statistically different (p > 0.05; Duncan's test)

Bulk density varies with depth. The highest values of the bulk density values were recorded at depths of 0-10 cm. The highest bulk density value was recorded to Tamarindus indica (1.61 ± 0.16 g/cm^3) savannah agrosystems. This may be due to soil compaction which is contrary to the other three in the savannah agrosystems studied where the soil is loosened due to fine root mat, microbial and arthropod activities leading to soil aeration. The analysis of variance shows that there is no significant difference between depths (P=0.085) on the one hand and between savannah agrosystems (P=0.065) on the other hand (Table 3).

Table 3. Variation in bulk density as a function of depth under different savannah agrosystems

Depths (cm)	*Detarium microcarpum*	*Haematostaphis barterii*	*Prosopis africana*	*Tamarindus indica*
0-10	1.58 ± 0.10a	1.59 ± 0.11a	1.63 ± 0.15a	1.68 ± 0.15a
10-20	1.43 ± 0.12a	1.44 ± 0.13a	1.53 ± 0.15a	1.58 ± 0.16a
20-30	1.15 ± 0.14a	1.17 ± 0.15a	1.22 ± 0.16a	1.28 ± 0.17a
Mean	1.25 ± 0.12A	1.43 ± 0.13A	1.53 ± 0.15A	1.61 ± 0.16A

Values assigned the same letter are not statistically different (p > 0.05; Duncan's test)

Moisture content varies with depth. The highest values of humidity were recorded at depths of 20-30 cm. Among savannah agrosystems, the highest value was recorded in Tamarindus indica (27.61 ± 2.39) savannah agrosystems. This may be influenced by the vegetation cover; Detarium microcarpum savannah agrosystems being much more exposed to solar radiation. The texture of these soils may also influence its moisture content. Indeed, a sandy soil allows water to pass easily while a clay soil retains water (Coudurier and Bourgogne, 2012). As for pH, it is more acidic in forest soils. Tree growth involves taking ions from the soil and releasing others with identical electrical charges in order to maintain their electrical balance (Munguakonkwa, 2018). Since they require more cations than anions, their growth releases many cations (often H^+) into the soil, making it more acidic (Ranger, 2018). The analysis of variance shows that there is no significant difference between depths (P=0.238) on the one hand and between savannah agrosystems (P=0.312) on the other hand (Table 4).

Table 4. Variation of moisture content as a function of depth under different savannah agrosystems

Depths (cm)	*Detarium microcarpum*	*Haematostaphis barterii*	*Prosopis africana*	*Tamarindus indica*
0-10	20.18 ± 2.31a	21.33 ± 2.33a	22.43 ± 2.33a	25.53 ± 2.35a
10-20	22.23 ± 2.32a	23.42 ± 2.35a	24.53 ± 2.35a	26.63 ± 2.38a
20-30	25.35 ± 2.36a	26.55 ± 2.37a	28.65 ± 2.38a	30.68 ± 2.44a
Mean	22.58 ± 2.33A	23.76 ± 2.35A	25.20 ± 2.35A	27.61 ± 2.39A

Values assigned the same letter are not statistically different (p > 0.05; Duncan's test)

Soil chemical characteristics

Soil reaction (pH) varies with depths. The highest values of the soil reaction were recorded at depths of 0-10 cm. Among savannah agrosystems, the highest value was recorded in the Detarium microcarpum (pH = 6.42 ± 1.42) savannah agrosystems. This can be explained by clearing by burning which brings large amounts of ash to the soil which can increase the initial pH. This result is in the range 4.5 to 6.5 (Dabin, 1985). The analysis of variance shows that there is no significant difference between depths (P=0.505) on the one hand and between savannah agrosystems (P=0.192) on the other hand (Table 5).

Table 5. Variation of pH as a function of depth under different savannah agrosystems

Depths (cm)	*Detarium microcarpum*	*Haematostaphis barterii*	*Prosopis africana*	*Tamarindus indica*
0-10	6.88 ± 1.50a	6.72 ± 1.33a	6.73 ± 1.65a	5.58 ± 1.47a
10-20	6.65 ± 1.44a	6.55 ± 1.35a	5.65 ± 1.26a	5.33 ± 1.46a
20-30	5.73 ± 1.32a	5.93 ± 1.23a	5.53 ± 1.35a	5.23 ± 1.34a
Mean	6.42 ± 1.42A	6.40 ± 1.30A	5.97 ± 1.28A	5.38 ± 1.25A

Values assigned the same letter are not statistically different (p > 0.05; Duncan's test)

The analysis of variance did not show a significant difference in nitrogen content between savannah agrosystems (P=0.544). Soils in Detarium microcarpum savannah agrosystems had the highest values of nitrogen content (6.64 ± 1.31 kg/ha). At only 5%, analysis of variance (P=0.360) did not reveal a significant difference between the C/N ratios of the different savannah agrosystems studied. Soils in Tamarindus indica savannah agrosystems have the highest C/N ratios (12.76 ± 5.03) (Table 6). Soils of Detarium microcarpum savannah agrosystems have a low biological activity (C/N greater than 12) and therefore a slow rate of OM decomposition, whereas for Detarium microcarpum, Haematostaphis barterii, Prosopis africana savannah agrosystems, this rate is higher with normal values (C/N between 8 and 12). Several other factors would explain these variations in C/N ratios such as particle size and pH (Decoopman et al., 2013).

Table 6. Total nitrogen and C/N ratio under the different savannah agrosystems

	Detarium microcarpum	*Haematostaphis barterii*	*Prosopis africana*	*Tamarindus indica*
Total Nitrogen (Kg/ha)	6.64 ± 1.31a	5.54 ± 1.28a	4.34 ± 1.15ab	4.05 ± 1.08a
C/N ratio	8.44 ± 2.20a	8.88 ± 2.54a	8.98 ± 2.38a	12.76 ± 5.03b

Values assigned the same letter are not statistically different ($p > 0.05$; Duncan's test)

Potassium (K^+), sodium (Na^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) contents of soils are higher in Detarium microcarpum savannah agrosystems with values of 47 ± 10.07; 16 ± 4.20; 22.1 ± 6.09 and 57.1 ± 15.30 Kg/ha respectively. At only 5 %, the analysis of variance revealed no significant difference in soil (K^+; P=0.433), (Na^+; P=0.542) and (Ca^{2+}; P=0.213) contents between the different savannah agrosystems studied. The analysis of variance revealed significant difference in soil (Mg^{2+}; P=0.410) contents between the different savannah agrosystems studied. The cation exchange capacity (CEC) of soils is higher in Tamarindus indica savannah agrosystems (24.72 ± 4.99 Kg/ha). The analysis of variance shows a significant difference in soil cation exchange capacity (CEC) (P=0.002) between different savannah agrosystems studied at the 5 % threshold (Table 7).

Table 7. Variation in exchangeable bases and CEC under the different savannah agrosystems

Parameters	*Detarium microcarpum*	*Haematostaphis barterii*	*Prosopis africana*	*Tamarindus indica*
K^+ (Kg/ha)	47 ± 10.07b	24 ± 10.04a	15 ± 10.06a	12 ± 10.01a
Na^+ (Kg/ha)	16 ± 4.20a	15 ± 4.16a	14 ± 4.12a	11 ± 4.10a
Ca^{2+} (Kg/ha)	22.1 ± 6.09bc	18.1 ± 6.05b	18.6 ± 6.06b	3.9 ± 1.03a
Mg^{2+} (Kg/ha)	57.1 ± 15.30d	38.5 ±10.08c	16.3 ± 5.12b	9.8 ± 2.23a
CEC (Kg/ha)	12.96 ± 1.09a	16.58 ± 2.23b	20.84 ± 3.76c	24.72 ± 4.99d

Values assigned the same letter are not statistically different ($p > 0.05$; Duncan's test)

Soil organic matter content in the savannah agrosystems studied decreased with depth of sampling. The highest values of soil organic matter content were observed at a depth of 0-10 cm. Detarium microcarpum Savannah agrosystems had the highest values of soil organic matter content (2.34 ± 0.13). The analysis of variance did not reveal any significant difference in soil organic matter content between depths on the one hand (P= 0.553) and between savannah agrosystems on the other (P= 0.548) (Table 8).

Table 8. Variation in organic matter content (OM) as a function of depth under different savannah agrosystems

Depths (cm)	*Detarium microcarpum*	*Haematostaphis barterii*	*Prosopis africana*	*Tamarindus indica*
0-10	2.45 ± 0.15a	2.47 ± 0.13a	2.48 ± 0.12a	2.58 ± 0.10a
10-20	2.23 ± 0.12a	2.24 ± 0.11a	2.25 ± 0.11a	2.39 ± 0.10a
20-30	2.00 ± 0.10a	2.05 ± 0.10a	2.08 ± 0.11a	2.11 ± 0.10a
Mean	2.34 ± 0.13A	2.23 ± 0.11A	2.21 ± 0.11A	2.16 ± 0.10A

Values assigned the same letter are not statistically different ($p > 0.05$; Duncan's test)

Soil organic carbon stocks

The highest values of soil organic carbon stocks were observed at a depth of 0-10 cm. The analysis of variance did not reveal any significant difference in soil organic carbon stocks between depths on the one hand (P= 0.207) and between savannah agrosystems on the other hand (P= 0.261) (Table 9). Soils in Tamarindus indica savannah agrosystems (36.03 ± 3.31 tC/ha) are those that store more carbon than those in other types of savannah agrosystems. This result is in the range 24.65 ± 2.51- 42.97 ± 4.35 tC/ha reported by (Awé et al., 2019c) for Burkea africana savannah agrosystems in the sudano-sahelian zone of Cameroon. Vegetation types can alter soil carbon stocks due to several key factors, including litterfall and root turnover, soil chemistry, root exudates, and microclimate (Ontl and Schulte, 2012; Awé et al., 2019c). Low carbon stocks of Detarium microcarpum savannah agrosystems are explained by the fact that agricultural practices such as deforestation, turning and frequent tillage, etc., cause a decrease in soil carbon stock (Swiderski et al., 2012). The maximum depth of 0 to 10 cm recorded the highest soil organic carbon stock under all types of savannah agrosystems (Bessah et al., 2016; Awé et al., 2019c; Awé et al., 2020).

Table 9. Variation in organic carbon stock as a function of depth under different savannah agrosystems

Depths (cm)	Detarium microcarpum	Haematostaphis barterii	Prosopis africana	Tamarindus indica
0-10	38.71 ± 3.31a	39.27 ± 3.33a	40.42 ± 3.38a	43.34 ± 3.45a
10-20	31.88 ± 3.20a	32.25 ± 3.22a	34.42 ± 3.25a	37.76 ± 3.28a
20-30	23.00 ± 3.06a	23.98 ± 3.10a	25.37 ± 3.18a	27.00 ± 3.22a
Mean	31.19 ± 3.19A	31.83 ± 3.21A	33.40 ± 3.27A	36.03 ± 3.31A

Values assigned the same letter are not statistically different (p > 0.05; Duncan's test)

Relationship between soil organic carbon stock and soil pysico-chemical characteristis

Soils with high carbon stock are clay loam soils (36.03 ± 3.31 tC/ha) followed by clay soils (33.40 ± 3.27 tC/ha); fine loam soils (31.83 ± 3.21 tC/ha) and clay-sandy soils (31.19 ± 3.19 tC/ha). The analysis of variance did not reveal a significant difference in soil carbon stock between textural classes (P= 0.164) (Figure 2).

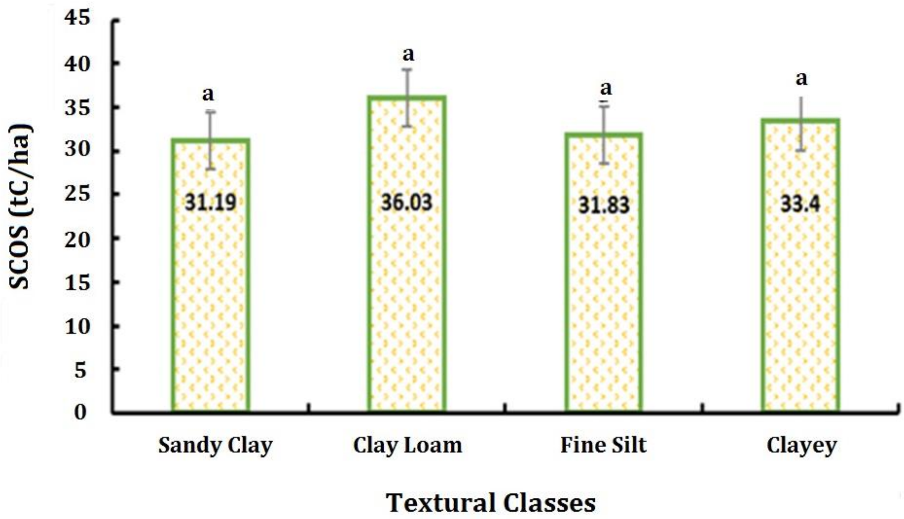

Figure 2. Organic carbon stocks by soil textural classes. Values assigned the same letter are not statistically different (p > 0.05; Duncan's test).

Results showed a positive and significant correlation (P<0.05) between soil organic carbon stock with basal area, biovolume, bulk density, moisture content, C/N ratio, Ca^{2+}, Mg^{2+}, OM (Table 10). This marks a dependence effect in the variation of SCOS. Also the negative and significant (P<0.05) correlation with Soil pH, Total Nitrogen, Na^{+} would show an inverse and dependence effect with SCOS (Table 10). Finally, the negative and non-significant correlation (P>0.05) of SCOS with Density, K^{+}, CEC would not reflect any dependence effect (Table 10). Results showed a negative and non-significant (P>0.05) correlation between soil organic C stock with % Sand, % Silt, % Clay, % Silt + Clay according to the three depth ranges of 0-10 cm, 10-20 cm and 20-30 cm respectively (Table 10). Soil organic carbon stocks decreased with increasing depth in all types of savannah agrosystems, as indicated in several results (Agboadoh, 2011; Jiao et al., 2012; Bessah et al., 2016; Awé et al., 2019c). On the other hand, there is no correlation between the density of savannah agrosystems and the amount of organic carbon sequestered in the soil. This can be explained by the presence of large trees in the savannah agrosystems studied. Organic carbon stock depends on basal area and biovolume in savannah agrosystems.

Conclusion

This study gives us a better understanding of the soil organic carbon stock in the savannah agrosystems studied. Soil is a non-renewable resource whose quality must therefore be preserved for its environmental functions. The results show that the soil organic carbon stock is higher in Tamarindus indica savannah agrosystems. However, the evolution of COS stocks is more or less decreasing as the savannah agrosystems evolve. From all the soil physico-chemical parameters measured, only bulk density, moisture content, C/N ratio, Ca^{2+}, Mg^{2+}, OM show a strong and positive linear correlation with soil carbon stock among all the physico-chemical parameters measured. Soil physico-chemical parameters (texture, total nitrogen, C/N ratio, pH, soil bulk density, moisture content, CEC, exchangeable bases) also vary according to the types of savannah agrosystems.

Table 10. Pearson correlation (R^2) result of SCOS with other parameters

Parameters	Soil organic carbon stocks		
	0-10 cm	10-20 cm	20-30 cm
Density	-0.18ns	-0.14ns	-0.23ns
Basal area	0.98***	0.93***	0.96***
Biovolume	0.98***	0.97***	0.98***
Bulk density	0.89***	0.90***	0.89***
Soil pH	-0.94***	-0.96***	-0.98***
Moisture (%)	0.98***	0.98***	0.98***
Total Nitrogen (Kg/ha)	-0.88***	-0.85***	-0.87***
C/N (%)	0.75*	0.71*	0.78*
K^+ (Kg/ha)	-0.28ns	-0.29ns	-0.27ns
Na^+ (Kg/ha)	-0.98***	-0.98***	-0.98***
Ca^{2+} (Kg/ha)	0.97***	0.98***	0.96***
Mg^{2+} (Kg/ha)	0.72**	0.70**	0.71**
CEC (Kg/ha)	-0.32ns	-0.41ns	-0.28ns
OM (%)	0.88***	0.85***	0.87***
% Sand	0.24ns	0.21ns	0.23ns
% Silt	0.22ns	0.24ns	0.26ns
% Clay	0.28ns	0.25ns	0.30ns
% Silt + Clay	0.38ns	0.31ns	0.29ns

Coefficients at p<0.05 are significantly correlated; *: p≤0.05; **: p≤0.01; ***: p≤0.001 (Pearson test); ns: not significant

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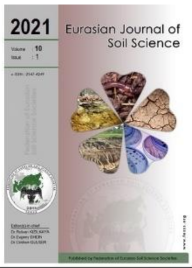

Fluoride contamination in wetlands of Kuttanad, India: Predisposing edaphic factors

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Abstract

Fluoride contamination has now become an emerging concern in agroecosystems. A diagnostic survey was conducted across the fluoride (F^-) contaminated wetlands of Kuttanad, India with an aim to examine the influence of edaphic factors on F^- concentration in soils. The soils (Inceptisols) predominantly sandy had a substantial percentage of clay and the soil characteristics such as bulk density (BD), moisture, temperature, pH, electrical conductivity (EC), cation exchange capacity (CEC) and organic carbon (OC) varied with soils. Similarly, the soil nutrients (NPK) and the oxides of Fe and Al as well as total sesquioxide differed with soils. Principal component analysis (PCA) revealed that the first two components (PC1 and PC2) significantly explained the variability existed in the data while the third component (PC3) did not explain any variation compared to the first two components. PC1, PC2 and PC3 accounted for 52.2%, 12.7% and 11.3% of the variation in the profiles respectively. Out of soil samples, 53% had a similar distribution of soil characteristics and F^- concentration and are grouped together in PC1 while, the remaining 47% of the samples had a similar distribution of characteristics and are grouped together in PC2. Among the soil characteristics examined, silt content, pH, EC, CEC, OC, N and P had a significant ($P<0.001$) positive association along PC1 indicating that these factors are contributing to the augmentation of F^- concentration in the wetlands of Kuttanad.

Keywords: Fluoride contamination, wetland soil, edaphic factors.

Introduction

Fluorine is the most reactive electronegative anion in the halide series (Greenwood and Earnshaw, 1997). Like other halides, it is a monovalent ion which has a strong affinity to combine chemically with other elements to form compounds called fluorides (F^-). Fluorides are ubiquitous in nature, including water, soil and plants (Singh et al., 2018). Fluoride accounts for about 0.06-0.09% of the Earth's crust (Koritnig, 1951). Major natural sources of F^- are F^- containing mineral rocks like fluorspar, rock phosphate, cryolite, apatite, mica etc. (Kinnunen et al., 2003). Application of F^- containing phosphate fertilizers (Loganathan et al., 2001; Borah and Saikia, 2011), fumigants and pesticides (Tsai, 2010; Li et al., 2015), irrigation water (Pettenati et al., 2013; Bustingorri and Lavado, 2014) or by deposition of gaseous and particulate emission from industry (Ozsvath, 2009; Jayarathne et al., 2014; Fuge, 2019) are some of the anthropogenic sources contributing to the elevated concentration of F^- in soil.

It is well-known that F^- is beneficial for humans and other animals in small quantities (Underwood, 1977; Adriano, 1986) as it is an essential element required for the integrity of teeth and bones (Jha et al., 2011). However, ingestion of elevated level of F^-, has a harmful effect, causing dental and skeletal fluorosis in

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humans (Annadurai et al., 2014; Choubisa, 2018a; Kabir et al., 2019; Dharmaratne, 2019) and animals (Choubisa, 2018b; Panchal and Sheikh, 2017; Yuan et al., 2019). In plants elevated levels of F^- exposure reduces germination, growth and productivity (Chakrabarti et al., 2013; Tyagi et al., 2017; Ahmed et al., 2019). Fortunately, the uptake of F^- by plants from the substrate is typically low because soil-borne F^- most often occurs in a form unavailable to plants hence plants will absorb amounts of this element under natural conditions. However, in soils polluted in F^-, uptake may take up its excessive quantities (Smolek et al., 2011) which affect crop production. Excessive F^- in the soil is reported to have adverse effect on microbial communities (Ropelewska et al., 2016; Qiao et al., 2018; Lu et al., 2019) and can inhibit the activity of a variety of microbial enzymes (Telesiński et al., 2008; Mondal et al., 2015).

Kuttanad, the well-known granary is situated in Alappuzha District of Kerala State in south India. It is a unique tropical wetland agroecosystem where below sea level farming practice is being continued for more than a century (Kumar and Devadas, 2016) in 55,000 hectares of rice fields. High F^- content in the sediments of Kuttanad waters has already been reported (Geetha et al., 2007) which is considered to be originated from dissolution of fluorapatite which is a common mineral in the Tertiary sediments of the area (Varma, 2017). Long residence time, sediment-groundwater interaction and facies changes ($Ca\text{-}HCO_3$ to $Na\text{-}HCO_3$) during groundwater flow regime are pointed out as the major factors responsible for the high F^- content in the groundwater of this area (Raj and Shaji, 2017). Besides this, Kuttanad being a major producer of rice for the state, to achieve high crop productivity targets, the farmers of this region are compelled to apply F^- bearing synthetic fertilizers and plant protection chemicals in large quantities which overburden the ecosystem with F^-. We presume that the edaphic factors could also have an influence on the F^- concentration in soil. To test this hypothesis we have conducted a diagnostic survey across the F^- contaminated areas of the Kuttanad wetlands with an aim to figure out the influencing edaphic factors which augment/alleviate the F^- concentration in soils.

Material and Methods

Location and study area

Kuttanad (289.39 km^2) located within Alappuzha District in the west coast of Kerala State in India lies between latitude 9^0 35'N and longitude 76^0 40'E (Figure 1). It has a summit elevation of 2. 2 m bsl. Kuttanad has a tropical humid climate with intermittent dry and wet period. From the middle of May to the middle of November, the wet season prevails with both north-east and south-west monsoons. The rainfall pattern varies with season. The average rainy days are about 120 per year with a mean annual precipitation of 153.28 mm. The mean annual temperature is 29^0C and means relative humidity is 79%. January and February are dry and cool months followed by summer from March to May. Kuttanad Below Sea-level Farming System (KBSFS) is unique as it is the only system in India where rice cultivation is practiced below sea level. The major land use structure within the area is flat stretches of rice fields in about 50,000 ha of mostly reclaimed delta swamps.

Figure 1. Location map showing study area

Sampling scheme

Soil samples were collected from 15 locations of Kuttanad rice fields during the fallow period (January) of 2016. Samples were withdrawn from a depth of 20 cm below the surface layer using a soil auger. Five replicate samples (ca 500 g) taken from each location were collected in polythene bags, labeled and taken to the laboratory and stored at 4^0C till analysis. All the soil samples taken were analyzed for soil characteristics and F^- concentration.

Evaluation of soil characteristics

Texture analysis was done by determining the percentage of sand, silt and clay in the soil sample following the micro-pipette method (Miller and Miller, 1987). The bulk density (BD) was calculated as the ratio between the air-dried soil mass and the soil volume from the fresh soil. Temperature expressed in ^{0}C was gauged using a thermometer. Moisture content was determined within 2-3 h of sample collection by drying 10 g soil sample in a hot air oven (105±1^0 C, 48 h). Gravimetric soil moisture was the difference in soil weights before and after drying (Gardner, 1986). The pH and electrical conductivity (EC) were measured in solution after placing 1 g of soil in 5 ml of deionized water. The pH was determined with a digital pH meter

(Systronics MK IV, Ahmedabad, India). EC of the soil expressed as dSm^{-1} was determined using Systronics 304 conductivity meter. Cation exchange capacity (CEC) was measured after saturating the soil with 1N ammonium acetate (NH_4OAc) and displacing it with 1N NaOAc (Chapman, 1965). For the measurement of organic carbon (OC), the method described by Islam and Weil (1998) was followed. Available nitrogen (N) in air-dried soil was determined by alkaline permanganate method (Subbaiah and Asija, 1956), phosphorus (P) by ascorbic acid method (Wantanabe and Olsen, 1965) and exchangeable potassium (K) was extracted in a 1N neutral (pH 7.0) ammonium acetate solution and measured using Elico-CL345 (Elico, India) digital flame photometer (Stanford and English, 1949). Free oxides of iron (Fe) and aluminium (Al) in soil were detected by dithionate extraction method (Mehra and Jackson, 1960). One gram air-dried soil was mixed with 2 g sodium dithionate, 20 g sodium citrate and 50 ml distilled water. After shaking the mixture overnight in a reciprocating shaker at 2000 rpm, the concentration of Fe and Al in the supernatant was measured at 248.3 nm and 309.3 nm respectively using Perkin Elmer-2380 Atomic absorption spectrophotometer. The elemental values were multiplied with the appropriate conversion factor Fe_2O_3 (1.43) and Al_2O_3 (1.89) to obtain their oxide values. The oxide values of Fe and Al were added to determine the total sesquioxides in soil. The sodium 2- (parasulphophenylazo)- 1, 8- dihydroxy- 3.6- naphthalene disulphonate (SPADNS) method was used to determine the F^- content in soil (Baird et al., 2017). Briefly, 0.5 g of air-dried finely ground soil sample was digested with 5 ml aqua regia for 45 min in a microwave digester. The digested sample was allowed to cool and then filtered through Whatman No 4 filter paper. The filterate was analyzed for F^- using UV-Vis spectrophotometer (Systronics, India) at 570 nm.

Statistical analyses

Descriptive statistical methods were used to explain soil characteristics. Principal component analysis (PCA) was applied to summarize correlation among treatment (location/soil characteristics) and variable (soil F^-) using R software (R Core Team, 2019).

Results and Discussion

Soil characteristics

Wetland soils (Inceptisols) of Kuttanad were predominantly sandy with silt and clay fractions (Table 1). Sand, silt and clay content in the soils ranged from 11.10-65.0, 12.0-53.85 and 6.0-48.50% respectively and the mean percentage were 39.17, 30.37 and 30.44% respectively. In an earlier study Thampatti and Jose (2000) reported that the incidence of same soil fractions in Kuttand wetlands, nevertheless, they could not find any definite pattern of distribution of sand, silt or clay in these soils.

Table 1. Descriptive statistical measurements of soil characteristics and F^-concentration in wetlands of Kuttanad

Variable	Min	Max	Mean	SD
Sand (%)	11.10	65.00	39.17	15.18
Silt (%)	12.00	53.85	30.37	13.22
Clay (%)	6.00	48.50	30.44	12.54
BD (mg m^{-3})	0.50	1.80	1.14	0.19
Moisture (%)	4.20	13.90	8.87	2.93
Temperature (^0C)	22.50	25.50	24.26	0.81
pH (1:5 H_2O)	3.40	4.80	4.23	0.32
EC (dS m^{-1})	0.35	1.52	1.03	0.29
CEC (cmol kg^{-1})	30.80	60.00	44.56	8.71
OC (g kg^{-1})	12.00	36.80	23.40	7.63
Available N (kg h^{-1})	275.70	502.95	397.68	80.57
Available P (kg h^{-1})	10.10	95.00	43.60	26.58
Available K (kg h^{-1})	46.50	383.20	169.66	112.72
Fe_2O_3 (mg kg^{-1})	1378.00	1431.00	1405.13	17.68
Al_2O_3 (mg kg^{-1})	222.50	356.10	282.43	35.65
Total sesquioxide (mg kg^{-1})	1610.50	1787.00	1687.56	50.21
Total Fluoride (mg kg^{-1})	5.88	37.77	25.88	7.29

Soil compaction is a problem that affects agricultural productivity particularly in clayey soils (Nunes et al., 2015) as it affects root growth and distribution (Taylor and Brar, 1991). The values of BD in the present study varied from 0.50-1.80 mg m^{-3}. None of the soils recorded a value beyond the critical limit suggesting that soil compaction is not an alarming issue in Kuttanad agroecosystem. Management of soils through tillage and related practices could be suggested as a reason for low soil compaction in these soils (Unger and Kaspar, 1994).

The soils of Kuttanad encounter frequent changes associated with flooding and associated drying (Suganya and Sivapullaiah, 2015). The soils showed lower moisture content ranging from 4.20-13.90% possibly due to the fast drainage through the spore space (Easton and Bock, 2016).

The results showed that the mean temperature of the soil (0-20 cm depth) ranged from 22.50-25.50^{0}C with an average of 24.26^{0}C which was matching with the atmospheric temperature. This is in agreement with the finding of Beena (2005) that the soil temperature of Kuttanad region is isohyperthermic as the annual soil temperature at a depth of 50 cm is 22^{0}C. It is rather difficult to corroborate with a single reason for the existence of a soil temperature as observed in the present study because of the high heterogeneity and complexity of the relationships (Lehnert, 2014).

All the soils analyzed had an acidic range of pH (3.4-4.8) which is in congruence with the early reports from this region (Beena and Thampatti, 2013). Soil acidity is determined by a number of factors of which the nature of the parent material from which the soil is derived is the principal one (Owolabi et al., 2003). Oxidation of pyrite in soil to sulphuric acid by rainwater during wet season in Kuttanad soils is another reason for the pH to decrease (Mathew et al., 2001).

Saline water intrusion during summer months is an ecological phenomenon contributing to the increase of salinity in Kuttanad soils. The present study reports a value of EC ranging from 0.35-1.52 dSm^{-1} which remained below the tolerable limit. This could be due to the flushing off/dilution of salts by rain water during monsoon season (Sarkar et al., 2019) or due to the movement of salts to the deeper soil profiles (Thampatti and Jose, 2000).

The CEC ranged from 30.80-60.00 cmol kg^{-1} in the soil samples. CEC is an important indicator of soil quality in agroecosystems (Khledian et al., 2017) as it represents soil's ability to hold positively charged ions (Saidi, 2012). The increase of clay fraction in the soil is reported to influence the CEC of soil (Khaledian et al., 2017).

Soils in general had a high OC (>7.5 g kg^{-1}) ranging from 12-36.80 g kg^{-1} with a mean value of 23.40 g kg^{-1} which was reported in other studies (Thafna et al., 2017). The presence of sand layers, differential accumulation of organic matter and sedimentary nature of the parent materials are attributed to be the reason for heterogeneity in OC distribution (Thampatti and Jose, 2000). Incorporation of crop residues into soil after rice cropping in Kuttanad fields could be another possible reason for the increase in OC.

Soil nutrient status

Nitrogen is a nutrient being applied in greater quantities in crop production (Pyngrope et al., 2019) which is a common practice in Kuttanad also. Despite this, the soils showed an available N content ranging from 275.70-502.95 kg h^{-1} which remained below the higher N availability class (>560 kg h^{-1}). This contrasts the finding of Thafna et al. (2017) who observed a high N content (771.91 kg h^{-1}) in Kuttnad soils. This is possibly due to an increased utilization of N by the previous crop (Guo et al., 2017). Losses through the mechanism such as high volatilization, denitrification, chemical and microbial fixation and runoff are suggested as other reasons for the reduction of N in soils (Kumar et al., 2014).

The soils of Kuttanad belonged to the higher (>25 kg h^{-1}) P availability class as it ranged from 10.10-95.0 kg h^{-1} with a mean P content of 43.60 kg h^{-1}. It is an established fact that the rice crop utilizes only 25-30% of applied P. and the remaining part which is not readily available remain in soil (Gudadhe et al., 2015) which gradually increase as available P over a period of time.

The available K content of the soils ranged from 46.50-383.20 kg h^{-1} which is in agreement with the earlier finding of Thafna et al. (2017) that the soils in this region had a high content of K. The increase in soil organic matter (Thafna et al., 2017), soil texture and irrigation regime are some of the reasons reported for the increase in K content in soil.

Elemental oxides in soil

Oxides of Fe and Al in the soils were in a range between 1378-1430 and 224.10-355 mg kg^{-1} respectively and its total value (total sesquioxide) ranged between 1612-1785 mg kg^{-1}. In the tropics, the oxides and hydroxides of Fe and Al otherwise known s sesquioxides form soil components of which a small proportion is present in the form of organic complexes (Lekwa and Whiteside, 1986). They are important parameters that influence some soil chemical reaction and properties (Ibia, 2005). Soils of Kuttanad differed in the quantity of sesquioxides they contain indicating that the parent material for the genesis of soils have undergone varied degree of weathering (Shaw and West, 2017). The maintenance of an acidic soil reaction might have triggered the distribution of more Fe and Al (Ebimol et al., 2017) to the soil which in turn reflected on sesquioxides.

Fluoride concentration in soil

Soil samples recorded a total F^{-} concentration ranging between 5.88-37.77 mg kg^{-1} with an average value of 25.88 mg kg^{-1} which was far above the normal value of 2.5 mg kg^{-1} reported from Indian soil (Naik et al., 2017). The possible route of F^- contamination in Kuttanad soils is mostly through the dissolution of fluorapatite which is a common mineral in the tertiary sediments of this area (Raj and Shaji, 2017). Long-term use of F^- containing ground water to irrigate crop (Mondal, 2017), use of synthetic fertilizers, pesticides and other agricultural chemicals (Annadurai et al., 2014) are other possible routes of contamination in Kuttanad soils.

Principal component analysis

Influence of soil characteristics on F^- concentration was evaluated by PCA. PC1 accounted for 52.2%, the second component PC2 for 12.7% and the third component PC3 for 11.3% of the variation in the profiles (Table 2). The first two components could explain significant variability existed in the data (~65%) and the third component PC3 did not significantly explain the variance compared to the first two components. It was evident from the biplot (Figure 2) that the soils 1, 3, 5, 6, 10, 12, 13 and 14 had a similar distribution of soil characteristics and F^- concentration and are grouped together in PC1 while, the soils 2, 4, 7, 8, 9, 11 and 15 had a similar distribution of soil characteristics and are grouped together in PC2. Among the soil characteristics, soil silt content, pH, EC, CEC, OC, available N and P had a significant (P<0.001) positive association along PC1 whereas, BD, extractable K, Al_2O_3, Fe_2O_3 and total sesquioxide had negative association with PC1. The variables clay content and temperature had a significant positive association along PC2. The soil sand content however exhibited negative association along PC2. Previous studies also corroborate our finding on the factors influencing F^- concentration in soil (Skjelkvåle, 1994; Xie et al., 2008). The study therefore warrants the need of a concern of these factors in the mitigation strategies of F^- in wetland soils.

Table 2. Loadings on the principal components

Measurements	Principal components		
	PC1	PC2	PC3
Eigen value	8.88	2.16	1.93
Percentage variance	52.20	12.70	11.30
Proportion	0.52	0.13	0.11
Sand	-0.187	-0.834a	-0.375
Silt	0.516a	0.291	0.495
Clay	-0.317	0.701a	-0.067
Moisture	-0.342a	0.057	-0.591a
Soil Temp	0.008	0.667a	-0.135
BD	-0.531a	-0.118	0.717a
pH	0.572a	-0.343	0.568
EC	0.904a	-0.020	-0.094
CEC	0.894a	0.067	-0.120
OC	0.674a	0.482	-0.017
Av.N	0.850a	0.032	0.278
Av.P	0.930a	-0.207	0.043
Av.K	-0.800a	-0.040	0.367
Fe_2O_3	-0.871a	-0.043	-0.116
Al_2O_3	-0.940a	0.129	0.099
Total Sesquioxide	-0.973a	0.077	0.030
Total Fluoride	0.927a	-0.014	-0.267

[a] Parameters with significant loadings on the within column principal component

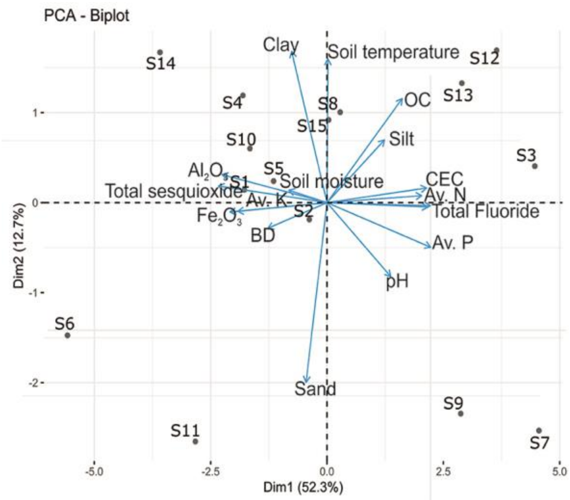

Figure 2. PCA biplot of individuals and variables. BD represent bulk density; OC, organic carbon; CEC, cation exchange capacity; Av. N, available nitrogen; Av. P, available phosphorus; Av. K, available potassium

Conclusion

The study conducted across the wetlands of Kuttanad brought out interesting information on the heterogeneity of soil characteristics and F^- concentration in soil. Similar was the case with soil nutrients (NPK), oxides of Fe and Al and total sesquioxides in soil. Among the soil characteristics, silt content, pH, EC, CEC. OC, N and P were identified as factors significantly contributing to the augmentation of F^- concentration in the wetlands of Kuttanad

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Soil data definition for hydrologic response unit analysis in SWAT model of Langkawi Island, Malaysia

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Abstract

Soil and water assessment tool (SWAT) have been assessed to examine environmental conditions and watershed scale, particularly for water quality and natural resource management. In this study, SWAT model has been applied to the main river basins in Langkawi Island. Soil data, one of the spatially distributed data needed for SWAT model interface. Currently, no soil interpretation record (s5id) data code available in readable format for user soil SWAT database for Langkawi Island. The purpose of soil data definition is to create a soil input data setup for hydrologic response unit (HRU) analysis in SWAT model which includes soil map, soil type, soil texture, and soil s5id code. Study by Leman et al. (2007) showed that geological formation of soil in Langkawi consists of alluvium, granite, Machincang, Setul, Chuping and Singa formation. The dominant soil group was Acrisols (soil unit name: Orthic Acrisols, Ao) and the dominant soil texture classification was sandy clay loam. MY4284 and MY4464 defined as the code for soil interpretation record number (s5id). Percentage of coverage for MY4464 was (62.21%; 10,865.87 ha [26,850.15 ac]) and the percentage of coverage for MY4284 was (37.79%; 6,599.8 ha [16,308.46 ac]) within the selected watershed boundary of Langkawi Island. This data setup has been successfully tested and fully functional for usersoil database of Langkawi SWAT model analysis.

Keywords: Hydrologic response unit (HRU) analysis, Langkawi Island, soil input data setup, soil S5id code, soil and water assessment tool.

Introduction

Soil water assessment tool (SWAT) is a hydrological model which currently been used widely and has been tested to examine environmental conditions and watershed scale particularly for water quality and natural resource management (Wang et al., 2019). The flexibility and capability of the SWAT model allow it to simulate the hydrological response of catchments from small watershed to large river basins. Furthermore, the model is widely utilized as it is flexible for new data adaptations and continued model development (Gassman et al., 2007).

Common application of SWAT model includes the delineation of watershed into subbasin using elevation and stream data. After watershed delineation, it is further divided into hydrologic response unit (HRU). HRU is defined as integrating land use, soil, and slope characteristics within subbasin. Integration of HRU in SWAT model has provided flexibility for simulating multiple range of condition for watershed (Kalcic et al., 2015).

The broad application of SWAT model has been simulated by software tools such as user documentation and numerous linked databases for soils, crops, pesticides, tillage, and fertilizers (Santhi et al., 2005). Soil

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properties are crucial for the simulation processes including soil water balance, sediment transport, evapotranspiration, and nutrient dynamics (Neitsch et al., 2011). Nevertheless, the existing built-in database is only valid for SWAT application in the United States (US), such as state soil geographic database (STATSGO) and the soil survey geographic database (SSURGO). This limitation urges for the development of a new soil's dataset for application outside the US. This process is time consuming because the properties of the dataset has to be stored in a single row in the usersoil table and it has to be in spatially defined format for it to be readable by SWAT and data requirement by the model not completely available for non-US countries (Cordeiro et al., 2018).

Previously, a large scale soil dataset standardized by Food and Agriculture Organization (FAO) has been prepared. Nonetheless, this dataset was not optimized for SWAT (Batjes, 1997). Soil terrain (SOTER) database was created as another initiative for global soil dataset with global coverage but SOTER is not optimized by SWAT (Dobos et al., 2005). Another database at continental scale such as hydraulic properties of European soils (HYPRES) database only covers soil hydrologic properties (Wösten et al., 1999). Few countries such as Brazil, China, and Australia have soil electronic database however it is not accessible in most countries (Shi et al., 2004; Cooper et al., 2005).

In Malaysia, the application of SWAT model mostly focus on the basin water resources and hydrologic behavior at the major river basin. In Langkawi Island particularly, there is no consistent and applicable of soil information for SWAT model. These limitations highlight the significance of the soil definition dataset presented in this paper. Due to the importance of the water resources and hydrological study, SWAT model has been used for integrated environmental modelling in Langkawi Island. The objective of this paper was to create a soil information dataset with the properties that is in readable format for SWAT model simulations. Soil data definition derived provided information for different soil types and attributed to a grid and polygon based soil map compatible for ArcSWAT version of the model.

Material and Methods

Study Area

Langkawi Island (6º19'47"N; 99º43'43") is one of the most popular tourist attractions in Malaysia, consists of six sub-districts; Kuah, Padang Mat Sirat, Ayer Hangat, Kedawang, Ulu Melaka, and Bohor. The total area of the main island including the surrounding islands is approximately 478.48 km^2. Study area covers approximately 174.66 km^2. The temperature is mainly uniform throughout the year with an annual average of 27.6°C (81.68°F). Average precipitation is 2,360 mm with a mild dry period from December to March. Long rainy season fall in March to November and September is the wettest month (Malaysian Meteorological Service, 2000-2003).

Soil and Water Assessment Tool (SWAT) Model

This continuous time, physical-based hydrologic model developed to predict the impact of land management practices on surface water, sediment, and agricultural chemical yields in simple watershed to a complex river basin with various characteristics land use condition, soil, and slope condition over long period of time (Arnold et al. 1998). The main driving forces behind SWAT model are divided into two hydrologic components; land phase and water routing phase. Land phase controls the water, sediment, and nutrient quantity flow into water body. Water routing phase simulates flow of water through the network channel. SWAT model deliberate both natural input such as mineralization of organic matter and N-fixation, as well as anthropogenic nutrient input such as fertilizers and manures (Somura et al., 2009). ArcSWAT, ArcView SWAT (AVSWAT), or MapWindow SWAT (MWSWAT) is the available model interfaces used by the model to configure input data in order to define subbasins and HRU (Kalcic et al., 2015). In this study, the model used ArcSWAT extension in the ArcGIS software (Figure 1). SWAT model configuration is expected to be able to provide useful information across various range of time scale such as hourly, daily, monthly, and yearly (Olivera et al., 2006).

Input Data for Model Setup

SWAT model requires spatial data such as selected basin of study area, land use map, soil map, and digital elevation model (DEM) map (Figure 2a,b,c,d). DEM was extracted from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite image. Land use map and soil geological map of Langkawi Island was retrieved from Special Area Plan 2020 (*Rancangan Kawasan Khas 2020*) by Langkawi Development Authority (LADA, 2019). Besides, daily meteorological data including temperature, rainfall, and precipitation of Langkawi Island from period 2005 to 2018 were obtained from Meteorological Terminal Aviation Routine Weather Report (METAR) by Malaysia Automated Surface Observing Systems (ASOS).

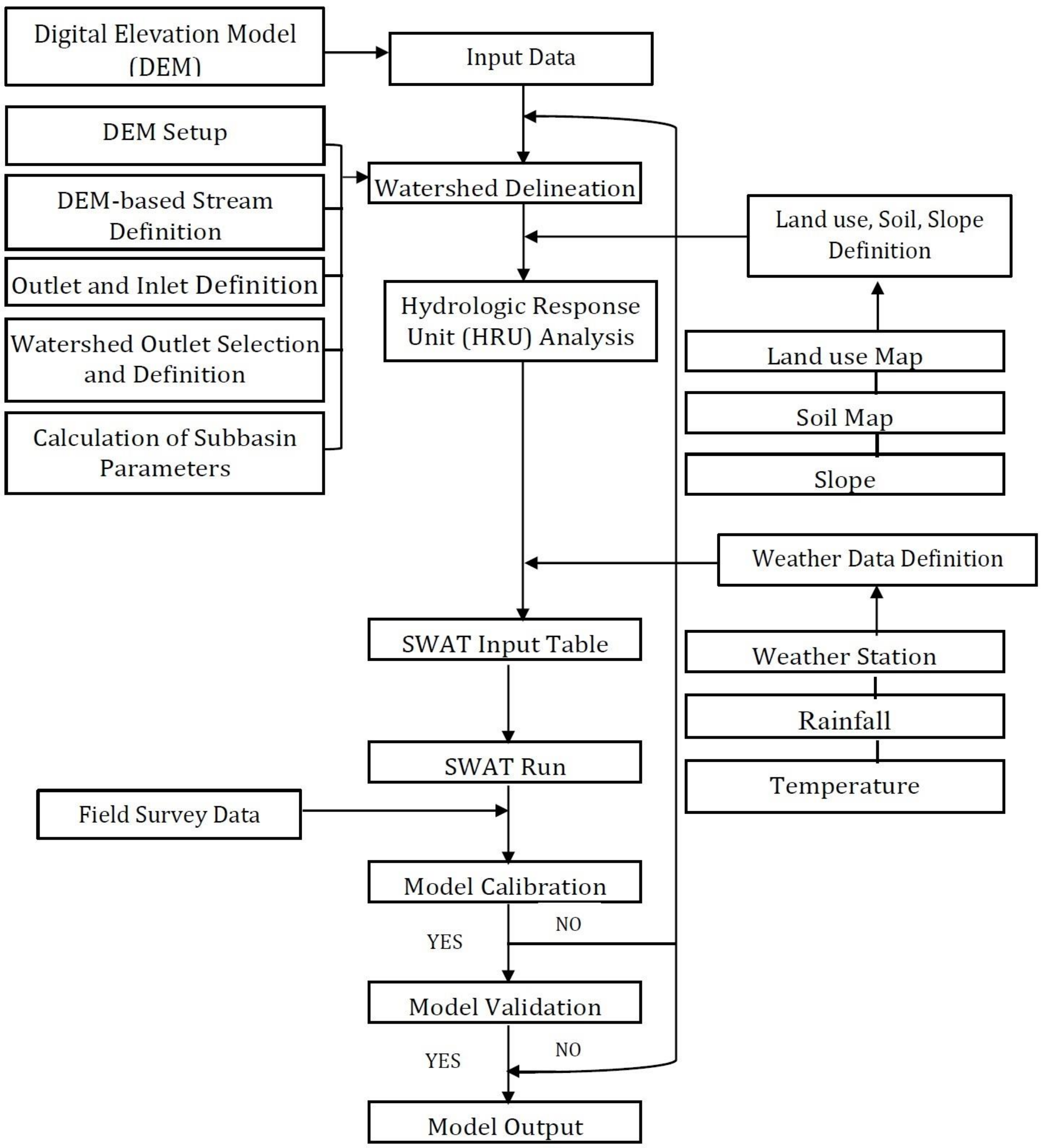

Figure 1. Application of soil and water assessment tool model on selected basin of Langkawi Island.

Land Use and Soil Definition Input Data for Hydrologic Response Unit Analysis

The land use map of Langkawi Island was used as land use layer map which was overlaid as land use grid data. User-identified land use lookup table was used as land use input for land cover classes (Table 1). Land use was categorized into seven classes; (1) urban (URBN) (included all type of housing, infrastructure, and recreation), (2) institution (UINS) (included school, mosque, hospital, shelter, cemetery, and church), (3) transportation (UTRN) (included the roads, terminal/station, and airplane runway), (4) agriculture (AGRL) (included any type of crop such as paddy, rubber plant, and palm oil), (5) commercial (UCOM) (included all type of businesses and services involved in that area), (6) industrial (UIDU) (included all type of industrial services involved in that area), and (7) forest (FRSE) (included all type of forest).

Table 1. User-identified land use lookup table.

Id	Land cover class	Abbreviation
1	Urban	URBN
2	Institution	UINS
3	Transportation	UTRN
4	Agriculture	AGRL
5	Commercial	UCOM
6	Industrial	UIDU
7	Forest	FRSE

HRU analysis required two types of data; land use and soil map. Both land use and soil map were overlaid with the watershed boundary and linked with the lookup table. Then, land use data and soil data were reclassified and defined before proceeded to HRU analysis (Figure 3).

Soil map of Langkawi Island was used as soil layer data to be overlaid as soil grid data. User-identified soil lookup table was used as soil input data for soil attributes (Table 2). Geological of Langkawi Island can be divided into five types of formation. Granite formation known as Gunung Raya granite mainly consist of coarse-grained granite with some porphyritic granite. Singa formation is known as Early Permian Singa consist of predominantly siltstone and mudstone with alternating sandy facies; the black mudstone contains clasts, blocks originated from glacial; and the basal part has redbed with dropstone formation with several limestone lenses on the upper part. Late Permian Chuping is recognized as Chuping formation consists of thin to thickly bedded limestone and dolomite which often light in color. Cambrian Machinchang or Machinchang formation is mostly cross-bedded sandstone with subordinate shale, mudstone, and conglomerate. Lastly, Ordovician to Middle Devonian Setul or recognized as Setul formation consists of predominantly thin to thickly bedded limestone often dolomitic with intervals of clastic rocks (Leman et al., 2007).

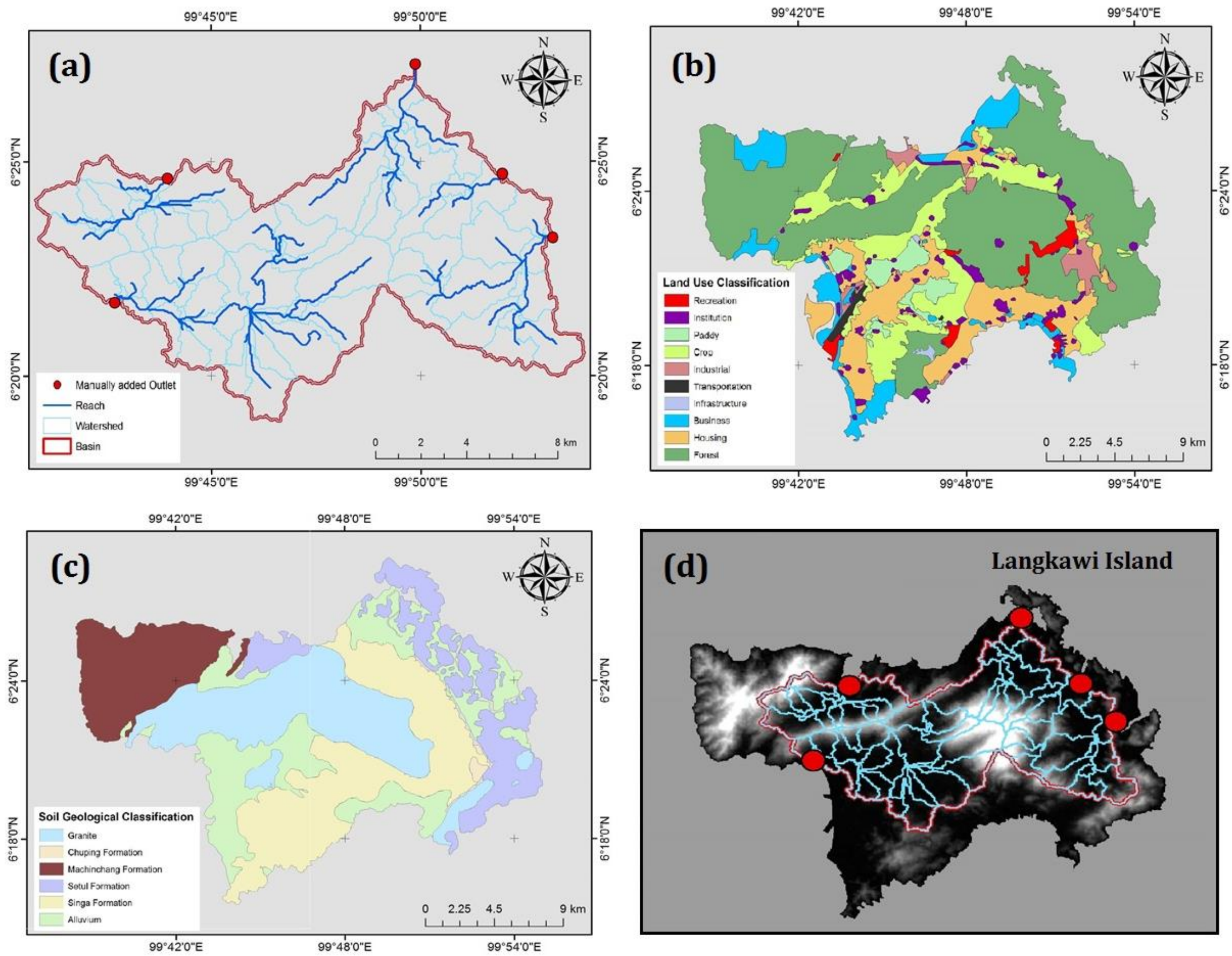

Figure 2. (a) Selected basin of study area, (b) Land use classification of study area, (c) Soil geological classification of study area, (d) Digital Elevation Model (DEM) of study area in Langkawi Island

Table 2. User-identified soil lookup table.

Id/Value	Type	S5id
1	Granite	MY4464
2	Singa	MY4284
3	Chuping	MY4284
4	Machinchang	MY4464
5	Alluvium	MY4464
6	Setul	MY4284

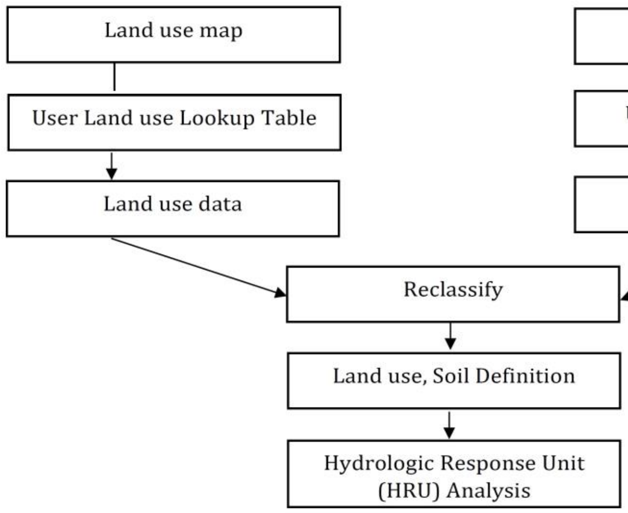

Figure 3. Hydrologic response unit analysis on selected basin of Langkawi Island

Results and Discussion

Reclassification of Hydrologic Response Unit Analysis

Land use, soil, and slope are the main component that consist of land use and soil grid data, user-identified land use and soil lookup table in the HRU analysis for definition or reclassification process.

Land Use and Soil Grid Data

The percentage of overlap between land use grid map and soil map within the watershed boundary was 100% (Figure 4a,b). According to the SWAT model simulation, the percentage of overlap less than 100% may result in some subbasins without any land use data or soil data overlap and lead to the failure of the overlapping process.

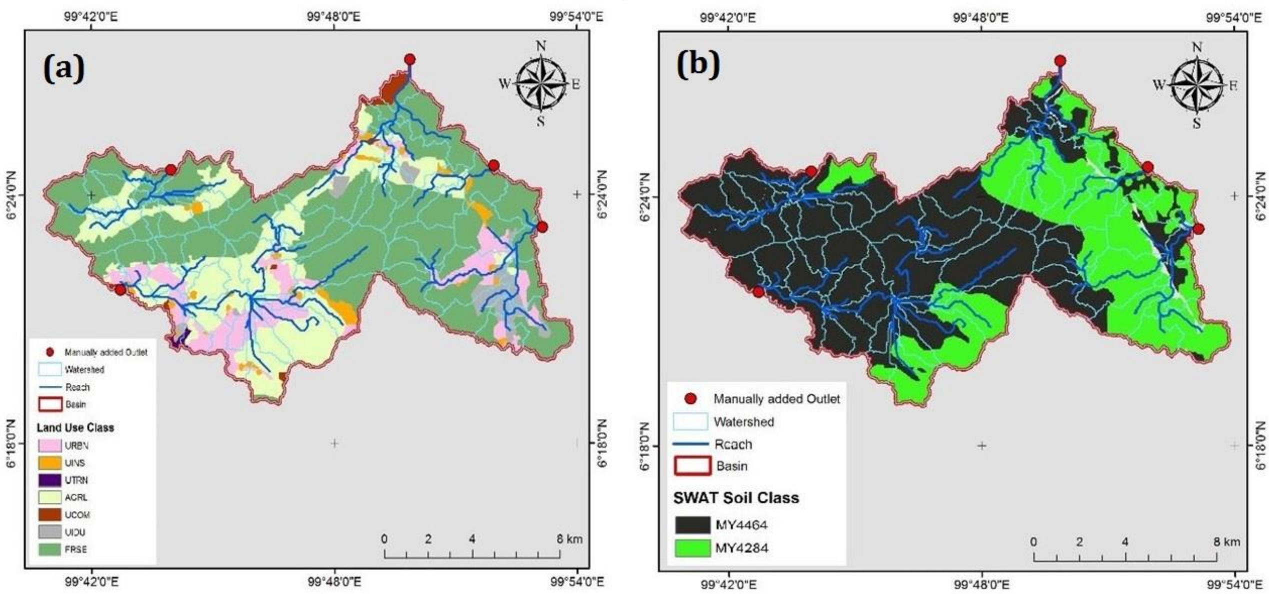

Figure 4. (a) Land use grid map overlapped with watershed boundary, (b) Soil grid map overlapped with watershed boundary of study area in Langkawi Island

User-identified Land Use and Soil Lookup Table

All the information and variables such as soil formation, soil group, soil texture and soil5ID in the input table prepared according to the properties of the dataset that is in readable format in the SWAT database to run the SWAT model simulation successfully (Table 3).

This study had produced the new soil interpretation record number (S5id) for soil in Langkawi Island which are MY4464 and MY4284. S5id (Soils5 ID number for USDA soil series data) is soil interpretation record number used to represent the map unit. MY is the prefix for the country which stand for Malaysia. The remaining number afterward (4464 and 4284) is the soil map unit which can be retrieved from Harmonized World Soil Database (HWSD).

Table 3. Soil classification for soil water assessment tool model soil input table.

Soil Formation	Soil Group							Soil Texture	Soil5 ID No. (S5id)
	Dominant Soil Group	Soil Unit Name	Topsoil Texture	Soil Unit Symbol	Drainage class (0-0.5% slope)	Topsoil USDA Texture Classification	Subsoil USDA Texture Classification	Code	
Granite, Machincang and Alluvium	Acrisols	Orthic Acrisols	Medium	Ao	Moderately Well	Sandy clay loam	Clay loam	SCL	MY4464
Singa. Setul and Chuping	Acrisols	Orthic Acrisols	Medium	Ao	Imperfectly	Sandy clay loam	Clay loam	SCL	MY4284

This study classified the soil formation for S5id MY4464 are Granite, Machincang, and Alluvium where S5id MY4284 had the soil formation of Singa, Setul, and Chuping. Soil formation for both S5id corresponds to dominant soil group Acrisols with the formation of these soils is mostly on residual of sedimentary, igneous, or metamorphic rock (FAO, 1979). According to FAO (1979), Acrisols with the unit symbol (Ao) is the most extensive soils spread around the Southeast Asia region. It can be subdivided into several types (1) Plinthic Acrisols, (2) Gleyic Acrisols, (3) Humic Acrisols, (4) Ferric Acrisols, and (5) Orthic Acrisols. The estimated soil cover is 197,000,000 ha [486,797,601.49 ac] (51%) of the region. Acrisols occur mostly in the region with annual precipitation exceeds 1,500 mm which is corresponds to the annual precipitation of Langkawi Island was 2497.1 mm (Malaysian Meteorological Service, 2000-2003). Soil unit name for MY4464 and MY4284 is Orthic Acrisols or known as other Acrisols that take place over massive tracts of steeply dissected terrain of the main mountain systems. The development of this soil type is predominantly on residuals of integrated elastic sediments, metamorphic, and acid intrusive rocks.

Both soil S5id had medium topsoil texture. Topsoil is the surface layer which usually darker than the subsurface layers based on the topsoil texture and topsoil USDA texture classification (Koenig and Isaman, 2010). Medium topsoil texture is referring to loamy soils that corresponds with sandy clay loam (SCL) soil textural class for both soil S5id with soil texture code SCL (García-Gaines and Frankenstein, 2015). The composition of sandy clay loam is 20% to 35% clay, less than 28% silt, and more than 45% sand (Soil Survey Staff, 1993). This study categorized the subsoil USDA texture classification for both MY4464 and MY4284 as clay loam. Subsoil is the layer immediately below the topsoil that consists of mainly minerals and leached materials. USDA classified subsoil texture as clay loam that composed of 27% to 40% clay, and more than 20% to 46% sand (García-Gaines and Frankenstein, 2015).

Considering the soil formation of MY4464 are Granite, Machincang, and alluvium, the drainage class was moderately well drainage class where the water removal is slightly slow and profiles are wet for short but significant periods where the drainage class for MY4284 with soil formation of Singa, Setul and Chuping was imperfectly drained where the water leaves soil slowly enough to keep it wet for significant periods but not all of the time (FAO, 2006).

Hydrologic Response Unit Analysis

The HRU analysis output was extracted after a successful run of model simulation in SWAT model. Forest (FRSE) was the highest land use area within Langkawi Island watershed; 13,202 ha [32,622.85 ac] with percentage of 75.59% (Figure 5a,b). The lowest land use area recorded was industrial (UIDU); 105.44 ha [260.55 ac] (0.60%). MY4464 showed the coverage percentage of 10,865.87 ha [26,850.15 ac](62.21 %) and MY4284 showed the coverage percentage of 6,599.8 ha [16,308.46 ac](37.79 %) within the selected watershed boundary of Langkawi Island (Figure 5c,d).

Conclusion

Soil data for HRU analysis were defined from soil geological map of Langkawi Island consisted of six (6) different type of formation; granite, Singa, Chuping, Machinchang, alluvium, and Setul with two (2) different soil interpretation record number (s5id) code; MY4464 and MY4284. These two codes were successfully tested and fully functional for usersoil SWAT database of Langkawi Island SWAT model analysis. This information may increase the usability of SWAT model to a wider range of applications in other regional and not only restricted to island only.

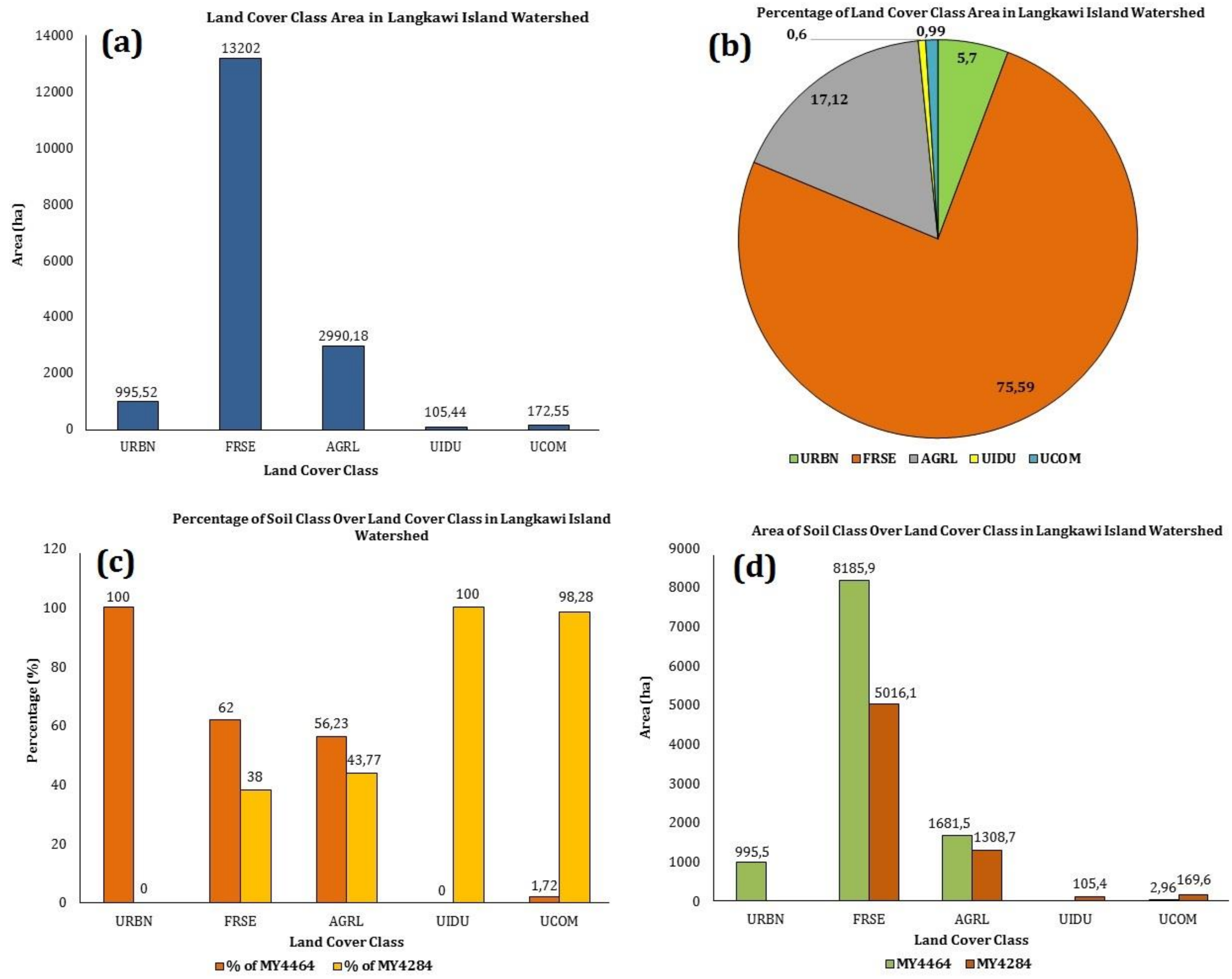

Figure 5. (a) Area of land cover class within the watershed boundary, (b) Percentage of area for land cover class within the watershed boundary of study area in Langkawi Island, (c) Percentage of soil class over land covers class within the watershed boundary, (d) Area of soil class over land cover classes within the watershed boundary

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Dry matter yield of okra and Nutrient Dynamics with cocoa pod husk-based compost and NPK fertilizer in an Ultisol

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Abstract

Dry matter yield of okra with cocoa pod husk-based (CPH) compost was assessed in a pot experiment. Three CPH-based composts: CPH+Neem leaf (CPH+NL), CPH+Poultry manure (CPH+PM) and CPH+PM+NL at the rate of 25, 50, 75, 100 kg N ha^{-1} each and NPK fertilizer at 40, 50, 60 kg N ha^{-1} and control, were applied to 5 kg soil each with three replicates and arranged in a completely randomized design. Two varieties of okra (NH47-4 and LD88) were grown. Plant height, stem girth and number of leaves were measured at 6 weeks after sowing while dry matter yield (DMY) and nutrient uptake were determined. Pre- and post- cropping soil analyses were done. Data were analyzed using ANOVA and means separated by DMRT at α = 0.05. DMY for NH47-4 ranged from 6.5g (control) to 16.7g (NPK 60 kg N ha^{-1}) and from 5.1g (control) to 7.5g (CPH+NL 100 kg N ha^{-1}) while LD88 ranged from 8.3 g (control) to 19.1g (CPH+PM 75 kg N ha^{-1}) and 4.0g (control) to 9.6g (CPH+PM75 kgNha^{-1}) in main and residual planting respectively. The N, P and K uptake of NH47-4 and LD88 were significantly enhanced with fertilizer treatments compared to the control. After the residual planting, pH of soil ranged from 6.2 (control) to 7.0 (CPH+NL 50 kg N ha^{-1}) with NH47-4 and 6.3 (control) to 6.9 (CPH+PM+NL 50 kg N ha^{-1}) with LD88. Organic carbon ranged from 9.7 gkg^{-1} (control) to 22.7 gkg^{-1} (CPH+PM+NL 50 kg N ha^{-1}) with NH47-4 and 13.9 gkg^{-1} (control) to 20.3 gkg^{-1} (CPH+PM+NL 50 kg N ha^{-1}) with LD88. Total N ranged from 0.1 gkg^{-1} (control) to 0.8 gkg^{-1} (CPH+PM+NL 100 kg N ha^{-1}) with NH47-4 and 0.1 gkg^{-1} (control) to 0.7 gkg^{-1} (CPH+PM+NL 75 kg N ha^{-1}) with LD88. The P, Ca, Mg and Na were significantly increased with fertilizer compared to control. It could therefore be concluded that CPH-based compost could be a good fertilizer for okra growth and soil fertility improvement.

Keywords: Cocoa pod husk, compost, dry matter yield, okra, Nutrient uptake..

Introduction

Cocoa pod husk (CPH) is considered a waste and vast quantity is being disposed off daily as a result of ignorance of its efficacy as an organic fertilizer source. Though CPH is being used in the manufacturing of local black soap, majority of the populace is oblivious of its ameliorating effects on nutrient depleted soils. It was estimated that 64,000-94,000 tonnes of nutrients like K, Ca and P and between 6,000-9,000 tonnes of N are lost from CPH annually. Cocoa pod husk is slow releasing relative to inorganic fertilizers (Adeoye et al. 2001) and it increased soil organic matter, soil total N, available P, exchangeable cations (such as K and Ca) compared to inorganic fertilizers (Moyinjesu, 2003).

Okra (*Abelmoschus esculentus*) is an important fruit vegetable cultivated in the tropical regions mainly for its pod (Olaniyi et al., 2010; Akintoye et al. 2011). It is an important vegetable crop throughout the tropics and

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sub-tropics (Akinyele and Osekita, 2006). The immature pods serve as ingredients of soup and stew (Osekita et al., 2000) and are eaten either fresh or cooked by boiling or frying. Okra is a popular vegetable among both the consumers and farmers because it is rich in vitamins and minerals (Oyelade et al., 2003). Application of compost has been reported to significantly increase growth, dry matter yield and fruit yield of okra (Akanbi et al., 2010). This was attributed to the fact that sufficient supply of nitrogen (N) from the compost will improve cell division and multiplication, foliage production and photosynthetic activity of the plant, thus improving the dry matter accumulation and partitioning into economic part of the plant. Also N is a major component of protein and chlorophl which will affect both yield and quality of crops. The distribution of biomass between roots and shoots influences the photosynthetic capacity and nutrient uptake of a plant, consequently affecting its relative growth rate (van der Werf, 1996). N is the most important nutrient required for adequate growth and high yield inokra. Unfortunately, N deficiency in plant is widespread in the tropics on account of low soil fertility while the coarse-textured nature of top soils and rainfall patterns favour high nitrate losses through leaching (Xu et al., 2013). The present study therefore was aimed at assessing the effect of soil amendment with cocoa pod husk-based compost and NPK mineral fertilizer on growth dry matter yield and nutrient dynamics of soil of okra.

Material and Methods

Soils (0-15 cm) were collected, bulked, properly mixed to ensure homogeneity, air-dried, sieved and sub-sampled for nutrient analysis and 5 kg soil was weighed into each plastic pot. Three types of compost were prepared using cocoa pod husk (CPH), neem leaves (NL) and poultry manure (PM) in the following ratios by weight.

(i) CPH + NL + PM (3:1:1)

(ii) CPH + PM (3:1)

(iii) CPH + NL (3:1)

The CPH was chopped into smaller pieces before composting to reduce the particle size. The temperature of each pile was monitored daily for the first week and every other day for the next four weeks and weekly until the end of the composting with the use of a soil thermometer. The mixtures were turned and watered every fortnight. The organic materials were composted for three months after which they were allowed to cure for two weeks, shredded and bagged for use

The treatments; 25, 50, 75, 100 kg N ha^{-1} of each compost and NPK mineral fertilizer at 40, 50, 60 kg N ha^{-1} and control, were applied to 5 kg soil each and arranged in a completely randomized design in three replicates. Two varieties of okra (NH47-4 and LD88) were used as test crop. There were 32 treatment combinations replicated three times to give 96 experimental units kg N ha^{-1}.

The CPH-based compost was applied two weeks before planting by mixing thoroughly with the soil in each pot after which water was added. Each pot was placed on saucer to collect leachates and poured back to the pot every other day. Three seeds of okra were sown per pot but later thinned to two plants per pot at 2 weeks after sowing. NPK fertilizer was applied one week after sowing. Supplementary watering was maintained throughout the growth period. At six weeks after planting (6 WAS) data were collected on plant height, stem girth and number of leaves after which the plants were harvested by cutting at soil surface in each pot. The roots were carefully removed and washed. Thereafter, roots and shoots were oven-dried at 70^{o}C until constant weight and plant dry matter yields calculated by adding the weight of the shoot and root. The dry matter partitioning was calculated as the ratio of either the root or the shoot to the total plant dry weight. After oven drying, the materials were milled and analyzed for N, P and K concentrations. Nutrient uptake in shootwas calculated using the formula:

$$\text{Nutrient uptake} = \%\ \text{nutrient concentration x dry matter yield (mg / plant)}$$

Residual effects of compost and inorganic fertilizer on dry matter yield and nutrient uptake of okra were investigated a week after harvesting. . The experiment was carried out without further fertilizer applications. The soil in each pot was watered to field capacity and okra varieties (NH47-4 and LD88) were re-seeded. At 6 weeks after sowing, data were collected on plant height, stem girth and number of leaves after which the plants were harvested by cutting at soil surface in each pot. The same procedure in the main planting was repeated. The data were subjected to statistical analysis using one way ANOVA and the means were separated by Duncan's Multiple Range Test (DMRT) at 5 % probability level.

The CPH, NL, and PM were analyzed for total carbon C, N, P, K, Ca, Na and Mg before composting. At maturity, samples were randomly taken from each compost type, milled and subjected to chemical analyses. The pH of the composts were determined in 1:2 sample water ratio using Electrometric method (IITA, 1982). Organic carbon was determined by dry ashing method (Nelson and Sommers, 1996). Total N was determined by the micro-Kjeldahl method (Bremner, 1996). The samples were digested with perchloric and nitric acids; P was determined by vanadomolybdate yellow color procedure (Olsen and Dean, 1965), K and Na by flame photometer; Ca and Mg by Atomic Absorption Spectrophotometer.

Representative soil samples were taken and used for the following analysis:soil particle size, pH (H_2O), organic C, Total N, available P as well as exchangeable K, Na, Ca and Mg. Particle size analysis was determined using the Bouyoucos hydrometer method (Sheldrick and Wang, 1993). Soil pH was determined in distilled water at a 1:2 (w/v) soil to water ratio using Electrometric method (IITA, 1982). Total N was determined using the micro-Kjedahl digestion method (Bremner, 1996) while organic carbon was determined using dichromate wet oxidation procedure of Walkley and Black (Nelson and Sommers, 1996). Available P was extracted using Bray-P1 method (IITA, 1982) and determined colourimetrically following the procedure of Murphy and Riley (1962). Exchangeable K, Ca, Mg, and Na were extracted with 1N (pH 7.0) ammonium acetate (Hendershot and Lalande, 1993). Thereafter, the amounts of K and Na in the filtrates were determined using flame photometer, while Ca and Mg were determined using Atomic Absorption Spectrophotometer (AAS). Exchangeable acidity was extracted with 1 N potassium chloride (KCl) (Thomas, 1982) and determined by titration with 0.05 N sodium hydroxide (NaOH) using phenolphthalein as an indicator. The effective cation exchange capacity (ECEC) was calculated as the total sum of exchangeable bases and total exchangeable acidity.

The soil was moderately acidic (with pH value of 5.6) and sandy loam in texture (Table 1). The total N of was low (0.7 g kg^{-1}) as the value was below the critical level of 1.6-2.0 g kg^{-1}while the available P values of the soil (5 mg kg^{-1}) was also below the critical level of 7-20 mg kg^{-1}. The K status of the soil (0.1 cmol kg^{-1}) was less than the critical level of 0.31 cmol kg^{-1}. The Ca content of the soil (1.6 cmol kg^{-1}) is below the critical value of 2.5 cmol kg^{-1}. The Mg content (0.4 cmol kg^{-1}) is moderate because it is within the critical value of 0.2-0.4 cmol kg^{-1}. The K content (0.1 cmol kg^{-1}) is low as it is below the critical level of 0.16-0.25 cmol kg^{-1}). The soil was generally low in organic carbon (7.2 g kg^{-1}) because it was below the critical level of 10-14 g kg^{-1} (FFD, 2012).

Table 1. Physical and chemical properties of pre-cropping soil

Parameters	**Value**
pH (H_20) (1:1)	5.60
OC, g kg^{-1}	7.20
Total N, g kg^{-1}	0.70
Available P, mg kg^{-1}	5.00
Exchangeable cations, cmol kg^{-1}	
Ca^{++}	1.60
Mg^{++}	0.40
K^{+}	0.10
Na^{+}.	0.20
Exchangeable acidity (Al^{3+} +H^{+})	0.13
ECEC	2.43
Particle size, g kg^{-1}	
Sand	776.0
Silt	124.8
Clay	109.2
Textural class	Sandy loam

Results

The results of the effect of treatments on the plant height of NH47-4 and LD88 presented in Table 2 showed that they were significantly affected by fertilizer treatments compared with the control. At the main planting, the highest plant height (51.2 cm) of NH47-4 was obtained from NPK at 60 kg N ha^{-1} while the highest plant height of LD88 was obtained from CPH+PM at 100 kg N ha^{-1}. The control gave the least plant height of NH47-4 and LD88 (29.5 and 34.4 cm respectively). At the residual planting, there were no significant differences in the plant height of NH47-4 across all the treatments. However, the plant height of LD88 was significantly affected by fertilizer treatments. The highest plant height (50.1 cm) was obtained from CPH+PM+NL at 100 kg N ha^{-1} which was significantly higher than all the NPK treated plants and the control (33.3 cm).

The number of leaves of NH47-4 was significantly affected by fertilizer treatments in main planting but the difference was not significant in LD88 (Table 2). The highest number of leaves (7.3) of NH47-4 obtained from NPK at 40 kg N ha^{-1} was not significantly higher than most of the fertilizer treatments but significantly higher than CPH+PM+NL at 100 kg N ha^{-1} (6.0), CPH+PM at 50 kg N ha^{-1} (5.7), CPH+PM+NL at 50 kg N ha^{-1} (5.5) and the control (5.3). However,at residual planting, there were no significant difference in the number of leaves of both NH47-4 and LD88 across all the treatments. The stem girth of NH47-4 was not significantly affected by fertilizer treatment at both main and residual planting (Table 2). However, the stem girth of LD88 was significantly affected in both main and residual planting. The highest stem girth obtained from NPK at 50 kg N ha^{-1} (5.9 mm) was significantly higher than CPH+PM+NL at 50 kg N ha^{-1} (4.5 mm) and the control (4.2 mm) in the main planting. At the residual planting, LD88 treated with NPK at 50 kg N ha^{-1} gave the highest stem girth (5.9 mm) which was significantly higher than that of CPH+PM+NL at 50 kg N ha^{-1} (4.5 mm) and the control (4.2 mm).

Table 2. Plant height (cm), number of leaves and stem girth (mm) of okra as influenced by applications of compost and NPK fertilizer at 6 weeks after sowing during the main and residual planting

Treatment	Main			Residual		
	Plant height	No of leaves	Stem girth	Plant height	No of leaves	Stem girth
NH47-4						
Control	29.5 i	5.3 e	4.1	27.0	4.7	4.1
CPH+PM+NL 25 KgN	40.2 de	6.8 abc	4.5	31.9	5.3	4.5
CPH+PM+NL 50 KgN	37.1 ef	5.5 e	4.6	33.0	4.5	4.6
CPH+PM+NL 75 KgN	47.5 abc	6.5 abcd	5.0	37.4	4.7	5.0
CPH+PM+NL 100 KgN	43.2 bcd	6.0 bcd	4.9	32.2	4.7	4.9
CPH+PM 25 KgN	33.4 fgh	6.3 abcd	4.9	34.5	5.0	4.9
CPH+PM 50 KgN	42.4 cd	5.7 cd	5.1	37.3	4.3	5.1
CPH+PM 75 KgN	40.2 de	6.2 abcd	4.9	36.0	5.0	4.9
CPH+PM 100 KgN	43.8 bcd	7.0 ab	5.1	37.5	4.8	5.1
CPH+NL 25 KgN	31.5 gh	6.2 abcd	5.6	28.7	5.2	5.6
CPH+NL 50 KgN	46.2 abc	7.2 ab	5.1	40.3	5.2	5.1
CPH+NL 75 KgN	42.4 cd	6.8 abc	4.8	39.1	5.0	4.8
CPH+NL 100 KgN	35.9 efg	6.5 abcd	5.6	40.0	4.7	5.6
NPK 40 KgN	45.3 bcd	7.3 a	4.9	30.4	4.5	4.9
NPK 50 KgN	47.9 ab	6.2 abcd	5.2	34.3	5.2	5.2
NPK 60 KgN	51.2 a	6.3 abcd	5.2	35.9	4.8	5.2
			ns	ns	ns	ns
LD88						
Control	34.4 f	6.5	4.2 c	33.3 e	4.2	4.2 c
CPH+PM+NL 25 KgN	41.4 e	6.3	5.0 abc	41.0 bcde	4.3	5.0 abc
CPH+PM+NL 50 KgN	41.0 e	6.3	4.5 bc	43.0 abcd	4.0	4.5 bc
CPH+PM+NL 75 KgN	42.2 de	5.7	5.1 abc	45.9 abc	4.8	5.1 abc
CPH+PM+NL 100 KgN	43.5 cde	5.5	5.3 ab	50.1 a	5.0	5.3 ab
CPH+PM 25 KgN	42.7 de	6.2	5.4 ab	38.2 bcde	4.7	5.4 ab
CPH+PM 50 KgN	46.5 bcde	6.8	4.9 abc	40.4 bcde	5.0	4.9 abc
CPH+PM 75 KgN	43.9 cde	6.5	5.5 a	44.2 abc	4.7	5.5 a
CPH+PM 100 KgN	54.5 a	6.8	5.6 a	44.2 abc	4.5	5.6 a
CPH+NL 25 KgN	39.5 ef	5.8	5.0 ab c	46.2 ab	5.0	5.0 abc
CPH+NL 50 KgN	50.0 abc	5.8	5.4 ab	34.3 de	4.2	5.4 ab
CPH+NL 75 KgN	43.5 cde	6.8	5.7 a	46.7 ab	4.5	5.7 a
CPH+NL 100 KgN	52.3 ab	5.8	5.2 abc	40.8 bcde	5.2	5.2 abc
NPK 40 KgN	43.7 cde	5.8	5.0 abc	32.9 e	5.0	5.0 abc
NPK 50 KgN	48.8 abcd	6.3	5.9 a	37.2 cde	5.2	5.9 a
NPK 60 KgN	54.3 a	6.5	5.3 ab	39.3 bcde	4.8	5.3 ab
		ns			ns	

ns - not significant; *- significant. Means with same letter (s) in a column under the same treatment are not significantly different at 5 % level of probability by Duncan's Multiple Range Test (DMRT). CPH= Cocoa pod husk, PM= Poultry manure, NL= Neem leaf

The dry matter yield of NH47-4 and LD88 were significantly affected by fertilizer treatments in both main and residual planting (Table 3). At the main planting, the highest dry matter yield of NH47-4 (16.7g) obtained from NPK at 60 kg N ha^{-1} was not significantly higher than CPH+PM at 75 kg N ha^{-1} (15.5 g), CPH+PM+NL at 75 kg N ha^{-1} (15.0 g), CPH+PM+NL at 50 kg N ha^{-1} (14.5 g) and CPH+PM+NL at 100 kg N ha^{-1} (14.4 g) but significantly higher than the other treatments and control which gave the least value (6.5 g). The highest dry matter yield of LD88 (19.1g) obtained from CPH+PM at 75 kg N ha^{-1} was not significantly higher than CPH+PM at 50 kg N ha^{-1} but significantly higher than other treatments and control which gave the least value (8.3 g). At the residual planting, the highest dry matter yield of NH47-4 (7.5 g) was obtained from CPH+NL at 100 kg N ha^{-1} while the highest yield of LD88 (9.6g) was obtained from CPH+ PM at 75 kg N ha^{-1}.

Table 3. Dry matter yield (g/plant) of okra as influenced by compost and NPK fertilizer in main and residual planting

Treatment	Main			Residual		
	Shoot	Root	Total	Shoot	Root	Total
NH47-4						
Control	5.8 f	0.7	6.5 f	4.6 ef	0.5 de	5.1 de
CPH+PM+NL 25 KgN	13.0 bc	0.8	13.9 bc	5.3 cde	0.6 cde	5.9 bcd
CPH+PM+NL 50 KgN	13.6 abc	0.9	14.5 abc	5.2 cdef	1.3 a	6.5 abcd
CPH+PM+NL 75 KgN	14.0 abc	1.0	15.0 abc	5.7 bc	0.9 b	6.6 abcd
CPH+PM+NL 100 KgN	13.6 abc	0.8	14.4 abc	6.2 ab	0.7 bcd	6.9 ab
CPH+PM 25 KgN	11.8 cd	0.9	12.7 cd	5.0 cdef	0.7 bcd	5.6 bcd
CPH+PM 50 KgN	13.0 bc	0.9	13.9 bc	5.7 bc	0.6 cde	6.3 abcd
CPH+PM 75 KgN	14.4 ab	1.1	15.5 ab	5.3 cde	0.7 bcd	6.0 abcd
CPH+PM 100 KgN	12.3 bc	0.9	13.1 bc	6.0 b	0.7 bcd	6.8c ab
CPH+NL 25 KgN	9.4 de	0.7	10.1 e	4.6 ef	0.7 cd	5.3 cde
CPH+NL 50 KgN	9.8 de	0.6	10.5 de	5.0 cdef	0.7 bcd	5.7 bcd
CPH+NL 75 KgN	8.3 e	0.8	9.1 e	4.7 ef	0.4 e	5.1 de
CPH+NL 100 KgN	8.1 e	0.7	8.9 e	6.7 a	0.8 bc	7.5 a
NPK 40 KgN	8.9 e	0.9	9.8 e	4.5 f	0.8 bc	5.3 cde
NPK 50 KgN	9.5 de	0.8	10.3 de	5.0 cdef	0.8 bc	4.1 e
NPK 60 KgN	15.9 a	0.8	16.7 a	5.0 cdef	0.8 bc	5.8 bcd
		ns				
LD88						
Control	7.5 f	0.8 cd	8.3 f	3.6 j	0.4 d	4.0 j
CPH+PM+NL 25 KgN	9.2 ef	0.9 bc	10.1 def	5.2 ghi	0.6 b	5.8 ghi
CPH+PM+NL 50 KgN	8.6 f	1.0 bc	9.6 ef	4.8 hi	0.4 d	5.2 gh
CPH+PM+NL 75 KgN	9.4 def	1.3 ab	10.7 de	5.8 efg	1.0 a	6.8 def
CPH+PM+NL 100 KgN	9.4 def	1.2 ab	10.6 def	6.1 defg	0.9 a	6.9 de
CPH+PM 25 KgN	11.2 cde	0.8 cd	12.0 cd	6.9 bcd	0.5 c	7.4 d
CPH+PM 50 KgN	16.2 ab	1.2 ab	17.4 ab	5.9 efg	0.6 b	6.4 efg
CPH+PM 75 KgN	17.8 a	1.3 ab	19.1 a	8.6 a	1.0 a	9.6 a
CPH+PM 100 KgN	16.5 ab	1.2 ab	17.6 ab	7.5 bc	0.8 a	8.3 bc
CPH+NL 25 KgN	8.6 f	0.7 cd	9.3 ef	6.2 def	0.5 c	6.7 def
CPH+NL 50 KgN	9.8 cdef	0.9 bc	10.8 def	7.8 b	0.6 b	8.4 b
CPH+NL 75 KgN	9.3 ef	1.0 bc	10.3 def	6.6 cde	0.6 b	7.2 de
CPH+NL 100 KgN	11.9 c	1.2 ab	13.1 c	7.2 bc	0.4 d	7.5 cd
NPK 40 KgN	11.7 cd	1.2 ab	13.2 c	5.5 fgh	0.5 c	5.9 fgh
NPK 50 KgN	8.3 f	0.5 d	8.8 f	4.6 i	0.5 c	5.1 i
NPK 60 KgN	14.8 b	1.6 a	16.4 b	5.5 fgh	0.4 d	6.0 fgh

ns - not significant. Means with same letter (s) in a column under the same treatment are not significantly different at 5 % level of probability by Duncan's Multiple Range Test (DMRT). CPH= Cocoa pod husk, PM= Poultry manure, NL= Neem leaf

The N, P and K uptake of the two varieties were significantly enhanced by treatments in both main and residual planting (Table 4). In the main planting, CPH+PM at 25 kg N ha^{-1} gave the highest N uptake of NH47-4 (190.6 mg/plant) which was not significantly different from value (171.0 mg/plant) obtained from CPH+PM+NL 50 kg N ha^{-1} but significantly higher than other fertilizer treatments and control which gave the least value (96.1 mg/plant). The highest N uptake of LD88 (192.7 mg/plant) obtained from CPH+PM at 50 kg N ha^{-1} was not significantly higher than CPH+PM at 75 kg N ha^{-1} (177.2 mg/plant) and CPH+PM at 100 kg N ha^{-1} but significantly higher than other treatments.

The highest P uptake of NH47-4 (29.9 mg/plant) obtained from CPH+PM+NL at 100 kg N ha^{-1} was not significantly higher than that of CPH+PM at 50 kg N ha^{-1} (28.7 mg/plant) but significantly higher than other treatments. The P uptake of LD88 (28.1 mg/plant) obtained from CPH+PM at 100 kg N ha^{-1} was significantly higher than other treatments. The mean uptake of K of NH47-4 (144.6 mg/plant) obtained from CPH+PM+NL at 100 kg N ha^{-1} was not significantly higher than the value obtained from CPH+PM+NL at 75 kg N ha^{-1} (125.5 mg/plant) but significantly higher than other treatments. The K uptake of LD88 (164.4 mg/plant) obtained from CPH+PM at 100 kg N ha^{-1} was not significantly higher than CPH+NL at 50 kg N ha^{-1}

(158.8 mg/plant), CPH+PM at 50 kg N ha^{-1} (150.4 mg/plant), CPH+PM at 75 kg N ha^{-1} (146.3 mg/plant) and CPH+NL at 25 kg N ha^{-1} (137.7 mg/plant) but significantly higher than other treatments.

In the residual planting, the highest N uptake of NH47-4 (74.2 mg/plant) obtained from CPH+PM at 100 kg N ha^{-1} was not significantly different from CPH+PM+NL at 50 kg N ha^{-1} (74.1 mg/plant), CPH+NL at 100 kg N ha^{-1} (70.2 mg/plant) and CPH+PM at 25 kg N ha^{-1} but significantly different from other treatments. The highest N uptake of LD88 (84.0 mg/plant) obtained from CPH+NL at 50 kg N ha^{-1} was significantly different from other treatments. The highest P uptake of NH47-4 (19.9 mg/plant) obtained from CPH+NL 50 kg N ha^{-1} was not significantly different from CPH+NL (19.2 mg/plant) but significantly different from other treatments. The P uptake of LD88 (14.8 mg/plant) obtained from CPH+PM at 100 kg N ha^{-1} was significantly higher than all the treatments. The highest K uptake of NH47-4 (98.0 mg/plant) obtained from CPH+NL at 100 kg N ha^{-1} was significantly different from other treatments. Also, LD88 had the highest K uptake (97.7 mg/plant) obtained from CPH+NL at 25 kg N ha^{-1} was not significantly different from CPH+NL at 50 kg N ha^{-1} (95.3 mg/plant) but significantly different from the other treatments. The control gave the least N, P and K uptake of NH47-4 and LD88 in both main and residual planting.

Table 4. Nutrient uptake (mg/plant) of okra as influenced by applications of compost and NPK fertilizer during the main and residual planting

Treatment	Main						Residual					
	N		P		K		N		P		K	
NH47-4												
Control	96.1	fgh	13.2	efg	67.5	gh	33.2	ef	4.5	f	30.4	g
CPH+PM+NL 25 KgN	130.1	cdef	16.6	defg	103.2	bc	38.4	def	7.1	def	56.2	cdef
CPH+PM+NL 50 KgN	171.0	ab	23.2	bcd	106.5	bc	74.1	a	10.5	cd	70.3	c
CPH+PM+NL 75 KgN	137.5	bcde	23.4	bcd	125.5	ab	40.8	cdef	10.4	cd	66.3	cd
CPH+PM+NL 100 KgN	139.4	bcde	29.9	a	144.6	a	45.9	cde	17.2	b	81.8	b
CPH+PM 25 KgN	190.6	a	21.1	bcde	115.2	de	68.0	ab	9.4c	de	35.6	fg
CPH+PM 50 KgN	120.3	defg	28.7	ab	121.5	d	55.3	bcd	13.5	bc	50.1	cdefg
CPH+PM 75 KgN	155.0	bc	26.7	bc	107.6	def	40.7	cdef	15.2	c	38.8	efg
CPH+PM 100 KgN	152.2	bcd	15.7	defg	115.3	de	74.2	a	8.1	def	58.7	cde
CPH+NL 25 KgN	73.1	h	9.3	g	43.2	h	49.4	cde	7.4	def	33.7	g
CPH+NL 50 KgN	108.7	efgh	14.2	efg	77.3	fgh	41.8	cdef	19.9	a	40.2	efg
CPH+NL 75 KgN	103.6	fgh	18.9	cdef	85.6	efg	58.6	bcd	19.2	a	48.2	defg
CPH+NL 100 KgN	102.7	fgh	11.5	fg	154.4	c	70.2	ab	9.7	cde	98.0	a
NPK 40 KgN	94.2	gh	9.7	g	66.1	gh	34.7	ef	5.3	ef	35.7	fg
NPK 50 KgN	93.3	gh	13.4	efg	83.8	efg	24.7	f	5.3	ef	32.6	g
NPK 60 KgN	152.9	bcd	20.2	cde	96.6	defg	44.8	cde	7.0	def	33.6	g
LD88												
Control	60.1	g	12.9	e	68.8	g	28.3	f	6.1	de	38.3	d
CPH+PM+NL 25 KgN	120.3	de	13.2	de	124.9	bcde	69.2	b	6.3	de	67.3	bc
CPH+PM+NL 50 KgN	118.1	de	17.3	cde	121.3	cde	63.7	bc	9.3	bcd	58.4	c
CPH+PM+NL 75 KgN	106.8	ef	18.1	cde	120.2	cde	48.7	de	11.5	b	72.8	bc
CPH+PM+NL 100 KgN	108.8	ef	13.8	de	139.9	abcd	49.8	de	9.1	bcd	87.0	b
CPH+PM 25 KgN	118.6	de	16.9	cde	114.8	def	50.7	de	10.4	bc	57.9	c
CPH+PM 50 KgN	192.7	a	12.5	e	150.4	ab	64.8	bc	4.5	e	36.5	d
CPH+PM 75 KgN	177.2	ab	24.7	b	146.3	abc	60.1	bcd	11.1	b	66.5	bc
CPH+PM 100 KgN	176.2	ab	28.1	a	164.4	a	55.1	cd	14.8	a	68.7	bc
CPH+NL 25 KgN	85.1	f	12.8	e	137.7	abcd	41.6	e	9.2	bcd	97.7	a
CPH+NL 50 KgN	110.6	def	15.1	cde	158.8	a	84.0	a	11.8	b	95.3	a
CPH+NL 75 KgN	102.8	def	16.4	cde	112.5	def	65.4	bc	11.5	b	77.7	bc
CPH+NL 100 KgN	135.3	cd	19.6	bcd	114.4	def	56.6	cd	11.3	b	65.0	c
NPK 40 KgN	157.8	bc	19.4	bcd	86.3fg		71.2	b	7.7	cde	70.0	bc
NPK 50 KgN	123.4	de	12.6	e	59.3	g	70.9	b	6.9	de	33.1	d
NPK 60 KgN	156.7	bc	21.3	bc	99.7	ef	56.8	cd	7.7	cde	26.8	d

ns - not significant; *- significant. Means with same letter (s) in a column under the same treatment are not significantly different at 5 % level of probability by Duncan's Multiple Range Test (DMRT). CPH= Cocoa pod husk, PM= Poultry manure, NL= Neem leaf

The effect of treatments was significant on all the chemical properties determined in soil planted with NH47-4 in the main planting (Table 5). The pH values of all the treatments increased with fertilizer treatments with the highest value (7.1) obtained from CPH+PM+NL at 50 kg N ha^{-1}, CPH+PM at 50 kg N ha^{-1} and CPH+NL at 50 kg N ha^{-1} while the least value was obtained from the control (6.0). Also, the pH of soil planted with LD88 increased with CPH–based fertilizer compared to the control. The organic carbon of the soil planted with NH47-4 increased from the initial value of 7.2 to between 21.2 and 24.6 g kg^{-1} with CPH+PM+NL at 25 and 50 kg N ha^{-1} respectively. However, the organic carbon of soil planted with LD88 were not significantly different among the CPH-based fertilizer but significantly higher than all the NPK rates (6.6 g kg^{-1}) and control (17.0 g kg^{-1}). There were significant increase in the N content of the soil planted with NH47-4 with the application of fertilizer. The highest N content (1.2 g kg^{-1}) obtained from CPH+PM+NL at 75 kg N ha^{-1} was significantly higher than some of the other fertilizer treatments and control (0.67 g kg^{-1}). There were no significant differences in the N content of soil planted with LD88. The l P, Ca, Mg K and Na contents of soil planted with NH47-4 were significantly enhanced by the application of fertilizer; the control gave the lowest value of P (3 mg kg^{-1}) and Mg (0.4 cmol kg^{-1}). Also, the P, Ca, Mg and K content of soil planted with LD88 were significantly enhanced with fertilizer treatments except Na that was not significantly enhanced.

Table 5. Effects of applications of compost and NPK fertilizer on soil chemical properties after the main planting

Treatment	pH (H_2O)		Org.C (g kg^{-1})		N (g kg^{-1})		P (mg kg^{-1})		Ca (cmol kg^{-1})		Mg (cmol kg^{-1})		K (cmol kg^{-1})		Na (cmol kg^{-1})	
NH47-4																
Control	6.0	e	15.1	e	0.67	d	3	c	2.3	b	0.4	f	0.1	b	0.2	d
CPH+PM+NL 25 KgN	6.8	bc	21.2	d	1.03	abc	6	a	2.2	b	0.9	e	0.1	b	0.2	d
CPH+PM+NL 50 KgN	7.1	a	24.6	a	1.03	abc	5	ab	2.3	b	0.8	e	0.2	a	1.7	a
CPH+PM+NL 75 KgN	6.8	bc	23.4	a	1.20	a	5	ab	2.3	b	1.3	c	0.2	a	1.1	b
CPH+PM+NL 100 KgN	7.0	ab	22.6	b	1.00	abc	5	ab	2.3	b	2.2	b	0.2	a	0.2	d
CPH+PM 25 KgN	6.6	d	20.9	d	0.80	cd	5	ab	2.3	b	0.8	e	0.1	b	0.2	d
CPH+PM 50 KgN	7.1	a	24.5	a	1.07	ab	5	ab	2.3	b	1.0	d	0.2	a	0.7	c
CPH+PM 75 KgN	6.9	bc	23.6	a	1.07	ab	5	ab	2.3	b	1.3	c	0.2	a	1.1	b
CPH+PM 100 KgN	7.0	ab	21.8	c	0.97	abc	5	ab	2.3	b	2.3	b	0.2	a	0.2	d
CPH+NL 25 KgN	6.7	cd	21.4	d	0.87	bc	4	bc	2.2	b	0.8	e	0.1	b	0.2	d
CPH+NL 50 KgN	7.1	a	24.3	a	1.07	ab	5	ab	2.3	b	0.8	e	0.2	a	1.7	a
CPH+NL 75 KgN	6.9	bc	23.6	a	1.03	abc	5	ab	2.2	b	1.3	c	0.1	b	1.2	b
CPH+NL 100 KgN	6.9	bc	21.6	c	0.90	c	5	ab	2.5	a	2.2	b	0.2	a	0.2	d
NPK 40 KgN	6.7	cd	23.8	a	0.67	d	3	c	2.2	b	2.4	a	0.2	a	0.2	d
NPK 50 KgN	6.7	cd	22.4	b	0.70	d	4	bc	2.2	b	2.2	b	0.2	a	0.2	d
NPK 60 KgN	6.8	c	21.7	c	0.73	d	6	a	2.2	b	2.2	b	0.1	b	0.2	d
LD88																
Control	6.1	c	17.0	c	0.7		5	a	2.3	cd	1.0	d	0.1	b	0.2	
CPH+PM+NL 25 KgN	6.8	ab	22.6	a	0.9		5	a	2.2	cd	1.1	c	0.2	a	0.2	
CPH+PM+NL 50 KgN	6.9	a	22.6	a	0.9		2	c	2.3	cd	1.1	c	0.2	a	0.2	
CPH+PM+NL 75 KgN	6.9	a	22.9	a	1.0		3	b	2.4	c	1.1	c	0.2	a	0.2	
CPH+PM+NL 100 KgN	6.9	a	22.7	a	1.0		5	a	2.3	cd	1.0	d	0.2	a	0.2	
CPH+PM 25 KgN	6.8	ab	22.9	a	0.9		5	a	2.3	cd	1.1	c	0.2	a	0.2	
CPH+PM 50 KgN	6.9	a	22.4	a	0.9		2	c	2.3	cd	1.1	c	0.2	a	0.2	
CPH+PM 75 KgN	6.7	bc	22.7	a	1.0		4	b	2.3	cd	1.1	c	0.2	a	0.2	
CPH+PM 100 KgN	6.9	a	22.0	a	0.8		5	a	3.0	a	1.9	a	0.2	a	0.2	
CPH+NL 25 KgN	6.8	ab	22.8	a	0.9		5	a	2.8	ab	1.1	c	0.2	a	0.2	
CPH+NL 50 KgN	6.7	bc	22.4	a	0.8		2	c	2.4	c	1.1	c	0.2	a	0.2	
CPH+NL 75 KgN	6.7	bc	22.2	a	1.0		4	b	2.4	c	1.1	c	0.2	a	0.2	
CPH+NL 100 KgN	6.9	a	23.0	a	0.9		5	a	2.7	b	1.1	c	0.2	a	0.2	
NPK 40 KgN	6.6	c	19.0	b	0.8		5	a	1.9	e	1.2	b	0.1	b	0.2	
NPK 50 KgN	6.6	c	18.6	b	0.9		3	b	2.4	c	1.2	b	0.2	a	0.2	
NPK 60 KgN	6.6	c	18.6	b	0.8		5	a	2.1	de	1.1	c	0.1	b	0.2	
					ns										ns	

ns - not significant; *- significant. Means with same letter (s) in a column under the same treatment are not significantly different at 5 % level of probability by Duncan's Multiple Range Test (DMRT). CPH= Cocoa pod husk, PM= Poultry manure, NL= Neem leaf

After the residual planting, the effect of compost and NPK fertilizer application was significant on all the parameters measured except K in soil planted with NH47-4 (Table 6). All the CPH-based fertilizer increased the pH of soil more than NPK and control. Soil applied with CPH+NL at 75 kg N ha^{-1} had the highest pH (7.0) which was significantly higher than NPK at 40 kg N ha^{-1} (6.3), 50 kg N ha^{-1} (6.4), 60 kg N ha^{-1} (6.3) and control (6.3). The same trend was observed in pH value of soil planted with LD88. The organic carbon and N contents of soils planted with NH47-4 and LD88 were significantly enhanced by CPH-based fertilizer compared to NPK and control. Also P, Ca, Mg and Na were significantly enhanced by CPH-based fertilizer compared to control in soils planted with NH47-4 and LD88; however, there was no significant difference in the K content of the soil planted to either NH47-4 or LD88.

Table 6. Chemical properties of soil as influenced by compost and NPK fertilizer after the residual planting

Treatment	pH (H_2O)		Org.C (g kg^{-1})		N		P (mg kg^{-1})		Ca (cmol kg^{-1})		Mg		K	Na	
NH47-4															
Control	6.3	e	9.7	f	0.1	g	3	e	3.8	e	5.3	i	0.1	0.5	ab
CPH+PM+NL 25 KgN	6.8	ab	17.8	bc	0.3	e	4	d	4.3	bcd	8.1	efgh	0.1	0.6	a
CPH+PM+NL 50 KgN	6.7	bc	22.7	a	0.4	d	6	b	5.1	abc	7.7	fgh	0.1	0.5	ab
CPH+PM+NL 75 KgN	6.6	c	17.3	bc	0.7	b	6	b	5.1	abc	8.6	defg	0.1	0.5	ab
CPH+PM+NL 100 KgN	6.8	ab	16.6	bc	0.8	a	6	b	5.8	a	7.9	fgh	0.1	0.6	a
CPH+PM 25 KgN	6.8	ab	16.0	bcd	0.5	c	5	c	5.3	ab	7.1	h	0.1	0.5	ab
CPH+PM 50 KgN	6.8	ab	14.9	cde	0.4	d	6	b	4.3	bcd	11.4	a	0.1	0.6	a
CPH+PM 75 KgN	6.9	ab	17.7	bc	0.3	e	5	c	5.3	ab	9.3	bcde	0.1	0.5	ab
CPH+PM 100 KgN	6.8	ab	18.5	b	0.4	d	7	a	5.1	abc	8.9	def	0.1	0.5	ab
CPH+NL 25 KgN	6.8	ab	18.2	b	0.3	e	5	c	4.4	bcd	10.6	ab	0.1	0.6	a
CPH+NL 50 KgN	6.7	bc	17.0	bc	0.5	c	4	d	5.7	a	10.4	abc	0.1	0.6	a
CPH+NL 75 KgN	7.0	a	16.9	bc	0.1	g	3	e	4.3	bcd	9.6	bcd	0.1	0.6	a
CPH+NL 100 KgN	6.7	bc	17.4	bc	0.5	c	4	d	4.3	bcd	11.2	a	0.1	0.5	ab
NPK 40 KgN	6.3	e	13.4	de	0.1	g	3	e	4.2	bcd	8.1	efgh	0.1	0.5	ab
NPK 50 KgN	6.4	d	13.7	de	0.1	g	6	b	3.9	cd	7.6	gh	0.1	0.4	c
NPK 60 KgN	6.3	e	12.0	ef	0.2	f	4	d	4.4	bcd	9.2	cde	0.1	0.5	ab
LD88													ns		
Control	6.3	f	15.5	de	0.1	g	3	e	3.0	d	7.6	bc	0.1	0.5	b
CPH+PM+NL 25 KgN	6.7	bc	16.8	bcd	0.4	d	3	e	3.6	cd	9.9	b	0.1	0.5	b
CPH+PM+NL 50 KgN	6.9	a	16.8	bcd	0.5	c	5	c	5.1	abcd	8.7	abc	0.1	0.5	b
CPH+PM+NL 75 KgN	6.8	a	19.0	abc	0.7	a	7	a	3.2	d	7.5	c	0.1	0.6	a
CPH+PM+NL 100 KgN	6.8	ab	17.9	abcd	0.3	e	8	a	5.8	ab	7.9	bc	0.1	0.6	a
CPH+PM 25 KgN	6.8	ab	18.1	abcd	0.4	d	4	cd	5.4	abc	8.1	bc	0.1	0.5	b
CPH+PM 50 KgN	6.7	c	19.7	ab	0.6	b	5	c	6.3	a	8.5	abc	0.1	0.6	a
CPH+PM 75 KgN	6.9	a	17.6	abcd	0.4	d	5	c	4.5	abcd	8.8	abc	0.1	0.5	b
CPH+PM 100 KgN	6.8	ab	20.3	a	0.4	d	8	a	4.8	abcd	8.9	abc	0.1	0.5	b
CPH+NL 25 KgN	6.6	cd	19.1	abc	0.5		3	e	4.0	bc d	10.0	a	0.1	0.5	b
CPH+NL 50 KgN	6.8	ab	17.0	bcd	0.2	f	3	e	4.1	bcd	8.5	abc	0.1	0.6	a
CPH+NL 75 KgN	6.6	cd	16.3	cde	0.6	b	5	c	3.9	bcd	8.4	abc	0.1	0.5	b
CPH+NL 100 KgN	6.8	ab	16.3	cde	0.4	d	5	c	3.9	bcd	7.4	c	0.1	0.6	a
NPK 40 KgN	6.4	ef	16.1	cde	0.2	f	4	d	6.5	a	7.5	c	0.1	0.5	
NPK 50 KgN	6.3f		17.3	bcd	0.1	g	6	b	4.0	bcd	8.7	abc	0.1	0.5	b
NPK 60 KgN	6.5e		13.9	e	0.2	f	3	e	4.7	abcd	9.2	ab	0.1	0.5	b
													ns		

ns - not significant; *- significant. Means with same letter (s) in a column under the same treatment are not significantly different at 5 % level of probability by Duncan's Multiple Range Test (DMRT)

Discussion

Inadequate availability of essential nutrients often limits the optimum performance of crops. Continuous cropping due to limited farm land has been found to reduce soil productivity (Li et al., 2016). Organic amendment not only influence soil properties, but also play a great role in the growth and development of plants and thus improve agricultural productivity (Lakhdar et al., 2011). In this study, okra growth was significantly improved as a result of added nutrient to the soil compared to the control. The observed taller plants and thicker plants with the application of compost and NPK fertilizer compared to the control was an indication of availability of more nutrients for plant growth (Kayode et al., 2018). Application of fertilizer increase the supply of nutrients which ultimately result in greater nutrient uptake. Plant growth and development depend on nutrient supply and in general enhances good yield. The findings with regard to nutrient uptake by okra revealed that the uptake of N, P and K were higher with the application of composts and NPK but least with control plants indicating short supply of these nutrient elements to okra in the control plots. This is in agreement with the findings of Kayode et al. (2018) that the application of compost improved N, P and K uptake of okra. Shoot:root ratio is also influenced by the nutrient status of the soil. The shoot:root ratio is an index that indicates growth and dry matter accumulation between shoot and root. Dry matter production of okra was considerably enhanced by compost and NPK compared to control. Taiwo et al. (2002) reported that adequate supply of nutrients favored the development of plant height, stem girth and number of leaves which culminated in better production of dry matter than the low dry matter yield and nutrient uptake produced by the control. The compost improving the chemical properties of soil is "in agreement with Blanchet et al. (2016)" who found that organic amendment improved chemical properties of soil and provided a significant amount of P and K. Also Achiba et al. (2010) observed that application of organic amendment contributed to increasing the N content in soil. The higher soil pH in soil treated with CPH- based composts than NPK and control could be as a result of buffering capacity of CPH-based composts. This confirms the findings of Adediran et al. (1999), Adeoye et al. (2001), Akande et al. (2003) that application of organic materials could ameliorate acidic tropical soils and thereby improve crop production. The CPH-based composts produced higher build up of organic carbon and increased total N in the soil than the control. This is in agreement with the findings of Moyinjesu (2007) and Ogunlade et al. (2009) that cocoa pod husk increased soil organic matter and total N.

The CPH-based composts resulting in higher soil available P than NPK and control treatments indicated that P was released from the organic amendments. This is in agreement with the work of Moyinjesu (2007) that cocoa pod husk increased available P. The soil K, Ca and Mg were increased by the application of CPH compost and NPK relative to the control in the soil.

The better performance of okra observed during the residual planting in CPH-based treated plots over the control showed that composts had residual effects on soil. Therefore, nutrient availability especially N, P and K could affect the photosynthetic activities of the plant and subsequent production of dry matter. The result of residual nutrient uptake effects on okra showed that compost performed better than NPK fertilizer and control. This is in agreement with Adediran et al. (1999) who stated that compost had been found to supply plant nutrients in slowly available forms.

Conclusion

The composting of organic wastes is the most common technology of recycling and disposing them easily in a safe way. The present study has revealed that composting cocoa pod husk with other organic materials can improve growth and dry matter yield of okra and chemical properties of soil.

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