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Agro-physiologic effects of compost and biochar produced at different temperatures on growth, photosynthetic pigment and micronutrients uptake of maize crop

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The production and use of biochart and compost present many opportunities for soil improvement and agricultural productivity. However, the yield and performance of biochar depend on the feedstocks, pyrolysing temperatures and rate of application. Experiments were conducted to find out the effect of compost and biochar produced from two different feed stocks (Rice husk and Mexican sunflower) and pyrolysed at different temperatures (300, 350 and 400°C) on the growth, yield, nutrient uptake and chlorophyll contents of maize (*Zea mays* L.,). These were applied at three levels (5, 10 and 15 ton/ha) and the pots were laid out in a Completely Randomized Design (CRD) with four replicates. Data were collected on growth and yield attributes of maize, photosynthetic pigments and nutrient uptake by maize crop.The results showed that the feedstock pyrolyzed at temperature between 300 to 350°C and compost applied at higher rate between 10 to 15 ton/ha performed better. On the growth and yield parameters, compost and biochar at relatively low temperature and applied at 15 t/ha performed better than other treatments including control both at the main and residual experiments On the residual effect, the two types of biochar performed better than compost most especially sunflower biochar pyrolysed at 300 and 350°C and applied at 15 t/ha. The chlorophyll formation was enhanced more in maize treated with higher rates of biochar than lower rates. The result indicates that depending on feedstock, biochar and compost have potentials to serve as nutrient sources.

Key words: Biochar, bioenergy, chlorophyll, pyrolysis, plant nutrition, photosynthesis.

INTRODUCTION

Conversion of agricultural wastes to soil amendments is now gaining attention worldwide as a sustainable method of waste management and is accepted as a good soil management practice for sustainable crop production. It

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helps in improving soil fertility through the modification of soil physical, chemical and biological properties (Haering and Evanylo, 2005). This in turn leads to the production of high quality food crops (Asuegbu and Uzo, 1984) through improved crop nutrient use efficiency (Tiessen et al., 1994; Bol et al., 2000; Diels et al., 2004). Several research findings have shown that improving plant nutrition through the use of organic amendments for sustainable crop production is a promising approach (Quansah, 2000; Basha et al., 2005).

Recently, the use of carbon rich organic amendments called black carbon or biochar for boosting soil fertility, sequestering atmospheric carbon and reducing the impact of agriculture on the environment is being promoted. Biochar is a kind of charcoal made from the pyrolysis of a range of biomass or feed stocks (Novak et al., 2009). It is the porous carbonaceous solid produced by thermo-chemical conversion of organic materials in oxygen depleted atmosphere. This has physiochemical properties suitable for safe and long-term storage of carbon in the environment and for soil improvement (Steinbeiss et al., 2009). Biochar in contrast to other organic manure or fertilizers is rich in carbon and is therefore not being easily susceptible to biological degradation. This makes it more stable and gives it the ability to stay longer in the soil (Skjemstad et al; 1996; Goldberg1985; Schmidt and Noack, 2000; Pessenda et al. 2001; Krull et al. 2006; Lehmann and Rondon, 2006).

Though, not like other fertilizers in term of soil fertility improvement, but the ash from biochar could have strong effect on yields after application (Chan et al., 2008). It can supply nutrients such as calcium, potassium and magnesium to the plants and also retain nutrients for plant uptake. Its application helps farmers in several ways; it reduces the amount of fertilizer needed, slowly releases nutrients to plants and improves soil moisture retention thereby securing the crops against drought. Biochar can also be used in all types of agricultural systems and unlike manure that emits methane into the atmosphere, biochar, reduces the greenhouse gases in the environment by increasing soil carbon sequestration thereby reducing atmospheric CO_2 concentrations (Laird, 2008; Liang et al., 2008; Woolf et al., 2010). Compared to other soil amendments, the high surface area and porosity of biochar enable it to adsorb or retain nutrients, water and provide a habitat for beneficial micro-organisms to flourish (Glaser et al., 2002; Lehmann and Rondon, 2006; Warnock et al., 2007).

Biochar production, yield and quality however pose a lot of challenges to its use and applicability. Biochars generally, are produced from a range of organic materials and under different conditions resulting in products of varying properties (Baldock and Smernik, 2002; Nguyen et al., 2004; Guerrero et al., 2005) but the ability of biochar to store C and improve soil fertility depends on its physical and chemical properties. This in turn varies based on the pyrolysis process and the choice of feedstock. The conditions under which a biochar is produced greatly affect its relative quality as a soil amendment (McClellan et al., 2007, McLaughlin et al., 2009). For instance, at high temperatures (400 to 700°C) according to Lehmann and Baldock (2002), biochar has fewer ion exchange functional groups due to dehydration and decarboxylation and this limits its usefulness in retaining soil nutrients. On the other hand, biochars produced at lower temperatures (250 to 40°C) have higher yield recoveries and contain more C=O and C-H functional groups that can serve as nutrient exchange sites after oxidation (Glaser and Lehmann, 2002). Moreover, biochars produced at these lower pyrolysis temperatures have more diversified organic character, including aliphatic and cellulose type structures which may be good substrates for mineralization by bacteria and fungi which have an integral role in nutrient turnover processes and aggregate formation (Thompson, 1978).

Feedstock selection also has a significant influence on biochar surface properties (Downie and Crosky, 2009) and its elemental composition (Amonette and Joseph, 2009). Meanwhile, the extent to which source of feedstock and pyrolysing temperature could increase the efficiency of applied biochar in sustaining soil and crop productivity has not received much research attention. Since, both feedstock and pyrolysis conditions affect physical (Downie and Crosky, 2009) and chemical properties likewise quantity and quality of biochar, there is need therefore to study the effect of pyrolysis temperature and processing time on biochar yield from different feedstocks as well as their consequent effects on crop production.

Similarly, compost is also considered as a valuable soil amendment for centuries. There is greater awareness that using composts is an effective way of increasing healthy crop production, reduce overdependency on chemical fertilizers and conserve natural resources (Storey, 1995; Epstein, 1997). The decomposition process converts potentially toxic or putricible organic matter into a stabile non-toxic product for soil improvement and plant growth. Compost fertilizer has been used as mulch for weed control as well as soil fertility improvement (Roe et al., 1997). This study was therefore conducted to determine the optimum temperature for pyrolysing different feedstocks (Rice husk and dry Mexican sunflower) on biochar yield and efficiency as well as assessing the variations in gaseous emission during pyrolysis in relation to different feed stocks and different temperatures. Effects of biochar made from different feed stocks and compost made from Mexican sunflower and poultry manure were also compared on soil fertility improvement and crop production. Maize which is one of the most important cereal crops world-wide was used as test crop for this study. In Nigeria, the cultivation of maize is very popular for its high productivity and diversity of use. The average yield of maize is considerably reduced due to decline in soil fertility and unfavourable climatic conditions. Soil fertility improvement through the use of biochar and compost would help in boosing maize production.

METHODOLOGY

The experiments which consisted of first and residual trials were carried out at the roof top of the Department of Crop Protection and Environmental Biology, University of Ibadan, Ibadan, Oyo state from March to November, 2014. The geographical location is 7° 24'N, 3° 54'E, and Elevation 234 m above sea level. The soil for the experiment was first homogenized and sieved before distributing them into 5 L capacity experimental pots with each containing 5 kg soil. Representative samples were taken for laboratory analysis. In the laboratory, the soil sample were air-dried, crushed using ceramic mortar and pestle and then sieved through a 2 mm mesh and the pre-cropping physicochemical properties of the soil were determined. Soil pH was measured in a 1:1 soil-water ratio using a glass electrode (H19017 Microprocessor) pH meter. Soil organic carbon was determined by the modified Walkley-Black method as described by Nelson and Sommers (1982). Total nitrogen was determined by macro-kjedahl method. Available P by Bray one method as described by Bray and Kurtz (1945). Exchangeable bases (calcium, magnesium, potassium and sodium) in the soil were determined in 1.0*N* ammonium acetate (NH_4OAc) extract. The results showed that the soil was slightly acidic (6.8) but it is within the pH range for agricultural production. The organic matter, total nitrogen and available phosphorus were 21.5, 1.01% and 60.3 g/kg respectively. Ca, Mg, K, and Na were 3.29, 0.54, 0.27 and 0.14 cmol/kg respectively. Mn, Fe, Cu and Zn were 73.9, 73.8, 0.30 and 1.8 mg/kg respectively.

Biochar and compost production

Biochar was produced from two types of feedstocks (Rice husk and dried Mexican sunflower). Rice husk was obtained from AfricaRice at International Institute of Tropical Agriculture (IITA) Ibadan Oyo state. The pyrolysis was carried out using the biochar reactor fabricated by the Department of Mechanical Engineering, University of Ibadan Oyo state. The reactor was allowed to warm for about 30minutes so as to gain heat energy. Then 10 kg of the rice husk was put in a piece of pyrolysis apparatus which consisted of a stainless reactor of 500 mm length with a 150 mm inside diameter. The rice husk was then heated at different temperature; which are 300, 350 and 400°C. This temperature was regulated by the thermocouple connected with the reactor. The gas analyzer was also used for analyzing and recording all the gases emitted during the pyrolysis process. Since the rice husk pyrolysis was being carried out at different temperature, at the end of each pyrolysis of a particular temperature, the thermostat stopped and it was allowed to cool for 30 min before opening so as to reduce the rate of burning when exposed to atmosphere. The biochar produced was then collected through an open channel in a tray and spread for further cooling. This process was used for all the biochar produced at different temperatures. The pyrolysis temperatures tested in this study can be classified as “slow pyrolysis” which is meant for soil improvement for planting.

Production of Mexican sunflower (*Tithonia diversifolia*) biochar

The Mexican sunflower plant was obtained from the crop garden of Crop Protection and Environmental Biology, University of Ibadan Oyo state. The plant was manually cut into 2 mm before pyrolyzing. The pyrolysis was carried out as described for rice husk. The Biochar moisture content was measured by oven drying a sub sample of 2 g at a temperature of 80°C for 24 h.

Composting

Compost was made from Mexican sunflower (*Tithonia diversifolia*) and poultry manure. The materials were laid out in ratio 3:1 of plant materials to poultry manure (on dry weight basis) after sorting and chopping using Partially Aerated Composting Technique (PACT-2) proposed by Adeniran et al. (2001). The heap was left to decompose for 3 months to allow for the proper decomposition of the organic materials for plant growth. Continuous turning and watering was done to quicken the decomposition rate, after which the matured composts were evacuated from the heap, air-dried, shredded and samples taken to the laboratory for physico-chemical analysis.

Chemical analysis of compost and biochar

The organic materials used in this experiment were characterized by determining their pH, organic carbon, exchangeable bases, and macro and micronutrients according to the method described by Ahmedna et al. (1997). pH was measured with a pH-meter (Jenway 3305). Total C was done using the method described in ASTM D 3176 (ASTM, 2006) and the total P was read with a spectrometer (Vitatron). Calcium, magnesium, potassium, sodium, manganese, iron, copper and zinc in the compost and biochar were determined using the Atomic Absorption Spectrometer (AAS). Sodium (Na) and Potassium (K) were read on a flame photometer. The percentage of oxygen that was generated during the pyolysis was recorded and stored in gas analyzer, the efficiency of the reactor during the pyrolysis was also determined with the use of gas analyzer. The percentage of the carbondioxide and other gases emitted during the pyrolysis was also monitored and saved in the gas analyzer.

Experimental procedure and treatments

The pots were arranged in Complete Randomized Design (CRD) replicated four times. The treatments consisted of three levels of compost (5, 10 and 15t/ha), three levels of rice husk and sunflower biochar (5, 10 and 15 t/ha) at 300, 350 and 400°C. The treatments were denoted as, Control (No compost or biochar), Compost at 5, 10 and 15t/ha as CR1, CR2 and CR3 respectively, while rice husk biochar as RR1, RR2 and RR3, Sunflower biochar as SR1, SR2, SR3 for temperatures T1, T2 and T3 respectively. The organic materials were mixed thoroughly with soil according to treatment rate for one week before planting of maize.

Data collection

The data collection commenced two weeks after planting and data were collected on vegetative and yield parameters of maize, nutrient uptake as well as chlorophyll contents. The plant nutrient uptake was determined using standard procedures while chlorophyll contents were determined using SPAD meter as well as the method described by Sarropoulou et al. (2012) with slight modifications. 1 g of fresh leaves was placed in 25 ml glass tubes and 15ml of 96% (v/v) ethanol was added to each tube. The tubes with the plant material were incubated in a water bath at a temperature of 79.8°C until complete discoloration of sample, after

Table 1. Biochar yield under different temperature.

Biomass	Temperature (°C)	Input (kg)	Duration (min)	Output (kg)	Efficiency (%)
Rice husk	300	10	30	2.80	28
Rice husk	350	10	30	2.20	22
Rice husk	400	10	30	3.5	35
Sunflower	300	2.5	30	1.55	62
Sunflower	350	2.5	30	0.85	34
Sunflower	400	2.5	30	1.50	60
Sunflower	300	2.5	30	0.92	37
Sunflower	350	2.5	30	0.82	33
Sunflower	400	2.5	30	0.92	37

about two to three hours. The absorbance of chlorophylls a and b was measured at 665 and 649nm respectively using visible spectrophotometer. Total chlorophyll was determined from the equations shown below:

Chl (*a*+*b*) = 6.10* A665 + 20.04*A649) * 15/1000/F.W (mg/g F.W)

The residual experiment was carried out after the first planting in order to determine the residual effect of the treatments on maize growth.

RESULTS

Biochar yield under different temperatures

The yields recorded after pyrolysing different feedstocks under different temperatures showed that the system was able to pyrolyze between 2.5 and 10 kg of biomass (Mexican sunflower and rice husk) with appropriate and moderate yield output of about 1:4 ratio per run. The relative yield of products from biochar varies with temperature, feedstocks and other factors.Temperature of 400°C produces more char from rice husk while 300 and 400°C were more effective in the case of sunflower biochar (Table 1).

Biochar and compost nutrients analysis

The physical and chemical properties of biochar produced from rice husk and Mexican sunflower under different temperatures of 300, 350 and 400°C showed that different pyrolysing temperatures and feedstocks influenced the nutrient compositions of biochar. Variations were observed in the carbon contents and concentrations of primary macro and micro nutrients which are essential for soil fertility improvement. The carbon content of Rice husk biochar was the highest (53 g/kg) under the pyrolysing temperature of 350°C followed by that of 400°C and the carbon content at 300°C was the lowest for Rice husk. Similarly, Fe and Mn were more in Rice husk under this temperature than other materials. The carbon content, potassium, calcium iron and manganese concentrations of Sunflower biochar however increased with increasing temperature and the highest concentrations were found at 400°C. However, it was observed that the dried compost contain high amount of primary nutrients and carbon content when compared to biochar. Organic Carbon content of the *Tithonia diversifolia* dry compost was 63g/kg. Nitrogen, Phosphorus and Calcium were 1.46%, 1.20 and 2.87 cmol/kg respectively. These analytical results revealed that both biochar and compost are good soil amendments to improve crop yield (Table 2).

Growth, yield, Chlorophyll content and micronutrient uptake by maize crop

There was a general increase in growth parameters of maize crop grown on soil amended with either compost or biochar throughout the growing period compared to control. However, there were variations among the treatments and application rates. For instance, among the compost rates CR3 recorded the highest mean values for plant height and leaf area. The trend was similar in other amendments with higher rate performing better than the lower rate. In the case of temperature, rice husk pyrolysed at 300°C and applied at 15 t/ha (RT3R3) and ST3R2 (sunflower biochar pyrolysed at 400°C and applied at the rate of 10 t/ha) increased the plant height and leaf area more than other treatments. It was observed that soil amended with RT1R3 (rice husk biochar 300°C at 15 t/ha) had the highest mean value (86.13 cm) for the plant height which was significantly different ($P \leq 0.05$) from every other treatments while sunflower biochar pyrolysed at 400°C and applied at the rate of 15t/ha gave the highest mean value for leaf area. The least mean value was recorded in maize crop treated with rice husk biochar (400°C) at the rate of 15 t/ha. The number of leaves produced by the maize plant in the soil treated with sunflower biochar pyrolysed at 350°C and

Table 2. Chemical properties of compost and Biochar produced from Rice husk and Mexican Sunflower under different temperature.

Properties	Compost	RT1	RT2	RT3	ST1	ST2	ST3
Carbon (%)	63	14	52	36	11	11	16
Total Nitrogen (%)	1.46	1.63	1.99	1.32	0.79	0.74	0.53
Exchangeable base (cmol/kg)							
Potassium	0.62	0.53	1.34	0.86	2.11	2.24	2.66
Calcium	2.87	0.02	0.84	0.09	1.44	0.81	1.64
Magnesium	0.03	0.02	0.02	0.02	0.04	0.02	0.02
Sodium	0.10	0.02	0.07	0.03	0.08	0.06	0.07
Phosphorus	1.20	0.42	0.71	0.80	1.09	0.91	0.98
Extractable micronutrient (mg/kg)							
Iron	1285.00	276.00	2230.00	366.50	139.50	106.00	187.50
Zinc	6.00	4.50	6.90	5.20	8.00	10.20	5.50
Copper	19.45	43.15	4.15	1.85	10.55	5.60	8.40
Manganese	276.50	81.50	310.00	175.50	93.00	59.50	123.00

RT1= Rice husk biochar at 300°C, RT2= Rice husk biochar at 350°C, RT3= Rice husk biochar at 400°C, ST1 = Sunflower, biochar at 300°C, ST2= Sunflower biochar at 350°C, ST3= Sunflower biochar at 400°C

applied at the rate of 15 t/ha recorded the highest mean values (Table 3)

On biomass production, soil amendment with RT2R2, ST3R3, ST1R3 and CR3 gave the highest shoot fresh weights which were significantly different (P≤ 0.05) from others including control. The root fresh weight was enhanced by the application of RT1R3, ST1R3 and ST3R3. These treatments also gave the highest shoot and root dry weight compared to all other treatments. Rice husk biochar 300°C at the rate of 15t/ha (RT1R3) recorded the highest root dry weight which was not significantly different (P≤ 0.05) from sunflower biochar 400°C at 15 t/ha (Figure 1a and b). On the chlorophyll content, rice husk generally performed better than sunflower biochar and compost. The chlorophyll content of maize grown on the soil amended with rice husk which was pyrolysed at 400°C and applied at the rate of 5 t/ha (RT3R1) was the highest compared to other treatments. This was followed by RT3R2, RT1R2 and RT1R3 though, with variations based on different temperatures and application rate. The addition of RT1R1, RT1R3, RT3R2, ST1R3 and ST2R2 increased the chlorophyll contents of maize crop compared with control. When comparing the chlorophyll content of maize crop from soil treated with compost, sunflower biochar and rice husk biochar at different rate and temperature, sunflower biochar at 300°C at 10 t/ha (ST1R2) gave the lowest chlorophyll concentration (Figure 2).

Micronutrient uptake by maize was also enhanced by biochar and compost. Rice husk biochar pyrolysed at 400°C and applied at 15 t/ha increased Zn accumulation in maize more than other treatments. This was followed by those of RT2R1, ST1R3, ST2R3, ST3R1 and ST3R2. They were all significantly different from those treated with compost and control. No significant difference was observed in the zinc concentration of the maize treated with RT2R1, RT2R2 RT3R2, ST1R2, ST3R1 and ST3R3. Similarly, pyrolysing rice husk at 400°C also increased Fe uptake by maize and performed better than control and those treated with compost. There were also no significant differences (P≤ 0.05) among compost treatments at 5, 10 and 15 t/ha (Figures 3a and b). The distribution of nutrient uptake among the maize plant varies.

Residual effect on growth and yield of maize

The residual effect of compost and biochar on plant height indicated that there was general increase over the growth period (Data not shown). As observed in the main planting, there were variations in the performance of different amendments based on feedstock, period of data collection, rate of application and pyrolysing temperatures. Rice husk biochar pyrolysed at 400°C and applied at 15 t/ha gave the highest mean value while rice husk biochar 300°C at 10 t/ha recorded the lowest mean value. On the leaf area, RT1R3 (Rice husk biochar at 300°C and at 15 t/ha) gave the highest mean value followed by compost at 15 t/ha while the lowest was recorded from rice husk biochar pyrolysed at 300°C and applied at 10 t/ha (Table 4). The number of leaf was also enhanced in all amended soils compared with control except that there were no significant differences among the organic treatments. Application of the rice husk biochar pyrolysed at 400°C and applied at 15 t/ha and

Table 3. Effect of compost and biochar produced at different temperature on vegetative parameters of maize.

Treatment	Plant height (cm)	Leaf Area (cm^2)	Number of leaf
CR1	57.13	118.60	6.43
CR2	54.54	131.45	6.75
CR3	61.75	134.79	6.68
RT1R1	57.93	119.52	6.48
RT1R2	56.63	118.48	6.83
RT1R3	58.76	126.89	6.70
RT2R1	62.63	132.76	6.48
RT2R2	61.91	139.47	6.78
RT2R3	58.33	145.10	6.63
RT3R1	59.18	116.54	6.63
RT3R2	57.72	131.55	6.60
RT3R3	55.04	111.18	6.50
ST1R1	59.87	127.72	6.43
ST1R2	61.20	130.96	6.65
ST1R3	56.83	119.58	6.75
ST2R1	55.62	119.23	6.45
ST2R2	68.24	126.40	6.83
ST2R3	65.16	134.00	7.00
ST3R1	60.52	106.37	6.45
ST3R2	59.38	116.14	6.10
ST3R3	66.82	136.96	6.63
Control	63.70	121.36	6.39
LSD (P≤0.05)	9.89	30.66	0.78

Means followed by the same letter in a column are not significantly different from each other at P≤ 0.05 by DMRT. R1, R2 and R3, = Application rate at 5, 10 and 15t/ha. R= Rice husk biochar, S=sunflower biochar, T1, T2 and T3 = 300, 400 and 500°C.

sunflower biochar 400°C at the rate of 10 and 15 t/ha gave the highest shoot fresh weight of 17.83, 17.37 and 17.06 g respectively in residual trial. It was clearly observed that most of the treatments with higher rate performed better than their lower rates. Also application of ST3R2 (sunflower biochar 400°C at 10 t/ha) and ST2R2 (sunflower biochar 350°C at 10 t/ha) and compost gave the shoot fresh weight values of 13.16, 12.37 and 12.32 g respectively. As observed with the shoot fresh weight, rice husk biochar pyrolysed at 400°C and applied at 15 t/ha also gave the highest dry matter yield and it was significantly different from other treatments. There was no significant difference between the sunflower biochar (at 300°C at 10 t/ha) and control. Among all the treatments, rice husk biochar pyrolysed at 300°C and at the rate of 5 t/ha gave the lowest shoot dry weight of 8.55 g (Figure 4). Sunflower biochar produced at 400°C and at the rate of 10 t/ha recorded the highest mean value of 17.50 g for the root fresh weight followed by compost at 15 t/ha while the lowest mean value was observed in rice husk biochar pyrolysed at 300°C and applied at 5 and 10 t/ha. Application of ST3R2 also gave the highest root dry weight of 6.23 g when compared to other treatments. Higher rate of all the treatments also performed better than their lower rates (Figure 5).

DISCUSSION

The result of this study showed clearly the potential of compost and biochar amendments under different conditions for improving maize yield. All the plants that received biochar treatments at low temperature and at higher rate between 10 to 15 t/ha performed better and this was supported by the report of Antal and Grønli (2003). The feedstock pyrolyzed at a low temperature possessed most of the essential nutrients required for plant growth.This is because as pyrolysis increases, volatile compounds in the biochar matrix are lost, surface area and ash increases but surface functional groups that can provide exchangeable capacity decreases (Giardina et al., 2000). Research has also shown that biochars are known to contain some condensed volatile compounds which can be easily converted to gaseous substances at high temperature (Antal and Gronli, 2003) and as a result of this, biochar yield decreases with increase in pyrolysis

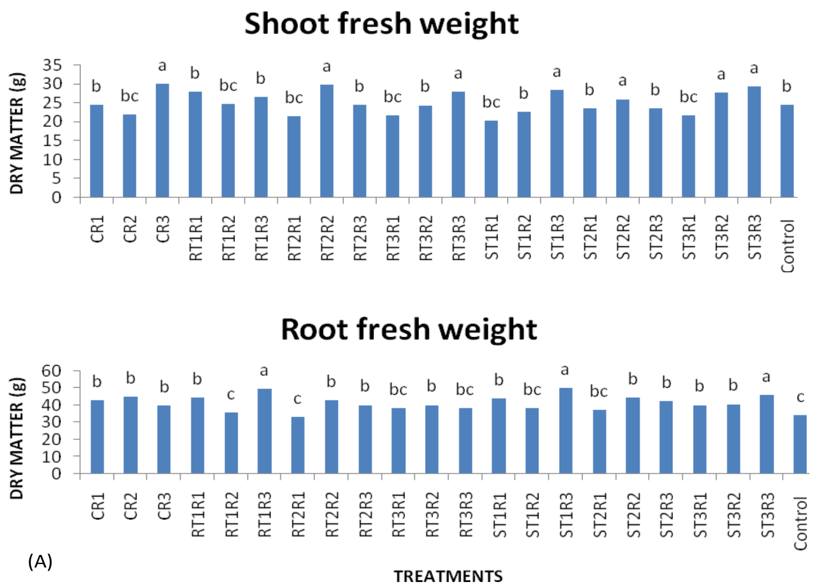


Figure 1a. Maize fresh weight in response to compost and biochar produced at different temperature. Footnotes: R1, R2 and R3, = Application rate at 5, 10 and 15t/ha. R= Rice husk biochar, S=sunflower biochar, T1, T2 and T3 = 300, 400 and 500°C.

Table 4. Residual effect of compost and biochar produced at different temperature on the growth parameters of maize.

Treatment	Plant height (cm)	Leaf Area (cm^2)	Number of leaf
CR1	50.76	81.28	6.00
CR2	44.46	88.92	5.43
CR3	49.88	107.10	6.30
RT1R1	42.21	82.70	5.75
RT1R2	37.78	71.99	5.18
RT1R3	52.74	109.67	6.20
RT2R1	42.04	83.80	5.60
RT2R2	51.87	101.59	6.35
RT2R3	45.83	87.21	5.90
RT3R1	45.85	80.17	5.68
RT3R2	46.25	95.73	6.08
RT3R3	52.89	99.00	6.10
ST1R1	45.32	89.09	6.05
ST1R2	42.88	81.51	5.60
ST1R3	45.54	88.24	6.20
ST2R1	45.46	98.51	6.10
ST2R2	42.74	99.04	6.10
ST2R3	43.60	89.84	5.78
ST3R1	44.98	67.51	5.98
ST3R2	41.00	88.10	6.08
ST3R3	41.88	90.48	5.88
Control	45.03	83.81	5.80
LSD ($P \leq 0.05$)	9.22	25.13	1.06

Footnotes: R1, R2 and R3, = Application rate at 5, 10 and 15t/ha. R= Rice husk biochar, S=sunflower biochar, T1, T2 and T3 = 300, 400 and 500^{O}C.

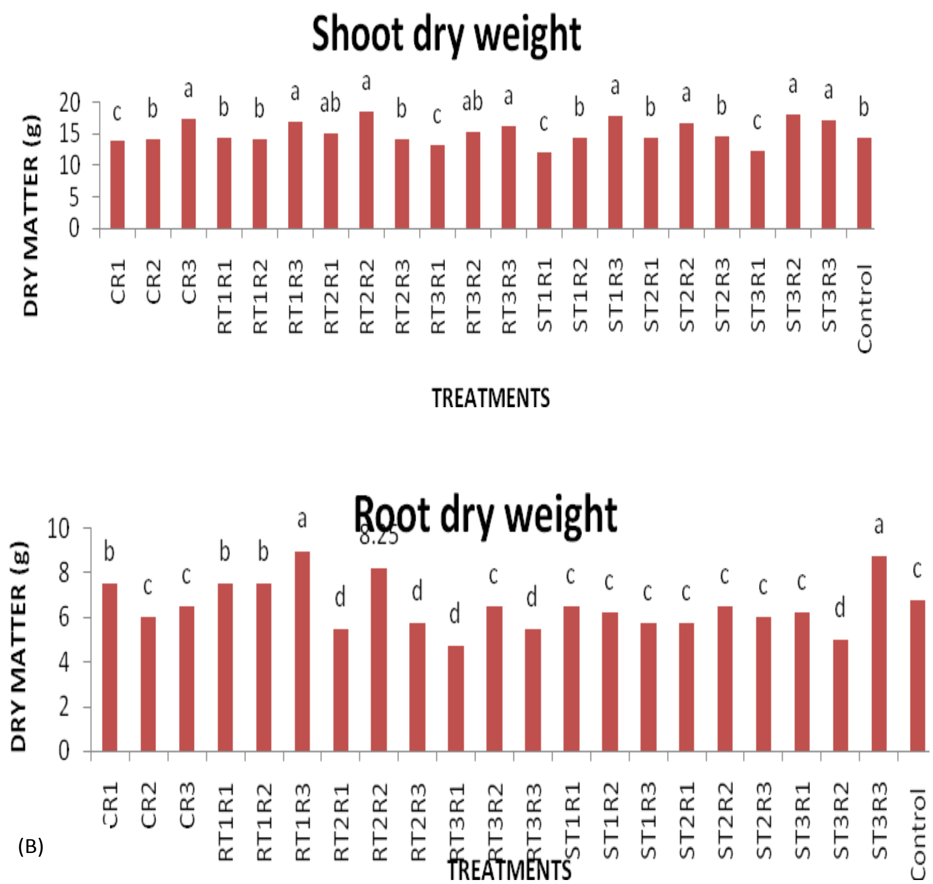


Figure 1b. Maize dry weight in response to compost and biochar produced at different temperatures. Footnotes: R1, R2 and R3, = Application rate at 5, 10 and 15t/ha. R= Rice husk biochar, S=sunflower biochar, T1, T2 and T3 = 300, 400 and 500°C.

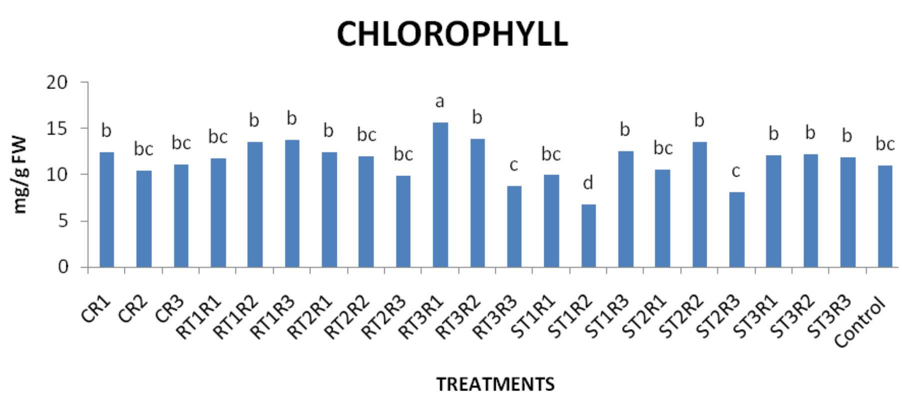
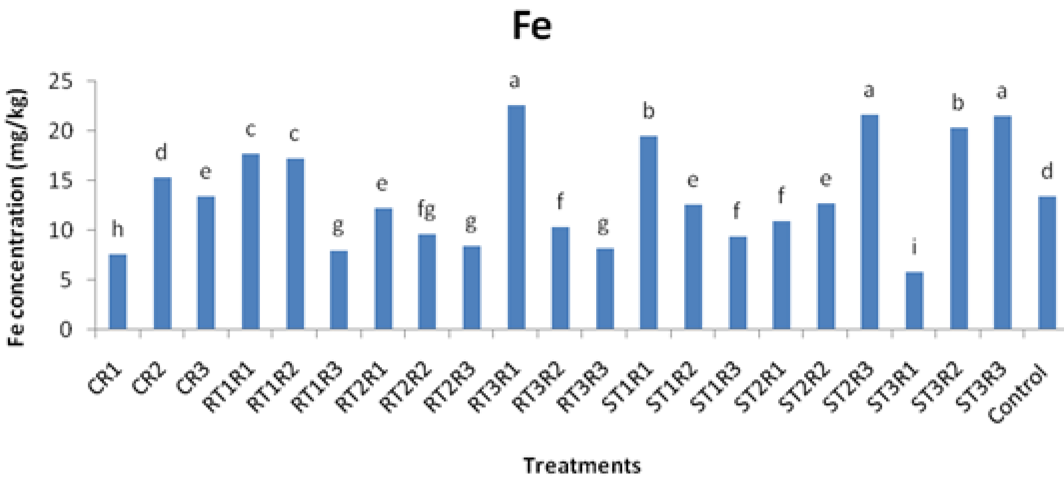


Figure 2. Effect of treatments on photosynthetic pigment (chlorophyll contents). Footnotes: R1, R2 and R3, = Application rate at 5, 10 and 15t/ha. R= Rice husk biochar, S=sunflower biochar, T1, T2 and T3 = 300, 400 and 500°C.

temperature. Most of the nitrogen contents are also lost to the atmosphere due to high pyrolysis but the proportion of the feedstock was conserved at low pyrolysis temperature (Knicker et al., 2000).

However, it was clearly observed from this study that the performance of biochar was lower than that of



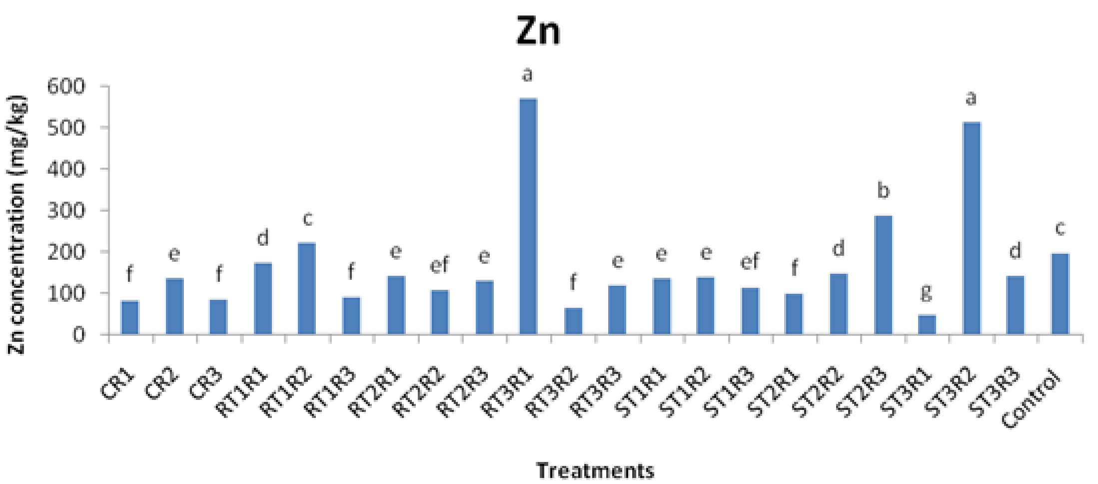


Figure 3. Effect of compost and biochar produced at different temperature on micronutrient uptake by maize. Footnotes: R1, R2 and R3, = Application rate at 5, 10 and 15t/ha. R= Rice husk biochar, S=sunflower biochar, T1, T2 and T3 = 300, 400 and 500°C.

compost in terms of vegetative growth. Comparatively, it was clearly observed that compost treatment performed much better than biochar alone probably because of reported properties of compost in terms of nutrient compositions (Adediran et al., 2006). This performance could therefore be attributed to availability of nutrients in the compost. The improvement observed in plant growth parameters and in dry matter yield was similar to the observation of Garllardo and Nogales (1987) that compost made available sufficient nutrients required for plant growth. It has also been asserted that nutrients availability in sufficient amount improves plant leaf area development (Akande et al., 2000). All the plants treated with compost treatment in the first experiment gave higher number of leaves, plant height, stem girth, leaf area and dry matter accumulation more than biochar and control treatments. This also confirmed the finding of Dale et al. *(*2006) that the application of compost contributed greatly to the plant growth when compared to control. This was in line with the reports of Asai et al. (2009) and Gaskin et al. (2010) that, though biochar possesses some essential elements required for plant growth but biochar can only be effective and improve plant growth when combined with other fertilizers (Blackwell et al., 2009). Many reports have also shown that there was regular decrease in plant growth with the application of biochar alone when not used in combination with other fertilizers (Gaskin et al., 2010).

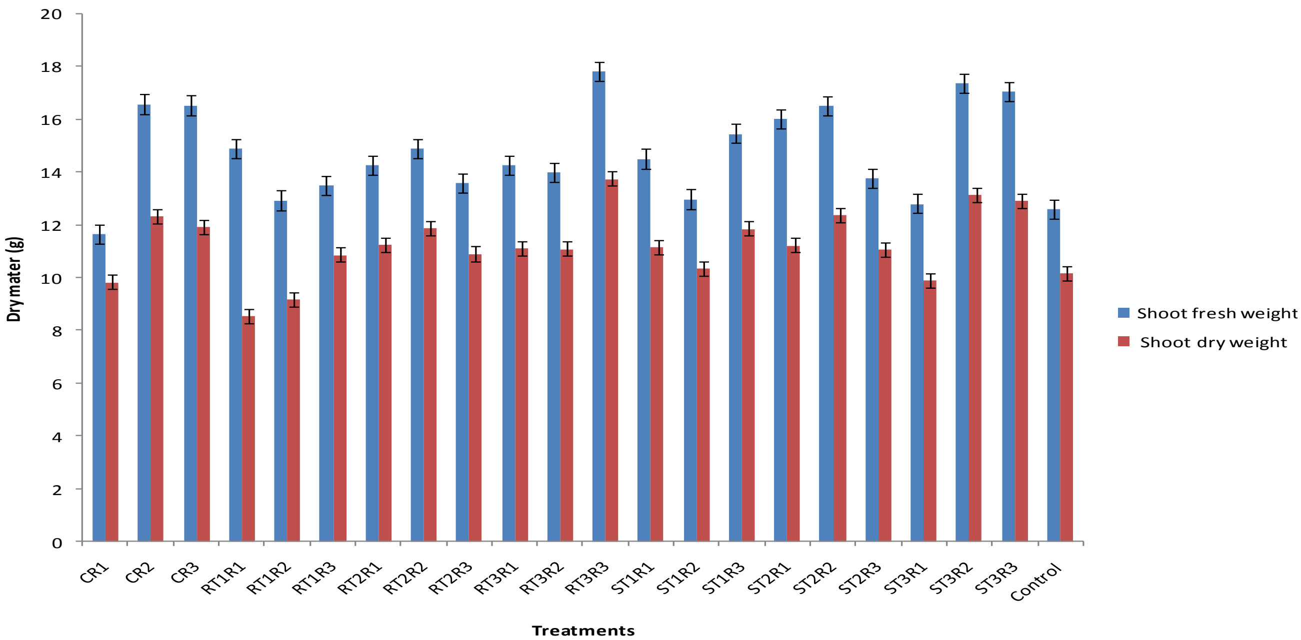


Figure 4. Residual effect of compost and biochar on shoot fresh and dry weight.

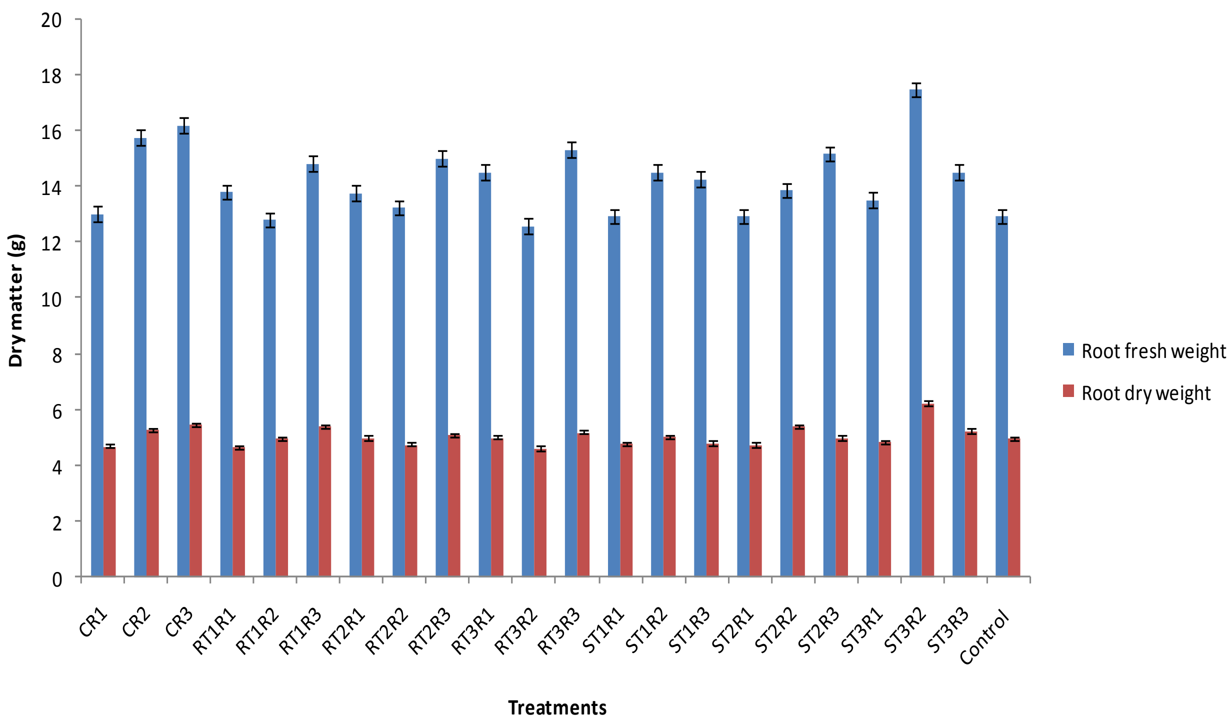


Figure 5. Residual effect of compost and biochar on root fresh weight and dry weight.

Chan et al. (2008) therefore gave a conclusion that biochar is not an actual fertilizer based on these observations. Better yield observed from 15t/ha treatment with compost could be attributed to the higher nitrogen availability as beneficial effect of tithonia compost on crop yield have been previously reported (Qureshi, 1990;

Adejumo et al., 2011).

Although biochar was not as effective as compost but nutrients such as calcium, potassium and magnesium which are usually limiting in poor soils have been reportedly supplied by the ash from biochar. This could in turn explain the strong effect of biochar on dry matter yield. Variation observed on the growth parameters with regards to different feedstocks (rice husk and Mexican sunflower) used for the biochar production could be due to variations in their nutrient compositions. For instance, rice husk has been reported to contain high content of silicon and potassium which have great potential for amending soil and also improve water holding capacity in soil (Oshio et al., 1981). This probably contributed to the improvement in the growth parameters of the plants treated with higher rates of this biochar. Similarly, the Mexican sunflower used as biochar feedstock is a good source of plant nutrients and according to previous research, it was reported to have high level of nutrients (Sacred Africa, 2007).

Application of biochar however, increased the photosynthetic pigment of maize when compared to control and compost. The plants amended with sunflower and rice husk biochar at 15t/ha showed maximum content of chlorophyll as compared to other treatments. This study indicated that maize plants responded better to the application of biochar pyrolysed under 300 to 350°C temperature and applied at 15 t/ha with respect to chlorophyll content. The effect of organic fertilizer on amount of chlorophyll pigments and rate of photosynthesis was studied by Fernendez-Luqueno et al. (2010) and concluded that application of organic fertilizers like biochar did not only enhance the synthesis and amount of chlorophyll but also increased the rate of photosynthesis. Photosynthesis is a complex process that is sensitive to availability of micronutrients (Marschner, 1995). The increase in the photosynthetic pigment with the addition of organic amendments might be attributed to high contents of Mg and Fe. Iron and Mg are the two important nutrients involved in chlorophyll synthesis (Nelson and Cox, 2004). The green pigment (chlorophyll) with magnesium at the core of heterocyclic protoporphyrin ring is the principal pigment responsible for light absorption and photosynthesis. This was also confirmed by the result of micronutrients (Fe and Zn) analysis where higher concentrations of the elements were found in maize treated with biochar compared to those of compost and control.

Residual effect of organic amendments is important for sustainability of nutrients and this was reflected in the residual trial. Maize growth and yield were found to be higher in the second trial than the first trial. The finding agreed with the report of Ramanurthy and Shawasshankar (1996) that residual effect of organic matter improves plant height, leaf area and dry matter production of maize crop at different growth stages. This was also confirmed by Tejada and Gonazalaz (2006) on rice. Biochar most especially can remain in soil for a longer period of time. It has therefore, been hypothesized that the long term effect of biochar on nutrient availability in the soil is due to an increase in surface oxidation and cation exchange capacity (CEC) of the soil (Liang et al., 2006) which can in turn lead to greater nutrient retention in soil. Therefore, high growth rate and dry matter accumulation observed in the residual experiment of this study indicated that biochar has a carrying over benefit on the succeeding crop. Besides, organic manures are generally known for their slow release of nutrients which probably explains the reasons for better residual effect.

Zinc and Iron uptake also increased in maize most especially in higher rates of biochar under residual trial. The same was observed with compost application and this is because the residual effect of compost application also maintained crop growth for a longer period of time. All these were attributed to the ability of organic amendments in maintaining crop yield for several years after application has ceased the explaination was that since only a fraction of the Nitrogen and other nutrients in the amendments become available in the first year of application (Motavilli et al., 1989; Eghball et al., 2002) others remain in the soil for soil improvement over a long time. The finding of Van Zwiten et al. (2010) also suggested that while biochar may not provide a significant source of plant nutrients, they can improve the nutrient assimilation capability of crops thereby positively influencing the soil environment.

Conclusion

This study showed that pyrolytic biochar has the potential to be used in agricultural production. Although pyrolysis conditions are known to affect the chemical and physical characteristics of biochar, at the relatively low pyrolysis temperature used in this study, feedstock characteristics had the greatest influence on key agricultural characteristics. Also, compost made from Tithonia diversifolia is an excellent source of plant nutrients which was confirmed by the increase in yield from 15 t/ha compost treatment which gave better crop yield and performed excellently. In addition, both sunflower and rice husk biochar at the low pyrolysis temperatures between 300 to 350°C at higher rate of 15 t/ha gave better performance. Therefore, the nutrient contents in biochar and performance depend on the source of the feedstock, pyrolysis conditions and rate of application (Kookana et al., 2011; Bagreev et al., 2001). Overall, compost performed better than biochar in terms of growth parameters but biochar increased the micronutrient contents in maize maore than compost. For increasing the efficiency of biochar, combining biochar with other organic amendments at the right propotions could be an efficient approach.

Conflict of Interest

The authors have not declared any conflict of interest.

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