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Effect of Biochar and Inorganic Fertilizer in Yam (*Dioscorea rotundata Poir*) Production in a Forest Agroecological Zone

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Abstract

Yam production is characterized by low fertilizer input and annual shifting in search for fertile lands. This practice usually leads to reduction in the yield potential of the crop and destruction of the environment. Biochar additions through its ability to improve soil fertility and increase crop yields could be used to solve these problems. This study therefore investigated the effect of biochar and inorganic fertilizer application on yam production in a forest agro ecological zone in Ghana. A 4×3 factorial experiment in a randomised complete block design with three replications was used. The treatments consisted of four application rates of wood shaving biochar (0 t ha^{-1} , 5 t ha^{-1} , 10 t ha^{-1} and 15 t ha^{-1}) and three inorganic fertilizer rates (0-0-0 N-P_2O_5-K_2O kg ha^{-1}, 30-30-30 N-P_2O_5-K_2O kg ha^{-1} and 60-60-60 N-P_2O_5-K_2O kg ha^{-1}). No significant differences in soil parameters in response to the treatment were observed, with the exception of total N, where a decline was observed for all the treatments compared to the controls after harvest. Vegetative growth parameters of yam were not significantly influenced by biochar and inorganic fertilizer application. The number of seed yams per hectare was the only yield parameter that was significantly ($p = 0.05$) decreased by biochar application. Dry matter, production was also significantly ($p = 0.05$) increased by fertilizer application at 24 weeks after planting and at harvest. It is suggested that aged and higher rates of biochar would efficiently support yam production.

Keywords: biochar, inorganic fertilizer, vegetative growth, yam, yield

1. Introduction

Yam (*Dioscorea* spp.) constitutes an important starchy staple in sub-Saharan Africa (SSA) where food security for the growing population is a critical issue (O'Sullivan, 2010). The yam zone in West Africa produces about 95 % of the world yam production of about 59 million tons in 2012 (FAO, 2012). The crop contributes more than 200 dietary calories per capita daily for more than 150 million people in West Africa and serves as an important source of income to the people (Babaleye, 2003).

Yams require soils of high fertility and are traditionally grown as the first crop after clearing the land. Its production is therefore characterized by shifting cultivation on yearly basis as farmers move in search of more fertile soils to sustain yields. Increases in yam production in Africa are mostly as a result of expansion in cultivated area. For example the increase in yam production from 41 million tons to 57 million tons during the 2002-2012 periods was as a result of a 17.1% increase in cultivated area (FAO, 2012). Production of yam therefore has the potential of degrading the environment in the long-term (Otoo, Anchirinah, Ennin, & Asiedu, 2008) as a result of the rapid depletion of soil nutrients and in some cases the deterioration of soil physical conditions.

Pressure on land for other purposes as a result of population increase with its changing socio-economic habitat, has led to shorter fallow periods. In addition the environmental effect of annual shifting cultivation has made yam production on previously used land necessary. This practice however usually leads to a reduction in the yield potential of the crop as a result of intensive cropping often without nutrient supplement.

The use of fertilizers, improved fallow systems, herbaceous legume rotation systems and agroforestry systems have been promoted and used to improve soil fertility and increase yield of yam (Akanbi, Olaniran, & Olaniyan, 2007; Adeleye, Ayeni, & Ojeniyi, 2010; Ernest & O'Sullivan, 2004). However the high price and low accessibility of inorganic fertilizers by resource-poor farmers, the rapid mineralization of organic fertilizers under tropical conditions after a few growing seasons and its bulkiness as well as the labour intensiveness of agroforestry systems has resulted in limited use by farmers. In addition, the benefits of organic matter from organic amendments are usually mineralized to CO_2 within a few cropping seasons (Bol, Amelung, Friedrich, & Ostle, 2000) and have to be applied with each growing season to sustain soil productivity.

Recent studies have shown the ability of charred biomass or biochar to improve soil quality, increase crop production and also have a long turnover time in the soil (Lehmann et al., 2003 ; Chan, Van Zwieten, Meszaros, Downie, & Joseph, 2008; Chintala et al., 2014a). The high surface area and porosity of biochar enable it to adsorb or retain nutrients and water (Chintala et al., 2013a; Chintala et al., 2013b), provide habitat for beneficial microorganisms to flourish and reduce the soil's nutrient depletion rate. Biochar also maintains a maximum amount of C in the soil as a result of its stability against microbial decay (Baldock & Smernik, 2002; Chintala et al., 2013a; Chintala, 2014b).

While the use of biochar with and without fertilizer has been reported for cereals, vegetables and legumes production (Karve et al., 2009; Solaiman, Blackwell, Abbott, & Storer, 2010), there is no reported work on its effects on yam, which is an important staple crop in West Africa. This study was therefore undertaken to investigate the agronomic effect of biochar and inorganic fertilizer application on yam production in a forest agroecological zone of Ghana.

2. Methods and Materials

2.1 Study Area

The study was conducted on the research field of Crops Research Institute (CRI) at Fumesua, Kumasi-Ghana from March to December 2012. Fumesua is located on latitude 06°41′N and longitude 01°28′W in the humid forest agro-ecological zone of Ghana. The area is characterized by a bimodal rainfall pattern with the major season spanning March to mid-August with a peak in June and a minor season from September to November which peaks in October. The annual rainfall of the area ranges between 1190 -1650 mm with an average of 1345 mm/year, while the mean annual temperature is between 22-31 °C. The soil type at the study site is a Ferric Acrisol, Asuansi series with a slope of 2-6% (Adu & Asiamah, 1992). Weather data during the trial study period was obtained from the CRI weather station and presented in Table 1.

Table 1. Monthly rainfall (mm), Temperature (°C), Relative humidity (%) and Solar radiation recorded at the study area for 2012

Month	**Rainfall (mm)**	**Temp (°C)**		**RH (%)**	**Solar radiation(W/m^2)**
		Min	**Max**		
Jan	9.00	25.86	28.52	61.02	156.59
Feb	17.80	26.71	30.15	70.01	164.68
Mar	82.40	27.22	30.17	76.76	184.90
Apr	152.61	26.68	29.82	83.46	181.36
May	170.43	26.15	29.42	85.28	167.07
Jun	202.83	24.92	28.09	89.46	138.28
Jul	43.60	24.09	27.15	89.12	118.22
Aug	4.60	23.99	26.73	86.73	102.15
Sep	46.60	25.02	28.13	86.69	121.41
Oct	215.22	25.34	28.69	88.42	154.94
Nov	41.40	26.17	29.27	85.16	156.04
Dec	40.80	25.89	28.75	80.09	149.13

Source: CSIR-Crops Research Institute weather station.

2.2 Experimental Design, Biochar Production and Land Preparation

The experimental design was a randomised complete block design with three replicates of 5 m x4 m plots. The treatments consisted of two factors, wood shavings biochar with four levels of (B1 = 0 t ha^{-1}, B2 = 5 t ha^{-1}, B3 =

10 t ha^{-1} and B4 = 15 t ha^{-1}) and fertilizer application with three levels (F1 = 0-0-0 N-P_2O_5-K_2O kg ha^{-1}, F2 = 30-30-30 N-P_2O_5-K_2O kg ha^{-1} and F3 = 60-60-60 N-P_2O_5-K_2O kg ha^{-1}).

The wood shaving feedstock used for the study was collected as waste from a local wood mill. The pyrolysis process was carried out in a locally designed reactor and heated with fuel wood also collected as waste from the local wood mill. The temperature inside the rector was monitored with a thermocouple and had an average temperature of 400^{o}C with an average of three days to carbonising.

The site was slashed, ploughed, harrowed and the residues removed without burning. Soil samples were randomly taken from the field after which the different levels of biochar were spread and incorporated into appropriate plots before constructing the mounds. The mounds were constructed in rows and were about 30 cm high. There were 20 mounds per plot at a spacing of 1 m × 1 m.

2.3 Soil Sampling and Biochar Analysis

Soil samples were randomly taken before planting from four different spots across each replicate at a depth of 0-20 cm using soil auger. Samples were bulked and sub-samples taken, air-dried and crushed in a mortar with a pestle to pass through a 2 mm sieve before being analysed using routine analysis methods. Samples of the biochar were also taken from the prepared biochar bulked and ground into powder before being analysed. The physical and chemical properties of both the soil and biochar were assessed. Soil samples were again taken at the same depth at harvest and analysed for the same parameters. The analysis of soil sample before planting and biochar samples are presented in Tables 2 and 3.

Soil pH was determined with WTW pH - electrode Sen Tix 41 meter calibrated with buffer solutions at pH 4 and 7. Organic matter (OM) and Carbon were measured by the dry combustion method (Chintala et al., 2013c). Total N was determined by the Kjeldahl distillation method, available P was by the Bray-1 method. Exchangeable cations (Ca, Mg, K and Na) were extracted with 1.0 N NH_4OAc using a soil solution volume ratio of 1:10. The K and Na in the extract were read using a flame photometer, while Ca and Mg content in the extract was read on the atomic absorption spectrophotometer (Chintala et al., 2014a). Exchangeable acidity (H^+ and Al^{3+}) was measured from 1N KCl extracts by titrating with 0.05N HC1 (Chintala et al., 2014a) while particle size distribution was determined using hydrometer method.

Table 2. Physicochemical properties (0-20 cm) of the experimental site

Soil parameters	**Value**
pH (H2O)	5.18
Organic C (%)	2.99
Organic matter (%)	5.15
Total N (%)	0.13
Available P ppm	10.74
Exchangeable cations (cmol$_c$/kg)	
Ca	6.60
Mg	1.00
K	0.12
Na	0.19
Al	0.40
H	4.00
Exchangeable acidity (Al +H) (cmol$_c$/kg)	4.40
Effective cation exchange capacity (cmol$_c$/kg)	11.71
Base saturation (%)	23.00
Bulk density (g/cm^3)	1.43
Texture (%)	
Sand	71.60
Silt	10.00
Clay	18.40
Textural Class	sandy loam

Table 3. Physicochemical properties of the biochar used for the experiment

Biochar	pH (H_2O)	P_a	K	Ca ($cmolkg^{-1}$)	Mg	Na	Org. M	Org. C	Total N (%)	Ash	C:N	Bulk density
	7.27	3.87	2.56	30.95	7.82	8.7	95.22	55.24	0.21	3.6	263.1	0.18

Note. [a] available nutrients.

2.4 Planting Materials and Cultural Practices

Yam setts with average weight of 300 g were treated with liquid mixture of Conti-Zeb ‘5’ (mancozeb 80%) and Dursban (480 g/l chlorpyrifos) and planted one per plot at the beginning of the rainy season. Each mound was mulched with a tuft of dried grasses and the yam staked. Fertilizer was split-applied at 8 and 16 weeks after planting (WAP). The field was sprayed with *Roundup* (360 g/l Glyphosate) before sprouting of the setts to control weeds. Hand-weeding was subsequently carried out using a hoe as and when necessary.

2.5 Crop Growth and Measurement

The vine length, vine girth and number of leaves were measured from five plants randomly selected from the middle row of each plot at monthly intervals. Vine girth was measured using a calliper at 10 cm above the mound, vine length with a tape measure and line whiles the number of leaves and sprouts were determined by count.

Two plants per plot were selected from the border rows and destructively sampled at 8 and 24 weeks after planting (WAP) and at harvest (37 WAP) for dry matter assessment. Yield and its parameters were assessed on yam tubers harvested from the two middle rows at 32 WAP when the plant had senesced.

2.6 Statistical Analysis

Statistical Analysis Systems (SAS) package version 9.2 was used for statistical analysis of all the soil, growth and yield parameters. Analysis of variance and means separations were done by the general linear model procedure. The least significant difference (LSD) test was used to determine significant differences ($p< 0.05$) between means.

3. Results

3.1 Soil Chemical Properties after Harvest

Addition of biochar and fertilizer resulted in a general increase in most of the soil parameters studied (Tables 2 and 4). The magnitude of increase was however marginal and not significant. Similarly, among the treatments, soil chemical properties after harvest were not significant with the exception of total N which was found to have declined significantly ($p = 0.02$) (Table 4). A decline in total N was observed for all the treatments compared to the control. Fertilization was found to have significantly ($p = 0.01$) decreased soil pH by 6.4 % and 7.2% and increased soil K ($p = 0.003$) by 51.9% at 30-30-30 N-P_2O_5-K_2O kg ha^{-1} and 60-60-60 N-P_2O_5-K_2O kg ha^{-1} fertilizer rate respectively compared to the control (Figure 1 and Figure 2).

Table 4. Chemical properties of the soil used for the experiment after harvest

	pH (H_2O)	Pa	K	Ca ($cmolkg^{-1}$)	Mg	Na	Org. M	Org. C (%)	Total N	C:N	CEC
B1F1	5.81	24.61	0.39	11.80	2.00	0.46	7.28	4.22	0.21	20.59	19.75
B1F2	5.16	5.63	0.39	6.30	1.30	0.36	5.30	3.08	0.14	21.96	15.34
B1F3	5.31	13.31	0.49	8.06	2.00	0.55	6.92	4.01	0.17	24.52	18.49
B2F1	5.41	6.16	0.19	6.50	1.30	0.35	3.08	1.79	0.14	13.54	15.53
B2F2	5.19	6.28	0.50	9.00	3.30	0.53	5.84	3.38	0.14	25.21	20.42
B2F3	5.28	5.16	0.38	10.50	3.30	0.40	6.01	3.49	0.17	20.50	21.37
B3F1	5.29	6.05	0.21	8.90	2.10	0.37	4.94	2.87	0.15	19.66	18.78
B3F2	5.27	7.98	0.35	8.50	2.40	0.37	4.95	2.87	0.18	15.94	19.12
B3F3	5.07	8.74	0.39	9.20	2.40	0.40	6.32	3.67	0.16	23.71	19.98
B4F1	5.87	11.14	0.30	7.60	0.40	0.35	6.77	3.93	0.15	27.17	13.99
B4F2	5.33	6.52	0.41	9.30	3.40	0.31	5.51	3.19	0.19	16.96	20.51
B4F3	5.14	9.96	0.40	7.80	1.70	0.38	6.21	3.61	0.16	23.31	17.67
LSD	ns	ns	ns	ns	ns	ns	ns	ns	0.0**	ns	ns

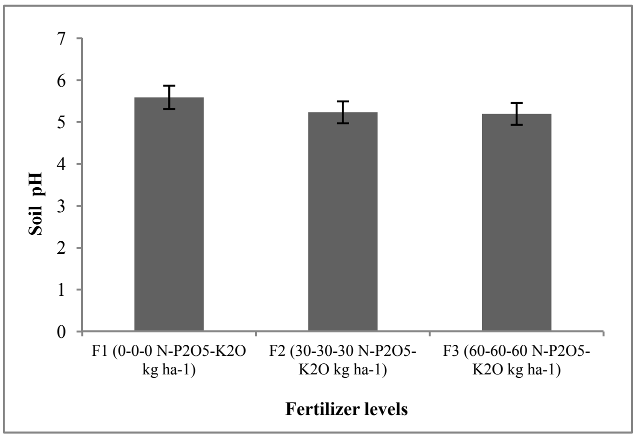

Figure 1. Effect of fertilizer application on soil pH after harvest

Note. Error bars represent standard error of means.

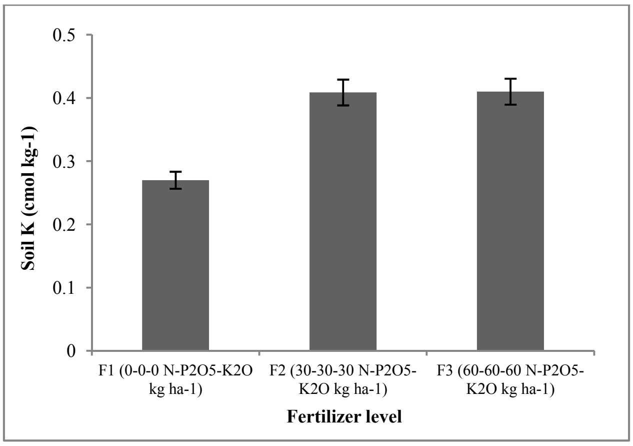

Figure 2. Fertilizer effect on soil K after harvest

Note. Error bars represent standard error of mean.

3.2 Vegetative Growth Parameters

Vegetative growth parameters of yam were not significantly influenced by biochar and inorganic fertilizer application (Table 5). There was no definite trend in the sprouting rate. Sprouting started in all treatments at approximately the 2nd month after planting. Vine girth per plant also did not follow any definite trend although there was an increase in all the treatments compared to the control. The treatment effects on vine length per plant and number of leaves per plant followed a similar trend to vine girth per plant.

Table 5. Effect of biochar and inorganic fertiliser application on the vegetative growth of yam

	Growth at 2 MAP				**Growth at 3 MAP**				**Growth at 4 MAP**	
	Stand count (ha^{-1})	Vine girth plant^{-1} (cm)	Vine length plant^{-1} (m)	Number of leaves plant^{-1}	Stand count (ha^{-1})	Vine girth plant^{-1} (cm)	Vine length plant^{-1} (m)	Number of leaves plant^{-1}	Stand count (ha^{-1})	Vine girth plant^{-1} (cm)
B1F1	5666.67	0.12	0.21	3.18	7000.00	0.12	0.29	13.51	9666.67	0.13
B1F2	5333.33	0.13	0.21	3.53	7500.00	0.13	0.33	15.03	9666.67	0.14
B1F3	4666.67	0.14	0.22	3.73	7166.67	0.13	0.33	15.70	9583.33	0.14
B2F1	3000.00	0.14	0.22	4.42	5583.33	0.13	0.34	16.55	8416.67	0.14
B2F2	7000.00	0.14	0.22	8.34	7750.00	0.14	0.35	18.33	9666.67	0.14
B2F3	3666.67	0.14	0.25	8.42	6416.67	0.14	0.36	19.19	9500.00	0.14
B3F1	4666.67	0.14	0.29	14.22	7250.00	0.15	0.42	23.13	9416.67	0.15
B3F2	5333.33	0.14	0.23	9.53	6333.33	0.13	0.37	19.50	8750.00	0.14
B3F3	6000.00	0.14	0.25	10.93	7166.67	0.13	0.38	20.84	8916.67	0.14
B4F1	5333.33	0.14	0.23	6.94	7750.00	0.14	0.36	16.63	9250.00	0.15
B4F2	4333.33	0.15	0.28	9.96	6500.00	0.15	0.39	20.65	8916.67	0.17
B4F3	5333.33	0.16	0.31	11.36	7416.67	0.14	0.42	21.20	8250.00	0.15
LSD	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Note. ns - not significant.

3.3 Tuber Yield

Number of seed yams per hectare significantly ($p = 0.05$) decreased by 32.7%, 18.4% and 44.9% for biochar rates of 5, 10 and 15 t ha^{-1} respectively compared to the control (Table 6). Plots without biochar had the highest number (5444.00) of seed yam per hectare. Biochar effect on total number of yams harvested per hectare and number of marketable yams per hectare were however not significant. Plots treated with biochar had the highest number of marketable yams compared to the control. The highest level of biochar (15 t ha^{-1}) recorded the highest number of marketable yams per hectare. There was however no significant difference for the interaction of biochar and fertilizer application on yam. Biochar and fertilizer treatment effect on total yam weight (t ha^{-1}), marketable yam weight and seed yam weight (t ha^{-1}) were not significant and did not follow any definite sequence (Table 7).

Table 6. Biochar effect on total number of yams harvested (ha^{-1}), number of marketable yams (ha^{-1}) and number of seed yams (ha^{-1})

	Total number of yam harvested (ha^{-1})	**Number of marketable yams (ha^{-1})**	**Number of seed yams (ha^{-1})**
B1	11111.11	5666.67	5444.44
B2	9333.33	5777.78	3666.67
B3	10222.22	5777.78	4444.44
B4	9333.33	6333.33	3000.00
LSD	ns	ns	1072.6*

Note. * - significant; ns - not significant.

Table 7. Biochar and inorganic fertiliser effect on total yam yield (t ha^{-1}), marketable yam yield (t ha^{-1}) and seed yam yield (t ha^{-1})

	Total yam yield (t ha^{-1})	**Marketable yam yield (tha^{-1})**	**Seed yam yield (t ha^{-1})**
B1F1	11.93	10.43	1.50
B1F2	13.90	11.27	2.63
B1F3	12.00	9.03	2.97
B2F1	9.87	7.63	2.23
B2F2	14.13	11.67	1.70
B2F3	15.67	13.97	2.47
B3F1	17.53	15.47	2.07
B3F2	13.60	11.90	1.70
B3F3	14.67	12.20	2.47
B4F1	16.13	15.27	8.67
B4F2	11.33	9.13	2.20
B4F3	16.40	15.23	1.17
LSD	ns	ns	ns

Note. ns - not significant.

3.4 Total Dry Matter

The application of fertilizer significantly ($p = 0.05$) influenced total dry matter of yam at 24 WAP and at harvest ($p = 0.02$) (Figure 3). Total dry matter increased with increasing fertilizer rate compared to the control. At 24 WAP, total dry matter was significantly increased by 12.9% and 0.82% respectively for 60-60-60 N-P_2O_5-K_2O and 30-30-30 N-P_2O_5-K_2O fertilizer rate. At harvest, the dry sample weight was also significantly increased by 3.31% and 1.19% for the same fertilizer rates. The influence of fertilizer on total dry matter at 8 WAP was however not significant. Similarly the interaction between biochar and fertilizer application on total dry matter was also not significant.

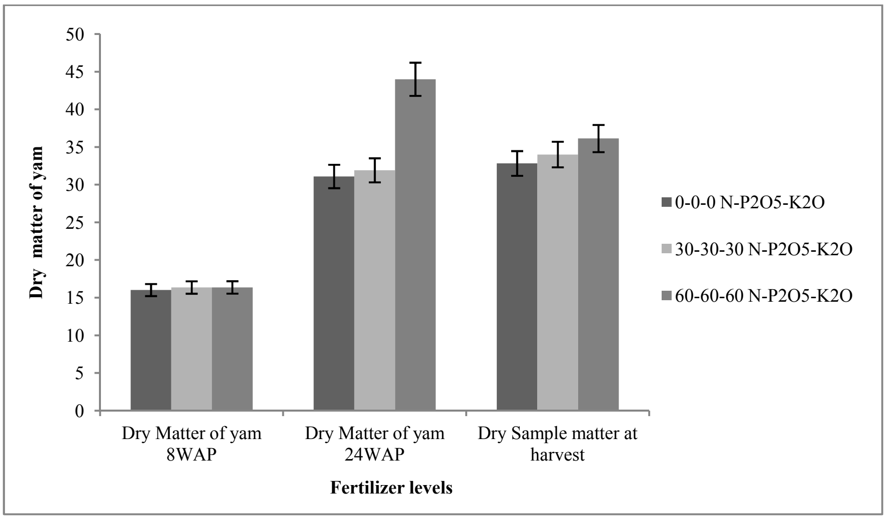

Figure 3. Inorganic fertilizer effects on total dry matter yield of yam at 8 WAP (%), 24 WAP (%) and at harvest (%)

4. Discussion

4.1 Soil Chemical Properties after Harvest

The general increase in most of the initial soil parameters following amendment with biochar and fertilizer may be explained by an increase in nutrient addition and retention as a result of their application to the soil. The biochar used in the study had higher values of pH, exchangeable (K, Ca, Mg, Na), organic matter, organic C and total N compared to the initial soil used for the experiment. Increase in soil parameters as a result of biochar and fertilizer amendment has been similarly reported by several workers (Utomo, Guritno, & Soehono, 2012; Zhang et al., 2012; Chintala et al., 2014a) and has been attributed to the nutrient content of the soil amendments used and the greater nutrient retention of the biochar applied to the soil.

Although the effect of the treatments on soil chemical properties was not significant in this study, the nature of biochar applied, the crop used and interval between biochar application and analysis of its effect, may have contributed to this finding. Major, Lehmann, Rondon, and Goodale (2010) reported that the beneficial effects of applying biochar to soil improve with time. Chan and Xu (2009) also suggested that the addition of freshly made biochar to soil does not consistently improve soil conditions. According to Liang (2006), the effect of biochar on nutrient availability is due to an increase in surface oxidation and cation exchange capacity which intensifies over time. Aged biochar with a much greater CEC may therefore have had a much greater nutrient retention capacity than the freshly made biochar used in this study.

Generally in yam production, one season of cropping results in a rapid decline in soil fertility due to the high soil nutrient mining by the crop. A ton of yam tubers is reported to extract 3.8-4.0 kg N, 0.39-1.1 kg P_2O_5, and 4.2-5.9 kg K_2O from the soil (Le Buanec, 1972). This implies that for a high nutrient demanding crop like yam, applied biochar should be allowed to age before planting. Higher levels of nutrients may also be required to elicit significant responses.

The decline in total N among the treatments compared to the control after harvest may be due to the rapid mineralization of the labile C fraction of the biochar as result of its high C: N ratio (263.05). Kolb, Fermanich, and Dornbush (2009) reported of similar finding in four soils from Wisconsin using manure-pine biochar. This high ratio is expected to cause N immobilisation and possibly induce N deficiency of plants when applied to soil alone (Lehmann & Joseph 2009; Chintala et al., 2014c).

The significant reduction in soil pH and increase in soil K as a result of fertilization observed in this experiment may be due to the acidifying effect on the soil due to the nitrification process of the ammonium sulphate fertilizer used in the experiment. Dharmakeerthi, Chandrasiri, and Edirimanne (2012) in their work on *Hevea brasiliensis* using rubber wood biochar and liquid fertilizer also reported similar findings and attributed the reduction in soil pH to ammonium sulphate fertilizer applied to the treatments. Ammonium or ammonium forming fertilizers are known to cause a reduction in soil pH over time. The increase in soil K, as result of fertilizer application, has also been reported by Agbede and Adekiya (2012) in their work on okra in an Alfisol in the forest - savanna transition zone of south western Nigeria.

4.2 Vegetative Growth Parameters

The non-significant effect of biochar application on the sprouting of yam setts observed in this study may be attributed to physiological differences in the yam setts used in planting. The head portion of yam setts has been reported to sprout and emerge faster than the lower portion (Tschannen, 2003). It is therefore likely that the influence of biochar on sprouting of the setts was influenced by the portion of the yam from which the sett was taken, thus accounting for the non-significant differences in treatments. The time of sprouting after sowing is of importance for uniformity of stand, and contributes to varying tuber maturity stages and sizes at harvest.

The non-significant difference in vine girth, vine length and number of leaves as a result of biochar and fertilizer application in this study may also have been due to the age, type, and rate of application of biochar and plant species used.

Freshly produced biochar is hydrophobic and contains few polar, functional groups at the surface (Cheng, Lehmann, Thies, & Burton, 2008; Chintala et al., 2014b). Biochar however develops reactive surfaces with time after exposure to water and oxygen in the soil, which allows it to adsorb nutrients, reduce leaching (B. Singh, B. P. Singh, & Cowie, 2010; Chintala et al., 2013a; Chintala et al., 2013b) and contribute to increased fertilizer use efficiency. Biochar also retains some of its feedstock nutrients in the biochar ash. Therefore biochar produced from nutrient rich feedstock such as animal manure will have high nutrient content than biochar produced from lignin rich plant biomass feed stocks (Filiberto & Gaunt, 2013). Alburquerque et al. (2014) also reported that nutrient–poor feedstock biochar may have limited soil fertility benefits in the short term leading to little improvement in the crop growth. Therefore the wood shaving feedstock used to produce the biochar may have led to the non-significant difference in the crop vegetative growth.

The quantity of biochar used in this experiment was probably not sufficient to produce a significant difference in a high soil nutrient mining crop like yam. Several studies, which have reported considerable improvement in the yield of various crops species with rates from 5-50 t ha^{-1} and appropriate nutrient management have mainly been on cereals, vegetables and legumes crops with short maturity periods (Blackwell, Krull, Butler, Herbert, & Solaiman, 2010; Glaser, Haumaier, Guggenberger, & Zech, 2001).

Therefore yam, which is a high nutrient demanding crop and has a long maturity period, may require higher application rates of biochar.

4.3 Yields Component of Yam

The results showed that biochar and fertilizer did not significantly influence yield. This may be due to the fact that the treatments did not significantly affect vegetative growth parameters which translated to the yields. Increase in vegetative growth helps in efficient interception of solar radiation (Okwuowulu, 1995) which results in better tuber bulking ability. Photosynthetic efficiency in the growth of yam, determines the size of the tuber (Orkwor & Adeniji, 1998). Additionally, the limited rainfall experienced during the tuber bulking phase from the month of July to September (Table 1) may have contributed to the non-significant effects on the yield of the crop even with soil amendment. This supports the findings by (Craufurd, Summerfield, Asiedu, & Vara Prasad, 2001) that the tuber bulking phase in the growth of yam is highly sensitive to water stress.

The non-significant effect of the treatments on yields observed in this study however contrasts the findings of (Yamato, Okimori, Wibowo, Anshori, & Ogawa, 2006; Schulz & Glaser, 2012) which found significant increase in crop yield as a result of biochar and fertilizer addition. They attributed it to biochar's ability to efficiently utilize nutrients by holding ammonium ions in soils and inhibiting nitrogen fertilizer nitrification.

Biochar however, caused a reduction in number of seed yams per hectare but a higher number of marketable yams per hectare compared to other treatments in this study. This observation suggests that biochar favours the growth of larger tubers (marketable yam) which is the real component of economic yield needed by farmers. Biochar can thus be recommended when the objective is for the production of larger tubers (marketable yam).

4.4 Effect on Total Dry Matter

The significant increase in total dry matter of yam on fertilized plots at 24 WAP and at harvest observed in this study may be due to a higher availability of nutrient and timing of the fertilizer application at the vegetative and tuber bulking stage of the crop development. The fertilizer used in this experiment was split applied at 8 and 16 WAP. Hgaza, Diby, Assa, and Ake (2010) in their work on *D. alata* L. also reported of increased dry matter of yam as result of fertilizer application. Contrary to this, Orkwor and Adeniji (1998) observed no effect of fertilisation on the dry matter content of yam. The timing of application of soil amendments in yam production should therefore be planned so that the crop can make good use of the nutrients they provide.

5. Conclusions

The biochar and inorganic fertilizer applied in this study did not have a significant effect on soil parameters with the exception of total N, vegetative growth and tuber yield of yam. The number of seed yams per hectare was however significantly decreased with biochar application. These effects were attributed to the age, rate of application of biochar and the type of crop grown (high nutrient requirement of yam). Since recommended application rates for any soil amendment must be based on extensive field testing and given the variability in biochar material and soils, there is the need for extensive field testing (on yam variety types, time of application of the soil amendment, aged and higher rate of biochar application) before making a general recommendation of biochar application in yam production. Notwithstanding this, aged biochar and higher rates of biochar may be useful for increasing the yield of marketing yam tubers.

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