AMELIORATION OF SOIL ACIDITY AND pH- BUFFERING CAPACITY OF AN ULTISOL IN UMUDIKE, SOUTHEASTERN NIGERIA AS INFLUENCED BY BIOCHAR APPLICATION

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ABSTRACT

Incubation experiment and laboratory analyses were carried out to investigate the effects of biochar on soil acidity and pH-buffering capacity of an Ultisol in Umudike, southeastern Nigeria. The treatments were 0 ton per hectare (t/ha) biochar, 1 t/ha biochar, 3 t/ha biochar, 5 t/ha biochar, 1t biochar + 400kg NPK (15:15:15) /ha, 3 t biochar + 400kg NPK (15:15:15) /ha, 5 t biochar + 400kg NPK (15:15:15) /ha, and 400 kg NPK(15:15:15) /ha. The treatments were replicated 3 times. The incubation studies were carried out to investigate the effect of the treatments on soil pH and exchangeable acidity over a period of four weeks, using the equivalent of the treatments outlined above. 0g biochar, 1.6g biochar, 5g biochar, 8g of biochar, 1.6g biochar + 0.6g NPK(15:15:15), 5g biochar +0.6g NPK(15:15:15), 8g biochar +1.6g of NPK(15:15:15) and 0.6g of NPK(15:15:15). Each of the treatments was added to 50g of soil in plastic containers of equal size and basal diameter and replicated three times. The soil used for the incubation studies was strongly acidic, having a pH (H_2O) of 4.38 and exchangeable acidity of 1.84. The soil pH (H_2O) and exchangeable acidity were determined on the incubated samples at weekly interval for 4 weeks, using standard laboratory procedures. The effect of the treatments on the pH-buffering capacity of the soil during incubation was also determined using standard procedures. Results obtained showed that 5 t/ha biochar significantly ($p<0.05$) increased soil pH from 4.38 to 8.1, 8.64, 8.20 and 8.42 from week 1 to week 4 of incubation respectively, while exchangeable acidity was reduced from 1.84 to 0.34, 0.61, 0.56 and 0.37 from week 1 to week 4 respectively throughout the incubation period. The pH-buffering capacity of the incubated soil was also increased by 96%, 97%, 87% and 92% from week 1 to week 4 respectively. It could therefore be concluded that the application of 5 t/ha biochar ameliorated soil acidity and increased soil pH-buffering capacity of the study area.

Key words: amelioration, amendment¸ soil acidity, pH-buffering capacity, ultisol, biochar.

INTRODUCTION

Soil acidity is a major factor that limits yield in crop production worldwide and acid soils account for approximately 4 billion hectares of the total world land area (FAO, 2015). This is 30% of the total world land area and 58% of land suitable for agriculture, inhabited by 73% of the world's population. As a result of extensive weathering and leaching, most soils found in South and North America, Asia and Africa, are acidic (Muindi *et al.*, 2016). Soil acidity is linked with toxicity of hydrogen (H), aluminium (Al), iron (Fe) and manganese (Mn) especially to plant roots and corresponding deficiencies of plant available phosphorus (P), molybdenum (Mo), calcium (Ca), magnesium (Mg) and potassium (K) (Giller and Wilson 1991) which negatively affects the fertility and productivity of the soil (Muindi *et al.*, 2016).

Soils found in southeastern Nigeria which are characterized by high acidity and low rate of exchangeable cations cannot support optimal crop production without the use of soil amendment. The application of biochar, has been proven to change soil pH to a more neutral pH, especially in acidic soils (Fowles, 2007). The changes in CEC and pH create a suitable environment for growing crops in an area that cannot support optimal crop production.

The use of biochar, as soil amendment to mitigate man-induced climate change, as well as to improve soil productivity was proposed as a new approach (McHenry, 2009). However, the usage of charred materials as soil amendment is not a new concept. In the Amazon River Basin, there are areas that have remained productive for thousands of years due to charcoal accumulation that significantly increased the carbon's stability against microbial decay (Steiner *et al.*,2007). The Amazonian Dark Earth now serves as a guide to create a carbon sink in soils as well as hold the possibility to reduce the amount of fertilizer farmers need to apply to fields.

Presently, application of biochar to soils is attaining universal attention due to the potential of it improving fertility in acidic soils by enhancing soil properties such as pH, cation-exchange-capacity and water-holding-capacity (Smebye, 2014) as well as soil nutrient retention capacity and sustaining carbon storage, thereby reducing the emission of greenhouse gas (Downie *et al.*, 2009; Abukari, 2014). As such, biochar can concurrently act in both soil modification, improving soil physical condition and as carbon sequestration medium, giving a high prospect that could help decrease atmospheric carbondioxide in the near future (Amonette and Joseph, 2009). Biochar is therefore seen as a simple approach, yet a very powerful tool to combat soil acidity challenge by significantly increasing soil cation exchange capacity (Yuan *et al.*, 2011b) thereby, increasing the pH buffering capacity of acidic soils (Xu *et al.*, 2012). Biochar contains ample amounts of oxygen-containing functional groups which supply negative surface charge of biochar (Yuan *et al.*, 2011a; Xu *et al.*, 2012). The oxygen-containing functional group is regarded as the main mechanism in biochar that increases the pH buffering capacity of acid soils treated with biochar (Xu *et al.*, 2012). Furthermore, biochar is known to have the capability of reducing soil compaction, improving soil physical condition, enhancing plant nutrient uptake from the soil and decreasing emission of nitrous oxide(Lehmann *et al.*,2005; Lehmann 2007; Kannan *et al.*, 2012). Biochar has the potential to increase the availability of plant nutrients (Lehmann *et al.*, 2008); through increasing cation exchange capacity (CEC), improving soil pH, or immediate nutrient contributions from the biochar itself. According to Mbagwu and Piccolo (1997) the potential mechanism for improved nutrient retention and supply due to biochar modification is the increase of cation exchange capacity up to 50% as compared to unamended soils. Biochar has a greater capacity to absorb and retain cations than other forms of soil organic amendment owing to its greater surface area, and the negative surface charge that is found on biochar (Liang *et al.*, 2006; Abukari, 2014).

The objectives were to:

i. asssess the acid neutralizing effect of biochar on the soil in a controlled environment.
ii. evaluate the pH-buffering capacity of biochar on an ultisol in Umudike southeastern Nigeria.

MATERIALS AND METHODS

DESCRIPTION OF EXPERIMENTAL SITE

Soil samples were collected from the Eastern farm of Michael Okpara University of Agriculture, Umudike, located on the following coordinates: Latitude 05°29' North and Longitude 07°33' East, elevated 122 meters above sea level. Umudike is located in the tropical rain forest area which has a mean annual rain fall of 2117mm distributed over 9 to 10 months in a bimodal rainfall pattern. Monthly average air temperature ranges from 20°C to 24°C and 28°C to 35°C for minimum and maximum temperatures respectively while the soil temperature ranges from 23°C to 24.6°C. Relative humidity varies from 51% to 87% (NRCRI, 2013).

SOIL SAMPLING

Initial soil samples were collected randomly from the experimental site at a depth of 0-20cm with a soil auger and bulked together into a composite sample before application of biochar. The composite sample was sent to the laboratory where it was air dried, crushed and sieved through a 2mm sieve for routine soil analysis using the following procedures:

- Particle size distribution of the sampled soils was determined by Bouyoucos hydrometer method as modified by Gee and Bauder (1986).
- Soil pH was determined using a suspension of soil and distilled water in the ratio of 1:2.5 soil:water, it was stirred for 30 minutes and the pH value read with the aid of a glass electrode pH meter (Thomas, 1996).
- Available Phosphorus was determined using Bray 2 method (Olsen and Sommers, 1982) and the concentration of Phosphorus was determined by the blue colour method of Murphy and Riley (1962).
- Total Nitrogen was determined following the Micro Kjeldahl digestion procedure (Bremner and Mulvaney, 1982).
- Organic Carbon was determined based on Walkey-Black chromic acid wet oxidation method.
- Soil exchangeable Calcium (Ca), Magnesium (Mg), Sodium (Na), and Potassium (K) were extracted with neutral ammonium acetate. Calcium and magnesium in the extracted leachate were determined by Ethylene Diamine Tetra-acetic Acid (EDTA) titration method as described by Lanyon and Heald (1984) while Sodium and Potassium were determined by flame photometric method (Kundsen *et al.*, 1982).
- Soil exchangeable acidity (Al^{3+} and H^+) was determined using the 1N KCl extractant method of Mclean (1982) as described by Udo *et al.* (2009).

TREATMENTS

The treatment used was biochar and NPK (15:15:15) fertilizer, applied at the following rates:

Treatments	**Meaning**
Treatment 1 (T_1)	zero ton per hectare of biochar (control)
Treatment 2 (T_2)	1 ton per hectare of biochar
Treatment 3 (T_3)	3 tons per hectare of biochar
Treatment 4 (T_4)	5 tons per hectare of biochar
Treatment 5 (T_5)	1 ton per hectare of biochar+ 400 kg per hectare NPK (15:15:15)
Treatment 6 (T_6)	3 tons per hectare of biochar + 400 kg per hectare NPK (15:15:15)
Treatment 7 (T_7)	5 tons per hectare of biochar + 400 kg per hectare NPK (15:15:15)
Treatment 8 (T_8)	400 kg per hectare NPK (15:15:15)

These treatment rates were replicated three (3) times to give twenty (24) observations.

BIOCHAR PRODUCTION

Biochar was produced locally using the following organic residues (150kg of saw dust, 150kg of cocoa pod, 150 kg of palm bunch, 150 kg of rice husk and 250 kg of poultry droppings). Animal dung (poultry droppings) was sourced from Michael Okpara University of Agriculture Animal farm. Saw dust from Timber Market Ahieke and rice husk from Bende rice mill in Uzoakoli LGA, AbiaState.Cocoa pod and palm bunch were sourced locally from farmers in Umudike.

These organic residues were subjected to slow pyrolysis to produce biochar, which was allowed to cool before collection into sacks.

Plate 1: Local Biochar Drum During Biochar Production

Plate 2: Biochar After Production

The biochar so produced was sent for analysis to determine both the physical and chemical properties of the biochar product.

BIOCHAR APPLICATION

INCUBATION STUDIES

To evaluate the effect of the biochar on the neutralization of soil acidity, incubation studies were carried out. Initial soil samples which were collected randomly from the experimental site at a depth of 0-20cm, were air-dried and sieved through 2mm sieve.

50 grams of the sieved soil sample was measured into plastic containers of equal size and basal diameter and replicated thrice. The equivalent of 1ton, 3 tons, 5 tons of the prepared biochar per hectare which was 1.6g, 5g and 8g of biochar per pot and the equivalent of 1 ton biochar +400 kg of NPK (15:15:15) per hectare, 3 tons biochar +400 kg of NPK(15:15:15) per hectare, 5 tons biochar + 400 kg of NPK(15:15:15) per hectare and 400 kg of NPK(15:15:15) only which was 1.6g biochar + 0.6g NPK(15:15:15), 5g biochar +0.6g NPK(15:15:15), 8g biochar +1.6g of NPK(15:15:15) and 0.6g of NPK(15:15:15) respectively was added to the soil samples in the plastic containers and mixed thoroughly.

The plastic containers were clearly labeled and arranged on top of the laboratory bench. 18ml of distilled water was initially added to the samples and subsequently once fortnightly to maintain the soil moisture content and the plastic containers were covered with cheese clothes to reduce evaporation.

Every week, soil pH (in water) was determined following standard laboratory procedures and exchangeable acidity was determined using 1N KCl extractant method.

pH- BUFFERING CAPACITY OF BIOCHAR

Soil pH was determined using a suspension of soil and distilled water in the ratio of 1: 2.5 soil:water. It was stirred for 30 minutes and the pH value read with the aid of a glass electrode pH meter (Mclean, 1982). This procedure was repeated weekly during incubation and the variation in pH was used in the calculation of the buffering capacity of the biochar on the soil as shown below:

$$\text{Buffering Capacity} = \frac{\text{pH WAA} - \text{Initial pH}}{\text{Initial pH}} \times \frac{100}{1}$$

(Nwosu and Chukwu 2009)

Where WAA = Weeks After Biochar Application

DATA ANALYSIS

Data collected were subjected to Analysis of Variance (ANOVA) using Genstat software. Mean separation was done according to Obi (2002) using Fischer's Least Significant Difference (FLSD) where significance existed.

RESULTS AND DISCUSSION

INITIAL SOIL ANALYSIS

The chemical and physical properties of the soil used for this study are presented in Table 1.The physical analysis of the soil showed that it contained 79.60% sand, 8.00% silt and 12.40% clay making the textural class sandy loam. The soil pH was strongly acidic (4.50), based on the pH interpretation rating given by Chude *et al*. (2005) and the value agreed with the findings of Akinmutimi and Ihejirika (2016) who reported that soils around the south east especially in Umudike are acidic. Most of the soils of South eastern Nigeria are acidic due to the nature of the parent material, weathering and heavy leaching of basic cations such as calcium and magnesium leaving behind aluminum and iron oxides and hydroxides (Akinmutimi and Osodeke, 2013; Brady and Weil, 2008). The organic carbon content was 0.94% and organic matter content was 1.63% which is rated low (< 2.0%) based on organic matter ratings of south eastern Nigeria soils by Enwezor *et al*. (1990). The low organic matter content of the soil can be attributed to the effect of temperature, soil management and the nature of the soil texture (sandy loam) which is well aerated, and the presence of oxygen results in a more rapid decay of organic matter (SSSA, 1987). Nitrogen content was low (0.056%) which is a common occurrence in soils of southeastern Nigeria as a result of losses arising from leaching of nitrates as well as the rapid mineralization of organic matter under the isohyperthermic soil temperature regime (Eshett, 1987; Eshett *et al*., 1990). The Phosphorus content was low (12.50 mgkg^{-1}) which is below the critical level of 15 mgkg^{-1}for southeastern Nigeria (Enwezor*et. al*., 1989). This is a well-known occurrence in the soils of south eastern Nigeria and is attributed to the high rate of phosphate fixation capacity of the soil arising from the highly acidic nature of the soil (Ahukaemere *et al*., 2014; Idigbor *et al*., 2008). In acidic soils, the oxides of aluminum and iron fix phosphorus to form complexes that are insoluble and thereby rendering phosphorus unavailable in the soil (Lee *et al*., 2010; Onwuka *et al*., 2009). Exchangeable acidity was 1.44 cmolkg^{-1} and the soil had Exchangeable bases (Ca, Mg, K and Na) of (2.80, 1.60, 0.21, and 0.18) cmolkg^{-1} respectively. The low value of Exchangeable potassium (0.21cmolkg^{-1}) can be attributed to low potassium reserve in acid soils. This may be caused by the highly mobile nature of exchangeable potassium relative to calcium and magnesium and its consequent massive loss through leaching (Ahukaemere *et al*., 2014). The values obtained for other exchangeable bases were low and agreed with the findings of Nwite *et al*. (2009); Ovie *et al*. (2013) and Akinmutimi and Ihejirika (2016) who reported that Ultisols of southeastern Nigeria were low in exchangeable bases. The low values of exchangeable bases can be attributed to high rainfall and consequent leaching of basic cations out of the root zone of the soil.

Table 1: Physical and Chemical Properties of the Soil used for the Field Experiment

Parameter	Values
Soil pH (1:2.5) H_20	**4.50**
Total Nitrogen (g/kg)	**0.60**
Organic Carbon (g/kg)	**9.40**
Organic Matter (g/kg)	**16.30**
Available Phosphorus (mgkg^{-1})	**12.50**
Exchangeable Calcium (cmolkg^{-1})	**2.80**
Exchangeable Potassium (cmolkg^{-1})	**0.21**
Exchangeable Magnesium (cmolkg^{-1})	**1.60**
Exchangeable Sodium (cmolkg^{-1})	**0.18**
Exchangeable Acidity (cmolkg^{-1})	**1.44**
Sand (gkg^{-1})	**796.00**
Silt (gkg^{-1})	**80.00**
Clay (gkg^{-1})	**124.00**
Soil Texture	**SL**

SL= Sandy loam.

BIOCHAR ANALYSIS

The results obtained from the analysis of the prepared biochar are shown in Table 2.

The biochar had a pH of 9.70; similar pH value was obtained from a study where cocoa shell and rice husk were subjected to slow pyrolysis (Smebye, 2014). Organic carbon content was 1.54%. Nitrogen content was 0.91% and organic matter content was1.72%. Phosphorus was 0.58%. Potassium content was 1.96%, calcium content was 9.24%, sodium content was 0.19% and magnesium content was 4.13%. The exchangeable bases were relatively higher in the biochar when compared to that of the soil used for this study. This indicates the potential of the biochar to enhance the chemical properties of the soil under study.

Table 2: Some Properties of the Biochar used for the Experiment

Parameters	Values
pH (H_20)	**9.70**
Organic carbon (g/kg)	**15.40**
Organic Matter (g/kg)	**17.20**
Nitrogen (g/kg)	**9.10**
Phosphorus (%)	**0.58**
Potassium (%)	**1.96**
Calcium (%)	**9.24**
Magnesium (%)	**4.13**
Sodium (%)	**0.75**

Table 3: Physical and Chemical Properties of the Soil before Treatment Application during the Incubation Studies.

Parameter	Values
Soil pH (1:2.5) H_20	4.38
Total Nitrogen (g/kg)	0.04
Organic Carbon (g/kg)	0.34
Organic Matter (g/kg)	0.59
Available Phosphorus (mgkg^{-1})	16.40
Exchangeable Calcium (cmolkg^{-1})	3.20
Exchangeable Potassium (cmolkg^{-1})	0.17
Exchangeable Magnesium (cmolkg^{-1})	2.00
Exchangeable Sodium (cmolkg^{-1})	0.19
Exchangeable Acidity (cmolkg^{-1})	1.84
Sand (gkg^{-1})	772.00
Silt (gkg^{-1})	150.00
Clay (gkg^{-1})	78.00
Soil Textural Class	SL

SL= Sandy Loam

EFFECT OF THE TREATMENTS ON pH AND EXCHANGEABLE ACIDITY DURING INCUBATION

The effect of the treatments on soil pH and Exchangeable acidity during the incubation study are shown in Figures 1 to 2

Figure 1 shows the effect of the treatments rates (T1, T2, T3, T4, T5, T6, T7 and T8) on soil pH during week 1 to 4 of incubation. The data revealed that there was a sharp and highly significant ($P<0.01$) increase in pH from the control T_1 (0 t ha $^{-1}$B) to T_7 (5 t ha^{-1}B+ 400 Kg ha^{-1} NPK) after which there was a sharp decline in soil pH for T_8(400 Kg ha^{-1} NPK). The highest pH value (8.61) during week 1 of incubation was observed at T_4 (5 t ha^{-1}B) and the lowest pH value (3.31) was observed at the control T_1(0 t ha $^{-1}$B).

The increase in pH as occasioned by the treatment can be attributed to the Acid Neutralizing Capacity of the biochar (ANC). According to a study done by Martinsen *et al* (2015), they reported that analysis of biochar produced from cocoa shell, oil palm shell and rice husk had ANC of 217 cmolkg^{-1}for cocoa shell, ANC of 36 cmolkg^{-1}for oil palm shell and ANC of 45 cmolkg^{-1} for rice husk. The high ANC of cocoa and that of oil palm and rice residues which were among the feedstock used to produce the biochar used for this study may have neutralized the aciditiy in the soil due to the high potential of biochar as a liming agent. The potential of biochar as a liming agent is based on the alkalinity of the biochar (Yuan and Xu, 2011; Martinsen *et al*., 2015) and the biochar used for this study has an alkaline pH of 9.70.

At week 2 of incubation, the highest increase in pH value (8.64) over the control was observed at T_4 (5 t ha^{-1}B) and the lowest pH value (5.96) apart from the control was from T_8(400 Kg ha^{-1} NPK). The pH values observed during week 2 of the incubation period ranged from (3.55) at the control to (8.64) at T_4 (5 t ha^{-1}B). The increase in pH as effected by the different treatment rates during week 2 of the incubation period was also highly significant ($P<0.01$).

At week 3 of incubation period. The highest increase in pH value of (8.20) over the control was still observed at T_4 (5 t ha^{-1}B) and the lowest pH value (5.90) apart from the control was from T_8(400 Kg ha^{-1} NPK). The pH values observed during week 3 of the incubation period ranged from (3.73) at the control to (8.20) at T_4 (5 t ha^{-1}B). The increase in pH as affected by the different treatment rates during week 3 of the incubation period varied distinctively from each other. Treatment rates that had only biochar gave higher pH values than those that had a combination of biochar and NPK fertilizer. The lower pH values from treatments that had a combination of NPK fertilizer can be attributed to the acidifying effect of the inorganic fertilizer. Ayeni (2010) reported that soil acidification is one of the major challenges associated with the use of mineral fertilizers. Soil acidification occurs as a result of the process of nitrification (Bolan and Hedley, 2003). The increase in pH at week 3 of incubation was also highly significant ($p<0.01$).

At week 4 of incubation period. The highest increase in pH value (8.42) over the control was still observed at T_4 (5 t ha^{-1}B) and the lowest pH value (5.80) apart from the control was observed at T_8(400 Kg ha^{-1} NPK). The pH values observed during week 4 of the incubation period ranged from (3.75) at the control to (8.42) at T_4 (5 t ha^{-1}B). The increase in pH as effected by the different treatment rates during week 4 of the incubation period was highly significant ($P<0.01$).

The data gathered on the effect of the treatment (biochar and NPK fertilizer) on the pH as showed in the Figure 4.1 was virtually the same throughout the incubation period (week 1 to week 4). This result agrees with the findings of Akinmutimi and Osodeke (2013) and Ayeni *et al*. (2008) who reported that there was no consistent relationship between the soil pH and the duration of the incubation.

Application of treatments T_2, T_3 and T_4 (1 t ha^{-1}B,3 t ha^{-1}B, 5 t ha^{-1} B) significantly ($P<0.01$) increased the pH of the soil over the control throughout the period of incubation. Treatment T_4 (5 t ha^{-1} B) gave the highest pH value and this is not far from the result obtained by Akinmutimi and Osodeke (2013) where an incubation study was carried out, using ash from oil palm bunch to increase pH of soils in Umudike. Ezekiel *et al.* (2009) also reported that oil palm bunch ash increased the pH of the soils of Umudike area. Comparing some properties of the biochar used for this study with properties of oil palm bunch ash used by Akinmutimi and Osodeke (2013), the values reveal that biochar has a higher potential as a liming agent than the oil palm bunch ash. However, treatments T_5, T_6, T_7 and T_8 (1 t ha^{-1}B + 400 Kg ha^{-1} NPK, 3 t ha^{-1}B + 400 Kg ha^{-1} NPK 5 t ha^{-1} B+ 400 Kg ha^{-1} NPK and 400 Kg ha^{-1} NPK) resulted in lower pH values compared to treatments T_2, T_3 and T_4. This effect can be attributed to the influence of the NPK fertilizer. The use of inorganic fertilizers has been associated with soil physical degradation, increased soil acidity and soil nutrient imbalance Iren *et al.* (2014).

Figure 2 shows the effect of the treatment rates (0 t ha $^{-1}$B, 1 t ha^{-1}B, 3 t ha^{-1}B,5 t ha^{-1}B, 1 t ha^{-1}B + 400 Kg ha^{-1} NPK, 3t ha^{-1}B+ 400 Kg ha^{-1} NPK,5 t ha^{-1}B+ 400 Kg ha^{-1} NPK and 400 Kg ha^{-1} NPK) on exchangeable acidity during week 1 to 4 of the incubation period.

Exchangeable acidity ranged from (0.34) at T_4 to (1.17) at T_8. Treatments T_2, T_3 and T_4 had lower exchangeable acidity values than the control T_1 (0.53), while treatments T_5, T_6, T_7 and T_8 had higher exchangeable acidity values than the control (T_1). The increase in the exchangeable acidity values for treatments T_5, T_6, T_7 and $T_8$was significant ($P<0.05$).

At week 2 of the incubation period.

Exchangeable acidity values ranged from (0.42) at both T_2& T_3 to (1.62) at T_5. Treatments $T_2$and T_3had lower exchangeable acidity values than the control T_1 (0.53), while treatments T_5, T_6, T_4, T_7 and T_8 had higher exchangeable acidity values than the control (T_1). The increase in the exchangeable acidity values for treatments T_5, T_6, T_4, T_7 and $T_8$was significant ($P<0.05$).

At 3 weeks of the incubation period.

Exchangeable acidity values ranged from (0.56) at the control T_1 to (1.38) at T_5. Treatment T_3 (0.53) had the only exchangeable acidity value that was below the control. However, treatment T_4 (0.56) had the same exchangeable acidity value as the control (0.56), while treatment T_2 (0.64) had a higher EA value than the control. Treatments T_5, T_6, T_7 and T_8 were significantly ($P<0.05$) different.

At 4 weeks of the incubation period.

Exchangeable acidity values ranged from (0.37) at treatment T_2 and T_4 to (1.09) at treatment T_5. Treatments T_2, $T_3$and T_4had lower exchangeable acidity values than the control (0.48). The lowest exchangeable acidity value at week 4 of incubation was obtained from treatment T_2 and T_4 (0.37). This suggests that in a controlled environment, where reduced acidity is required for crop growth, 1 t ha^{-1}B is sufficient to reduce soil acidity, considering the challenge of gathering large quantities of feedstock required for biochar production. The highest exchangeable acidity value was from treatment T_5(1.09). Treatments T_5, T_6, T_7 and T_8 had significantly ($P<0.05$) higher exchangeable acidity values than the control in this order ($T_5>T_8>T_7>T_6$).

The data gathered on the effect of the treatment (biochar and NPK fertilizer) on the exchangeable acidity throughout the incubation period showed a positive effect. Application of the treatment rates (T_2, T_3 andT_4), that had only biochar resulted in lower exchangeable acidity value. This agrees with the work of Chintala *et al*. (2014), where it was observed that the application of biochars to acidic soil increases its sorption capacity for nutrients (Sohi *et al*., 2010) and reduces the exchangeable acidity (Van *et al*., 2009). However, treatment rates (T_5, T_6, T_7 and T_8), that had a combination of biochar and NPK fertilizer resulted in higher exchangeable acidity values. This could be attributed to the acidifying effect of the N fertilizer. According to a study, carried out on the effect of N fertilizers on pH and exchangeable acidity? The result showed that N fertilizer causes soil acidification (Barak *et al.*, 1997). According to the study, exchangeable acidity was strongly dependent upon the rate of N fertilizer applied, though not in a linear manner.

LSD(0.05)@ 1WAA= 0.23
LSD(0.05)@ 2WAA=0.28

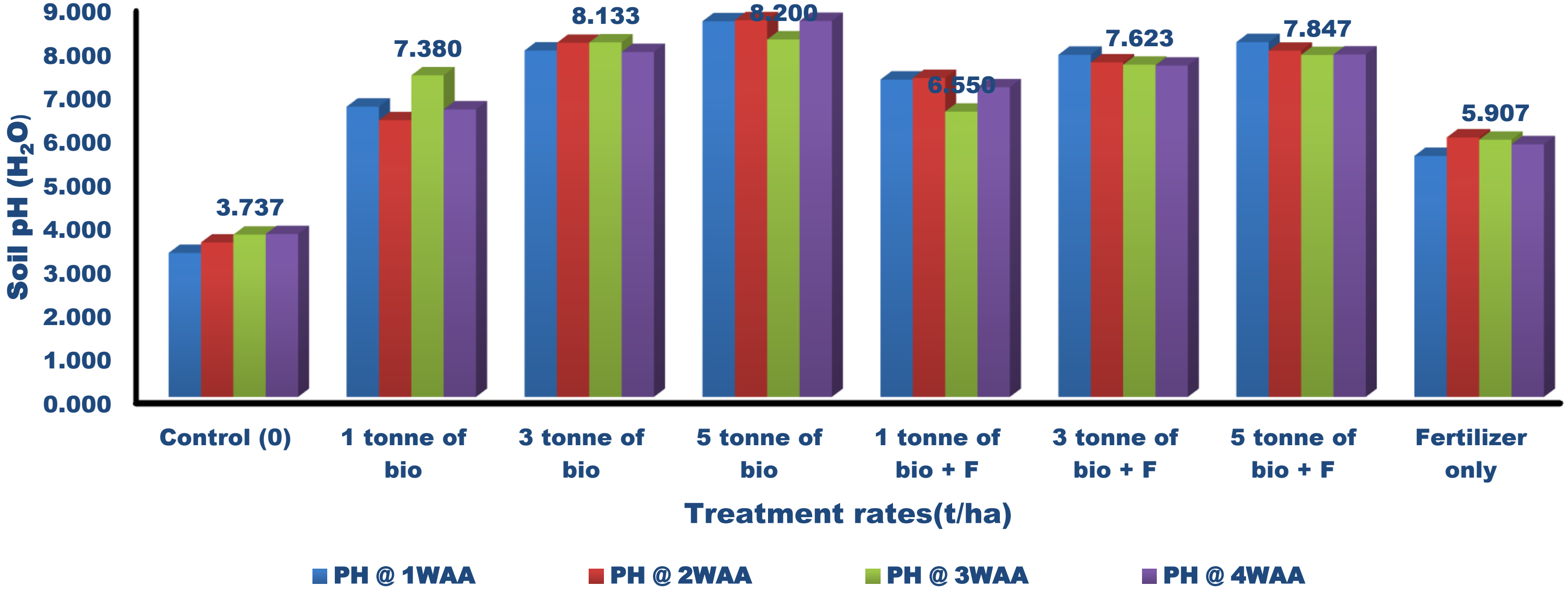

Fig 1: Effect of Treatment on Soil pH at 1, 2, 3 and 4 WAP

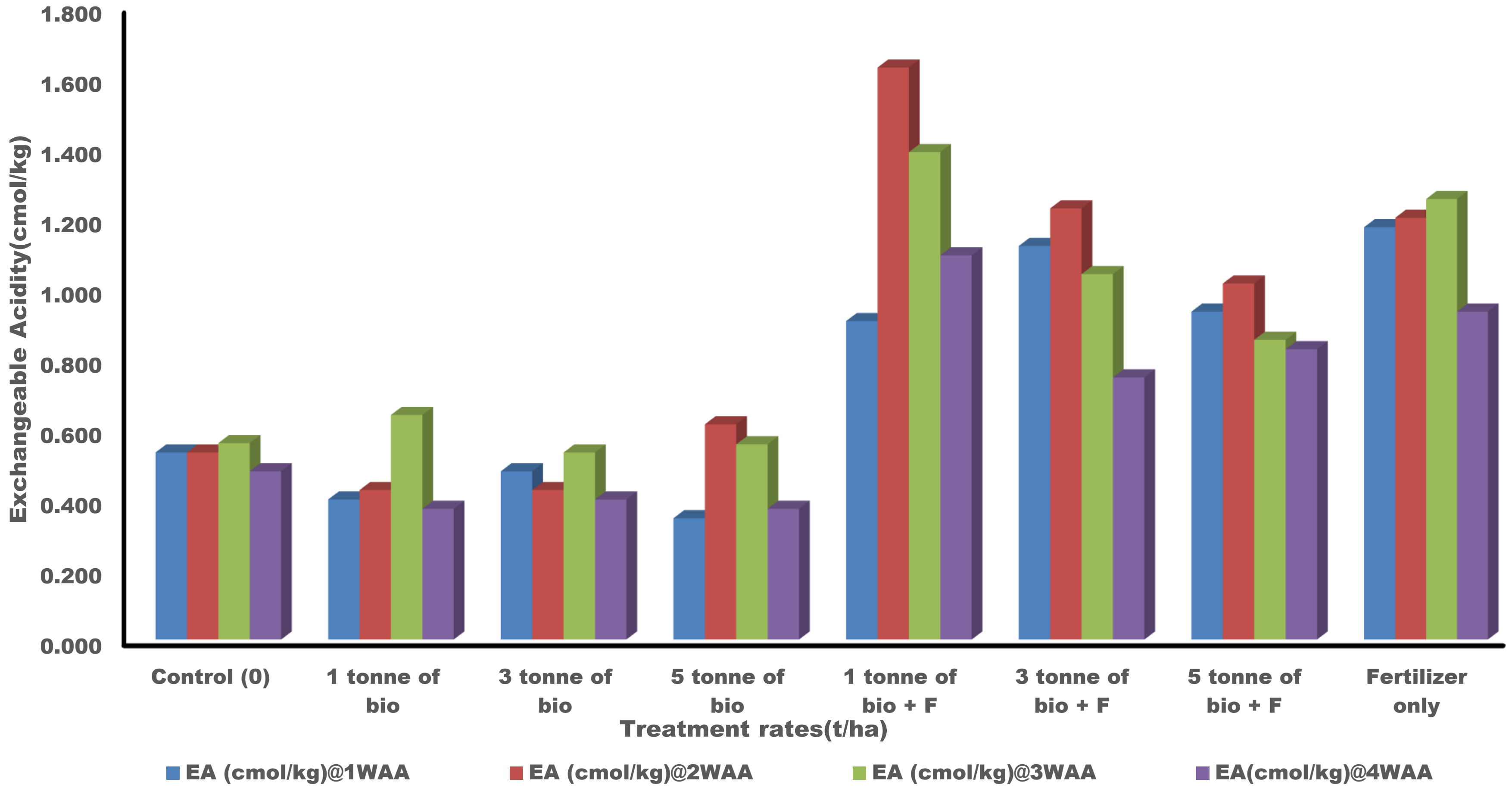

Fig. 2. Effect of Treatment on Exchangeable Acidity (cmol/kg) at 1, 2, 3 and 4 WAP

EFFECT OF THE TREATMENTS ON pH BUFFERING CAPACITY OF THE SOIL DURING INCUBATION

Table 4 shows the effect of the treatments on pH buffering capacity of the soil during incubation.

The data revealed the effect of the treatments rates (0 t ha $^{-1}$B, 1 t ha^{-1}B, 3 t ha^{-1}B,5 t ha^{-1}B, 1 t ha^{-1}B + 400 Kg ha^{-1} NPK, 3 t ha^{-1}B+ 400 Kg ha^{-1} NPK,5 t ha^{-1}B+ 400 Kg ha^{-1} NPK and 400 Kg ha^{-1} NPK) on pH buffering capacity (pHBC) of the soil. Treatments (T_2,T_3,T_4,T_5,T_6,T_7 & T_8) significantly increased the pHBC of the soil throughout the incubation period, only treatment T_1 (control) had a negative pHBC throughout the period of incubation. The coefficient of variation among the treatment means for week one and week two were the same (2.3%). 2.6% for week three and 2.0% for week four, which implies that at week four variation among data set was minimal. Treatment T_4(5 t ha^{-1}B) increased the soil pHBC the most throughout the incubation period (96%, 97%, 87%, 92%), but treatment T_8 (400 Kg ha^{-1} NPK) produced the lowest soil pHBC (26%, 36%, 34%, 32%) after treatment T_1 (control). The application of biochar increased soil pHBC, and higher rates of biochar incorporation led to a greater increase in pHBC. The change in soil pHBC due to biochar application is attributed to change in soil CEC induced by biochar (Xu *et al*., 2012; Aitken 1992). Yuan *et al*.(2011a) and Xu *et al*. (2012) reported that there are ample amounts of oxygen-containing functional groups on biochar such as (–COO^{-} and –O^{-}) and such groups contribute considerably to negative surface charge of biochars and are the reason for increasing soil CEC with incorporation of biochars. The oxygen-containing functional groups of biochars can absorb and provide protons through association reactions at low pH and dissociation reactions at high pH and thus buffer the change in soil pH. This is considered as the main mechanism for the increased pHBC of acid soils treated with biochar (Xu *et al*., 2012).

Table 4: Effect of the Treatments on Soil pH Buffering Capacity during Incubation

Treatments	pH week 1	Buffering capacity at week1(%)	pH week 2	Buffering capacity at week2 (%)	pH week 3	Buffering capacity at week3(%)	pH week 4	Buffering capacity at week 4(%)
T_1	3.31	-24	3.55	-18	3.75	-14	3.75	-14
T_2	6.66	52	6.35	44	7.38	68	6.60	50
T_3	7.94	81	8.12	85	8.13	85	7.91	80
T_4	8.61	96	8.64	97	8.20	87	8.42	92
T_5	7.28	66	7.32	67	6.55	49	7.10	62
T_6	7.85	79	7.67	75	7.62	73	7.60	73
T_7	8.14	85	7.94	81	7.84	78	7.85	79
T_8	5.53	26	5.96	36	5.90	34	5.80	34
LSD		2.26		2.29		2.55		1.97
CV%		2.3		2.3		2.6		2.0

CORRELATION MATRIX FOR SOIL PROPERTIES

Correlation matrix for soil properties is show in Table 5. Soil pH correlated positively with all soil properties but significantly with phosphorus, calcium and magnesium. This mirrors the influence of pH on soil properties and especially on nutrient availability. Soil pH affected nutrient availability and this is due to the H^+ ions taking up space on the negative charge along the soil surface displacing nutrients which may be consequently leached beyond plant root zone. Soil pH had a highly significant ($P<0.01$) and positive relationship with phosphorus(r=0.835). This explains the reaction of phosphorus with oxides of iron and aluminum in a phenomenon called P-fixation at low pH,and the increase in availability of Phosphorus as the pH increases to between 6.5 and 7.0. However, beyond pH of 7.5, phosphorus forms complexes with Calcium.

Soil pH significantly correlated with calcium (r=0.897) and magnesium (r=0.832) at 0.01 level and 0.05 level respectively. And correlated positively but non-significantly with exchangeable acidity (r=0.163). This is consistent with the fact that soil pH affects all physical, biological and chemical soil properties (Brady and Weil, 2002).

Phosphorus correlated positively and significantly with organic carbon (r=0.751), organic matter(r=0.747) and magnesium (r=0.759) at 0.05 level and with calcium (r=0.896) at 0.01 level.

Organic carbon had a significant and positive correlation with organic matter(r=1.000) at 0.01 level and potassium (r=0.737) at 0.05 level. While organic matter correlated significantly with potassium (r=0.740) at 0.05 level.

Calcium correlated significantly with magnesium (r=0.938) at 0.01 level while potassium had a negative but non-significant correlation with exchangeable acidity.

Table 5: Correlation Matrix for Soil Properties

Soil properties	1	2	3	4	5	6	7	8	9	10
1). pH	-									
2). Phosphorus	0.835**	-								
3). Nitrogen	0.265	0.163	-							
4). Organic Carbon	0.592	0.751*	0.112	-						
5). Organic Matter	0.589	0.747*	0.109	1.000**	-					
6). Potassium	0.630	0.472	0.049	0.737*	0.740*	-				
7). Calcium	0.897**	0.896**	0.019	0.572	0.567	0.462	-			
8). Magnesium	0.832*	0.759*	0.024	0.561	0.557	0.439	0.938**	-		
9). Sodium	0.099	0.202	0.311	0.603	0.604	0.639	0.052	0.062	-	
10). Exchangeable acidity	0.163	0.477	0.051	0.344	0.339	-0.191	0.490	0.576	0.117	-

* Correlation is significant at the 0.05 level (2-tailed), ** Correlation is significant at the 0.01 level (2-tailed)

CONCLUSION AND RECOMMENDATION

The results obtained from this study proved that biochar is an effective acid neutralizing agent (liming material) in ameliorating the acidity problem of this region; the equivalent of 5tonne of biochar per hectare was found to be sufficient in increasing pH and reducing exchangeable acidity, thereby neutralizing acidity in the ultisol of Umudike and could also buffer the pH capacity of the soil significantly.

Therefore, based on the soil pH response of this study, we recommend the use of 5tonne per hectare biochar as a material to ameliorate soil acidity in the study area.

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