Pyrolyzed agricultural wastes for improving degraded soil, nutrient use efficiency and growth performance of maize

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Abstract

The need for cheap and affordable alternate sources of plant nutrient inputs to boost the nutrient level of degraded arable farmlands has been a major concern for soil scientists. In 2018, a field study was carried out under rain-fed conditions to evaluate the effect of palm waste biochar (PWB), poultry litter biochar (PLB) and inorganic fertilizer on the properties of soil, N and P use efficiency on a sandy Ultisol. The treatments consisted of T_1 (control), T_2 (625 kg ha⁻¹ NPK fertilizer), T_3 (10 t ha⁻¹ PWB + 625 kg ha⁻¹ NPK fertilizer), T_4 (10 t ha⁻¹ PLB + 625 kg ha⁻¹ NPK fertilizer), T_5 (5 t ha⁻¹ PWB + 5 t ha⁻¹ PLB + 625 kg ha⁻¹ NPK fertilizer) and T_6 (10 t ha⁻¹ PWB + 10 t ha⁻¹ PLB + 625 kg ha⁻¹ NPK fertilizer). These treatments were arranged in a randomized complete block design and replicated three times. Data were analysed using Analysis of Variance (ANOVA) and significant effects among treatment means were determined using Fishers Least Significant Difference (F-LSD) at a 5% probability level. Results showed that biochar application significantly ($p = 0.05$) reduced soil bulk density by 9.9%, increased soil organic matter by 28.4%, total exchangeable bases by 34.8% and raised soil pH by 19.2%. The number of leaves, plant height and leaf area of maize were significantly higher in the amended plots than that of the control plots after six weeks of planting. Plots amended with 10 t ha⁻¹ PLB + 625 kg ha⁻¹ NPK fertilizer had the highest grain and fresh cob yield of 3.08 t ha⁻¹ and 7.53 t ha⁻¹, respectively, while the least values were obtained in the control plots (2.18 t ha⁻¹ and 4.03 t ha⁻¹, respectively). The highest values of nitrogen uptake (70.84 kg ha⁻¹), physiological efficiency of (27.47 kg ha⁻¹), phosphorus uptake (78.54 kg ha⁻¹), phosphorus use efficiency (80.14%), agronomic efficiency of N (9.6 kg ha⁻¹), agronomic efficiencies of P (22.02 kg ha⁻¹), partial factor productivity of N (32.85 kg ha⁻¹) and P (75.34 kg ha⁻¹) as well as N physiological efficiency (30.6 kg ha⁻¹) were obtained in plots amended with 10 t/ha PLB + 625 kg ha⁻¹ NPK fertilizer. Therefore, application of 10 t ha⁻¹ PLB + 625 kg ha⁻¹ NPK fertilizer is recommended for improved N and P use efficiencies, N and P uptakes, yield performance of maize and improvement in the soil properties of a degraded acidic soil.

Keywords: Biochar, partial factor productivity, pyrolysis, soil amendment, soil fertility, ultisol

Introduction

In South-eastern Nigeria, there has been a reduction in the food supply over the years due to low soil nutrient levels and high level of soil degradation (Onwudike *et al.*, 2015). Researchers have recommended application of mineral fertilizer to boost food production (Amanullah, *et al.*, 2014; Seran *et al.*, 2010; Stewart *et al.*, 2005). However, due to the negative effects of inorganic fertilizers such as nutrient imbalance, nutrient antagonism, soil acidification (Onwudike, *et al.*, 2015), poor residual effect, use of organic fertilizers has been advocated (Nwonuala, *et al.*, 2013; Onwudike *et al.*, 2015). Sole application of chemical fertilizer generates several deleterious effects on the environment and human health (Aisha *et al.*, 2007). Nutrient elements in chemical fertilizer are easily lost through leaching and evaporation and could cause dangerous

environmental pollution such as water pollution in fields along watersheds (Stewart *et al.*, 2005). Therefore, there is need to search for materials that can counteract the negative effect of mineral fertilizers by improving the nutrient use efficiency (NUE) of crops, while considering the triple bottom line of sustainable agriculture which includes social responsibility, economic prosperity and environmental stewardship especially in South-eastern Nigeria where the soils have been designated as highly weathered, leached and acidic (Onwudike *et al.*, 2015).

Application of pyrolyzed agro-wastes (biochar) made from palm waste and poultry droppings have the potential to reduce the need for mineral fertilizers, as well as improve soil physico-chemical properties (Muhammad *et al.*, 2018). These materials are cheap, available and less bulky than mineral fertilizers and organic manures. Pyrolyzed agro-

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wastes popularly known as biochar is fine-grained charcoal produced through pyrolysis or heating highly carbonated organic material in the absence or low supply of oxygen. It does not decompose easily and its effect last for hundreds of years. Biochar application on soils has significant effect on physical and chemical properties of soil (Major *et al.*, 2010, Muhammad *et al.*, 2018). Onwudike *et al.* (2015) observed that burnt carbonaceous agricultural wastes increased plant height, economic yield and leaf area of maize in relation to the un-burnt agricultural wastes.

Nutrient Use Efficiency (NUE) is a measure of the ability plant utilize available nutrients in the soil and it is the yield (biomass) per unit fertilizer input (Malcom, 2012). Nitrogen or phosphorus use efficiency estimates the quantity of total biomass that is being produced per unit of nitrogen or phosphorus absorbed by plants. Nutrient Use Efficiency is an important concept in the crop production evaluation system. According to Paul *et al.* (2014), the intention of nutrient use efficiency is to boost the overall performance of cropping systems by providing economically optimum nourishment to crop and to minimizing nutrient losses from the field. Pyrolyzed materials contain essential nutrients with high pH level that reduces the acidity of acidic soils thereby improving nutrient use efficiency. Limited literature is available regarding the effects of pyrolyzed agro-wastes on nutrient use efficiency in degraded acidic Ultisol.

Materials and Methods

The study was performed during the planting season of 2018 at the University Research Farm, Federal University of Technology Owerri, South-eastern Nigeria. The area lies between the latitude 5°22'43"N and longitude 6°59'37"E. The area has mean annual rainfall and temperature of 2000 - 2500 mm and 25-30°C, respectively. The study area is a humid tropical region with soil type classified as typic-haplustult (FDALR., 1985).

The study area was 180 m². This area was mapped out, and manual clearing was done using cutlass and spade, making sure all stumps were removed. Six experimental plots were mapped out and each plot measured 2 m x 2 m. Each experimental plot was replicated three times given a total of eighteen experimental plots. There was 1 m space between one plot and another and 1 m gap between the blocks. The experiment was arranged using randomized complete block design (RCBD). The experimental plots were tilled and properly labelled on the basis of the treatment. To minimize the pest attack and to prevent human intrusion, a fence of Bamboo sticks and ropes was built around the experimental plots.

Maize (*Zea mays* L.) cultivar (Wacot) was bought from Imo State Agricultural Development Programme. One bag of poultry litter (manure) and four bags of oil palm bunch waste were obtained from Imo State Agricultural Development Programme. The materials were pyrolyzed at 300 °C using a well-constructed biochar drum under controlled condition. Treatments comprised of: T1 as Control, T2 = 0 t ha⁻¹ + 625 kg ha⁻¹ NPK, T3 = 10 t ha⁻¹ PWB + 625 kg ha⁻¹ NPK, T4 = 10 t ha⁻¹ PLB + 625 kg ha⁻¹ NPK, T5 = 5 t ha⁻¹ PWB + 5 t ha⁻¹ PLB + 625 kg ha⁻¹ NPK, T6=10 t ha⁻¹ PWB+ 10 t ha⁻¹ PLB + 625 kg ha⁻¹ NPK.

Treatments were applied using broadcasting method on the tilled plots after weighing 4 kg(4m²)⁻¹ of the PWB and PLB, 4 kg(4m²)⁻¹ of PWB + PLB, and 2 kg(4m²)⁻¹ of PWB + PLB biochar. These quantities gave 10 t ha⁻¹ PWB and PLB, 10 t ha⁻¹ of PWB+PLB and 5 t ha⁻¹ PWB+5 t ha⁻¹ PLB per experimental plot, and 0.25 kg(4m²)⁻¹ of NPK 15:15:15 fertilizer. Planting of test crop was done 7 days after treatment application to allow incubation process. Three maize seeds were planted per hole at a planting space of 75 cm x 25 cm between and within rows at a depth of 4 cm on the 10th of April 2018. Germination started 5 - 6 days after planting (DAP) and the supply of empty stands was done immediately. One week of planting, germinated seeds were thinned down to one plant per stand making 53,333 plants/ha and 21 plants per plot. 625 kg ha⁻¹ of NPK fertilizer was applied manually using ring application method at 8-10 cm radius to all plots excluding control plot. Weeds were controlled manually using hoe and by hand picking to keep the plots weed-free and this was done regularly as the need arose while 10% Saproca-neem (*Azadiracta indica*) solution was sprayed on the leaves twice per week during the period of the research for pest control. The crop was harvested on the 6th of July 2018 (12WAP).

Soil samples were collected from each plot at 0-30 cm soil depth using a soil auger attached with a core sampler before and after harvest for soil analysis. The samples were air-dried at room temperature; sieved using 2 mm mesh size for laboratory analysis. Particle size distribution (PSD) was determined by the Bouyoucos Hydrometer method (Gee and Or, 2002) using sodium hexametaphosphate (calgon) as a dispersant. Bulk density was calculated using the formula by Post and Kwon (2000).

$$\text{Bulk Density } (\rho_B) = \frac{100}{\left(\frac{O.M}{0.244}\right) + \left(\frac{100-O.M}{1.64}\right)} \dots\dots\dots 1$$

Where, O.M= % Organic matter.

Total porosity was computed as followed

$$TP = 1 - \frac{\rho_B}{\rho_d} \times 100 \dots\dots\dots 2$$

Where, particle density (ρ_d) = 2.65 g cm^{-3}

Soil pH was determined in the distilled water at 1:2.5 soil suspension ratio using a pH meter (Hendershot *et al.*, 1993). Total organic carbon was determined by Walkley-Black wet oxidation method (Nelson and Sommers, 1982). Organic matter was calculated by multiplying total organic carbon (TOC) by a factor of 1.724 (Nelson and Sommers, 1982). Total nitrogen was determined using the modified Kjeldahl method (Bremner and Muvaney, 1982). Available phosphorus was determined according to Olsen and Sommers (1982) method. The exchangeable cations (Ca^{++} , Mg^{++} , K^+ , Na^+) were extracted with 1N neutral ammonium acetate at pH 7.0 (McLean, 1982). Exchangeable calcium and magnesium were determined with EDTA complexometric titration while exchangeable potassium and sodium were read using flame photometer. Exchangeable acidity (H^+ and Al^{3+}) was determined by extraction using 1 N KCl (Thomas, 1982) and read titrating with 0.5 N NaOH with phenolphthalein indicator. Summation of exchangeable Mg, K, Ca, Na and exchangeable Hydrogen and Aluminum is used to calculate ECEC (effective cation exchange capacity). Percentage Base Saturation (% BS) was calculated by dividing total exchangeable cations with ECEC and the quotient multiplied by 100. The carbon and nitrogen ratio were calculated as used by Brady and Weil (1999). The value of the silt fractions was divided by clay fractions gave silt/ clay ratio. Clay activity was computed by dividing ECEC with percentage clay particles (Brady and Weil (1999).

Four plants were selected randomly and tagged in each plot and used for all the agronomic measurements such as plant height, number of leaves and leaf area. Fresh cob yield was determined using a weighing balance. The number of leaves was determined by counting the number of leaves on the four tagged plants and dividing the total by 4. Leaf areas of the four tagged plants were measured using meter rule. Length and breadth of the leaves were measured, and values were multiplied by 0.6654 according to Nwafor *et al.* (2010). Measurement of plant height was done with meter rule (Nwafor *et al.*, 2010). Grain yield was determined using a weighing balance after drying the grains up to 13% moisture content to get dry mass weight. Straw dry matter was determined using a weighing balance after oven drying to a constant weight. Harvest Index (HI) was calculated according to Agnieszka *et al.* (2013) as

$$\text{HI} = \frac{\text{Grain yield (kg/ha)}}{\text{Total biomass produced by the plants (kg/ha)}} \dots\dots\dots 3$$

Nutrient uptake (kg ha^{-1}) was determined by using the formula according to (Sharma *et al.*, 2012)

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{plant dry weight(kg/ha)}}{\text{nutrient concentration (\%)}} \times 100 \dots\dots 4$$

Nutrient use efficiency was calculated according to Paul *et al.* (2014) as

$$\text{NUE} = \text{Percent Fertilizer Recovery} = \frac{\text{NF}-\text{NC}}{\text{R}} \dots\dots\dots 5$$

Where, NF = total crop nutrient uptake from fertilized plots (grain) (kg ha^{-1}), NC= total crop nutrient uptake from unfertilized plots (Grain) (kg ha^{-1}), R = amount of fertilizer (nutrient) applied (kg ha^{-1}).

$$\text{NUE (\%)} = \text{NUE} \times 100 \dots\dots\dots 6$$

Partial Factor Productivity (PFP) was computed using the relationship:

$$\text{PFP} = Y/F \dots\dots\dots 7$$

Where, Y = crop yield with applied nutrients (kg ha^{-1}), F = amount of fertilizer (nutrient) applied (kg ha^{-1}). Agronomic efficiency (AE) was calculated by

$$\text{AE} = (Y - Y_o)/F \dots\dots\dots 8$$

Where, Y_o = crop yield without applied treatments (kg ha^{-1}).

Physiological efficiency (PE) was calculated by

$$\text{PE} = \frac{Y-Y_o}{U-U_o} \dots\dots\dots 9$$

Where, U = Nutrient uptake in plants receiving fertilizer (kg ha^{-1}), U_o = Nutrient uptake in plants receiving no fertilizer (kg ha^{-1}).

Before applying the biochar in the soil, some samples were ground and sieved to less than 0.5 mm in diameter for the determination of nutrient composition. Total nitrogen was determined using the modified Kjeldahl method while calcium, magnesium, sodium, potassium was determined by subjecting the sample to wet digestion using 25 - 5 - 5 mL of HNO_3 - H_2SO_4 - HClO_4 and the nutrients determined by using the filtrate.

After harvesting, the maize plants (grain + straw) were collected according to the plots. The grains were sun-dried to about 13% moisture content and the yield per plot and per hectare was also calculated. The samples were washed with distilled water and oven-dried at 65°C for 72 hours. The samples were ground with pestle and mortar to pass a 0.25 mm pore size sieve and ashed using porcelain crucible. Five mL of 0.5 M HCl was added in the ash. 100 mL of the filtrate was used to determine the nutrient concentration and uptake in maize (Brady and Weil (1999). methods. Significant differences between the

means were ranked with Fisher's Least Significant Difference (F-LSD) at 5% probability the level using analysis of variance.

Physico-chemical properties of soil before planting

The selected pre-planting soil properties are presented in Table 1. The soil was texturally loamy sand with 849.6 g/kg sand, 75 g kg⁻¹ silt and 75.4 g kg⁻¹ clay. These results were similar with the observations of Onwudike *et al.* (2015) who had related report for soils in Owerri, Imo State, South-eastern Nigeria. The textural class may negatively affect plant growth by exhibiting low water and nutrient retention capacities. The soil was low in available phosphorus, low in pH (strongly acidic), total N, and exchangeable bases. The bulk density was 1.54 g cm⁻³, which was less than the critical limit for root restriction (1.75 - 1.85 g cm⁻³) as described by Soil Survey Staff (2003). The organic matter content of the soil was low. The organic matter content was deficient when compared to the critical level of 20–30 g kg⁻¹ reported by Enwezor *et al.* (1989). Therefore, since the critical levels of this soil was lower than the critical limits recommended by FAO (2006), the fertility level of these soil needs good nutrient management practices such as biochar application.

Table 1: Soil properties before planting (0-30 cm depth)

Properties	Value
Sand (%)	84.96
Silt (%)	7.50
Clay (%)	7.54
Textural class	Loamy sand
Total Porosity (%)	41.77
Bulk Density (g cm ⁻³)	1.54
Clay activity	0.05
Silt/Clay ratio	0.24
Total Nitrogen (g kg ⁻¹)	0.56
Organic Carbon (g kg ⁻¹)	6.36
C/N ratio	11.36
Organic Matter (g kg ⁻¹)	10.96
Available Phosphorus(mg kg ⁻¹)	5.21
Exchangeable Acidity (H ⁺ +Al ³⁺) Cmol kg ⁻¹	0.91
Exchangeable calcium (Cmol kg ⁻¹)	1.4
Exchangeable Magnesium (Cmol kg ⁻¹)	1.01
Exchangeable Sodium (Cmol kg ⁻¹)	0.04
Exchangeable Potassium (Cmol kg ⁻¹)	0.12
ECEC (Cmol kg ⁻¹)	3.48
Base Saturation (%)	73.85

Chemical properties of the pyrolyzed Agro-wastes

Proximate analysis of pyrolyzed agro-wastes is presented in Table 2. High pH in biochar materials indicated that they could be effective as alkaline materials which when added to the soil can increase the soil pH of the study site. Thus, the biochars (PLB and PWB) with their high pH values could be effective as liming materials. Soil organic carbon (97.53 g kg⁻¹) and total nitrogen (22.30 g kg⁻¹) of PLB were higher than that of PWB (46.55 g kg⁻¹ and 15.17 g kg⁻¹), respectively. There was higher P content in the pyrolyzed PWB (0.51 g kg⁻¹) and PLB (0.41 g kg⁻¹) and therefore, they could serve as good soil amendments.

Results and Discussion

Soils properties:

The effects of the pyrolyzed agro-wastes on physical parameters of soil are presented in Table 3. No significant change was observed in soil texture. It supports previous work performed by Fitzpatrick (1986) who suggested that soil texture is a function of an inherent characteristic of soil which can be influenced by parent material and climatic conditions over time. The pyrolyzed agro-wastes indicated significant ($p < 0.05$) effect on soil bulk density. Control plots and plots treated with 625 kg ha⁻¹ NPK (T2) recorded bulk densities of 1.51 g cm⁻³ and 1.49 g cm⁻³, respectively, which are higher than the bulk densities of plots amended with biochar. Plots amended with 10 t ha⁻¹ PWB+625 kg ha⁻¹ NPK (T3) and 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK (T4) recorded bulk densities of 1.38 and 1.36 g cm⁻³, respectively, and these values were lower than the bulk density of soils which were not amended with biochar. This was in line with the reports of Ekebafe *et al.* (2013), Lehmann *et al.* (2011) and Major *et al.* (2010) who found a significant decrease in bulk density in biochar-amended soils. The values of total porosity were significantly ($p < 0.05$) different between plots amended with biochar and plots not amended with biochar (Table 3). Results showed a similar trend with bulk density confirming the inverse correlation between the density of the soil and total porosity. The trend in the decrease in soil bulk density was T4 > T3 > T6 = T5 > T2 > control. This was in concord with the observations of Ekebafe *et al.* (2013) and Major *et al.* (2010) who observed an increase in soil macro and mesopore volume, increased organic matter content and water transmission rate in soil amended with biochars.

Table 4 showed the effect of the pyrolyzed agro-wastes on soil chemical parameters. Amended plots significantly ($p < 0.05$) raised soil pH in relation to plots free from biochar.

Table 2: Nutrient composition of biochar material

Chemical Properties	PWB	PLB
Organic carbon (g kg ⁻¹)	46.55	97.53
Total nitrogen (g kg ⁻¹)	15.17	22.3
C/N ratio	3.07	4.37
Available phosphorus (g kg ⁻¹)	0.51	0.41
pH (H ₂ O)	10.48	9.67
Exchangeable calcium (%)	3.763	7.7
Exchangeable magnesium (%)	0.367	1.859
Exchangeable sodium (%)	0.207	0.316
Exchangeable potassium (%)	0.157	0.183

PWB = palm waste biochar, PLB = poultry litter biochar

Table 3: Effect of pyrolyzed agro-wastes on soil physical properties

Treatment	Sand (g kg ⁻¹)	Silt (g kg ⁻¹)	Clay (g kg ⁻¹)	TC	BD (gcm ⁻³)	TP (%)	SCR
T ₁	840.2	77.8	82.0	LS	1.51	43.20	0.95
T ₂	838.7	74.2	87.1	LS	1.49	43.77	0.85
T ₃	830.6	75.4	94.0	LS	1.38	47.92	0.80
T ₄	826.7	74.0	99.3	LS	1.36	48.68	0.75
T ₅	842.0	66.7	91.3	LS	1.42	46.42	0.73
T ₆	834.7	73.3	92.0	LS	1.42	46.42	0.80
F-LSD(<i>p</i> <0.05)	Ns	Ns	Ns		0.10	1.45	Ns

Ns = not significant, TC = Textural Class, BD = Bulk density, TP = Total porosity, SCR = Silt-Clay ratio, LS = Loamy sand, T₁=Control, T₂= 0 t ha⁻¹ +625 kg ha⁻¹ NPK, T₃= 10 t ha⁻¹ PWB+625 kg ha⁻¹ NPK, T₄= 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK, T₅= 5 t ha⁻¹ PWB + 5 t ha⁻¹ PLB +625 kg ha⁻¹ NPK, T₆=10 t ha⁻¹ PWB+ 10 t ha⁻¹ PLB +625 kg ha⁻¹ NPK; where: PWB = palm waste biochar, PLB = poultry litter biochar. LS = loamy sand.

Table 4: Effect of pyrolyzed agro-wastes on soil chemical properties

Treatment	pH (H ₂ O)	OC	OM	TN	AVP	Ca	Mg	Na	K	TEA	TEB	ECEC	BS
			g kg ⁻¹		mg kg ⁻¹			cmol kg ⁻¹					%
T ₁	5.25	7.20	12.41	0.62	5.30	1.33	0.87	0.07	0.17	1.07	2.44	3.51	69.52
T ₂	5.47	7.40	12.76	0.63	6.57	1.53	1.00	0.08	0.19	0.93	2.80	3.73	75.07
T ₃	6.07	9.00	15.52	0.70	6.58	1.80	1.13	0.11	0.21	0.77	3.25	4.02	80.85
T ₄	6.26	9.20	15.86	0.76	7.02	1.80	1.15	0.10	0.24	0.83	3.29	4.12	79.85
T ₅	6.10	8.10	13.96	0.80	6.59	1.68	1.10	0.10	0.19	0.77	3.07	3.84	79.95
T ₆	6.21	8.80	15.17	0.83	7.11	1.60	1.13	0.12	0.22	0.76	3.07	3.83	80.16
F-LSD)	0.51	1.37	1.10	0.08	0.39	0.21	0.19	0.02	0.01	0.16	0.42	0.29	1.27

OC = Organic carbon, OM = Organic matter, TN = Total nitrogen, AVP = Available phosphorus, TEA = Total exchangeable acidity, TEB = Total exchangeable bases, ECEC = Effective cation exchange capacity, BS = Base saturation. T₁=Control, T₂= 0 t ha⁻¹ +625 kg ha⁻¹ NPK, T₃= 10 t ha⁻¹ PWB + 625 kg ha⁻¹ NPK, T₄= 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK, T₅= 5 t ha⁻¹ PWB + 5 t ha⁻¹ PLB +625 kg ha⁻¹ NPK, T₆= 10 t ha⁻¹ PWB + 10 t ha⁻¹ PLB + 625 kg ha⁻¹ NPK; Where: PWB = palm waste biochar, PLB = poultry litter biochar.

Comparing the pyrolyzed agro-wastes, the plots treated with 10 t ha⁻¹ PWB+625 kg ha⁻¹ NPK had soil pH of 6.07 while plots treated with 10 t ha⁻¹ PLB + 625 kg ha⁻¹ NPK had a soil pH value of 6.26. The plots treated with 10 t ha⁻¹ PWB+ 10 t ha⁻¹ PLB +625 kg ha⁻¹ NPK had a pH value of 6.21 while Control recorded the least soil pH of 5.25. The order of improvement was T₄>T₆>T₅>T₃>T₂> control. This was in line with the observations of Arocena and Opio (2003) and Khanna *et al.* (1994) who reported high soil pH when soils

were treated with pyrolyzed organic materials. Ekebafé *et al.* (2013) reported that pyrolyzed agricultural products at 10 t ha⁻¹ made from palm fronds increased soil pH from 5.9 to 6.5. Lehmann *et al.* (2002) attributed the increase in soil pH to ash accretion as ash residues are generally dominated by carbonates of alkali and alkaline earth metals, sesquioxides, phosphates and small amounts of organic and inorganic nitrogen. High pH on soils amended with pyrolyzed agro-wastes could be traced to high pH of the palm waste and

poultry litter biochar (Table 2). Soil carbon content was significantly ($p<0.05$) increased by the application of biochar. Plots treated with 10 t ha⁻¹ PWB+ NPK gave the highest organic carbon content. Plot without biochar recorded the lowest soil organic carbon of 7.20 g kg⁻¹ while plots treated with 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK, (T4) recorded the highest value of 9.20 g kg⁻¹. This was in line with the observations of Abebe *et al.* (2012), who reported a significant increase (>0.71-unit increase compared to control) in soil organic carbon content when biochar from maize stalk was applied to soils. There was significant increase in the total nitrogen content of soil in the biochar-amended plots (Table 4). Plots treated with 5 t ha⁻¹ PWB + 5 t ha⁻¹ PLB + 625 kg ha⁻¹ NPK (T6) recorded nitrogen content of 0.83 g kg⁻¹, followed by plots treated with 5 t ha⁻¹ PWB+ 5 t ha⁻¹ PLB +625 kg ha⁻¹ NPK (T5) with 0.80 g kg⁻¹ total N. The sequence of performance was T6>T5>T4>T3>T2>control. Plots treated with 625 kg ha⁻¹ NPK (T2) recorded available-P value of 6.57 mg kg⁻¹ while plots treated with 5 t ha⁻¹ PWB+ 5 t ha⁻¹ PLB + 625 kg ha⁻¹ NPK (T5) recorded available P of 6.59 mg kg⁻¹. Control plots recorded the least available P of 5.30 mg g⁻¹ while plots treated with 10 t ha⁻¹ PWB+ 10 t ha⁻¹ PLB +625 kg ha⁻¹ NPK (T6) recorded the highest value of 7.11 mg kg⁻¹ and plots treated with 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK (T4) recorded available P of 7.02 mg kg⁻¹. This was in concord with the findings of (Abebe *et al.* 2012 and Chan *et al.* 2008) who reported an increase in soil available-P after the application of biochar over time. The exchangeable calcium, magnesium, potassium and sodium of biochar-amended soils were higher when compared to the non-amended plots. Moreover, these values ranged from very low to moderate when compared to the standard critical values for exchangeable bases by Adaikwu and Ali (2013). Biochar application significantly ($p<0.05$) increased the percentage base saturation relative to un-amended plots. This was in line with the observations of Chan *et al.* (2008), who reported increase in soil CEC and percentage base saturation after the application of biochars. Plots treated with 10 t ha⁻¹ PWB+625 kg ha⁻¹ NPK (T3) recorded the highest value of base saturation (80.85%) while plots treated with 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK (T4) recorded base saturation of 79.85%. Control plots recorded the least value of 69.52% followed by plots treated with sole mineral fertilizer (T2). An increase in percentage base saturation could be attributed to the high pH values of the biochar materials (Table 2). It has been observed by critical analysis that biochars possess high surface area and is highly porous, a variable charge organic material that has the potential to increase CEC, surface

sorption capacity and percentage base saturation when added to the soil (Chan *et al.*, 2008).

Effect of pyrolyzed agro-wastes on the yield of maize

Table 5 showed the results of pyrolyzed agro-wastes on the number of maize leaves. The treatments significantly ($p<0.05$) influenced the number of maize leaves in relation to the control in the sixth and eighth weeks after planting. Plots treated with only inorganic fertilizer (T2) showed higher number of leaves at the early stage (4WAP). The rate of release of nutrients is much higher in the inorganic fertilizers since they provided major elements at the early stage of plant growth and development. Thus, plants exhibited accelerated growth rate than biochar-combined treated plots. At 6 WAP,

Table 5: Effect of palm waste biochar and poultry litter biochar on the number of maize leaves

Treatment	4WAP	6WAP	8WAP
T1	6.42	8.50	9.33
T2	7.17	10.92	10.83
T3	6.33	10.75	10.58
T4	6.75	11.42	11.25
T5	6.67	10.75	9.83
T6	6.58	11.42	10.92
F-LSD ($p<0.05$)	NS	1.31	1.15

WAP = weeks after planting, Ns = not significant, T1=Control, T2= 0 t ha⁻¹+625 kg ha⁻¹ NPK, T3= 10 t ha⁻¹ PWB+625 kg ha⁻¹ NPK, T4= 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK, T5= 5 t ha⁻¹ PWB + 5 t ha⁻¹ PLB +625 kg ha⁻¹ NPK, T6=10 t ha⁻¹ PWB+ 10 t ha⁻¹ PLB +625 kg ha⁻¹ NPK; Where: PWB = palm waste biochar, PLB=poultry litter biochar

Table 6: Effect of palm waste biochar and poultry litter biochar on the height of maize (cm)

Treatment	4WAP	6WAP	8WAP
T1	32.7	60.0	136.9
T2	34.4	79.0	171.6
T3	31.4	84.6	191.5
T4	36.7	94.8	188.8
T5	32.0	91.5	176.3
T6	37.9	87.4	180.7
F-LSD ($p<0.05$)	NS	14.63	33.12

WAP = weeks after planting, Ns = not significant, T1 = Control, T2= 0 t ha⁻¹ + 625 kg ha⁻¹ NPK, T3 = 10 t ha⁻¹ PWB + 625 kg ha⁻¹ NPK, T4 = 10 t ha⁻¹ PLB + 625 kg ha⁻¹ NPK, T5= 5 t ha⁻¹ PWB+ 5 t ha⁻¹ PLB + 625 kg ha⁻¹ NPK, T6 = 10 t ha⁻¹ PWB+ 10 t ha⁻¹ PLB + 625 kg ha⁻¹ NPK.

plots treated with 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK (T4) and 10 t ha⁻¹ PWB+ 10 t ha⁻¹ PLB +625 kg ha⁻¹ NPK (T6) gave the highest number of leaves. At 8WAP, there was significant difference ($p<0.05$) between the control and the amended plots. Plots amended with 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK (T4) gave the highest number of maize leaves (11.25). Moreover, the high number of maize leaves were observed in plots treated with PLB+625 kg ha⁻¹ NPK (T4) due to the high levels of nitrogen and phosphorus in the poultry litter biochar (Table 2). Similar results were reported by Sarah *et al.* (2013) which showed that pyrolyzed agro-wastes have the capacity to increase the number of plant leaves by providing essential nutrients required.

The amendments increased the height of maize from 6 WAP as compared to control plots (Table 6). At 8 WAP, plots treated with 10 t ha⁻¹ PWB+625 kg ha⁻¹ NPK (T3) recorded a higher plant height (191.5 cm). Plots treated with 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK (T4) recorded maize height of 188.75 cm while the lowest value was recorded from control soil (136.92 cm).

There was no significant difference in the maize leaf area at 4 WAP (Table 7). Higher value of leaf area was obtained in plots treated with 10 t ha⁻¹ PLB + 625 kg ha⁻¹ NPK (T4)

relative to the control. Plots treated with 10 t ha⁻¹ PWB+625 kg ha⁻¹ NPK (T3) gave the highest leaf area of 480.97 cm² followed by plots treated with 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK (T4) which recorded the value of 477.3 cm². The sequence of performance was T3>T4>T6>T2>T5>T1. Thus, there was a positive impact of biochar on increasing maize leaf area when compared to T2 where only mineral fertilizer was applied. This is in accordance with the observations of Awodun *et al.* (2007) and Odeyemi *et al.* (2013) who reported a significant increase in the growth performance of crops when agro-waste was applied combined with NPK fertilizers. Thus, this was due to the high organic carbon contained in the pyrolyzed agro-wastes.

There significant ($p<0.05$) increase in the straw dry matter yield and fresh cob yield while grain yield and harvest index showed no significant difference (Table 8). Plots amended with 10 t ha⁻¹ PWB+625 kg ha⁻¹ NPK (T3) recorded higher dry matter yield of 10325 kg ha⁻¹. Plots treated with combinations of the pyrolyzed agro-wastes had less straw dry matter as against the plots amended with single pyrolyzed waste. The percentage increase in the straw dry matter yield on plots treated with biochars (22.9%) over the plots treated with only mineral fertilizer (14.6%) showed the positive impact of the pyrolyzed wastes in increasing the growth and

Table 7: Effect of palm waste biochar and poultry litter biochar on the leaf area of maize (cm²)

Treatment	4WAP	6WAP	8WAP
T1	65.87	201.61	254.93
T2	100.43	260.73	458.79
T3	69.97	352.81	480.97
T4	95.53	365.3	477.25
T5	97.58	334.86	447.76
T6	97.44	343.74	464.72
F-LSD ($p<0.05$)	Ns	71.38	48.79

WAP = weeks after planting, Ns = not significant, T1 = Control, T2 = 0 t ha⁻¹ + 625 kg ha⁻¹ NPK, T3 = 10 t ha⁻¹ PWB+625 kg ha⁻¹ NPK, T4 = 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK, T5 = 5 t ha⁻¹ PWB+ 5 t ha⁻¹ PLB +625 kg ha⁻¹ NPK, T6=10 t ha⁻¹ PWB + 10 t ha⁻¹ PLB + 625 kg ha⁻¹ NPK

Table 8: Effect of palm waste biochar and poultry litter biochar on the yield attributes of maize

Treatment	Straw dry matter yield (kg ha ⁻¹)	Grain yield (t ha ⁻¹)	% Grain yield increase over control	Fresh cob yield (t ha ⁻¹)	% HI
T1	4725	2.18	0	4.03	31.42
T2	8400	2.58	18.35	5.60	23.38
T3	10325	2.65	21.56	6.83	20.48
T4	9625	3.08	41.28	7.53	24.76
T5	9100	2.46	12.84	5.43	22.01
T6	8575	2.79	27.98	5.95	24.57
F-LSD($p<0.05$)	2939.42	Ns	-	1.54	Ns

yield of maize. This was in line with the observations of Major *et al.* (2010) who opined that biochar has the capacity to enhance maize development and growth.

Plots amended with 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK (T4) recorded the highest fresh cob weight of 7.53 t ha⁻¹ followed by plots treated with 10 t ha⁻¹ PWB+625 kg ha⁻¹ NPK (T3). The sequence of performance was T4>T3>T6>T2>T5> control. The control plots gave the least grain yield (2.18 t ha⁻¹) of maize. Also, plots treated with 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK (T4) gave the highest percentage grain yield (41.28%) over control. From these results, it can be deduced that higher grain yields were obtained from the plots treated with pyrolyzed

photosynthesis, grain formation as well as fruit development. Result showed that biochar can be combined with mineral fertilizers to improve crop performance and subsequently enhance yield especially in acidic, low nutrient soils of the tropics. The highest percentage harvest index was recorded in the control (31.42%), followed by plots treated with 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK (24.76%). The lowest percentage harvest index was recorded in plots treated with 10 t ha⁻¹ PWB+625 kg ha⁻¹ NPK (20.48%). The higher % HI recorded in the control plots showed that the grain yield occupied a larger proportion of the plant total biomass, though with a lower yield when compared to plots treated with biochar.

Table 9: Effect of palm waste biochar and poultry litter biochar on nitrogen uptake and use efficiency of maize

Treatment	Amt. of N applied (kg ha ⁻¹)	N-Straw (%)	N-Grain (%)	N-Uptake (kg ha ⁻¹)	N-NUE (%)	AE (kg kg ⁻¹)	PFP (kg kg ⁻¹)	PE (kg kg ⁻¹)
T1	0	1.56	1.9	41.42	-	-	-	-
T2	93.75	1.9	2.4	61.92	21.87	4.27	27.52	19.51
T3	93.75	1.84	2.45	64.93	25.08	5.01	28.27	20
T4	93.75	2.1	2.3	70.84	31.38	9.60	32.85	30.6
T5	93.75	1.91	2.5	61.5	21.42	2.99	26.24	13.94
T6	93.75	2.31	2.65	73.94	34.69	6.51	29.76	18.76
%CV		13.05	10.83	18.29	54.36	68.56	49.88	58.45

NNUE=nitrogen use efficiency, AE= agronomic efficiency, PFP=partial factor productivity, PE= physiological efficiency. CV=0-15%, Low variability; CV=15-35%, Medium variability; CV= >35%, High variability. T1=Control, T2= 0 t ha⁻¹+625 kg ha⁻¹ NPK, T3= 10 t ha⁻¹ PWB+625 kg ha⁻¹ NPK, T4= 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK, T5= 5 t ha⁻¹ PWB+ 5 t ha⁻¹ PLB +625 kg ha⁻¹ NPK, T6 =10 t ha⁻¹ PWB+ 10 t ha⁻¹ PLB + 625 kg ha⁻¹ NPK; PWB = palm waste biochar, PLB = poultry litter biochar.

Table 10: Effect of palm waste biochar and poultry litter biochar on phosphorus uptake and use efficiency of maize

Treatment	Amt. of N applied (kg ha ⁻¹)	P-Straw (%)	P-Grain (%)	P-Uptake (kg ha ⁻¹)	P-NUE (%)	AE (kg kg ⁻¹)	PFP (kg kg ⁻¹)	PE (kg kg ⁻¹)
T1	0	0.82	2.1	45.78	-	-	-	-
T2	40.88	1.75	2.2	56.76	26.86	9.78	63.11	36.43
T3	40.88	1.8	2.2	58.3	30.63	11.5	64.82	37.54
T4	40.88	1.92	2.55	78.54	80.14	22.02	75.34	27.47
T5	40.88	2.0	2.4	59.04	32.44	6.85	60.18	21.12
T6	40.88	2.15	2.7	75.33	72.28	14.92	68.25	20.64
%CV		27.18	9.89	19.84	74.85	68.59	49.89	57.61

P-NUE= phosphorus use efficiency, AE= agronomic efficiency, PFP=partial factor productivity, PE= physiological efficiency. CV=0-15%, Low; CV=15-35%, Medium; CV= >35%, High. T1=Control, T2= 0 t ha⁻¹+625 kg ha⁻¹ NPK, T3= 10 t ha⁻¹ PWB+625 kg ha⁻¹ NPK, T4= 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK, T5= 5 t ha⁻¹ PWB+ 5 t ha⁻¹ PLB +625 kg ha⁻¹ NPK, T6 =10 t ha⁻¹ PWB+ 10 t ha⁻¹ PLB + 625 kg ha⁻¹ NPK; PWB = palm waste biochar, PLB = poultry litter biochar.

agro-wastes (biochars). The order of increase in grain yield was T4>T6>T3>T2>T5> control. Therefore, the application of pyrolyzed agro-wastes had a positive effect on the yield of maize. The higher yield in plots treated with 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK (T4) could be attributed to nutrient contained in PLB especially N, P and K which are important in

Effect of pyrolyzed agro-wastes on phosphorus and nitrogen use efficiency

Effects of biochars on N and P use efficiency are presented in Tables 9 and 10, respectively. Plots treated with 10 t ha⁻¹ PWB+ 10 t ha⁻¹ PLB +625 kg ha⁻¹ NPK recorded the highest value of N-uptake (73.94 kg ha⁻¹) and this was

followed by plots treated with 10 t/ha PLB+625 kg ha⁻¹ NPK (70.84 kg ha⁻¹). According to Pietikainen *et al.* (2000), biochar inhabits soil microorganisms that play an important role in N, P or S dynamics. Plots treated with 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK recorded the highest P-uptake of 78.54 kg ha⁻¹ followed by plots treated with 10 t ha⁻¹ PWB+ 10 t ha⁻¹ PLB +625 kg ha⁻¹ NPK (75.33 kg ha⁻¹). Control plots showed lowest P-uptake (45.78 kg ha⁻¹) followed by the plots treated with mineral fertilizer (56.76 kg ha⁻¹). Plots treated with 10 t ha⁻¹ PWB+ 10 t ha⁻¹ PLB +625 kg ha⁻¹ NPK recorded the highest N-NUE of 34.69% followed by the plots treated with 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK (31.38%).

Like N-NUE, phosphorus use efficiency (P-NUE) showed high variability between the treatment means (74.85%). Plots treated with 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK (T4) recorded the highest P-NUE of 80.14% followed by plots treated with 10 t ha⁻¹ PWB+ 10 t ha⁻¹ PLB +625 kg ha⁻¹ NPK (T6) (72.28%). Plots treated with NPK fertilizers recorded least P-NUE (26.86%). This was in concord with the observations of Abebe *et al.* (2012), who reported similar effects of biochar on N-uptake and P-uptake in lettuce. The observed increase in N-uptake, P-uptake, N-NUE and P-NUE with biochar applications indicated the potential of biochar in improving nutrient use efficiencies especially in soils of the tropics where fertility depends highly on N, P and K availability.

Results of nitrogen Agronomic Efficiency (AE), Partial Factor Productivity (PFP) and Physiological Efficiency (PE) are presented in Table 9. Plots amended with 10 t ha⁻¹ PLB +625 kg ha⁻¹ NPK (T4) recorded the highest N AE, PFP and PE of 9.6 kg ha⁻¹, 32.85 kg ha⁻¹ and 30.6 kg ha⁻¹, respectively. The lowest values of N AE, PFP and PE were recorded on plots treated with 5 t ha⁻¹ PWB+ 5 t ha⁻¹ PLB +625 kg ha⁻¹ NPK. Results on phosphorus PE, AE and PFP are presented in Table 10. Plots amended with 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK (T4) recorded the highest P AE and PFP of 22.02 and 75.34 kg ha⁻¹, respectively, while plots treated with 10 t ha⁻¹ PWB+625 kg ha⁻¹ NPK (T3) recorded the highest PE of 37.54 kg ha⁻¹. According to Baligar *et al.* (2001), Partial Factor Productivity (PFP), Physiological Efficiency (PE) and Agronomic Efficiency (AE), are the main indicators of crop response to amendment practice. St. Kalinova and Hristoskov (2014) have reported values for N-PFP to be 37-53 kg ha⁻¹ and N-AE to be 2-10 kg ha⁻¹ on soils treated with mineral fertilizers in maize fields.

Conclusions

The work has shown that pyrolyzed agro-wastes have proved effective in the improvement of soil properties, growth and yield of maize. There was significant effect on

fresh cob yield, N and P uptakes as well as nutrient use efficiency with the application of pyrolyzed palm waste biochar and poultry litter biochar. Plots amended with 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK gave the highest maize grain and maize fresh cob yield when compared to other treatments. The highest values of N uptake, P uptake and N and P nutrient use efficiency were obtained with application of 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK fertilizer. The application of biochar increased the pH of acid soil and therefore should be adopted as liming material. Among the treatments evaluated, 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK fertilizer increased the yield of maize more than other treatments. This rate is recommended for optimum maize yield. Since N and P are major nutrients that are always deficient in acidic soils, application of 10 t ha⁻¹ PLB+625 kg ha⁻¹ NPK fertilizer may be adopted for effective nutrient management of these nutrients.

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