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The Contributions of Different Ash Sources to the Improvement in Properties of a Degraded Ultisol and Maize Production in Southeastern Nigeria

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J.C. Nwite C.A. Igwe, S.E. Obalum: The Contributions of Different Ash Sources to the Improvement in Properties of a Degraded Ultisol and Maize Production in Southeastern Nigeria

ABSTRACT

The soils in Afikpo agro-ecological zone of southeastern Nigeria are plagued with characteristics that impede optimal crop production. Appropriate soil management practices are needed in order to arrest the declining productivity of the soils in this zone. Three different ash materials (rice husk ash-RHA, wood ash-WA, and leaf ash-LA) were applied to the soil (Ultisol) at the rate of 3 tons/ha, with the aim of evaluating their immediate effects on soil properties and maize (*Zea mays* L.) yield during 2007 growing season. Soil chemical properties evaluated were pH, organic carbon, and exchangeable bases (K^+, Ca^{2+}, Mg^{2+} and Na^+) and acidity. Others included CEC, total nitrogen, and available phosphorus while the maize grain yield was measured. The soils are loose, low in pH and poor in plant nutrient elements except in magnesium. In spite of that, the ashes were able to increase the soil's pH by up to 100% in two of the ash- (WA and LA) amended soils. Generally, essential plant nutrients such as exchangeable K^+, Ca^{2+}, and Na^+ were improved by the applied ashes. Similarly, the CEC and available phosphorous of the soil were significantly improved by the soil amendments. Maize grain yield was enhanced in all the ash-amended soils relative to the control, with significant increase in the RHA (5.75 ton/ha) over WA (1.51 ton/ha) and LA (0.60 ton/ha). The study revealed the superiority of RHA over the other ash sources in the improvement of most of the plant nutrients and in production of maize in southeastern Nigeria.

Key words: Ash source, degraded Ultisol, maize grain yield, rice-mill wastes, saw-mill wastes, organic amendments, soil chemical properties, soil productivity

Introduction

Maize is a staple food in many parts of the tropics. It is also an important food for livestock. The grain is used industrially for starch and oil extraction. In recognition of the current global food crises, Nigeria currently pursues policy of expanding the land area under cultivation as well as intensifying crop production by continuous cropping system, of which maize is included. Over the years, the intensive cultivation of introduced high-yielding crop varieties has resulted to depletion of mineral nutrients and hence increased soil acidity. Incidentally, the supply of organic manure is not enough especially in urban areas to substitute the use of chemical fertilizer that has been increasing the acidity levels of tropical soils, as a quick means of restoring the soil fertility without possible increase in pH of the soils. Soils of southeastern Nigeria are poor in their native availability of nutrients (Unamba-Oparah, 1985; Mbagwu, 1989; Nwite *et al.*, 2008). Ash application may help in coping with the low nutrient levels in this soil. Witt *et al.* (2005) showed that nutrient management should be offered greater attention in order to obtain appreciable yield. In Ebonyi State of southeastern

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Nigeria, large quantities of fresh partially burnt rice-mill and saw-mill wastes accumulate respectively from numerous rice mills and saw mills in different parts of the State.

Despite the magnitude of these wastes generated daily and the possible effects on the environment, no serious attempts have been made either for their effective utilization or safe disposal. The only disposal attempt is the partial burning of the wastes at the various dumping grounds, after which no agricultural uses of the wastes are made as a way of recycling. Ash is the substance that remains after any material has been burnt. The term is usually applied to the minerals obtained from burning wood, coal, rice husk or other fuel. A chemical analyses of ashes from foodstuffs determines the amounts of minerals they contain (Claphan and Ziblske, 1992; Lickazz, 2002). Continued crop production can gradually decrease the organic matter content of soils and, hence, soil fertility and crop yields. Applying ash and animal waste to farmland after recycling has been one effective way to improve the physical, chemical and microbiological properties of soils.

Ash is as valuable as fertilizers and insecticides. For instance, ash from leaves yield iodine and that of wood is a source of potash. The concentrations of soluble carbohydrates in soils usually decrease in harmony with the amounts of leaf ash applied. Research has shown that the effect of leaf ash on the soil properties did not depend on the amount applied and that the concentrations of soluble carbohydrates and biomass decreased with the rate of application (Entry et al., 1996; Klo-eiko, 2003; Ots and Haugas, 2004). However, changes in the mineral composition of soils and plants usually result in serious alterations in the plants' metabolism. Increased Mg and Fe in the needles under the influence of wood ash may favour biosynthesis, just as changes in potassium and phosphorous concentrations may alter several pathways in plant metabolism (Mandre and Korsjukov, 2004; Mandre *et al.*, 2004). Ash improves soil texture, bulk density, permeability, water holding capacity/porosity/aeration, fertility status, resistance to pest attack, and reduces crust formation (Jayalakshini *et al.*, 2007). Earlier studies on ash chemistry in Scots pine (*Pinus sylvestris* L.) have revealed the positive effects of wood ash on Ca and K contents of the soil as well as an increase of K, Mg, S, Bo, Fe and Zn in tissues of the Scots pine (Vuorinen and Kurkela, 2000; Demeyer *et al.*, 2001; Jacobson, 2001). Wood ash amendment in mineral soils usually does not give any positive growth response in plants growing on such soils (Jacobson, 2001; Saarsalmi *et al.*, 2004). Adekayode and Olojugba (2010) reported that significantly higher maize grain was obtained in 200 kg/ha NPK 15-15-15 plus 2 t/ha wood ash mixture. They further confirmed that a combination of both organic and inorganic nutrient sources gave higher maize grain yield than when each was applied separately and the reduction in the rate of inorganic fertilizers would increase the profit margin of maize production. An increase was observed in the concentration of almost all nutrients except nitrogen in a soil amended with wood ash (Saarsalmi *et al.*, 2001). It is evident that the confirmed enrichment of the soil due to ash would cause changes in the metabolism and physiological activity of plants (Bramryd and Fransman, 1995; Saarsalmi *et al.*, 2001; Arvidsson and Lundkvist, 2003), and this may manifest in crop yield. Mbah *et al.* (2010) reported that applied wood ash reduced soil acidity to levels required for maize production.

In the present study, effects of ashes from different sources on soil chemical properties and yield of maize were evaluated in an Ultisol at Ishiagu in Afikpo Agroecological Zone of southeastern Nigeria. The objectives were to ascertain: (1) the ash-induced enhancement in the properties of the soil and maize yield, and (2) the relative improvements of the soil chemical properties and maize production by the three sources of ash in the zone.

Materials and methods

Experimental Site:

The experiment was conducted in 2007 at the Research Farm Complex of Federal College of Agriculture, Ishiagu. The area lies within latitude 05°56′N and longitude 07°41′E in the Derived Savannah Zone of southeastern Nigeria. The mean annual rainfall for the area is 1350 mm, spread from April to October with average air temperature being 29°C. The underlying geological material is Shale formation with sand intrusions locally classified as the 'Asu River' group. The soil is hydromorphic and belongs to the order Ultisol. It has been classified as Typic Haplustult (FDALR, 1985). Using a composite sample from the top- (0-20 cm) soil region at the study site, the soil was characterized before land preparation. The soil is sandy loam with moderate soil organic carbon (OC) content, low in pH and cation exchange capacity (CEC), with dominance of the exchange complex site by calcium and magnesium (Table 1).

The Soil Amendments and the Field Set-up:

The soil amendments comprised partially burnt rice-mill wastes, saw-mill wastes and leaves of *Acacia* plant, collected respectively from a rice-mill industry, a saw-mill industry and *Acacia* plantation; all within the vicinity of the study site. After burning, they were designated rice husk ash (RHA), wood ash (WA) and leaf ash (LA). Each of these three ash (the freshly burnt wastes) materials was black in colour. These ashes were analyzed for pH, organic carbon, total nitrogen, available phosphorus, and exchangeable bases (K, Na, Ca and Mg) (Table 2a). Each of the ash treatments was applied at the rate of 3 tons ha^{-1}. The area was manually tilled into seedbeds using African hoe, followed by application of the amendments. The field layout was a randomized complete bock design (RCBD) in which the four treatments (including the control) were replicated four times. The treatments and the rate of application are shown in Table 2b. The treatments were spread and incorporated within the top- (0-10 cm) soil and left for two days before sowing of the test crop (maize; var. Orba-super II), which was done on 15 April, 2007. The study site has been under cultivation of short-season crops (arable crops) before the study.

Soil and Crop Data Collection and Analyses:

At maturity (mid of July, 2007), maize dried cobs were harvested and de-husked. This was followed by shelling of the maize grains, which were later sun dried and the yield computed at 90% dry matter content. At the end of the harvest, soil samples were collected from all the plots for chemical analyses. The soil samples were air-dried and sieved with 2-mm sieve, and analysis done using the soil fractions less than 2 mm. Soil pH was measured in a 1:2.5 (soil:0.1 M KCl) suspensions. The soil OC was determined by the Walkley and Black method as described by Nelson and Sommers (1982). Exchangeable bases were determined by the method of Thomas (1982). The CEC was determined by the method described by Rhoades (1982), while exchangeable acidity (EA) was measured using the method of McLean (1982). Available phosphorus was measured by the Bray II method (Bray and Kurtz, 1945). Statistical analysis of all the data was performed by the analysis of variance (ANOVA) test, and statistical differences among treatment means were estimated by Fishers Least significant Difference (F-LSD).

Table 1: Some properties of the topsoil (0-20 cm) before tilling and amendment

Soil property	Value
Clay %	10
Silt %	21
Total sand %	69
Organic carbon (OC) %	1.42
Total nitrogen (N) %	0.09
pH (H_2O)	3.7
pH (KCl)	1.7
Exchangeable bases (cmol kg^{-1})	
Sodium	0.40
Potassium	0.80
Calcium	1.0
Magnesium	3.5
Cation exchange capacity (cmol kg^{-1})	8.22
Exchangeable acidity (cmol kg^{-1})	2.52
Available P (mg kg^{-1})	4.30

Results and discussion

Characteristics of the Selected Ashes:

The analytical results presented in Table 2a showed that wood ash (WA) had high alkaline properties with a pH of 12.7 and 15.6 cmol kg^{-1} of Ca, relatively higher than that of leaf ash (LA) and rice husk ash (RHA).

Compared to WA and LA, RHA had a higher elemental phosphorous, but lower content of N, Na, K, Ca and Mg. The LA had 5.0 cmol kg^{-1} Mg, and this was much higher than that of WA and RHA. A comparison of WA and LA shows that, except in C-organic content, both materials had relatively similar properties.

Effects of the Amendments on Soil Ph, Organic Carbon and Total Nitrogen:

The effects of the soil amendments on the soil pH, OC and N are shown in Table 3. Generally, the amended plots showed a significant ($P < 0.05$) improvement in soil pH over the control plots. The increase in pH was higher in plots amended with WA and LA compared with plots amended with RHA. In the case of the WA, it could be due to its higher contents of Ca, Mg and K compared to the RHA (Table 2a). It has been shown that the oxides and hydroxides of Ca, Mg and K contained in WA makes its mode of actions similar to that of burnt or hydrated lime (Lickazz, 2002). On the other hand, the increase in pH in the LA-amended plots relative to the RHA-amended plots could be attributed to the usually high pH in soils cleared of their vegetation by bush burning (Ulery *et al.*, 1993; Certini, 2005). These authors found that the topsoil pH could increase as much as three units immediately after burning. Indeed, *Acacia* leaves which was the source of the LA shares some resemblance with the leaves of mixed plant species burnt during bush burning. The lower pH in the soil amended with RHA could be accounted for by the production of organic acids during the decomposition of burnt rice wastes and the accompanying evolution of CO_2 (Nnabude and Mbagwu, 2001).

The soil OC was significantly ($P < 0.05$) improved in all the ash-amended plots compared to the control plots (Table 3). Generally, the OC contents of the amended soils were very low when related to its initial values in the soil (Table 1). The low percent of OC could be related to losses through crop removal. This agrees with Rasmusen *et al.* (1980) and Biederback *et al.* (1998), who had reported losses in surface soil OC levels through burning and removal of crop residue. Soil total nitrogen differed significantly ($P < 0.05$) among the treatments, with each of the ash-amended plots showing higher value than the control (Table 3). This increase in the soil total nitrogen was higher in the RHA than the others. Generally, the ash amendments showed high levels of N except the RHA (Table 2a). The overall low magnitude in the enhancement of N by the ash amendment suggests, therefore, a situation of high level of topsoil N volatilization and denitrification (Ayeni, 2010). It agrees also with Sobulo and Osiname (1987), who reported that low N might be as a result of early mineralization of nutrients especially N for maize uptake. This also agrees with Saarsalmi *et al.* (2001) and Arvidsson and Lundkvist (2003) who observed an increase in ash-amended soils of almost all the soil nutrients except nitrogen.

Effects of the Soil Amendments on the Exchangeable Bases:

Exchangeable potassium (K^+) increased significantly ($P < 0.05$) in the ash-amended plots relative to the control plots (Table 4). Furthermore, the results showed that the LA- and the WA-amended plots contained higher soil K^+ than the rice RHA-amended plots. This reflects the relative contents of K^+ in the ash materials (Table 2a). Notably, the RHA-amended plots gave statistical higher K^+ than the control plots, despite the low K^+ in the RHA when compared to WA and LA. Since ashes are known to be of high potash content, the above observation is understandable. This is in line with some previously reported observations that crop residue ash as cocoa pod ash contained N, P, K, Ca and Mg (Odedina *et al*., 2003; Ayeni *et al*., 2008). Ayeni (2010) also reported that cocoa pod ash contains as high as 12.36% K in its nutrient composition, with Ca and Mg values of 3.40% and 0.76% respectively. This also agrees with Ogbodo (2009), that plots treated with crop residue ash had significantly higher levels of exchangeable K, Ca, and Mg than other crop residue. This according to him was because residue ash specifically had liming effect on the soil owing to its higher Ca and Mg content. Moreover, the result underlines the importance of ash in coping with the high level of K leaching in this sub-humid tropical environment. This rise was essentially due to the production of K oxides, hydroxides and carbonates, which did not persist through the wet season.

All the treatments gave statistically same values of exchangeable magnesium, although the ash-amended plots showed numerically higher value than the control plots (Table 4). The inability of the ash amendments to significantly increase Mg^{2+} over the control in spite of the variability in their Mg^{2+} contents (Table 2a) could be attributed to the initially high amount of Mg^{2+} (3.5 cmol kg^{-1}) in the soil.

It appears therefore that there is a threshold level of Mg^{2+} in this soil, beyond which the excess is leached out of the topsoil. The drastic drop in the overall Mg^{2+} content of the soil after the study in spite of the amendments could be related to the findings of Ristanovic (2001) that maize has exhausting effects on the soil nutrients and needs the supply of necessary nutrients in the correct proportions to produce a satisfactory yield.

The result is also in line with the report of Modi and Asanzi (2008) that Magnesium was confirmed to be a major constituent of chlorophyll, protochlorophyll, pectin and phytin in maize; and the crop Mg removal is 40 kg ha^{-1} MgO. Therefore, the total Mg requirement should be related to Mg level in the soil. The result on sodium indicated significantly ($P < 0.05$) lower value in the LA-amended plots compared to the rest of the treatments – including the control (Table 4).

Effects of the Soil Amendments on Cec, Ea and Available Phosphorus:

Table 5 shows that all the amendments exerted positive and significant ($P < 0.05$) influence on the CEC of the soil over the control. The best improvement over the control was recorded in the LA-amended plots, followed by RHA-amended plots. Effects of the amendments on EA show that significant ($P < 0.05$) reduction in EA occurred in the three ash-amended plots relative to the control plots (Table 5). The lowering of the EA in the amended soils is considered to be a desirable attribute of the ash materials, as this could be a quick means of reducing acidity and increasing cation availability in soils (Omoti *et al.*, 1991; Adetunji, 1997; Odedina *et al.*, 2003).

Soil available P increased significantly ($P < 0.05$) due to the applied amendments. The results show that the highest available P was obtained in RHA treated plots and was followed by WA treated plots. Though WA and LA significantly improved available P over the control, there was no statistical difference between soil amended with LA and WA. This means that RHA exerted positive and significant improvement on available P over LA, WA and control. The increased available P in the amended soils could be attributed to increase in the soil pH which must have released the fixed P in the soil colloids. Generally, this result is in line with the findings of Martins (1971), Claphan and Ziblske (1992), and Lickazz (2002) that P availability was enhanced in some P-deficient agricultural soils by applied WA. A significant amount of P, Ca and Mg are also added to soil in form of potash when wood ash is used as living materials (Kakier and Summer, 1996; Demeyer *et al.*, 2001; Saarsalmi *et al.*, 2001).

Effects of the soil amendments on maize grain yield:

Table 6 presents the effects of the different ash sources on the shelled maize grain yield. The results show significantly ($P < 0.05$) higher grain in the RHA-amended plots compared to the other plots. However, irrespective of the source of ash, the amended plots yielded higher than the non-amended plots. The result is in line with the findings of Odiete *et al.* (2005) that the application of ash to young maize plants significantly increased the grain yield. The relatively high yield increase recorded in RHA compared to other treatments might be attributed to high Mg^{2+} produced in plots treated with RHA which Modi and Asanzi (2008) reported to be a major constituent of chlorophyll, proto-chlorophyll, pectin and phytin in maize. These constituents are directly related to plant grain yield.

Table 2a: Nutrient compositions of the amendments.

Property	Amendment		
	Rice husk ash (RHA)	Wood ash (WA)	Leaf ash (LA)
pH (H_2O)	6.9	12.7	10.4
pH (KCl)	6.5	12.2	10.0
Organic carbon (%)	3.89	1.07	3.89
N (%)	0.056	0.28	0.28
Na	0.33	0.33	0.45
K	0.65	3.08	1.77
Ca	1.0	15.6	10.4
Mg	1.4	3.6	5.0
P	11.94	4.98	1.94

Table 2b: Treatments applied .

Treatment label	Treatment name	Symbol	Application rate
I	Rice husk ash	RHA	3 tons ha^{-1}
II	Wood ash	WA	3 tons ha^{-1}
III	Leaf ash	LA	3 tons ha^{-1}
IV	Control	CT	0 ton ha^{-1}

Table 3: Effects of the different ash amendments on the pH, organic carbon and total nitrogen in top- (0-20 cm) soil.

Amendment	pH	OC (%)	N (%)
RHA	5.9	0.57	0.070
WA	6.4	0.49	0.055
LA	6.4	0.53	0.062
CT	4.5	0.44	0.040
$LSD_{(0.05)}$	1.33	0.015	0.015

OC = organic carbon, N = total nitrogen;
RHA = rice husk ash, WA = wood ash,
LA = leaf ash, CT = control;
LSD = Fisher least significant difference

Table 4: Effect of the soil amendments on the exchangeable bases in the top-(0-20 cm) soil.

Amendment	K^+	Ca^{2+}	Mg^{2+}	Na^+
			cmol kg^{-1}	
RHA	0.14	0.98	1.85	0.29
WA	0.23	1.70	1.83	0.29
LA	0.24	2.38	1.65	0.19
CT	0.05	0.93	1.40	0.29
$LSD_{(0.05)}$	0.10	1.28	NS	0.01

Table 5: Effect of the soil amendments on CEC, EA and available phosphorus in the topsoil.

Amendment	CEC (cmol kg^{-1})	EA (cmol kg^{-1})	Avail. P (mg kg^{-1})
RHA	5.34	2.53	31.04
WA	4.78	2.40	22.05
LA	5.48	2.45	23.75
CT	3.24	3.05	8.22
$LSD_{(0.05)}$	1.53	0.48	5.38

CEC = cation exchange capacity, EA = Exchangeable acidity

Table 6: Effects of the soil amendments on shelled maize grain yield.

Amendment	Maize grain yield (tons ha^{-1})
RHA	5.75
WA	1.51
LA	0.60
CT	0.34
$LSD_{(0.05)}$	3.42

Conclusions:

From the present study, the following conclusions can be drawn. The soils are loose, low in pH and poor in plant nutrient elements. In spite of that, the ash improved the pH by about 100%. Moreso, essential plant nutrients such as exchangeable K^+, Ca^{2+}, Mg^{2+} and Na^+ including such a key fertility index as the CEC were improved by the amendment with ashes. In general terms, it will be concluded that well or better managed soil, as in the ash applications in the present study, improved nutrient supply, reserve and release of their exchangeable forms, which are very essential in plant nutrition.

Maize grain yield also increased due to the applied ashes, but this was due solely to the rice husk ash. It would be therefore be preferable to use rice husk ash instead of the other forms of ash as a soil amendment for improving the nutrient status and maize production in this and similar Ultisols which abound in southeastern Nigeria.

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