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Properties and Potential of Selected Ash Sources for Improving Soil Condition and *Sawah* Rice Yields in a Degraded Inland Valley in Southeastern Nigeria

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Abstract: The soils in Ebonyi State agro-ecological zones of southeastern Nigeria are plagued with characteristics that impede optimal crop production. Failures in agricultural development in this part of southeastern Nigeria may have been caused by the inability of the farmers to develop the abundant inland valleys for such crops like rice using appropriate water management seasons. There is the need to arrest the declining productivity of the inland valley soils in these zones. In this study, different ash materials and their mixtures were applied to the soil at 10 tons/ha and cropped to rice (*Oryza sativa*) with the novel *sawah* rice-production technology in 2008 and 2009 cropping systems in southeastern Nigeria. The treatments included wood ash (WA), leaf ash (LA), rice husk ash (RHA), WA+LA, WA+RHA, LA+RHA and WA+LA+RHA. A 'control' was included, bringing to eight the total number of treatments. The objective was to evaluate the immediate effects of the treatments on the soil chemical properties and productivity assessed by grain yield of the rice crop. The field layout was a randomized complete block design, with three replications. Poultry droppings were applied at 10 tons/ha as basal application. The test crop was a high yielding variety of rice (FARO 52/WITA 4). The amendments were analyzed for pH, organic carbon, N, Na, K, Ca, Mg and P. Soil chemical properties tested included organic carbon, total N, pH, exchangeable bases (K^+, Ca^{2+}, Mg^{2+}), cation exchange capacity (CEC), exchangeable acidity (EA), base saturation (BS) and available P; while the grain yield of rice was measured. The analytical results of the amendments showed that WA had high alkaline properties with a pH of 12.7, relative to LA and RHA. However, the WA and LA had lower elemental P but higher contents of N, Na, K, Ca and Mg than the RHA. The soil analyses at harvest indicated that all the exchangeable bases were significantly improved by the amendments in both years of the trial. The results also showed improvements in soil pH, organic carbon and total N in the amended plots over the control. Also, rice grain yield increased due to the soil amendments from 1.8 to 6.5 t/ha in the first year and from 2.1 to 6.8 t/ha in the second year, with LA consistently giving the highest values.

Key words: *Sawah* · Ash source · Soil amendment · Soil chemical properties · Rice grain yield

INTRODUCTION

Rice (*Oryza sativa*) is the second most important cereal in Nigeria in terms of area cultivated, output and consumption and is cultivated under diverse ecological conditions including uplands and lowlands. Fortunately, inland valleys, which have specific hydrological conditions and have high potential for the development of rice-based small scale farming systems at village levels, occur abundantly in Nigeria and other West African sub-region in general [1-4]. Poor soil fertility and inefficient weed and water control are the major constraints to utilization of these inland valleys for sustainable rice-based cropping [5]. The African adaptive *sawah* lowland farming, with small scale irrigation scheme for integrated watershed management, will be the most promising strategy to tackle these problems restore the degraded watersheds in these tropical environments for increased and sustainable food production. The term '*sawah*' refers to a puddled and leveled rice field

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surrounded by bunds with inlets and outlets for irrigation and drainage, respectively. *Sawah* is the prerequisite technology for restoring and conserving the degraded watersheds in these tropical environments, for increasing and sustaining food production, and ultimately for realizing the elusive but much needed Green Revolution in West Africa.'

Most soils in southern Nigeria, as in other parts of the humid tropics, are acidic due to nature of their parent material, high rainfall regime and intensity and associated leaching of nutrients and weathering [7]. Low inherent fertility of most of these soils is responsible for poor crop yield. Soils are generally characterized by low pH and exchange capacity, poor buffering capacity and low plant-nutrient status and rapid loss of fertility on intensive cultivation [4, 8]. Ashes generally have good acid-neutralizing capacity and ability to supply the soil are basic elements (Ca, K, Mg, Na) and P; and this depends on the contents of oxides, hydroxides and carbonates of these elements. It has been shown that ash could be used to counteract natural and anthropogenic acidification of soil and loss of nutrients [9, 10]. Ash is a powder that remains after burning of such materials as wood, leaf and coal. Particularly, wood ash reactivates arable soils of the physical, chemical and biological qualities that have been previously damaged as a result of adverse climatic condition, inappropriate handling, continuous cropping and persistent use of NPK fertilizer. All these activities cause an increase in soil acidity and degradation in soil physical and chemical properties which lead to declines in crop yields [11, 12].

According to Martikainen [13], ash could induce a pH increase by as much as 0.6-1.0 units in humus soils. An increase in the soil pH may increase the decomposition rate of soil organic matter by soil microbes and this may speed up the rate of release of such plant nutrients as nitrogen [10, 13]. For *sawah* rice farming, burning of rice husk and incorporating the ash into the soil has been reported to increase the soil exchangeable Ca and the grain yield of rice in southeastern Nigeria [4]. In a similar study in this environment with maize (*Zea mays*) as the test crop, essential plant nutrients such as available phosphorous and exchangeable K and Ca, as well as the fertility index of cation exchange capacity (CEC) were improved by wood, leaf and rice husk ash materials applied as soil amendments [14]. The present study aimed at ascertaining the characteristics of selected ashes and also evaluating their influence on soil chemical properties and grain yield of rice grown with the *sawah* system in an inland valley in southeastern Nigeria.

MATERIALS AND METHODS

The experiment was carried out in the flood plain of Ivo River in Ishiagu, Ebonyi State of Nigeria. The area is located by 06°25 N and 8°03 E. The mean annual rainfall and mean monthly temperature are 1350 mm and 29°C, respectively. The area lies within the derived savanna vegetation zone of southeastern Nigeria, with grassland and shrub tree combinations. There are two distinct seasons; the dry season which spans November to March and the rainy season which spans April to October. The soil temperature regime is about 32.2°C [4].

Geologically, the area is underlain by sedimentary rocks derived from successive marine deposits of the cretaceous and tertiary period. According to Lekwa *et al.* [15], the location lies within the Asu River Group and consists of olive brown sandy shale, fine grained micaeous sandstones and mudstones deposited in an alternating sequence. The soil is described as Aeric-Tropoaquent [16] or Gleyic Cambisol [17]. The soil is a sandy loam with moderate organic carbon (OC) content in the topsoil and low in pH and CEC. The soils are mainly used for rainfed rice farming and vegetable production as the rain recedes (Table 1).

Field Study: The experiment was carried out in the 2008 and 2009 cropping seasons. The experimental design was Randomized Complete Block Design (RCBD). Eight treatments of single and combined soil amendments including the control were replicated three times. The soil amendments were different ash materials and their mixtures in equal amounts. These included wood ash (WA), leaf ash (LA), rice husk ash (RHA), WA + LA, WA + RHA, LA + RHA and WA + LA + RHA. They were applied to the soil at the rate of 10 tons/ha. In the control (CT) plots, no ash was applied. The WA, LA and RHA materials were from saw-mill wastes, leaves of Acacia plant and partially burnt rice-mill wastes, respectively. They were all collected within the vicinity of the study site. Poultry droppings were applied in all the plots at a basal dose of 10 t/ha, to supplement for nitrogen in the ash materials. The nutrient compositions (%) of the poultry droppings included: OC (16.52), N (2.10), Na (0.34), K (0.48), Ca (14.4), Mg (1.2) and P (2.55).

Field Preparation: The site was cleared of vegetation and topsoil samples were taken to determine the initial soil characteristics. The marked area was bunded 0.6-m high, ploughed, puddled and leveled with power tiller machine.

The poultry droppings were applied one week before transplanting, whereas the ash application was done two days before transplanting. Two weeks after transplanting water sourced from a nearby spring was introduced into the rice plots through a constructed canal. The bunds with inlets and outlets drains were used to impound and control water throughout the growing period of the rice crop. The quantity of water introduced into the plots was not measured rather the depth of water was maintained at 5-10 cm throughout the growing period of the crop. Water was introduced into the field when needed; when in excess, it was drained from the field. The test crop was a high-yielding rice variety, FARO 52/WITA 4. The rice seedlings were transplanted at the age of three weeks after nursery and transplanting was carried out in rows using a spacing of 20 cm x 20 cm with 2 seedlings per hill. At maturity, the rice crop was harvested, threshed and the grain weight measured. Soil samples were collected from 0-15 cm depth at harvest, to assess the level of changes that occurred in the soil due to the treatments. All the data were analyzed statistically using analysis of variance (ANOVA) procedures appropriate for an RCBD trial, as described by Obi [18].

Laboratory Methods: Soil samples were air-dried and sieved with 2-mm sieve. Soil fractions less than 2 mm from each of the replicates were then analyzed using the following methods. Particle size distribution of the fine earth fractions was measured by the hydrometer method [19]. 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 described by Nelson and Sommers [20]. Exchangeable cations were determined by the method of Thomas [21]. The CEC was determined by the method described by Rhoades [22], while exchangeable acidity (EA) was measured using the method of McLean [23]. Available phosphorous was measured by the Bray II method [24].

RESULTS AND DISCUSSIONS

Characteristics of the Soil and the Selected Ashes: Table 1 shows the chemical properties of the soil before the study. The soil is sandy loam in texture. The analytical results presented in Table 2 show that WA had high alkaline properties with a pH of 12.7 and Ca^{++} of 15.6 cmolkg^{-1}, relative to LA and RHA. The results also show that WA and LA had a lower elemental P but higher content of N, Na, K, Ca and Mg than RHA.

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

Soil property	Value
Clay %	10.00
Silt %	21.00
Total sand %	69.00
Organic carbon (OC) %	1.61
Total nitrogen (N) %	0.09
pH (H_2O)	3.70
Exchangeable bases (cmolkg^{-1})	
Sodium (Na)	0.40
Potassium (K)	0.11
Calcium (Ca)	1.00
Magnesium (Mg)	1.56
Cation exchange capacity (CEC)	5.06
Exchangeable acidity (EA)	2.52
Available P (mg/kg)	4.30

Table 2: Nutrient compositions (%) in the amendments

	Amendment		
Property	Rice husk ash (RHA)	Wood ash (WA)	Leaf ash (LA)
pH (H_2O)	6.900	12.70	10.40
OC	3.890	1.07	3.89
N	0.056	0.28	0.28
Na	0.330	0.33	0.45
K	0.650	3.08	1.77
Ca	1.000	15.60	10.40
Mg	1.400	3.60	5.00
P	11.940	4.98	1.94

A comparison of WA and LA shows that, except in OC content, both materials generally have similar properties.

Effects of the Different Ash Sources on Soil pH, Organic Carbon and Total Nitrogen: The data in Table 3 show that the soil pH increased significantly ($P < 0.05$) with the application of the different ash materials and their mixtures in both years of the study. In the first year, WA treatment showed the highest improvement in the soil pH, with a mean of 5.2. However, in the second year, WA+RHA treatment showed the highest improvement in the soil pH, with a mean of 6.0. The pH of the soil in all the amended plots increased over the control. This increase in pH level could be attributed to the significant improvement in the exchangeable bases of the soil. Similar observation has been reported elsewhere [13].

Table 3: Effects of the different sources of ash on soil pH, organic carbon and total nitrogen at the end of the study

Treatment	pH (H_2O)	Organic carbon (%)	Total nitrogen (%)
First year			
WA	5.20	0.76	0.065
LA	5.10	0.86	0.056
RHA	4.90	1.07	0.056
WA+LA	5.00	0.65	0.047
WA+RHA	4.90	0.87	0.065
LA+RHA	4.80	0.92	0.057
WA+LA+RHA	4.90	0.91	0.056
CT	4.00	0.54	0.043
Mean	4.90	0.82	0.056
LSD (0.05)	0.22	0.22	0.006
Second year			
WA	5.70	0.95	0.070
LA	5.30	2.15	0.058
RHA	5.30	1.12	0.067
WA+LA	5.90	0.53	0.099
WA+RHA	6.00	0.85	0.071
LA+RHA	5.30	1.60	0.113
WA+LA+RHA	5.00	1.50	0.089
CT	2.60	0.07	0.026
Mean	5.10	1.10	0.074
LSD (0.05)	0.14	0.17	0.007

WA - wood ash; LA - leaf ash; RHA - rice husk ash; CT - control

Table 4: Effects of the different sources of ash on exchangeable bases in the soil at the end of the study

Treatment	Ca^{2+}	K^{+}	Mg^{2+}
First year			
WA	2.53	0.22	1.20
LA	2.20	0.21	2.20
RHA	1.87	0.13	0.87
WA+LA	2.13	0.14	1.27
WA+RHA	1.93	0.12	1.13
LA+RHA	1.73	0.18	0.93
WA+LA+RHA	2.00	0.17	1.20
CT	1.47	0.07	0.73
Mean	1.98	0.16	1.19
LSD (0.05)	0.36	0.02	NS
Second year			
WA	4.00	0.30	2.81
LA	3.22	0.21	1.23
RHA	2.47	0.17	2.03
WA+LA	4.03	0.20	1.60
WA+RHA	3.63	0.16	2.40
LA+RHA	2.97	0.16	2.83
WA+LA+RHA	3.27	0.20	2.00
CT	1.01	0.10	1.13
Mean	3.08	0.19	2.00
LSD (0.05)	0.271	0.04	0.26

WA - wood ash; LA - leaf ash; RHA - rice husk ash; CT - control

Table 3 also shows the effect of different sources of ash on OC content of the soil. There were significant ($P < 0.05$) differences among the treatments, with RHA improving OC compared to the other treatments in both years of the study. Also, all the treatments significantly increased OC over the control plots in both years. The results show that soil total nitrogen was significantly ($P < 0.05$) influenced by the treatments. The LA+RHA indicated the highest mean value (0.113), followed by WA (0.065) in the first year and WA+LA (0.099) in the second year. However, there was reduction in the soil total nitrogen in some treated plots compared to the initial value. This could be due to relative N volatilization during burning process and relative levels of topsoil N volatilization and denitrification [25]. The results also are in agreement with Saarsalmi *et al.* [26] and Arvidsson and Lundkvist [27]. This reduction in soil total nitrogen could be related to the fact that in flooded condition, after oxygen is consumed, virtually all the nitrates present in the soil are denitrified and lost to the atmosphere [28].

Effects of the Different Ash Sources on Exchangeable Bases: Table 4 shows that the exchangeable bases (Ca^{2+}, K^{+}, Mg^{2+}) were significantly ($P < 0.05$) improved by the application of the treatments in both years except Mg for which differences were not significant in the first year of study. The significant improvement in the exchangeable bases could be as a result of the release of the organic forms of these elements in these ashes and their mixtures. Also, the residue ashes specifically had liming effect on the soil owing to the higher levels of Ca, K and Mg detected in the ash materials. The data also show that in the second year, the exchangeable Mg varied significantly. It changed from1.13 cmol/kg in the control plot to 2.83 in the LA+RHA plots. Similar to these results, cocoa pod ash was reported to have positive effect on soil exchangeable bases in southwestern Nigeria, expressed by increasing Ca and Mg levels with increasing levels of the ash [25].

Effects of the Different Ash Sources CEC, Exchangeable Acidity and Base Saturation: The data in Table 5 show that the soil CEC was improved significantly ($P < 0.05$) by the application of ashes in the two years of the study. The LA gave the highest value in the second but not the first year. The EA was significantly ($P < 0.05$) higher in the control plots than the treated plots in both years of study. Apart from the fact that EA differed significantly ($P < 0.05$) due to the amendments, there was also a general decrease in values of the EA in the second year compared to the first year. The overall drop in the mean EA values in the second year of the trial was considered to be a nice attribute for the *sawah* system.

Table 5: Effects of the different sources of ash on soil CEC, exchangeable acidity and base saturation at the end of the study

Treatment	CEC (cmolkg[1])	EA (cmolkg[1])	BS (%)
First year			
WA	3.72	1.73	50.50
LA	4.06	1.70	56.80
RHA	3.26	1.87	52.50
WA+LA	5.87	1.87	50.70
WA+RHA	3.71	1.18	48.60
LA+RHA	4.03	1.97	49.70
WA+LA+RHA	5.56	1.93	53.30
CT	2.79	2.87	37.70
Mean	4.13	1.89	50.00
LSD (0.05)	0.96	0.80	7.40
Second year			
WA	7.75	1.26	84.60
LA	9.10	2.17	81.59
RHA	6.3	1.62	82.71
WA+LA	6.6	1.75	72.56
WA+RHA	7.7	1.14	70.45
LA+RHA	8.01	1.44	77.43
WA+LA+RHA	8.5	1.88	71.53
CT	3.95	2.65	38.64
LSD (0.05)	1.0	0.27	23.85

WA - wood ash; LA - leaf ash; RHA - rice husk ash; CT - control

Table 6: Effect of the different ash sources on rice grain yield

	Mean yield (t/ha)	
Treatment	First year	Second year
WA	6.37	6.65
LA	6.50	6.80
RHA	5.26	6.15
WA+LA	5.45	6.07
WA+RHA	6.44	5.55
LA+RHA	5.37	6.13
WA+LA+RHA	5.31	5.41
CT	1.80	2.10
Mean	5.31	5.61
LSD (0.05)	0.32	0.80

WA - wood ash; LA - leaf ash; RHA - rice husk ash; CT - control

On the other hand, the results showed an overall trend of significant ($P < 0.05$) increase in CEC and percent BS in the second compared to the first year. With the traditional system of rice farming, these soil properties normally decrease in the second year of cropping. These results thus further confirm the superiority of the *sawah* system of rice production. Previous experiments conducted near the present site to evaluate the effect of the *sawah* system on soil properties similarly showed the system to be superior to non-*sawah* system with respect to generation, release and reserve of soil plant available nutrients [4, 28]. Other studies elsewhere also upheld the superiority of *sawah* system over non-*sawah* system especially in terms of nutrient reserve for a profitable rice production [29, 30, 31].

Effects of the Different Sources of Ash on Grain Yield of Rice: Table 6 presents the effects of the different ash materials and their mixtures on the grain yields of rice. Generally, there were significant ($P < 0.05$) improvements in the rice yields in the amended over the non-amended (CT) plots. In the first year of planting, the rice grain yield increased significantly ($P < 0.05$) from 1.80 tons/ha in the control plots to 6.50 tons/ha in the LA-treated plots. Also, in the second year of planting, yield increased significantly ($P < 0.05$) from 2.1 tons/ha in the CT plots to 6.80 tons/ha in the LA-treated plots. The high yields of rice due to applied ashes could be attributed to the fact that ash has the ability to buffer the soil and this may initiate the release of available plant nutrients in the soil [32]. Furthermore, the good water management condition prevailing in the *sawah* system might have contributed to the high grain yield response of rice to the investigated input in the form of ashes [33]. The data in Table 6 show, in addition to the consistently low yields in the CT plots, that the grain yield responded differently to the soil amendments. Notably, the LA-treated plots always gave the highest yield and there was an overall increase in grain yield in the second compared to the first year of the study.

CONCLUSIONS

From the present study, the following conclusions can be drawn. The soils are low in pH and poor in plant nutrient elements. In spite of that, the ash materials were able to improve the pH of the soil by raising the pH in the first and second year of planting. Generally, essential plant nutrients such as exchangeable Ca, K and Mg including the fertility index like CEC were improved upon due to the ash amendments under the *sawah* system of rice production within the period. The organic carbon and total nitrogen were improved by the ash amendments. The rice yield performance was enhanced by the soil amendments under the *sawah* system in both years of the study, with the highest grain yield coming from the plots amended with leaf ash.

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