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Restorative Potential of Residual Soil Amendments and One-Year Fallow on Top Soil Chemical Properties of a Tropical Ultisol

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Authors' contributions

This work was carried out in collaboration between all authors. Authors RAE and CLAA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors PIE and AOO managed the analyses of the study. Author PKK managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Quantitative information on the contribution of residuals of soil nutrient management on natural nutrient recovery capacity of soil through fallowing is scanty. To evaluate the contributions, soil samples were collected from soils amended with 50 tha^{-1} boiler ash (BA),10 tha^{-1} poultry droppings (PM_{10}), 150 and 300 kg ha^{-1} NPK fertilizer, combinations of BA and PM or NPK and a control. The samples were collected at the end of first and second year of maize cultivation and after one year of fallowing to assess changes in pH, total nitrogen, available phosphorus, % organic carbon, exchangeable bases (Ca, Mg, Na, K), cation exchange capacity and % base saturation. The study showed that type and quantity of soil nutrient recovered through fallowing significantly (p=0.01)

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differed in respect to the type of amendment previously applied. High pH level (7.0) and increase in Ca obtained in plots treated with BA_{50} either sole or combined was sustained up to the end of the fallow year. . Recovery of organic carbon and available P was more in plots with residuals of BA_{50} + PM_{10} while, nitrogen (0.26%) and exchangeable K (0.26 $cmol_c$ Kg^{-1}) were obtained in BA_{50} +$NPK_{150.}$ The highest CEC and % BS values (23.85 $cmol_c$ Kg^{-1} and 76.7%), respectively were obtained from the control plots. Significant fallow effect on soil pH occurred only in NPK treated plots as % OC depleted in NPK_{300} and BA_{50} +PM_{10}. Compared to the second cropping season, one year of fallow on the average resulted in an increase in the top soil pH, % OC, N, Ca, K and %BS; but reduced available P, Mg, Na and CEC. A combination of BA and PM or NPK had synergistic effects that exceeded the effect of applying them alone.

Keywords: Fallowing; soil amendments; Ultisol; boiler ash; poultry dropping.

1. INTRODUCTION

Increasing population pressure and increased emphasis on food security have led to intensive agriculture, with its characteristic negative effects on soil quality and resilience. Continuous cultivation, a consequence of intensive agriculture leads to a decline in total nitrogen, organic carbon, potassium, zinc and the acidification of soils [1-3]. Plant nutrient balances are usually negative indicating that farmers are mining their soil [4]. Physical properties such as hydraulic conductivity, bulk density, total porosity, and aggregate stability also deteriorate as soil organic matter falls [5].

Soils' ability to produce crops is partly a function of its resilience, that is, the ability to recover, to the antecedent state following a cultivation phase [6]. In the above scenario, the recovery of the degraded soil and its maintenance to the adequate level is a critical task. Proper management of the soil to replenish its soil nutrient reserves through application of soil amendments as well as inclusion of periods of unmanaged or natural fallow are thought to be sustainable approaches especially among resource poor-farmers. Fallowing plays important roles in fertility restoration, weed control, interruption of pest and disease cycles as well as reservoirs of above- and belowground biodiversity [7].

In young fallows, soil nutrient uptake is rapid and may accumulate in fallow biomass leading to a net loss of nutrients from the top soil [8]. This coupled with indiscriminate bush burning and uncontrolled grazing are serious limitations to fallowing under short fallow periods as obtained now. In such circumstances, fallowing is often not sufficient to restore soil fertility, leading over time to soil and vegetation degradation and to noticeable declines in crop yields. Therefore, emphasis should be placed on how to implement management strategies with short-term fallows that would encourage higher build-up of nutrients in the soil.

Several studies have indicated that initial soil quality governs the rate, path and pattern of recovery to the antecedent state following a cultivation phase [9,6,10]. Aguilera et al. [2] observed that fallowing restored total and active soil organic carbon and nitrogen more rapidly in higher elevations than lower ones due to differences in initial soil properties. However, Asadu et al. [11] observed that changes in the nutrient elements in a cleared forestland cultivated and fallowed for seven years were not attributed to the inherent variations across the field but to the different cropping systems, fallow and perhaps other factors such as climate.

Most researchers appreciate the influence of initial soil properties on restorative- effectiveness of fallowing but the contributions of residual soil amendments, which could induce such differences, are rarely considered. Information on their influence is scanty, and needs to be studied. The objectives of this study were to compare the contribution of residuals of different soil amendments on chemical properties of an Ultisol subjected to one-year fallow period and to identify the soil-specific chemical properties that were restored after fallowing in each soil nutrient management option.

2. MATERIALS AND METHODS

2.1 Description of Study Area

The study was conducted at the Research Farm of the Department of Soil Science, Faculty of Agriculture, University of Nigeria, Nsukka. The site is located by Latitude 06° 25′ N and Longitude 07° 24′ E and at an altitude of approximately 400 m above sea level. The major soils were derived from the disintegrated rock materials of either false-bedded sandstone or upper-coal measures [12] and these respectively gave rise to sandy and clayey soils found in the lower and upper slopes [13]. These soils are exposed to high temperatures and rainfall of high intensity and erosivity, which results in erosion and leaching.

Generally, the area of the study is within the humid tropical climate characterized by mean annual rainfall of 1700 – 1800 mm. The rainfall distribution is bimodal and falls between April and October while the dry season is between November and March. It is characterized with mean annual maximum (day) and minimum (night) temperatures of 31°C and 21°C respectively, while the average relative humidity is rarely below 60% [14].

2.2 Plot Descriptions and History of Use

The experiment was initiated in 2013 to compare the effects of boiler ash (BA), poultry droppings (PM), inorganic fertilizer (NPK, 20-10-10) and their combinations on the chemical properties of an Ultisol. The experiment consisted of six treatments and a control, laid out in a Randomized Complete Block Design (RCBD) replicated three times giving twenty-one plots. Two seeds of maize (*Zea mays* L.) var. Oba super 11) were sown per hole using inter-row and intra row spacing of 0.75 m by 0.25 m on each of the 4m by 3m plots and later thinned to one. The treatments, their designations and application rates are shown in Table 1.

The field experiment was repeated by the second season in May 2014 without application of amendments to determine their residual effects. The site was later left to fallow from the growing period of 2015 to May 2016. Prior to planting of crops during the years of cultivation, auger soil samples were collected from random locations on the experimental site at a depth of 0-20 cm. Soil samples were equally collected at the end of each cropping season and fallowing from each of the plots. The soil samples were air-dried and passed through a 2 mm sieve. The fine earth fractions were collected and used for the determination of the chemical properties.

2.3 Laboratory Analyses

The following analyses were carried out on the BA, PM and soil samples collected from the field following known standard methods; soil pH [15], organic carbon [16], total nitrogen [17], available phosphorus [18], while exchangeable bases (Na^+, K^+, Ca^{2+} and Mg^{2+}) and CEC were determined by the method described by Thomas [19]. Base saturation was obtained by dividing total exchangeable bases by cation exchange capacity and multiplying by100.

2.4 Fallow Effect

Fallow effect (FE) was calculated as follows:

FE (%) = [{(Value in fallow year – Value in second cropping season)/ Value in second cropping season} X 100/1]

2.5 Statistical Analysis

The data collected were subjected to analysis of variance (ANOVA) using GENSAT Discovery Version [20]. Differences between means of treatments were compared using the Fisher's Least Significant Difference (F- LSD) at 5% probability.

Table 1. Treatments applied, their designations and application rates

S/N	Treatments	Designation	Rate (kg/plot)	Rate (t/ha)
T1	Boiler ash (BA)	BA_{50}	60	50
T2	Poultry droppings (PM)	PM_{10}	12	10
T3	N.P.K 20: 10: 10	NPK_{300}	0.36	0.3
T4	N.P.K 20: 10: 10	NPK_{150}	0.18	0.15
T5	BA+ PM	BA_{50} + PM_{10}	60 + 12=72	50 +10= 60
T6	BA + N.P.K	BA_{5O} + NPK_{150}	60 + 0.18=60.2	50+0.15=50.2
T7	Control	Control	Nil	Nil

3. RESULTS AND DISCUSSION

3.1 Soil Properties Prior to Treatment Application

The physical and chemical properties of the soil prior to application of amendments are shown in Table 2. The soil was sandy clay loam in texture with bulk density value of 1.98 Mgm^{-3}. It was characterized by moderately rapid saturated hydraulic conductivity (10.14 $cmhr^{-1}$) and a total porosity of 48%, indicating high rate of water infiltration into the soil, a situation which would encourage leaching of plant nutrients. Its low value of water holding capacity (24.4%) coupled with low value of mean weight diameter (MWD) (0.53 mm) implied that the soil was physically degraded and required amelioration for sustainable crop production.

The soil was very strongly acidic with pH 4.8. Soil exchangeable K (0.2 $cmol_c\ kg^{-1}$), Na (0.3 $cmol_c\ kg^{-1}$), Ca (0.8 $cmol_c\ kg^{-1}$), and Mg (1.0 $cmol_c\ kg^{-1}$) were low, indicating poor soil fertility. This result agrees with the findings of Nwite et al. [21] that Ultisols of southeastern Nigeria are low in exchangeable calcium, potassium and magnesium. The organic carbon content (1.29 %) and total nitrogen (0.23%) were moderate but available phosphorus (7.5 mg kg^{-1}) and potassium (0.2 $cmol_c\ kg^{-1}$) were low.

The BA and PM are strongly alkaline as shown by their pH values of 9.2 and 8.3, respectively. Poultry droppings had higher levels of OC, total N, and smaller ratios of C: N and C: P, suggesting that mineralization of its organic forms of N and P will be faster compared to the BA. The low nitrogen content of the ash could be attributed to the volatile nature of the element under combustion [22] and a remarkable constraint to its agronomic utilization.

3.2 Effect of Soil amendments, Cultivation and Fallowing on Soil Chemical Properties

3.2.1 Soil pH

The soil pH differed significantly (p=.01) in response to the type of amendments applied, year of cultivation and fallowing (Table 3). Soil pH was generally higher in plots amended with BA_{50} either as sole or in combination with PM or NPK fertilizer. The control plots and NPK treated plots were lower (5.2). In the second cropping season, pH decreased in BA_{50} and BA_{50} + NPK_{150} treated plots by 0.3 and 0.2 units, respectively but increased in others. The pH of the control plots did not differ significantly from the NPK fertilizer treated plots. Soil pH generally reduced in the fallow year except in plots treated with BA_{50} + PM_{10}.

The increase in pH due to the application of BA may be attributed to ash accretion as ash residues are generally dominated by carbonates of alkali and alkaline earth metals [23]. The non-significant difference between the control and NPK_{300} plots agrees with the findings of Ayeni and Adeleye [24]. The higher soil pH in the BA_{50} plots during the fallow year appeared to suggest that the BA is still decomposing and mineralizing and contributing exchangeable bases to depress hydrogen and aluminum ions and raised the pH level. The general reduction in pH of treated soils in the fallow year may be explained by the fact that after a cropping phase, soil pH tends to decline progressively as fallow ages given that the basic cations are being accumulated in the plant biomass [25].

3.2.2 Soil organic carbon, total nitrogen, and available phosphorus

Table 3 also shows the effects of residual soil amendments on soil carbon, total nitrogen and available phosphorus. Soil organic carbon concentration did not differ significantly at the end of the first cropping season. In the second cropping season, PM_{10} and NPK_{150} had the highest value (1.1%) and differed significantly (p=0.01) from the rest except BA_{50} + NPK_{150}. During the fallow year, BA_{50} + PM_{10} treated plots had the highest value of 1.34%, which was 103% higher than the control plot and 58% higher than the plot which received NPK150. The non-significant effect of the amendments on % OC in the first cropping season collaborates the findings of Haynes [26] and Liu et al. [27] who observed that soil organic carbon is not sensitive to short term changes resulting from soil or crop management practices which may be attributed to high background level and natural soil variability.

During the fallow year, the increase in organic carbon in the BA_{50} +PM_{10} and NPK_{300} may be attributed to the decomposition of accumulated biomass due to improved nutrition in the previous cropping seasons. The result was contrary to the findings of Masse et al. [28] who reported that a

4-year fallow in sandy soils in Senegal did not significantly increase SOM or soil nutrient concentrations. The higher organic C content in the BA_{50} +PM_{10} treated plots indicates that organic C sequestration in soil differs in response to the type of amendment previously applied. This is of environmental importance, in terms of the relationship between soil organic C content and one of the principal radioactively -active greenhouse gases, CO_2. Organic C sequestration or increases in soil organic C (SOC) reduces the emission of CO_2 into the atmosphere, as well as the greenhouse effect. Also, increases in SOC results primarily in improvement in soil physical and chemical fertility, soil water conservation, biotic activity and fertility status for increases in crop production.

The plots amended with BA_{50} had the highest total nitrogen a year after application, although it did not differ significantly from BA50 + Pm10, and BA50 + NPK150. The control plot had the same value (0.08 %) with the NPK and PM treated plots. Similar trend was observed in the second cropping season. However, during the fallow year, total nitrogen increased considerably in the BA50 + NPK150 plot (0.26 %), followed by BA_{50} (0.13%), while there was non-significant differences among the other treatments. There was an appreciable contribution by BA in increasing soil nitrogen. BA_{50} amendment may have provided the needed conditions that stimulated soil microbial nitrogen fixation. The increase in nitrogen levels could as well be ascribed to increased decomposition and subsequent mineralization of biomass.

Table 2. Physico-chemical characteristics of the experimental soil and the amendments

Properties	Soil	Boiler ash	Poultry droppings
pH (H_20)	4.8	9.2	8.3
Coarse sand (gkg^{-1})	380		
Fine sand (gkg^{-1})	290		
Silt (gkg^{-1})	110		
Clay (gkg^{-1})	220		
Textural class	Sandy clay loam		
Bulk density(Mgm^{-3})	1.98		
Organic carbon (%)	1.3	12.4	43.1
Total nitrogen (%)	0.2	0.2	4.2
C:N	5.4	62	10
Available P (mg kg^{-1})	7.5	293.8	8.3
C:P	0.2	24	0.2
Exchangeable Ca (cmol$_c$ kg^{-1})	0.8	1.5	4.8
Exchangeable Mg (cmol$_c$ kg^{-1})	1.0	7.2	6.8
Exchangeable K (cmol$_c$ kg^{-1})	0.2	10.6	1.7
Exchangeable Na (cmol$_c$ kg^{-1})	0.4	599.7	1.2

Table 3. Effects of soil amendments on soil pH, organic carbon, total nitrogen, and available phosphorus during continuous cultivation and fallowing

Treatment	pH			Organic carbon			Total nitrogen			Available phosphorus		
				---------------- % ----------------						--------mgkg^{-1}------		
	1st C.S	2nd C.S	1st Y.F	1st C.S	2nd C.S	1st Y.F	1st C.S	2nd C.S	1st Y.F	1st C.S	2nd C.S	1st Y.F
BA_{50}	7.7	7.4	7.0	0.74	0.97	0.75	0.13	0.10	0.13	110.67	77.91	60.7
PM_{10}	6.1	6.6	5.6	0.81	1.10	0.80	0.08	0.09	0.08	32.99	26.30	34.4
NPK_{300}	5.3	5.9	5.3	0.71	0.90	1.16	0.08	0.06	0.07	9.05	19.09	19.2
NPK_{150}	5.2	7.1	5.2	0.79	1.10	0.85	0.08	0.09	0.06	18.81	15.84	13.8
BA_{50} +PM_{10}	6.8	7.0	7.0	0.76	0.97	1.34	0.10	0.10	0.09	98.68	85.94	104.9
BA_{50} + NPK_{150}	7.4	7.2	7.0	0.78	1.09	0.64	0.11	0.10	0.26	124.61	105.90	90.5
0 (Control)	5.2	5.3	5.1	0.60	0.97	0.66	0.08	0.08	0.08	16.34	16.23	11.0
F-LSD$_{(0.05)}$	0.43	0.37	0.32	n.s	0.10	0.176	0.03	0.01	0.043	7.738	4.663	5.46

1st C.S= First cropping season, 2nd C.S= Second cropping season, 1st Y.F _=First Year of Fallow, n.s = non-significant at 5% level. F-LSD$_{0.05}$= Fishers least significant difference at 5% level of probability

There were significant differences (p=0.01) in available P among the treatments. At the end of the first cropping season, BA_{50} + NPK_{150} had the highest value (124.61 $mgKg^{-1}$) followed by BA_{50} (110.67 $mgKg^{-1}$) while the least was observed in the NPK_{300} treated plot. In the second year, the available P generally reduced except in the NPK_{300} plot that increased to about 110%. The highest available P content in the fallow year (104.9 mg Kg^{-1}) was observed in the BA_{50} + PM_{10} treated plot while the least was observed in the control plot. There was an additive effect of the BA_{50} and PM_{10} in the fallow year. Available P was generally higher than 15 mg kg^{-1} critical value stipulated for southeastern Nigeria [29]. The high percentage organic carbon in the BA_{50} + PM_{10} may have reduced phosphorus fixation in soil which lead to the remarkably increase in available P during the fallow period. This decline may have been due to P fixation (tying up of P by clay minerals) common in acid soils of the tropics [30].

3.2.3 Soil exchangeable bases (Ca, Mg, K, Na)

The concentrations of soil exchangeable bases (Ca, Mg, K, Na) were significantly (P=0.01) influenced by the type of soil amendment applied, cropping season and fallowing (Table 4). In the first cropping season, the highest Ca concentration (6.35 $cmol_c$ kg^{-1}) was observed in BA_{50} + PM_{10} treated plots, followed by PM_{10}. The least value was obtained in the BA_{50} treated plot. The control plot maintained a common value in the first and second cropping seasons. At the end of the second cropping season, calcium concentration in all treatments was significantly (p=0.01) lower than that of the control plot (4.1 $cmol_c$ kg^{-1}). Integration of BA with either PM or NPK fertilizer did not lead to additional increase in the calcium content of the soil. Allowing the BA_{50} treated plot fallowed for one year increased the soil Ca content from 2.25 $cmol_c$ kg^{-1} during the last year of cultivation to 3.00 $cmol_c$ Kg^{-1}.which was the highest among the treated plots. It however, did not significantly differ from PM_{10}, BA_{50} + PM_{10} and BA_{50} + NPK_{150}.

The highest magnesium content (11.95 $cmol_c$ Kg^{-1}) during the first cropping season was recorded in plots treated with BA_{50} + NPK_{150} while the least was in PM_{10} treated plot. Magnesium concentration in the second cropping season was highest in BA_{10} treated plots, followed by its combinations. During fallowing exchangeable magnesium decreased in all treatments except in, PM_{10} and BA_{50} + PM_{10} treated plots where it increased. However, Mg was consistently higher in the BA treated plots.

In the first cropping season, BA_{50} + PM_{10} had the highest Na content (0.90 $cmol_c$ Kg^{-1}) but did not differ significantly from NPK_{300}, and BA_{50} +NPK_{150}. During the second cropping season, the Na content reduced remarkably in all treatments, although they differed significantly (p=0.01) from each other. The residual soil amendments did not differ in their influence on Na content of the soil during the fallow period.

Exchangeable K concentration in the first cropping season was highest in the plots treated with BA_{50} (0.54 $cmol_c$ Kg^{-1}), followed by BA_{50} + NPK_{150} treated plot while the least was in the control plot. Similar trend occurred in the second year. During the fallow year, exchangeable K significantly (p=0.01) differed in respect to the type of amendment previously applied. It was highest (0.26 $cmol_c$ Kg^{-1}) in BA_{50} +NPK_{150} treated plot. The control plot had the least value (0.08 $cmol_c$ kg^{-1}.The above results are in tandem with the findings of Styger and Fernandes [31] and Asadu et al. [6] that in early stages of fallow, there may be a net loss of nutrients from the top soil due to rapid intake of nutrients because of increasing biomass.

3.3 Cation Exchange Capacity and Percent Base Saturation

Table 4 shows that during the cropping phase, the soil had significant (p=0.01) differences in CEC in response to the type of amendment applied. The CEC was highest in plots amended with BA_{50} + NPK_{150} in the first and second cropping seasons. It increased remarkably in the control plot in the second cropping season. During the fallow year, CEC was highest in the control plot (23.85 $cmol_c$ Kg^{-1}). The least was observed in the NPK_{150} treated plots. The increase may be attributed to the increase in organic carbon content of the soil. Percentage base saturation was highest in plots treated with BA_{50} + NPK_{150} during both first and second cropping seasons. Base saturation increased considerably in all plots during the fallow year except in the NPK_{300} treated plots. The highest value (76.7%) was observed in the control plot while the least was observed in the NPK_{300} and NPK_{150}, respectively in the fallow year.

Table 4. Effects of soil amendments on soil exchangeable calcium, magnesium, sodium and potassium during continuous cultivation and fallowing

Treatment	Exchangeable Calcium			Magnesium			Sodium			Potassium		
	cmolc kg-1											
	1st C.S	2nd C.S	1st Y.F	1st C.S	2nd C.S	1st Y.F	1st C.S	2nd C.S	1st Y.F	1st C.S	2nd C.S	1st Y.F
BA_{50}	2.80	2.25	3.00	9.55	9.8	6.05	0.80	0.18	0.51	0.45	0.22	0.20
PM_{10}	5.55	2.30	2.95	0.80	1.7	1.95	0.75	0.20	0.10	0.26	0.11	0.26
NPK_{300}	4.40	1.65	1.50	0.45	1.6	0.65	0.81	0.13	0.09	0.23	0.14	0.10
NPK_{150}	5.45	1.45	1.55	1.70	1.2	1.10	0.71	0.14	0.07	0.54	0.11	0.09
BA_{50} +PM_{10}	6.35	2.35	2.95	4.35	5.4	5.75	0.90	0.19	0.06	0.38	0.21	0.25
BA_{50} + NPK_{150}	5.45	2.05	2.95	11.95	7.1	4.55	0.87	0.14	0.05	0.48	0.25	0.34
No amendment	4.10	4.10	1.80	0.85	1.0	0.70	0.71	0.20	0.04	0.19	0.10	0.08
F-$LSD_{(0.05)}$	0.05	0.23	1.13	2.14	0.56	2.59	0.13	0.05	n.s	0.08	0.02	0.08

1st C.S= First cropping season, 2nd C.S= Second cropping season, 1st Y.F _=First Year of Fallow, n.s = non significant at 5% level. F-$LSD_{0.05}$= Fishers least significant difference at 5% level of probability

Table 5. Effects of soil amendments on soil cation exchange capacity and percent base saturation during continuous cultivation and fallowing

Treatment	Cation exchange capacity			Base saturation		
	$cmol_c\ kg^{-1}$			%		
	1st C.S	2nd C.S	1st Y.F	1st C.S	2nd C.S	1st Y.F
BA_{50}	14.39	19.20	14.65	14.39	19.0	61.3
PM_{10}	10.60	15.60	12.80	10.60	15.60	32.5
NPK_{300}	11.40	16.80	13.20	11.40	16.80	15.3
NPK_{150}	11.10	14.60	11.50	11.10	14.60	21.0
BA_{50} +PM_{10}	12.15	19.40	15.55	12.15	19.40	49.7
BA_{50} + NPK_{150}	18.95	19.90	14.15	18.95	19.90	56.3
No amendment	10.65	19.40	23.85	10.65	19.40	76.7
F-$LSD_{(0.05)}$	1.905	1.99	4.39	1.905	1.99	8.78

1st C.S= First cropping season, 2nd C.S= Second cropping season, 1st Y.F _=First Year of Fallow, n.s = non-significant at 5% level. F-$LSD_{0.05}$= Fishers least significant difference at 5% level of probability

3.4 Percentage Fallow Effects on Soil Chemical Properties as Influenced by Soil Amendment History

The mean effects of fallowing on soil chemical properties in soils of varying amendment history expressed in percentages are shown in Table 6. There was notable increase in pH of plots amended with NPK_{150} (27%) and NPK_{300} (10%). In BA_{50} + PM_{10} treated plot, soil pH reduced by 1%. Generally, pH increased in most plots probably due to a reduction in the leaching of basic cations resulting from the non-till condition of the soil, while, the remarkable increase in the NPK treated plots may have been due to a reduction in the acidifying effect of the chemical fertilizer.

Organic carbon in BA_{50} + NPK_{150} treated plot increased by 41% while BA_{50} + PM_{10} reduced by 38 %. Relative increases in organic carbon were recorded in almost all the plots except BA_{50} +PM_{10} and NPK_{300} when the fallow year was compared with the last year of cultivation. These increases might have been due to increase in litter addition and reduced oxidation of the available organic matter. The total nitrogen ranged from 31% reduction in NPK_{150} treated plot to 170% increase in BA_{50} + NPK_{150} treated plot. Available P increased by 31% in the PM_{10} treated plots but reduced by 32% in the control plot. The result indicates that during fallowing, available P increase more rapidly in soils low in available P. The level of increase in C and N in the BA_{50} + NPK_{150} treated plots underline the importance of integrated nutrient management system. The BA_{50} may have increased the pH of the soil, while the NPK_{150} provided the initial N for enhanced microbial activity and biomass that may have promoted nitrogen fixation.

Table 6. Percentage fallow effects on soil chemical properties as influenced by residual soil amendments

Treatment					--------- Exchangeable -------					
	pH	% C	% N	Av. P	.Ca	Mg	Na	K	% BS	CEC
BA_{50}	5	23	29.5	-22	33	-39	27	-9	31	5
PM_{10}	5	27	-17	31	28	15	-47	131	24	-18
NPK_{300}	10	-20	17	4	-10	-59	-53	-32	-27	-21
NPK_{150}	27	22	-31	-12	7	-7	-34	-18	-7	-19
BA_{50} +PM_{10}	-1	-38	-10	22	25	9	-75	18	52	-20
BA_{50} + NPK_{150}	2	41	170	-14	44	-36	-71	35	33	-29
No amendment	4	32	-1	-32	-56	-29	-73	-18	187	23
F-$LSD_{(0.05)}$	5.1	19.2	43.9	12.2	47.3	34.1	37.7	n.s	95.9	24.0

% C, percent organic carbon; Ca, calcium; Mg, magnesium; K, potassium; Na, sodium; % B.S, percentage base saturation; CEC, Cation exchange capacity; Av. P, available phosphorus; ;F- LSD, least significant difference

Calcium increased in all amended plots except NPK_{300}. The highest increase (44%) was observed in the BA_{50} + NPK_{150} treated plots. Magnesium content increased in PM_{10} and BA_{50}+PM_{10} by 15 and 9 %, respectively. The highest reduction was in NPK_{300} (59%) treated plot which did not differ significantly from BA_{50}, BA_{50}+NPK_{150} and the control. Sodium increased in only the sole BA_{50} treated plot by about 27%. This indicates that the initial high sodium content of the BA persisted up to the fallow year. The type of soil amendment applied prior to fallowing did not significantly influence the percentage increase in the soil K.

The % BS of control plot increased by about 187% while NPK_{300} treated plots reduced by 27%. Cation exchange capacity of the soil increased only in the control plot (23%) and BA_{50} treated soil (5%). The differences observed in soil percentage BS and CEC may be attributed to less plant uptake of basic cations and increased % OC.

Generally, the result of the fallow effect revealed a reduction in the soil concentration of most the nutrients evaluated. This may be attributed to the fact that at the start of a fallow period nutrients are taken up from the soil and are stored in the vegetation leading to a net loss of nutrients from the topsoil. It is only later in the fallow development, when litter fall greatly exceeds the increase of nutrient uptake into biomass, that the amount of nutrients in the topsoil may be increased and restored. The assertion by Brand and Pfund, [32] that in natural fallows, topsoil nutrient concentrations start to increase only after 3 to 5 years of fallow was dependent on the antecedent nutrient status of the soil prior to fallowing. The time needed for nutrient restoration varies greatly across elements [8] but as well dependent on nutrient status of the soil before fallowing.

4. CONCLUSION

Soil fertility recovery through short-term fallows was influenced by previous fertilization regimes. Amendments like boiler ash may have induced important rhizospheric processes that encouraged build-up of nutrients in the soil rather than in plant biomass. This is important to management as nutrients tied up in higher plants are subject to be exported by man, grazed by animals or burnt. The study further emphasized that integrated plant nutrient management system is a sustainable soil management practice for tropical soils.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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