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RESEARCH ARTICLE

Improving the soil available phosphorus and exchangeable calcium of three parent materials of the smallholder farmers using amendments in Abia State, Southeastern Nigeria

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Abstract

Enhancing the soil properties of the smallholder farmers' farm will increase the soil productivity potentials, boost crop production and empower the farmers economically. It is upon this framework that this incubation study was set up at the Soil Science and Meteorology Laboratory of Michael Okpara University of Agriculture Umudike. The aim was to ascertain the effect of amendments on soil available phosphorus and exchangeable calcium of three parent materials namely; Sandstone, Shale and Alluvium in Abia State. The treatments comprised of seven amendments namely: Control (no amendment), Biochar, Ash, Lime, Biochar + Poultry Manure, Ash + Poultry Manure and Lime + Poultry Manure. They were applied at a sole rate of 1.43g to 100g of the soil and the ton equivalent was 2t/ha. The treatments were replicated three times in a Completely Randomized Design. The incubation study lasted for twelve weeks and available phosphorus alongside exchangeable calcium was determined at two weeks intervals. Experimental soil baseline showed that the soils had low available Phosphors with the following values; Shale 7.20 mg kg^{-1}, Sandstone 10.11 mg kg^{-1} and Alluvium 9.06 mg kg^{-1}. In Sandstone, Biochar + PM significantly ($p<0.05$) increased the available Phosphorus at 2, 4, 6, 8 and 10 weeks of incubation with 34.70, 25.45, 26.85, 21.65 and 19.40 mg kg^{-1} respectively. The highest value of exchangeable calcium was recorded at the 10th week of incubation for Shale with a value of 12.38 $comlkg^{-1}$. On the average Biochar + PM increased available phosphorus and also the exchangeable calcium. Further field investigation is recommended.

INTRODUCTION

The smallholder farmers who are the major producer of food crops in the Southeastern Nigeria are faced with the challenges of increasing the food production to meet the increasing population. One of the constraints to increasing food production is the soil factors. The major soil factors that affect crop and soil productivities are soil acidity and decline in soil fertility due to mining of nutrients by the crops without external addition of adequate nutrients (Mutegi *et al.*, 2012). Soil acidity which is caused by the leaching of the basic cations such as calcium, magnesium, sodium and potassium results to their deficiencies. The acidic condition allows the presence of phytotoxic nutrient such as soluble aluminum (Olfa *et al.*, 2011) which forms a complex with phosphorus and makes it non available.
Calcium is a major cation on the cation exchange capacity in most soils and it is also one of the major nutrient elements needed by crops in large quantity (Antonio *et al.*,2007). It is essential for the crops because it ensures

proper cell division and elongation, nitrate uptake and metabolism, enzyme activity and starch metabolism among others (Silva and Uchida, 2000). This essential nutrient is affected by the type of soil, total calcium supply and soil acidity. It can be lost in the soil through plant uptake, retention by the soil and it's precipitation as secondary minerals and leaching (Huntington *et al.,* 1999). Since the majority of the smallholder rural farmers farms in Southeastern Nigeria are characterized by pronounced soil degradation due to poor aggregation (Onweremadu *et al*., 2010), the presence of exchangeable calcium is important in their soils, as this may promotes flocculation of soil colloids (Dontsova and Norton, 2002).

Phosphorus is one of the essential nutrients and it is needed by crops to stimulate root development which will help in nutrient uptake, increase stalk and stem strength, increase nitrogen-fixing capacity of legumes, improve crop quality, increase plant resistance to diseases and improve flower and seed formation (Silva and Uchida, 2000). Phosphorus is affected by aluminum in acidic condition. Aluminum forms a strong bond with phosphorus making phosphorus unavailable. With the advocacy for the smallholder farmers to conserve their soils through the inclusion of legume in the crop rotation, the increase of the amount of phosphorus and calcium becomes necessary in the soil.

Allowing the soil to rest by fallowing is one of the natural ways of replenishing the exhausted nutrients in the soil which leads to decline in soil fertility and productivity. Due to the increasing population which mounts pressure on the limited available land, fallowing may not be achievable. The next alternative is the use of amendments and the type of amendment use will largely depend on the causative agent of the soil fertility declination. When acidity is the causative agent to low soil productivity and poor crop performance, materials that neutralize the acidity effects are added to the soil. The choice of the liming materials will depend largely on their availability and affordability especially by the smallholder farmers.

Materials like calcium carbonate, calcium oxides; calcium hydroxide among others are being used as liming materials. The problems found with these conventional liming materials were that they are usually scarce and can decrease the availability of phosphorus due to the formation of insoluble Ca-P minerals (Lee *et al;* 2007). When such condition arises, it becomes a problem fixing it to release phosphorus which is important in the crop nutrition. The smallholder farmers may not be economically empowered to afford materials that will release the fixed phosphorus from Ca-P complex.

It is therefore proper and important to reduce the financial pressure on the smallholder farmers by looking for alternatives to the lime that are available, affordable and within their reach. The conversion of agricultural wastes into beneficial materials for the smallholder farmer is a welcome development. One of such conversions is the production of ash and biochar from agricultural wastes. Though ash has been in use by the farmers for sometimes now, biochar is novel and needed to be exploited.

Biochar is a solid material produced during a process known as pyrolysis from the thermo-conversion of biomass under little or no oxygen for use in soils as an amendment, carbon sequester and off set carbon emission (Lehmann, *et al.,* 2009, Bell and Worrall, 2011). It has been reported to increase the soil pH, available P, organic carbon and reduce acidity (Novak, *et al*: 2009).

In this study, we hypothesized that amendments produced from agricultural wastes will moderately increase the soil exchangeable calcium and increase the available phosphorus above the critical level. The goal of this work was to determine the effect of soil amendments on selected soil chemical properties. Specifically, the objective was to ascertain the effect of calcium carbonate, ash, biochar and the combinations of these with poultry manure on the available phosphorus and exchangeable calcium of Sandstone, Shale and Alluvium of Abia State, Southeastern Nigeria.

Materials and Methods

An incubation study was carried out for twelve weeks at the Laboratory of Soil Science and Meteorology Department, Michael Okpara University of Agriculture Umudike (05° 29` N, 07° 33` E and 122 m above sea level). Soils of the parent materials used for the study were collected from the farms of some smallholder rural farmers located in Abia State. The parent materials were Shale from Bende (5° 34' 0N, 7° 37' 60E) , Sand stone from Abiriba (5° 42' 0N, 7° 43' 60E) and Fresh water alluvium from Owerrinta village (5° 15' 4N, 7° 18' 56E). Soils were collected from each of these villages at a sampling area of 50m x 50m and 15 soil samples randomly taken from each sampling farm.

Amendment preparation

The biochar and Ash were prepared from the following feed stocks namely; rice husk, cowpea husk and spent mushroom substrate others were maize husk, sawdust and 2:1 clay type. Biochar was produced from the pyrolysis process using the pyrolysis drum at the temperature of 450°C and afterwards characterized according to Biochar material test categories and characteristic of the IBI Biochar Standards *Version* 2.0 (2014).The biochar properties and other amendments determined (Table 1) were limited to the two soil properties focused on this study.

Table 1: Chemical composition of the amendments used for the study

Properties	Lime	Ash	Biochar	Poultry manure
Total P (%)	0.09	1.48	2.37	3.18
Calcium (%)	45.98	32.60	21.10	5.78

Soil Sampling, treatments and experimental procedures

The sampling depth was from 0- 15 cm. The chemical characteristics of the soil used for the study are shown on Table 2. The soil samples were bulked, air-dried, ground, and pass through a 2mm sieve mesh. From the composite soil, 100g of the soil was taken for each treatment into 500mL beaker and labelled appropriately. The soil samples were kept on the laboratory benches. Its moisture was maintained at field capacity and the samples covered with cheese cloth to prevent evaporation. The treatments comprised of Control (no amendment), Biochar, Ash, Lime, Biochar + Poultry Manure, Ash + Poultry Manure and Lime + Poultry Manure. They were applied at 2 ton/ha with its equivalent of 1.43g to the 100g of the incubated soils. The study was a factorial experiment in completely randomized design (CRD) with two factors, namely, amendments and weeks of incubation. The treatments were replicated three times. The samples were incubated for twelve weeks and the soil properties determined at two weeks intervals.

Soil properties determination

The following soil properties were determined; Available phosphorus was determined by Bray 2 method of Bray and Kurtz (1945) as outlined by Anderson and Ingram (1993). Exchangeable Calcium was extracted with NH_4OAC buffered at pH 7.0 (Thomas, 1982) and determined using Ethylene Diamine Tetra – Acetic (EDTA) titration method. Particle size analysis was done using the hydrometer method (Gee and Border, 1986).

Statistical Analysis

The data generated were subjected to analysis of variance (ANOVA) for factorial experiment in completely randomized design (CRD) using the GENSTAT package. The means were separated using the Fisher's Least Significant difference (LSD).

Results

The result of some of the selected physicochemical properties of the parent materials (Table 1) shows that Sandstone, Shale and Alluvium had initial available phosphorus values of 7.21, 10.11 and 9.06 $mgkg^{-1}$respectively. These values were below the critical values of 12ppm – 15ppm for most crops in southeastern Nigeria (Enwezor, *et al.;* 1988). The value of the soil exchangeable calcium ranged from 0.13 to 0.48 and this was below 2 $comlkg^{-1}$ which, was reported by Halving, *et al.,* (2005) as the critical level for calcium.

Table 2: Some selected physicochemical properties of the parent materials.

Properties	Values		
	Sandstone	Shale	Alluvium
Sand (gkg^{-1})	820	480	900
Silt (gkg^{-1})	150	220	10
Clay (gkg^{-1})	300	300	90
Texture	Loamy sand	Sandy clay loam	Sand
Av. P ($mgkg^{-1}$)	10.11	7.20	9.06
Ex.Ca ($cmolkg^{-1}$)	0.13	0.48	0.47

Effects of amendments on the soil available phosphorus at the weeks of incubation on three different parent materials.

Table 3 shows the effect of the added amendments on soil available phosphorus changes in Shale. Biochar + PM significantly ($p<0.05$) increased the amount of available phosphorus among the means of the amendments. For the means of the weeks of incubation, the highest value for available phosphorus was recorded at the 2nd week of the incubation. Ash + PM significantly ($p<0.05$) increased the available phosphorus at the 4th week of incubation.

Table 3: Amendments effect on soil available phosphorus (mg kg^{-1}) modification in Shale during the twelve weeks of incubation

Treatment	Weeks of incubation						
	2	4	6	8	10	12	Mean
Control	2.23	2.38	1.12	1.00	0.62	1.29	1.44
Ash	12.60	9.95	7.25	5.85	6.55	8.75	8.49
Biochar	13.25	13.30	12.35	13.50	9.05	8.90	11.73
Lime	6.75	7.15	4.30	4.70	3.75	1.70	4.73
Ash +PM	12.25	18.40	12.55	11.15	10.55	12.25	12.86
Biochar +PM	16.15	14.80	12.50	12.90	12.50	10.15	13.17
Lime +PM	12.85	6.25	3.20	2.60	2.80	2.72	5.07
Mean	10.87	10.32	7.61	7.38	6.54	6.54	
LSD	3.09	4.66	2.65	2.01	1.89	1.13	

Lsd (0.05) for weeks of incubation (I) = 1.78, Lsd (0.05) for treatments (T) = 2.01, Lsd (0.05) for I x T = 3.91

The result obtained on Table 4 showed that at the 2nd, 4th, 6th, 8th and 10th weeks of incubation Biochar + PM significantly ($p<0.05$) increased the level of soil available phosphorus in Sandstone. At the 12th week of incubation, Ash gave the highest soil available phosphorus amount. The data for the mean of treatment showed that Biochar + PM had the highest available phosphorus value of 23.80 (mg kg^{-1}). The percentage increases over the other treatments are as follows: 64.36%, 9.70% and 19.53% for Control, Ash and Biochar respectively. Others are 80.54%, 34.34% and 73.10% for Lime, Ash + PM and Lime + PM respectively. Among the means of weeks of incubation, the 2nd week had the highest available phosphorus value.

Table 4: Amendments effect on soil available phosphorus (mg kg^{-1}) modification in Sand Stone at twelve weeks of incubation

Treatment	Weeks of incubation						
	2	4	6	8	10	12	Mean
Control	11.35	8.55	6.25	10.00	5.01	9.70	8.48
Ash	29.18	25.25	23.00	20.70	15.75	15.05	21.49
Biochar	24.10	21.60	25.75	17.75	15.05	10.66	19.15
Lime	5.15	4.95	4.60	4.30	3.40	2.35	4.63
Ash +PM	25.00	16.95	15.00	15.60	11.45	9.80	15.63
Biochar +PM	34.70	25.45	26.85	21.65	19.40	14.75	23.80
Lime +PM	9.00	8.60	7.15	6.40	2.70	4.55	6.40
Mean	19.78	15.91	15.51	13.77	10.39	9.55	
LSD	6.47	6.89	4.92	5.47	6.01	5.78	

Lsd (0.05) for weeks of incubation (I) = 1.43, Lsd (0.05) for treatments (T) = 1.08, Lsd (0.05) for I x T = 4.71

The result of the amendments on soil available phosphorus of Alluvium at the twelve weeks of incubation is presented on Table 5. The means of the treatments showed that Biochar +PM significantly ($p<0.05$) increased the amount of soil available phosphorus among the treatments while the least value of 2.95 was recorded in the control. The means of the weeks of incubation showed that the 2nd week had a significantly increased value of phosphorus over the other weeks of incubation. At the 2nd, 4th, 6th, 8th, and 12th weeks of incubation, Biochar + PM significantly ($p<0.05$) increased the available phosphorus in the soil. The highest significant ($p<0.05$) value for the available phosphorus for the 10th week of incubation was recorded with the application of Biochar.

Table 5: Amendments effect on soil available phosphorus (mg kg^{-1}) modification in Alluvium at twelve weeks of incubation

Treatment	Weeks of incubation						
	2	4	6	8	10	12	Mean
Control	3.34	3.62	2.68	2.63	2.80	2.63	2.95
Ash	16.60	16.05	15.80	15.35	15.35	15.05	15.70
Biochar	22.40	18.85	18.50	18.55	20.20	19.20	19.62
Lime	8.05	5.20	4.60	5.05	5.75	5.80	5.74
Ash +PM	20.25	15.40	16.85	10.60	10.05	9.40	13.76
Biochar +PM	25.30	19.75	19.54	19.07	19.25	19.50	20.40
Lime +PM	9.90	5.20	5.90	5.71	5.02	4.60	6.06
Mean	15.12	12.01	11.98	10.99	11.20	10.88	
LSD	5.40	7.14	4.77	6.24	5.43	4.20	

Lsd (0.05) for weeks of incubation = 1.90, Lsd (0.05) for treatments = 1.75, Lsd (0.05) for I x T = 4.67

The means of amendments effect on soil available phosphorus of the three parent materials are shown on Fig 1. From the graph, Biochar + PM significantly increased the soil available phosphorus in all the three parent materials. The values of the amendments were highest in Sandstone followed by Alluvium and lastly Shale.

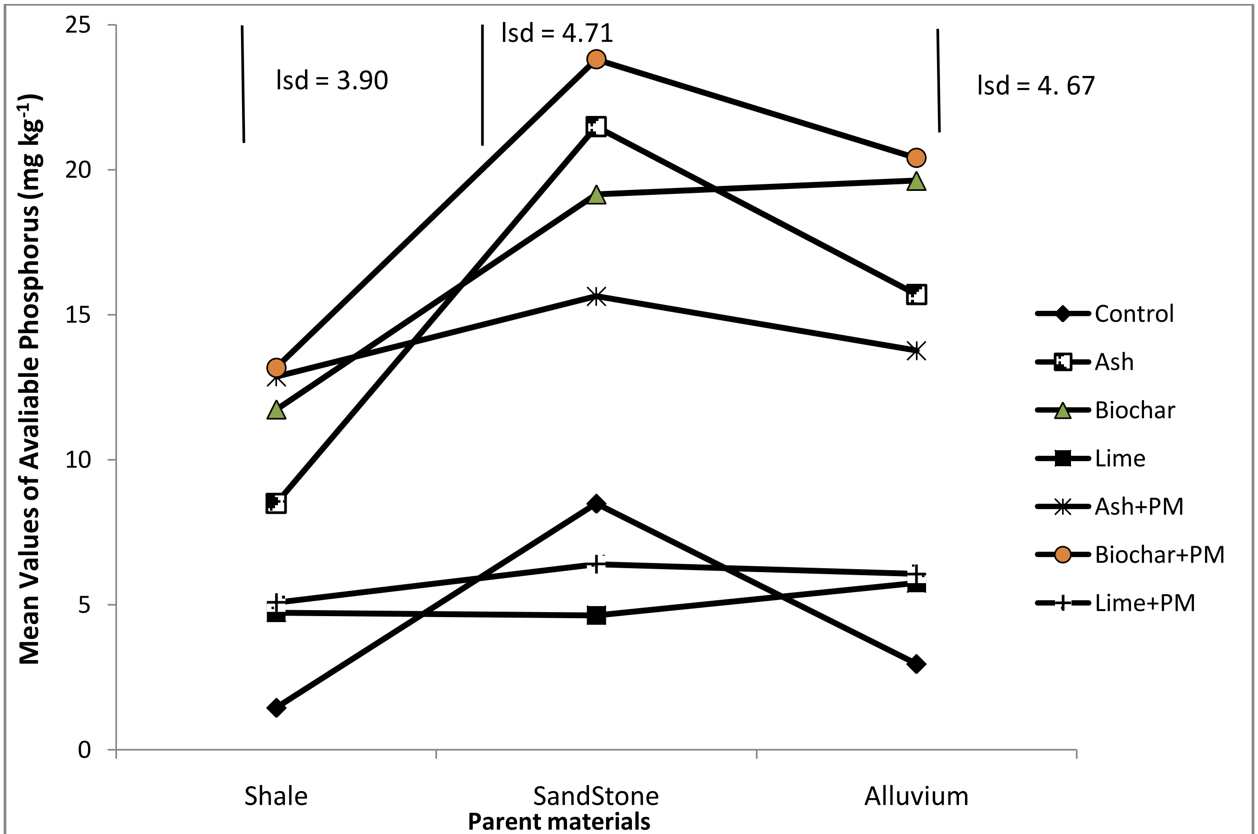

Fig 1: Means of amendments effect on soil avalibale Phosphorus (mg kg^{-1}) of the three parent materials. Vertical bars represent Lsd at 0.05.

The values of available phosphorus (Fig 2) were highest for all the parent materials in week two of incubation and then it gradual declined to the last week of the incubation study. The values obtained in Sandstone were higher than the ones obtained in the other parent materials.

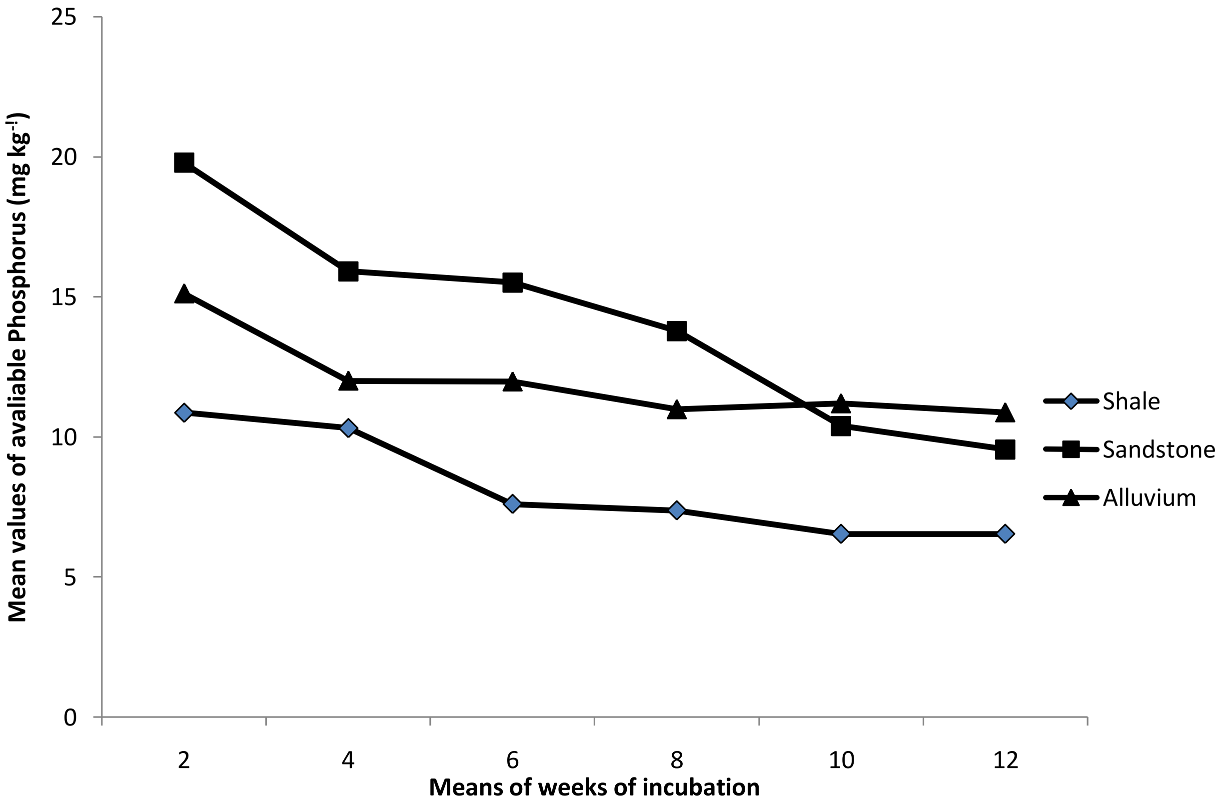

Fig 2: Effect of means of weeks of incubation on avaliable phosphorus of the three parent materials.

Effect of amendments on soil exchangeable calcium modification in Parent materials at the weeks of incubation

The applied lime (Table 6) significantly ($p<0.05$) increased the exchangeable calcium in Shale at 2nd, 4th, 6th, 8th, 10th, 12th weeks of incubation and also among the treatment means. It was at the 2nd week of incubation that the highest value of exchangeable calcium was recorded when the means of the weeks of incubation was considered.

Table 6: Amendments effect on soil exchangeable calcium (cmolkg^{-1}) modification in Shale at the twelve weeks of incubation

Treatment	Weeks of incubation						
	2	4	6	8	10	12	Mean
Control	0.45	0.45	0.32	0.35	0.23	0.21	0.33
Ash	19.67	22.00	17.00	11.03	10.60	9.89	15.03
Biochar	18.04	19.07	16.88	12.89	10.01	9.54	14.41
Lime	37.12	27.12	25.51	25.10	24.89	23.99	27.28
Ash +PM	22.02	25.66	22.15	22.06	20.18	18.13	21.70
Biochar +PM	15.02	16.76	16.27	10.80	8.19	7.77	12.47
Lime +PM	29.17	24.12	23.19	22.09	22.00	21.78	23.73
Mean	23.58	22.53	20.22	17.38	16.01	15.22	
LSD	1.74	2.89	2.00	1.89	3.98	2.44	

Lsd (0.05) for weeks of incubation =1.04, Lsd (0.05) for treatments = 1.53, Lsd (0.05) I x T = 5.89

The result obtained from Table 7, revealed that the lime increased the soil exchangeable calcium among the treatment means of Sandstone, while the 10th week of incubation gave the highest value among the weeks of incubation means. Considering the interaction between the weeks of incubation and treatments, Lime significantly ($p<0.05$) increased the value of the exchangeable calcium at the 6th week of the study, this was the highest value got for the interaction.

Table 7: Amendments effect on soil exchangeable calcium ($cmolkg^{-1}$) modification in Sandstone at the twelve weeks of incubation

Treatment	Weeks of incubation						
	2	4	6	8	10	12	Mean
Control	0.13	0.15	0.22	0.16	0.14	0.13	0.16
Ash	4.30	6.70	9.30	9.00	9.70	5.00	0.73
Biochar	4.70	6.70	6.70	7.70	9.70	9.70	8.03
Lime	17.30	18.00	26.70	16.70	20.70	12.70	18.18
Ash +PM	5.30	6.00	12.30	11.30	13.70	6.00	9.10
Biochar +PM	6.30	8.30	10.00	12.00	14.70	6.00	9.55
Lime +PM	12.30	17.70	16.30	15.30	18.00	11.00	15.1
Mean	7.19	9.08	11.64	10.31	12.38	7.21	
LSD	0.02	0.41	1.31	1.86	2.05	0.74	

Lsd (0.05) for weeks of incubation = 2.22, Lsd (0.05) for treatments = 3.15, Lsd (0.05) = 3.67

The amendments effect on the exchangeable calcium of Alluvium is shown on Table 8. The result indicated that the applied lime significantly ($p<0.05$) increased the value of exchangeable calcium at the 2nd, 4th, 8th and 10th weeks of incubation. Lime + PM significantly ($p<0.05$) increased the values at 6th and 12th week of incubation. The 8th week of incubation gave the highest significant ($p<0.05$) value for exchangeable calcium among the weeks of incubation means. Considering the treatment means, lime gave the highest significant (0.05) value of 17.40 $cmolkg^{-1}$.

Table 8: Amendments effect on soil exchangeable calcium ($cmolkg^{-1}$) modification in Alluvium at twelve weeks of incubation

Treatment	Weeks of incubation						
	2	4	6	8	10	12	Mean
Control	0.55	0.55	0.56	0.56	0.55	0.56	0.55
Ash	7.00	5.78	9.54	9.88	7.04	5.88	7.52
Biochar	6.02	6.88	13.89	15.55	9.43	5.06	9.47
Lime	15.10	19.07	15.00	25.01	20.11	10.15	17.40
Ash +PM	5.06	7.77	9.05	13.76	11.98	8.55	9.36
Biochar +PM	5.07	7. 65	9.11	12.55	13.98	11.91	10.05
Lime +PM	9.77	17.90	23.76	17.12	14.55	12.09	15.87
Mean	6.94	8.27	11.55	13.49	11.09	8.31	
LSD	2.01	2.34	4.93	3.70	3.13	3.11	

Lsd (0.05) for weeks of incubation =2.43, Lsd (0.05) for treatments = 2.81, Lsd (0.05) = 5.12

It was observed in Fig 3 that the application of Lime significantly ($p<0.05$) increased the values of the exchangeable calcium in all the parent materials studied. All the applied treatments improved the level of exchangeable calcium in Shale when compared to the other parent materials.

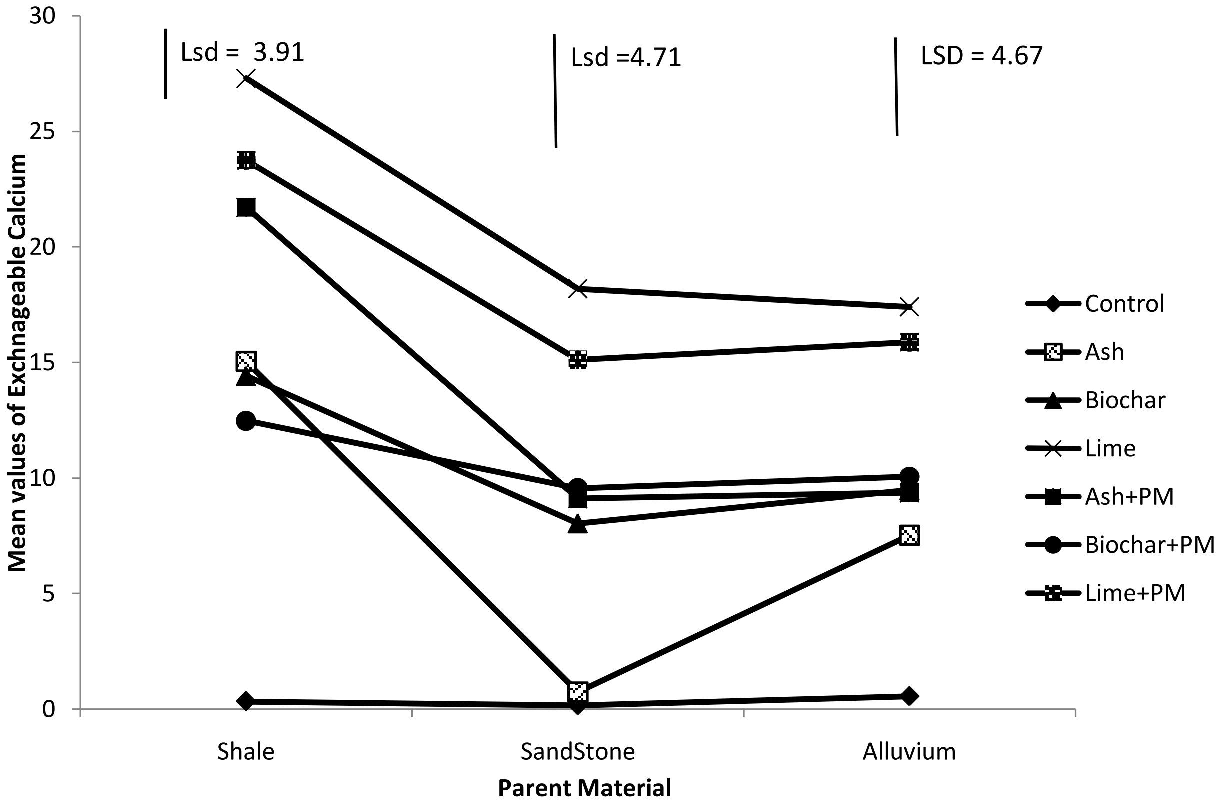

Fig 3: Mean amendments effect on soil exchangeable calcium (cmol kg^{-1}) of the three parent materials. Vertical bars represent Lsd at 0.05.

The result of the effect of means of weeks of incubation on exchangeable calcium of the three parent materials is presented on Fig 4. The result showed that Shale had higher exchangeable calcium values all through the weeks of the incubation. In Shale, the highest value for exchangeable calcium was obtained at two weeks of incubation and thereafter, the values started decreasing until the last week of the incubation. Whereas in Sand stone and Alluvium, the values started increasing from two weeks, got to their peak at the 8^{th} and 10^{th} week of incubation respectively, and subsequently decreased to the 12^{th} week.

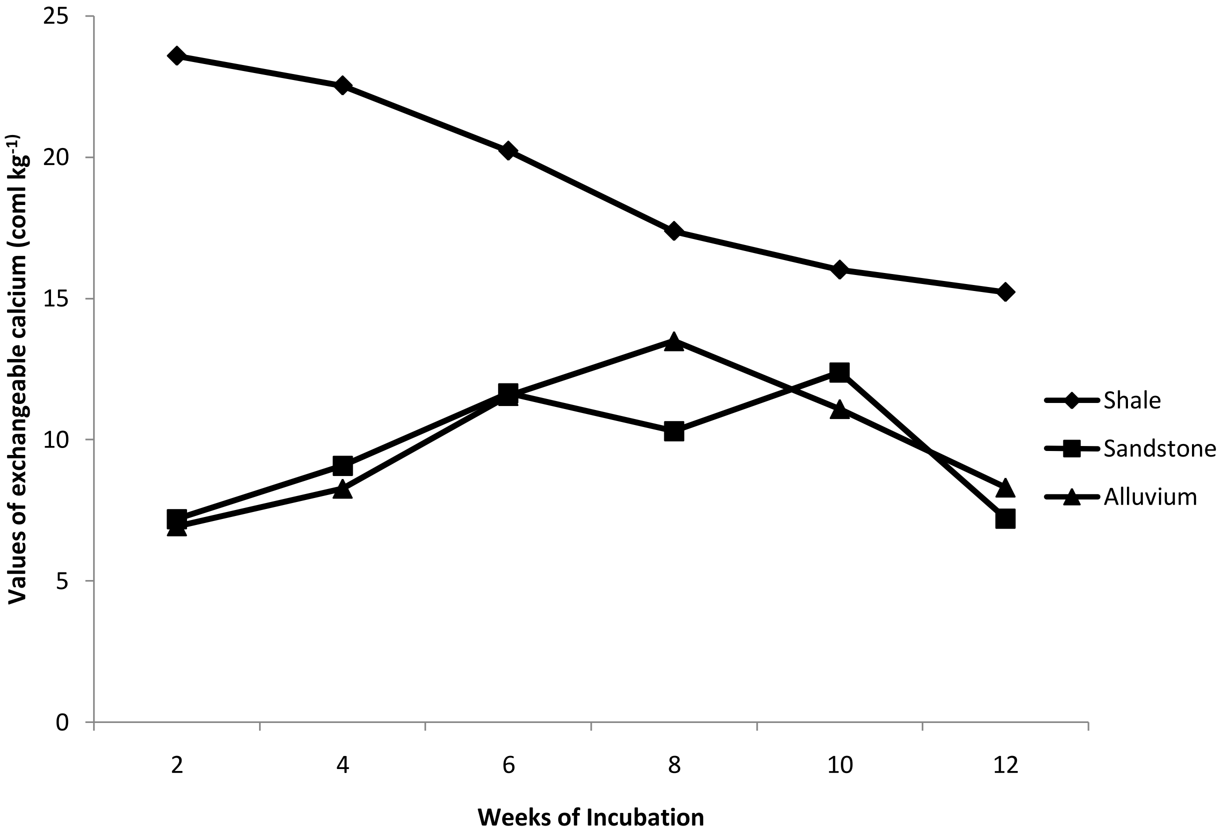

Fig 4: Effect of means of weeks of incubation on exchnageable calcium (cmol kg^{-1}) of the three parent materials.

Discussions

The low level of phosphorus recorded in this work agrees with the findings of Igwe, *et al.;* (2010), who studied Fe and Al distribution in some Ultisols and inceptisols of Southeastern Nigeria in relation to soil total phosphate. They observed from their results that the level of phosphorus was low. Phosphorus has been reported to be one of the limiting factors to crop production in Southeast of Nigeria. The reason for this is not farfetched; as the study areas has been reported to be acidic (Onwuka and Kanu, 2012). When the soil is acidic, the oxides of aluminum and iron fix phosphorus to form complexes that are insoluble (Lee, *et al.*, 2007) and thereby making phosphorus unavailable in the soil. Similarly, the exchangeable calcium values were low as shown on Table 2. The reason for the low level of exchangeable calcium could be attributed to crop uptake and leaching (Lekwa and Whiteside 1986), which is caused by heavy rainfall experienced in the area.

The increase in available phosphorus recorded in all the parent materials studied by the application of Biochar and Biochar+ PM agreed with the result of Hossain *et al*., (2010], who also observed in their work on the agronomic properties of wastewater sludge biochar and bioavailability of metals in production of cherry tomato (*Lycopersicon esculentum*), that there was an increased P availability in the presence of applied biochar. Lehmann *et al*., (2006) stated that phosphorus is made available in the soil by the biochar adsorbing the phosphate, thereby reducing the amount that would have been lost. The increase in the amount of the available phosphorus could be attributed to the combine effects of biochar and poultry manure as shown in their chemical composition on Table 1. The feedstock from which the biochar was produced would have had a part to play in increasing the amount of the phosphorus in the soil. Poultry manure has also been reported by Waldrip-Dail *et al.,* (2009) to increase the soil concentrations of both total and available P. Most researchers have reported that calcium precipitation with P occurs as Ca-P minerals and this decreases P availability (Lee *et al.,* 2007). Cui *et al*., (2011) reported that P sorption inducement occurs because the applied organic amendments increased the soil Ca-P fraction. This may be the reason why biochar and poultry were able to increase the amount of phosphorus because of the less amount of calcium (Table 1) they contain as compared to lime and ash.

The applied Lime increased the amount of the exchangeable calcium in the soil. The reason may also be attributed to the amount of calcium present in the lime used for the study as shown on Table 1. This agreed with the findings of Onwuka (2011) who worked on the chemical composition of different sources of liming materials and their effect on soil chemical properties. The researcher observed that lime had the highest amount of calcium as compared to the other liming materials studied. Lime has been reported to increase the amount of exchangeable calcium when added to the soil (Osundare, 2014).

The higher values for available P and exchangeable calcium recorded in Sandstones and Shale (Figures 1 and 3) could be attributed to their inherit properties (Table 2) which the application of the amendments improved upon. This result is in agreement with the findings of Onweremadu (2007), who also observed higher values of exchangeable calcium for Shale. The weathering processes, amount of clay, soil reaction etc., play important role in the chemical constituent of a parent material.

Conclusion

It could be deduced from this incubation study involving six soil amendments and three parent materials that the application of the soil amendments namely Ash, Lime, Biochar and their combinations with poultry manure increased the available phosphorus and exchangeable calcium studied. However, on the average, Biochar +Poultry manure increased the amount of available phosphorus in Sandstone, Shale and Alluvium while lime increased the exchangeable calcium in these soils. Since Biochar + Poultry manure on the other hand increased exchangeable calcium above the critical limit and at the same time, make Phosphorus available in the soil, it will be more appropriate to encourage the smallholder farmers to use Biochar in combination with poultry manure based on the result of this study. Further field work is critically important in order to verify this result and assess the potential from the synergy between biochar and poultry manure.

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