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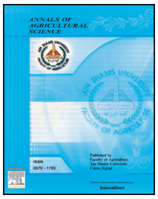

Productivity of pigeonpea genotypes as influenced by palm bunch ash and NPK fertiliser application and their residual effects on maize yield

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ABSTRACT

A field study was undertaken in the semi-deciduous forest agro-ecological zone of Ghana to assess the impact of palm bunch ash (PBA) and phosphorus and potassium (PK) fertiliser application on yield and key agronomic traits of three early maturing pigeonpea genotypes (ICPL 87091, ICPL 88034 and ICPL 88039), their residual effect on soil chemical properties and a succeeding maize crop grown in rotation. The results indicated that neither the genotype nor fertilisation had any significant effects on the grain yield of the pigeonpea genotypes. The total dry matter yield was significantly influenced by both genotype and fertilisation with the genotype ICPL 88034 significantly producing the highest dry matter (7.29 t ha^{-1}) while ICPL 88039 produced the lowest dry matter (4.95 t ha^{-1}). The PBA-treated plots produced significant dry matter yield compared with the control. Application of PBA also increased the pH of the experimental field from 5.19 to 5.82, 40 weeks after application with increase in available P and exchangeable cations (K, Ca and Mg) content of the soils. Yield of maize planted on pigeonpea plots previously fertilised with PBA was increased by 25% relative to yield of maize planted to pigeonpea on control plots. The study suggests that in the oil palm growing areas in Ghana where soils are acidic, PBA which are found in abundance could be used as a liming material and as organic fertiliser supplement to improve the yield of staple food crops.

1. Introduction

The potential of the semi-deciduous agro-ecological zone of Ghana for the production of major staple crops such as plantain, maize and cassava are hampered by poor soil fertility especially nitrogen (N) and phosphorus (P). In the past, farmers in this area relied on the extended bush fallowing system for maintaining the fertility of their soils. However, population-induced pressure on land has reduced the fallow period (Ahn, 1961). This problem is further compounded by competition for the limited land between food and tree crops, particularly cocoa, citrus and oil palm to the detriment of food crop production. This has led to a situation where the limited land reserved for food crop production is continuously being cropped without application of nutrients resulting in nutrient mining. Although, mineral fertilisers could improve crop nutrition, fertiliser use in Ghana is limited, averaging 7.42 kg/hectare/year which are among the lowest in Sub-Saharan Africa (MoFA, 2010). This is due to prohibitive cost as a consequence of removal of government subsidies (Gerner et al., 1995; MoFA, 2010). This situation necessitates an alternative means of improving the productivity of the land so that farmers can cultivate on the same piece of land for a longer period without degrading the soil.

In smallholder farming systems in Ghana, legumes can play a complementary role as source of organic fertiliser. Research in many parts of sub-Saharan Africa including Ghana has shown that legumes have the potential to sustain soil fertility in smallholder farming systems (Hughes and Venema, 2005; Adjei-Nsiah, 2006, 2012b). Pigeonpea (*Cajanus cajan* L. Mills.) has been found to have a great potential in this respect because of its ability to recycle nutrients and tolerate wide environmental conditions and low soil fertility (Hughes and Venema, 2005). The grain can be used for food and for sale. Pigeonpea is well balanced nutritionally and is an excellent source of proteins (20–30%) (Deshbhratar et al., 2010).

In addition, pigeonpea improves N availability for subsequent crops. The net-nitrogen contribution however depends on the amount of nitrogen fixed and the proportion of plant N that is harvested. In Ghana, Adjei-Nsiah (2006) estimated that pigeonpea can contribute up to 200 kg N ha^{-1} over a period of 16 months through N-fixation. Positive effects of grain legumes on yields of cereals grown in rotation may also

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be due to other non-nitrogen effects such as breaking of cereal pest and disease cycles (Francis and Clegg, 1990), soil structure improvement (Peoples and Craswell, 1992), enhanced P-availability through secretion of enzymes and acids in the legume rhizosphere (Schlecht et al., 2006), and enhanced arbuscular mycorrhizal colonisation (Harinikumar and Bagyaraj, 1988).

Pigeonpea genotypes are generally grouped into extra short duration (< 105 days), short duration (≈105–145 days), medium (≈146–199 days), and late maturing (> 200 days) genotypes (van der Maesen, 1980). Shorter-duration lines frequently are determinate, although indeterminate growth habit occurs across maturity groups. All the available pigeonpea genotypes in Ghana are late maturing indeterminate types that mature in about 260 days (Adjei-Nsiah, 2006). Although, these genotypes produce copious biomass, the yields of these genotypes are very low ranging from 0.5 to 1.0 ton ha^{-1}. New genotypes developed by breeding programmes by the International Crop Research Institute of the Semi-Arid Tropics (ICRISAT) in India have short duration, high yielding and resistant to most soil-borne diseases compared with the local landraces. Pigeonpea genotypes that combine a reasonable grain yield with a large volume of leaf biomass could offer a useful compromise to meeting farmers' food security needs and improving soil fertility.

Pigeonpea like other legumes makes very little demand on soil nitrogen but requires moderate amount of P and K for growth and yield. However, increasing K and P through mineral fertiliser application is difficult as these fertilisers are not readily available in rural markets, and smallholder farmers hardly apply mineral fertilisers to legumes. Most soils in the forest parts of southern Ghana are also acidic due to the nature of the parent material, high intensity of rainfall regime and associated leaching of nutrients (Adu-Dapaah et al., 1994; Obiri-Nyarko, 2012). This often results in a situation where most of the major nutrients become unavailable for plants uptake. Palm bunch ash (PBA) has been found to have high pH and contains varying amounts of other nutrients such as calcium (Ca), magnesium (Mg), potassium (K) and phosphorus (P) (Safo et al., 1997; Adjei-Nsiah, 2012a). This makes PBA a suitable material for reducing soil pH and raising the levels of other nutrients for uptake by crop plants.

In southern Ghana, where this study was undertaken, there is abundance of PBA generated through the burning of empty fruit bunches of oil palm which is 'an agro by-product' from small and medium scale processing of palm fruits into palm oil. Although, PBA could be used in the preparation of soap due to its high potassium content, it is currently not being utilised for any purpose resulting in several heaps of ashes in the area.

We evaluated the response of three early maturing pigeonpea genotypes to PBA and PK fertiliser application and their effect on soil physico-chemical properties of an acid soil in the semi-deciduous forest zone of Ghana. We also assessed the residual effect of the pigeonpea fertilisation on the growth and yield of a succeeding maize crop grown in rotation.

2. Materials and methods

2.1. Study site

The current study was undertaken at the Forest and Horticultural Crops Research Centre, Kade which lies within latitude 6°09′ and 6°06′ N and longitude 0°55′ and 0°49′ W in the Kwaebibrim district of the Eastern region of Ghana. The centre which is located in the semi-deciduous forest agro-ecological zone of Ghana is 135.9 m above sea level. The study site is characterised by a bi-modal rainfall pattern with peaks in June and October and a short break in August and a dry period from December to March. The total annual rainfall during the experimental period was 1677.9 mm. The soils at the experimental site which are mainly forest Ochrosol derived from precambium phyllitic rocks are deep, well-drained and are generally classified as Acrisols in the FAO-UNESCO Revised Legend (Ahn, 1961; FAO-UNESCO, 1998). The physico-chemical properties of the surface soil of the experimental plots are presented in Table 1.

Table 1
Physico-chemical properties of 0–20 cm layer of soil and PBA used for the experiment.

Soil Property	Soil	PBA
pH (1:1.25 H_2O)	5.09	10.89
Total Nitrogen (%)	0.24	0.08
Organic matter (%)	4.20	
Organic carbon (%)		0.55
Available P (mg kg^{-1} soil)	6.81	269.57
Sand	36	
Silt	53	
Clay	11	
	Exchangeable cations	
Calcium (Ca^{++})	3.56	34.93
Potassium (K^{+})	1.00	582.77
Magnesium (Mg^{++})	1.32	29.08

2.2. Experimental layout

The experimental plot which was dominated by *Chromolaena odorata* had been fallowed for 1 year. The *C. odorata* was initially cleared by slashing with a cutlass. Four weeks later, herbicide (glyphosate; 36% active ingredients) was applied at the rate of 2.5 L per hectare. Prior to clearing the field, surface soil (0–20 cm) and PBA samples were collected from the experimental site and analysed for both chemical and physical properties (Table 1).

2.3. Pigeonpea agronomic practices and field management

Three pigeonpea genotypes namely ICPL 87091, ICPL 88034 and ICPL 88039 obtained from the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) in India were planted between 14 and 15 June 2011. Treatments were randomised within four replicates. The pigeonpea was planted at 1 × 0.5 m at three seeds per hill. Two weeks later, pigeonpea was thinned to 1 seed per stand. The plot size was 12 × 8 m with 3 m paths between plots and replicates. Two weeks after planting, the pigeonpea plots were divided into three sub-plots with the treatments: 2 ton ha^{-1} PBA (4.8 kg plot^{-1}), 20 kg ha^{-1} PK (30–20) (48 g plot^{-1}) and control (without PK). Each sub-plot consisted of three rows of pigeonpea each measuring 8 m long leaving one row as border between treatments. The PBA and the PK-fertiliser were ring-applied around the plant and worked into the soil. Weeds were manually controlled at 3 weeks after planting and subsequently at 8, 13 and 21 weeks after planting (WAP). Insecticide (containing cypermethrin and dimethoate) was applied at 6 weeks after planting and at flowering to control insects.

2.3.1. Pigeonpea nodule assessment

At flowering, ten plants were randomly selected and tagged for growth and nodulation assessments. To prevent loss of some of the nodules to the soil, the sampled plants were carefully dug out together with a ball of earth around them. The plants together with the soil were placed in plastic buckets and sent to the laboratory. The number of nodules on each plant was recorded after careful search of the nodules was done on each plant and fresh weight taken by weighing them on an electronic scale. The nodules of each plant were put into labelled envelopes and oven-dried at 70 °C for 48 h. After assessing the nodules, each plant was separated into tops and roots and each portion chopped into pieces and placed in paper bags and oven-dried at 70 °C for 48 h to constant weight.

2.3.2. Pigeonpea yield assessment

At maturity, plants within an area of 5 m^2 were tagged for yield analysis. The pods were removed every two weeks, dried and shelled. The grains were then oven-dried at 70 °C for 48 h. A total of three harvests were done from Mid-November to December 2011 and a total of another three harvests also done from January to March 2012 and mean harvest yield was estimated. The fallen leaf litter was collected from around the ten tagged plants every month beginning from 21 weeks after planting.

2.3.3. Plant and soil analyses

All pigeonpea plant samples (stover and grains) were taken at harvest and analysed for N and P. The N was determined using micro-Kjeldahl method (Kjeldahl, 1883) and P by molybdenum blue calourimetric method (Ahn, 1961). Soil samples taken before the commencement of the experiment and at 40 weeks after fertilisation were analysed for pH, total N, organic matter, available P and exchangeable bases. Soil pH was determined in water suspension at 1: 1 and 1:2.25 ratios for soil and PBA, respectively; organic C by Walkley-Black procedure, total N by Kjeldahl method (Kjeldahl, 1883); available P by Bray-1 method and exchangeable bases (K, Na, Ca and Mg) by 1 M NH_4 OAC method (Page et al., 1982).

2.4. Planting of maize test crop

At 44 weeks after pigeonpea planting, the plants were cut down at the soil level and weighed. Sub-samples were taken for dry matter determination. The stover was left on the soil. Two weeks later, herbicide (glyphosate) was applied at the rate of 2.5 L/hectare. A local maize variety "Obaatampa" was planted on all plots at a spacing of 1 × 0.2 m with three seeds per hole. The maize pockets without germination were replanted 10 days after planting. The stand was thinned to one seed per stand two weeks later. All plots were then split into two sub-plots, with one plot receiving 200 kg NPK (15-15-15) per hectare while the other plot was without NPK (control). Weeds were manually controlled in the maize plots at 4 and 8 weeks after planting.

2.4.1. Maize chlorophyll content index and plant height determination

At 50% tasselling, the chlorophyll concentration of the maize was determined using a portable chlorophyll metre (Apogee Model CCM-200 plus, USA). Maize plant height was also measured from the ground level to the point of the plant from where the tassel emerges.

2.4.2. Maize yield assessment

At maturity, maize ears and stover were harvested from the three middle rows leaving 1 m border at both ends. The cobs were weighed and a sub-sample of 10 cobs per plot was taken, weighed and oven-dried at 70 °C for 2 days. The grains were then extracted and weighed again to determine the dry matter (DM). The stover was however, weighed in the fresh state and sub-sample taken to determine the DM.

2.5. Statistical analyses

Agronomic data collected for all plots were subjected to analysis of variance (ANOVA) using the GenStat statistical software package (version 9.2). The standard analysis procedure for split-plot in randomised complete block design (RCBD) (Gomez and Gomez, 1984) was followed. Least significant difference (LSD) test at 5% probability level was used to compare the treatment means.

3. Results and discussion

3.1. Soil physico-chemical properties

Results of the initial soil analysis for the experimental media are presented in Table 1. The soil of the experimental site was strongly acidic, moderately high in N and exchangeable Ca and Mg and low in organic matter (Hoskins, 1997; Hazelton and Murphy, 2007). The PBA used for the experiment was alkaline (pH, 10.89), very low in organic carbon and N (Hoskins, 1997) and contained relatively high values of K, P, Ca and Mg (Table 1). PBA has been reported to have high pH value (Safo et al., 1997; Awudin et al., 2007a; Adjei-Nsiah, 2012a). According to Safo et al. (1997) application of 4 mg kg^{-1} PBA could be as effective as lime in improving soil acidity in poorly buffered soils.

Table 2
Nodule number and nodule dry weight per plant of three pigeonpea genotypes as influenced by PBA and PK.

Genotype	PBA and PK fertilisation			Mean
	Control	2 ton ha^{-1} PBA	20 kg ha^{-1} PK (30–20)	
		Number of nodules		
ICPL 87091	18	31	29	26
ICPL 88034	24	44	40	36
ICPL 88039	24	47	41	37
Mean	22	41	37	
$LSD_{(0.05)}$: Genotype (G) = 2.1; PBA and PK fertilisation (PA) = 3.1 G × PA = NS				
		Nodule dry weight per plant (g)		
ICPL 87091	0.36	0.92	0.75	0.68
ICPL 88034	0.56	1.23	1.00	0.93
ICPL 88039	0.50	1.32	1.08	0.97
Mean	0.47	1.16	0.95	

$LSD_{(0.05)}$: Genotype (G) = 0.0816; PBA and PK fertilisation (PA) = 0.1008; G × FA = NS.

3.2. Nodulation in pigeonpea

Nodulation in the different pigeonpea genotypes differed significantly ($p \leq 0.05$) with the genotype ICPL 88039 producing the highest number of nodules while the genotype ICPL 87091 produced the lowest number of nodules (Table 2). Nodule dry weight also varied significantly among the different genotypes with ICPL 88039 having the highest weight while the ICPL 87091 had the least dry weight (Table 2). The differences in nodulation among the different genotypes could be attributed to differences in tolerance to environmental stress factors, particularly soil acidity. The existence of genetic variability for tolerance to most environmental stress factors has been shown in both legume host plants and their respective rhizobial strains (O'Hara et al., 2002). Acid tolerant host genotypes and inoculants strains have been used for reducing the negative effects of environmental stress on nodulation and nitrogen fixation in legumes (Serraj and Adu-Gyamfi, 2004).

Number of nodules and nodule dry weight were also significantly influenced by fertilisation. Number of nodules ranged from 22 with the control plots to 41 with plots that received PBA. Nodule dry weight was lowest in the control plots and highest in the PBA-amended plots. Several factors including soil acidity and mineral nutrition might have accounted for the differences in nodulation among the different fertilisation treatments. Several studies (Giller, 2001; Mapfumo et al., 2001; Brauer et al., 2002; Serraj and Adu-Gyamfi, 2004; Odeny, 2007; Egbe and Vange, 2008; Mohammadi et al., 2012) have demonstrated that acidic soils reduce nodulation and N_2-fixation in legumes. Reduced nodulation in acidic soils is partly attributed to lowered number of rhizobia but also because acidity impedes attachment of nodules to the roots (Mapfumo et al., 2001). N_2-fixation in acidic soils can be markedly reduced with the effect due to H^+ concentration, toxic levels of Al and Mn and deficiencies of Ca, P and Mo (Giller, 2001; Serraj and Adu-Gyamfi, 2004). Nodules are known to be important sinks for P and commonly have the highest concentration of that element in the plant (Sinclair and Vadez, 2002). Under deficient conditions, P fertilisation will usually culminate in enhanced nodule number, mass and

Table 3
Grain yield (kg ha^{-1}) of pigeonpea genotypes as influenced by PBA and PK in the early and late harvest.[a]

Genotype	PBA and PK fertilisation							
	Early harvest			Mean	Late harvest			Mean
	Control	PBA	PK		Control	PBA	PK	
ICPL 87091	0.18	0.38	0.22	0.26	0.82	1.09	0.69	0.87
ICPL 88034	0.78	1.00	1.18	0.99	0.82	0.87	0.80	0.83
ICPL 88039	0.51	0.89	0.76	0.72	0.86	1.04	0.79	0.89
Mean	0.49	0.76	0.72		0.83	1.00	0.76	

Early harvest: LSD $_{(0.05)}$; Genotype (G): 0.2455; PBA and PK-fertilisation (PF): G*PF: NS.

Late harvest: LSD $_{(0.05)}$; Genotype (G): NS; PBA and PK (PF): NS; G*PF: NS.

[a] After the first set of harvest from mid-November to December 2011, Pigeonpea plants flowered again and produced another set of grains which were harvested from January to March 2012.

significant N_2-fixation per plant and per gram of nodules (Serraj and Adu-Gyamfi, 2004). In this study, the PBA-amended plots which had high levels of P and Ca also had higher nodule number and nodule dry weight (Table 3) and hence it is possible that these might have influenced the high nodulation in the PBA-amended plots.

3.3. Grain, stover yield and harvest index in pigeonpea

The grain yield varied among the different genotypes although the differences were not significant (Tables 3 and 4). In the early harvest, there were significant differences among the treatments with respect to grain yield with the genotype ICPL 87091 producing the least grain yield while the genotype ICPL 88034 produced the highest yield but was not significantly different from the yield of the genotype ICPL 88039. The ICPL 87091 is a late maturing genotype and produced only few pods during the early harvest but flowered and produced substantial amount of pods during the late harvest. The total yield for the two harvests suggest that the genotype ICPL 88034 gave the highest grain yield while ICPL 87091 gave the least grain yield although the differences were not significant. Grain yield also differed among the different fertilisation treatments with the PBA amended-plots producing the highest grain yield of 1.76 t ha^{-1} but not significantly ($P \le 0.05$) different from that of the control (1.32 t ha^{-1}) and the PK-treated plots (1.48 t ha^{-1}). The grain yields reported in this study however compares favourably with yields reported in other parts of Africa (Hogh-Jensen et al., 2007; Egbe and Vange, 2008).

Table 4
Effect of fertilisation on dry matter accumulation and harvest index in three pigeonpea genotypes.

Genotype	Fertilisation			Mean
	Control	2 t ha^{-1} PBA	PK	
Stover dry matter (t ha^{-1})				
ICPL 87091	3.57	5.50	3.67	4.27
ICPL 88034	3.45	4.51	5.27	4.91
ICPL 88039	2.50	2.82	2.84	2.72
Mean	3.17	4.28	3.93	
LSD$_{(0.05)}$: Genotype (G) = 1.01; PBA and PK-fertilisation (PA) = NS; G*PA = 1.47				
Grain dry matter (t ha^{-1})				
ICPL 87091	1.00	1.48	0.91	1.13
ICPL 88034	1.60	1.87	1.98	1.82
ICPL 88039	1.37	1.92	1.56	1.62
Mean	1.32	1.76	1.48	
LSD$_{(0.05)}$: Genotype (G) = NS; PBA and PK-fertilisation (PA) = NS; G*PA = NS				
Litter dry matter (t ha^{-1})				
ICPL 87091	1.56	1.97	1.86	1.80
ICPL 88034	0.69	0.93	1.12	0.91
ICPL 88039	0.57	0.74	0.55	0.62
Mean	0.94	1.21	1.18	
LSD$_{(0.05)}$: Genotype (G) = 0.42; PBA and PK-fertilisation (PA) = NS; G*A = NS				
Total dry matter (t ha^{-1})				
ICPL 87091	6.12	8.95	6.45	7.17
ICPL 88034	5.73	7.31	8.83	7.29
ICPL 88039	4.43	5.48	4.95	4.95
Mean	5.43	7.24	6.74	
LSD$_{(0.05)}$: Genotype (G) = 1.90; PBA and PK-fertilisation (PA) = 1.30; G*PA = NS				
Harvest index				
ICPL 87091	0.17	0.16	0.14	0.16
ICPL 88034	0.28	0.25	0.23	0.25
ICPL 88039	0.31	0.33	0.33	0.32
Mean	0.25	0.25	0.23	

LSD$_{(0.05)}$: Genotype (G) = 0.066; PBA and PK-fertilisation (PA) = NS; G*PA = NS

Total above-ground dry matter varied significantly ($P \le 0.05$) among the different genotypes. Total dry matter for the different genotypes were 4.95; 7.17 and 7.29 tons/ha for ICPL 88039, ICPL 87091 and ICPL 88034, respectively (Table 4). Fertilisation also significantly influenced the total dry matter with the PBA-amended plots producing the highest total dry matter of 7.24 t ha^{-1} while the control plots produced the least total dry matter of 5.43 t ha^{-1}. The stover made the highest contribution to the total dry matter while the litter made the least contribution to the total dry matter.

The dry matter (DM) harvest index (HI) varied significantly among the different genotypes (Table 4). ICPL 87091 which had the lowest grain yield also had the lowest HI while ICPL 88039 which had the least stover and litter DM had the highest HI. Due to its low HI in terms of DM, ICPL 87091 could contribute to the soil fertility due to the higher proportion of its non-edible crop organs especially the stover and the litters that are returned to the soil (Hogh-Jensen et al., 2007). Thus, pigeonpea genotypes that combine a reasonable grain yield with a large volume of leaf biomass could offer a useful compromise to meeting farmers' food security needs while improving soil fertility.

3.4. Nitrogen and phosphorus accumulation in pigeonpea

The accumulation of N in the grain did not differ significantly ($P \le 0.05$) among the different genotypes although ICPL 88034 gave the highest grain N (Table 5). Grain N (kg ha^{-1}) across the different fertiliser treatments was 47.3 for the control plot, 52 for the PK-treated plot and 60.9 for the PBA-amended plots although the differences were not significant ($P \le 0.05$). Significant proportion of the plant N was however accumulated in the stover with ICPL 88034 accumulating the highest amount of N while ICPL 88039 accumulated the least amount of N. Fertilisation also significantly ($P \le 0.05$) influenced N accumulation in the stover. Stover N was 86.5 kg ha^{-1} for the control, 130.1 for the PK-treated plots and 130.7 for the PBA-amended plots. Pigeonpea is known to contribute substantially to soil fertility through its leaf litters as well as through return of stover to the soil because of the high nitrogen content of the leaves (Adjei-Nsiah, 2012a).

Phosphorus concentration in the grain was not significantly influenced by genotype although the genotype ICPL 88034 appeared to have the highest P concentration in the grain while the genotype ICPL 88039 appeared to have the least grain P concentration. Phosphorus accumulation in the stover was however significantly influenced by genotype. The genotype ICPL 87091 had the highest P concentration in the stover while the genotype ICPL 88039 had the least stover P concentration.

3.5. Effect of PBA and PK-fertilisation on soil nutrient status

The pH of the soils used for the field experiment was 5.19 (Table 1) which suggests that the soil was strongly acidic. Forty weeks after application of the PK and PBA, the pH of the control and the PK-treated plots did not change very much while that of the PBA-amended plots

Table 5
Effect of fertilisation on N and P accumulation in three pigeonpea genotypes.

Genotype	Fertilisation			Mean
	Control	2 t ha^{-1}PBA	PK	
		Stover N (kg ha^{-1})		
ICPL 87091	97.4	180.6	121.4	133.2
ICPL 88034	96.5	128.6	186.3	137.1
ICPL 88039	65.7	82.8	82.5	77.0
Mean	86.5	130.7	130.1	
LSD$_{(0.05)}$: Genotype (G) = 36.03; PBA and PK-fertilisation (PA) = 31.49; G*PA = 53.36				
		Grain N (kg ha^{-1})		
ICPL 87091	32.6	48.0	31.1	37.2
ICPL 88034	59.4	65.2	68.6	64.4
ICPL 88039	49.8	69.5	56.3	58.6
Mean	47.3	60.9	52.0	
LSD$_{(0.05)}$: Genotype (G) = NS; PBA and PK-fertilisation (PA) = NS; G*PA = NS				
		Stover P (kg ha^{-1})		
ICPL 87091	8.99	16.60	11.23	12.28
ICPL 88034	7.75	11.32	13.92	11.00
ICPL 88039	5.82	7.37	7.95	7.05
Mean	7.52	11.76	11.03	
LSD$_{(0.05)}$: Genotype (V) = 0.42; PBA and PK-fertilisation (PA) = NS; G*PA = NS				
		Grain P (kg ha^{-1})		
ICPL 87091	6.12	8.95	6.45	7.17
ICPL 88034	5.73	7.31	8.83	7.29
ICPL 88039	4.43	5.48	4.95	4.95
Mean	5.43	7.24	6.74	

LSD$_{(0.05)}$: Genotype (G) = NS; PBA and PK-fertilisation (PA) = NS; G*PA = NS.

Table 6
Effect of PK and PBA application on soil chemical properties of the experimental field 40 weeks after planting.

Genotype	PK and PBA Application			Mean
	Control	PK	2 t ha^{-1} PBA	
		pH		
ICPL 87091	5.13	5.20	5.79	5.37
ICPL 88034	5.11	5.15	5.77	5.34
ICPL 88039	5.15	5.21	5.88	5.21
Mean	5.13	5.19	5.81	
LSD$_{(0.05)}$: Genotype (G) = NS; PBA and PK-fertilisation (PF) = 0.048; G*PF = NS				
		Organic matter (%)		
ICPL 87091	2.29	2.42	2.62	2.45
ICPL 88034	2.29	2.45	2.67	2.46
ICPL 88039	2.24	2.45	2.59	2.43
Mean	2.26	2.44	2.63	
LSD$_{(0.05)}$: Genotype (G) = NS; PBA and PK-fertilisation (PF) = 0.04; G*PF = 0.0582				
		Total N (%)		
ICPL 87091	0.28	0.32	0.43	0.34
ICPL 88034	0.29	0.34	0.38	0.34
ICPL 88039	0.25	0.33	0.39	0.32
Mean	0.27	0.33	0.40	
LSD$_{(0.05)}$: Genotype (G) = NS; PBA and PK-fertilisation (PF) = 0.0149; G*PF = 0.0286				
		Available P (ppm)		
ICPL 87091	6.35	8.60	9.37	8.11
ICPL 88034	6.51	12.64	11.61	10.26
ICPL 88039	6.54	12.91	12.56	10.67
Mean	6.47	11.39	11.18	
LSD$_{(0.05)}$: Genotype (G) = 1.068; PBA and PK-fertilisation (PF) = 1.321; G*PF = NS				
		Exchangeable K (Me/100 g)		
ICPL 87091	0.84	1.25	1.28	1.13
ICPL 88034	0.96	1.06	1.14	1.05
ICPL 88039	1.01	1.06	1.10	1.05
Means	0.94	1.12	1.17	
LSD$_{(0.05)}$: Genotype (G) = 0.0381; PBA and PK-fertilisation (PF) = 0.0654; G*PF = 0.0970				
		Exchangeable Ca (Me/100 g)		
ICPL 87091	3.10	3.20	4.14	3.48
ICPL 88034	3.16	3.49	4.08	3.58
ICPL 88039	2.95	3.22	3.88	3.35
Mean	3.07	3.30	4.03	
LSD$_{(0.05)}$: Genotype (G) = 0.126; PBA and PK-fertilisation (PF) = 0.089; G*PF = 0.164				
		Exchangeable Mg (Me/100 g)		
ICPL 87091	1.79	2.75	3.46	2.67
ICPL 88034	1.41	2.38	3.52	2.44
ICPL 88039	1.37	2.50	3.44	2.43
Mean	1.52	2.54	3.47	

LSD$_{(0.05)}$: Genotype (G) = 0.060; PBA and PK-fertilisation (PF) = 0.073; G*PF = 0.114.

increased to 5.82 (Table 6). The increase in the pH level of the soil after the application of the PBA may be ascribed to the high pH level of the PBA. PBA is alkaline and contains relatively high amounts of Ca and Mg and thus has a liming effect on the soil. The increase in pH was also due to decrease in Al^{3+} as a result of precipitation of Al as hydroxyl–Al (Mbah et al., 2010) as ash has been found to contain oxides and hydroxides of potassium, sodium, calcium and magnesium (Demeyer et al., 2001) resulting in low exchangeable acidity in the ash-amended plots (Table 6). This could also be responsible for the significantly higher potassium, calcium and magnesium levels in the PBA-amended plots compared with the control and the PK-treated plots (Table 6) (Adekayode and Ololuba, 2010). The high soil OM and nutrient content of the PBA-treated plots compared with the control also confirms the findings of Awudin et al. (2007b) and Bougnom et al. (2009) who observed significant increase in OM and nutrient content of acidic soils after application of PBA. The increased available P content of the soil with increased application of PBA could be attributed to release of complexes of Al and Fe under increasing soil pH (Mbah et al., 2010). The increase in soil nutrients as a result of application of PBA could also be ascribed to increased microbial activities in the soil and increased OM production with its resultant increased availability of N, P, K and Mg (Saarsalmi et al., 2001; Ojeniyi et al., 2009, 2010).

3.6. Residual effect of pigeonpea genotype and fertilisation with PBA and PK and NPK fertiliser application to subsequent maize grown in rotation on its yield

3.6.1. Maize leaf chlorophyll content index at 50 % tasselling

The results of the residual effect of pigeonpea genotype and its fertilisation with PBA and PK and NPK fertiliser application to maize on its leaf chlorophyll content index (CCI) at 50% tasselling are presented in Table 7, which shows that while pigeonpea genotype did not influence maize leaf CCI at 50% tasselling, soil amendment with PBA and PK significantly ($P < 0.001$) influenced maize leaf CCI at 50% tasselling with maize grown on plots that were previously fertilised with PBA having the highest leaf CCI. Application of NPK fertiliser to the maize also significantly influenced maize CCI with the plots that received 200 kg NPK ha^{-1} having higher CCI. There was also significant interaction between previous soil amendment and NPK application to maize. The higher maize leaf CCI recorded by maize grown on plots that were previously fertilised with PBA and/or received NPK fertiliser is an indication of high nitrogen uptake by the maize since nitrogen has been found to be the major constituent of chlorophyll (Baharvand et al., 2014). Studies by Hokmalipour and Darbandi (2011), Baharvand et al. (2014) and Rao et al. (2017) have shown that nutrient application to maize results in higher maize leaf CCI. Application of PBA is known to increase soil nutrient content due to increased microbial activities resulting in enhanced soil organic carbon with its associated increase in N, P, K and Mg (Mbah et al., 2010). Thus, the higher nutrient content of the PBA applied plots enhanced nutrient uptake by the maize thereby resulting in the higher CCI. The higher CCI resulted in better growth and significant yield of maize that were planted on plots that were previously amended with PBA and or received NPK fertiliser (Table 7).

3.6.2. Growth and grain yield of maize

Table 8 shows the results of the effect of pigeonpea genotype and

Table 7

Residual effects of pigeonpea and its fertilisation with PBA and PK and NPK fertiliser application to subsequent maize grown in rotation on leaf chlorophyll content index (CCI) of maize at 50% tasselling.

Genotype	PBA and PK fertilisation								
	2 t ha^{-1} PBA		Mean	*PK (30–20)		Mean	Control		Mean
	0 kg N ha^{-1}	200 kg NPK ha^{-1}		0 kg N ha^{-1}	200 kg NPK ha^{-1}		0 kg NPK ha^{-1}	200 kg NPK ha^{-1}	
	Chlorophyll content index (CCI)								
ICPL 87091	35.74	43.23	39.49	32.28	43.56	37.92	30.65	45.84	38.25
ICPL 88034	38.25	45.55	41.90	31.78	44.06	37.92	27.14	40.37	33.76
ICPL 88039	37.87	45.59	41.73	30.85	38.04	34.45	31.28	41.33	36.31
Mean	37.29	44.79	41.04	31.64	41.89	36.76	29.69	42.50	36.11

LSD$_{(0.05)}$: Pigeonpea genotype (PG) = NS; PBA and PK-fertilisation (PF) = 1.86; mineral fertiliser application to maize (MFA) = 1.4; PG*PF = 3.96; PG*MFA = NS; PG*PF*MFA = NS.

PBA and PK fertilisation and mineral fertiliser (NPK 15-15-15) application on the growth and yield of maize. Both plant height and the number of days to tasselling was not significantly influenced by pigeonpea genotype. Pigeonpea fertilisation with PBA and PK and application of mineral fertiliser to the maize however significantly ($P \leq 0.05$) influenced plant height and number of days to tasselling. Maize on the plots that previously received PBA tasselled first and produced taller plants, followed by maize planted on plots that previously received PK fertilisation. Maize plots that received mineral fertiliser also tasselled earlier and produced taller plants than those that did not received any mineral fertiliser. The results of the effect of pigeonpea genotype, previous fertilisation as well as maize fertilisation on maize grain yield followed the same pattern as those of the effects on leaf CCI and plant growth. Grain yield increased by 25% on the plots that previously received PBA application compared with the pigeonpea plots that did not receive any fertilisation and by 20% over the plots that received PK-fertilisation. The improved plant growth (early tasselling and taller plants) and higher grain yield of maize grown on plots previously cropped to pigeonpea that was fertilised with PBA was due to improved nutrition. At the same location, Adjei-Nsiah (2012a) reported improved plant growth and increased maize grain yield when maize received 2 t ha^{-1} PBA. Application of PBA is known to increase soil nutrient content due to increased microbial activities resulting in enhanced soil organic carbon with its associated increase in N, P, K and Mg (Mbah et al., 2010). Owing to its high pH, PBA also results in release of P from complexes of Al and Fe thereby making P available for uptake by plants. In the present study the results show that treatments that received PBA had significantly higher soil pH, soil N, soil available P as well as higher exchangeable K, Mg and Ca compared with the control plots (Table 8). Application of 200 kg ha^{-1} NPK (15-15-15) to the maize effected about 44% increase in maize yield, an indication that the soil nutrient level was still not adequate for maize production in spite of the increased nutrient level of the soil after fertilisation with the PBA or PK.

4. Conclusion

The results of the study suggest that while pigeonpea fertilisation with PBA may not significantly increase grain yield in pigeonpea, it can significantly enhance nodulation and increase nitrogen fixation in pigeonpea on acid soils. Moreover, PBA application may increase soil pH and exchangeable bases and release P from complexes of Al and Fe under increasing pH making it available for use by subsequent plants grown in rotation. The study also shows that maize could exploit the residual effects of pigeonpea fertilisation due to improved nutrition and availability of nutrients from PBA application for increasing yield.

Table 8

Effect of pigeonpea genotype and its fertilisation with PBA and PK and NPK fertiliser application to subsequent maize grown in rotation on growth and yield of the maize.

Genotype	PBA and PK fertilisation								
	2 t ha^{-1} PBA		Mean	*PK (30–20)		Mean	Control		Mean
	0 kg NPK ha^{-1}	200 kg NPK ha^{-1}		0 kg NPK ha^{-1}	200 kg NPK ha^{-1}		0 kg NPK ha^{-1}	200 kg NPK ha^{-1}	
	Number of days to 50% tasselling								
ICPL 87091	48	44	46	49	44	47	52	46	49
ICPL 88034	49	45	47	50	45	48	51	47	49
ICPL 88039	49	45	47	51	47	49	52	48	50
Mean	49	45	47	50	45	48	52	47	49
LSD$_{(0.05)}$: Pigeonpea genotype (PG) = NS; PBA and PK-fertilisation (PF) = 1.33; mineral fertiliser application to maize (MFA) = 0.56; PG*PF = NS; PG*MFA = NS; PG*PF*MFA = N									
	Plant height (cm) at 50% tasselling								
ICPL 87091	289.7	299.3	294.5	274.8	294.4	284.6	260.5	287.8	274.2
ICPL 88034	280.8	300.2	290.5	267.2	296.0	281.6	266.4	292.6	279.5
ICPL 88039	266.8	304.7	285.8	251.5	280.2	265.9	263.3	287.8	275.6
Mean	279.1	301.4	290.3	264.5	290.2	277.4	263.4	289.4	276.4
LSD$_{(0.05)}$: PG = NS; PF = 9.47; MFA = 5.15; PG*PF = NS; PG*NFA = NS; PG*PF*MFA = NS									
	Maize grain yield (t ha^{-1}) at 12% moisture content								
ICPL 87091	3.44	3.88	3.66	2.52	3.72	3.12	2.10	4.55	3.33
ICPL 88034	3.16	4.35	3.76	2.38	4.26	3.32	2.55	3.42	2.99
ICPL 88039	3.19	4.80	4.00	2.70	3.46	3.08	2.52	3.08	2.80
Mean	3.26	4.34	3.81	2.53	3.81	3.17	2.39	3.68	3.04

LSD$_{(0.05)}$: PG = NS; PF = 0.42; NFA = 0.35; PG*PF = NS; PG*NFA = NS; PG*PF*NFA = 0.84; PG*PF*NFA = 0.54; PG: pigeonpea genotype; PF: PBA and PK fertilisation; MFA: mineral fertiliser application *0-30-20 kg N-P_2O_5-K_2O.

References

Adekayode, F.O., Ololuba, M.R., 2010. The utilisation of wood ash as manure to reduce the use of PK-fertiliser for improved performance of maize (*Zea mays* L.) as measured in the chlorophyll content and grain yield. J. Soil. Sci. Environ. Manag. 1, 40–45.

Adjei-Nsiah, S., 2006. Cropping systems, land tenure and social diversity of Wenchi, Ghana: implications for soil fertility management. PhD Thesis. Plant Production Systems Group, Wageningen University and Research Centre, The Netherlands. pp. 47.

Adjei-Nsiah, S., 2012a. Response of maize (*Zea mays* L.) to different rates of palm bunch ash application in the semi-deciduous forest agro-ecological zone of Ghana. Appl. Environ. Soil Sci (Article ID: 870948).

Adjei-Nsiah, S., 2012b. Evaluating sustainable cropping sequences with cassava and three grain legume crops: effects on soil fertility and maize yields in the semi–deciduous forest zone of Ghana. J. Soil. Sci. Environ. Manag. 3, 49–55.

Adu-Dapaah, H.K., Cobbina, J., Asare, E.O., 1994. Effect of cocoa pod ash on maize growth. J. Agric. Sci. 122, 31–33.

Ahn, P.M., 1961. Soils of the Lower Tano Basin. South Western Ghana, Accra, pp. 73–87.

Awudin, M.A., Ojeniyi, S.O., Adeboye, A., Odedina, A.S., 2007a. Effect of oil palm bunch ash on soil and plant nutrient composition and yield of maize. Am.-Eurasian J. Sust. Agric. 1, 50–54.

Awudin, M.A., Otaru, M.S., Ojeyi, S.O., 2007b. Effect of saw dust ash plus urea on maize performance and nutrient status. Asian. J. Agric. Res. 1, 27–30.

Baharvand, Z.A., Zahedi, H., Rafiee, M., 2014. Effect of vermicompost and chemical fertilisers on growth parameters of three corn cultivars. J. Appl. Sci. Agric. 9, 22–26.

Bougnom, B.P., Mair, J., Etoa, F.X., Insam, H., 2009. Composts with wood ash addition: a risk or a chance for ameliorating acid tropical soils. Geoderma 153, 402–407.

Brauer, D., Ritchey, D., Belesky, D., 2002. Effects of lime and calcium on root development and nodulation of clovers. Crop Sci. 42, 1640–1646.

Demeyer, A.V., Nkana, J.C., Verloo, M.G., 2001. Characteristics of wood ash and influence on soil chemical properties and nutrient uptake: an overview. Bioresour. Technol. 77, 287–295.

Deshbhratar, P.B., Singh, P.K., Jambhulkar, A.P., Ramteke, D.S., 2010. Effect of sulphur and phosphorus on yield, quality and nutrient status of pigeonpea (*Cajanus cajan*). J. Environ. Bio. 31, 933–937.

Egbe, O.M., Vange, T., 2008. Yield and agronomic characteristics of 30 pigeon pea genotypes at Otobi in Southern Guinea Savanna of Nigeria. Life Sci. J. 5, 70–80.

FAO-UNESCO, 1998. FAO UNESCO soil map of the world. World soil resources report, Rome.

Francis, C.A., Clegg, M., 1990. Crop rotation in sustainable production systems. In: Edwards, C.A., Lal, R., Madden, P., Miller, R.H., House, G. (Eds.), Sustainable agricultural systems. Soil and Water Conservation Society, Ankeny, IA, USA, pp. 107–122.

Gerner, H., Asante, E.O., Owusu-Benoah, E., Marfo, K., 1995. Ghana fertiliser privatisation scheme. Private sector role and public sector responsibility in meeting needs of farmers. IFDC-Africa, Lome, Togo, pp. 7.

Giller, K.E., 2001. Nitrogen Fixation in Tropical Cropping Systems, second ed. CAB International, Wallingford.

Gomez, K.A., Gomez, A.A., 1984. Statistical Procedures for Agricultural Research, Second ed. John Willey & Sons, Toronto.

Harinikumar, K.M., Bagyaraj, D.J., 1988. Effect of crop rotation on native vesicular arbuscular mycorrhizal propagules in soil. Plant Soil. 110, 77–80.

Hazelton, P., Murphy, B., 2007. Interpreting Soil Test Results: What do all the Numbers Mean? CSIRO Publishing, Australia p. 7.

Hogh-Jensen, H., Myaka, F.A., Sakala, W.D., Kamalongo, D., Ngwira, A., Vesterager, J.M., Odgaard, R., Adu-Gyamfi, J.J., 2007. Yield and qualities of pigeonpea genotypes grown under smallholder farmers' conditions in Eastern and Southern Africa. Afr. J. Agric. Res. 2, 269–278.

Hokmalipour, S., Darbandi, M.H., 2011. Effects of nitrogen fertiliser on chlorophyll content and other leaf indicates in three cultivars of maize (*Zea mays* L.). World Appl. Sci. J. 15, 1780–1785.

Hoskins, B.R., 1997. Soil Testing Handbook for Professionals in Agriculture, Horticulture, Nutrient and Residuals Management, third ed. University of Maine, Orono, Maine.

Hughes, O., Venema, J.H., 2005. Integrated soil, water and nutrient management in semi-arid Zimbabwe. Farmer Field Schools Facilitators' Manual, vol. 1. FAO, Harare, Zimbabwe.

Kjeldahl, J.Z., 1883. A New Method for the Determination of Nitrogen in Organic Bodies. Zeitschrift für analytische Chemie [Analytic. Chem.] 22, 366–382.

Mapfumo, P., Campbell, B.M., Mpepereki, S., Mafongoya, P., 2001. Legumes in soil fertility management: the case of pigeonpea in smallholder farming systems of Zimbabwe. Afr. Crop. Sci. J. 9, 629–644.

Mbah, C.N., Nwite, J.N., Njoku, C., Nweke, I.A., 2010. Response of maize (*Zea mays* L.) to different rates of wood-ash application in acid ultisol in Southeast Nigeria. Afr. J. Agric. Res. 5, 580–583.

MoFA, 2010. Agriculture in Ghana: facts and figures, Accra. Available at: < https://s3.amazonaws.com/ndpc-static/Caches/Publications/2016/04/16/Agriculture-in-Ghana-Facts+and+Figures-2010.pdf > (accessed October 19, 2016).

Mohammadi, K., Sohrabi, Y., Heidari, G., Khalesro, S., Majidi, M., 2012. Effective factors on biological nitrogen fixation. Afr. J. Agric. Res. 7, 1782–1788.

Obiri-Nyarko, F., 2012. Ameliorating soil acidity in Ghana: a concise review of approaches. ARPN J. Sci. Techno. 2, 143–153.

Odeny, D.A., 2007. The potential of pigeonpea (*Cajanus cajan* L. Millsp.) in Africa. Natural Resour. Forum 31, 297–305.

O'Hara, G.W., Yates, R., Howieson, J., 2002. Selection of strains of root nodule bacteria to improve inoculant performance and increase legume productivity in stressful environments. In: Herridge, D. (Ed.), Inoculants and Nitrogen Fixation of Legumes in Vietnam, ACIAR Proceedings 109e, pp 75–80.

Ojeniyi, S.O., Awanlemhen, B.C., Adejoro, S.A., 2010. Soil plant nutrient and maize performance as influenced by oil palm bunch ash plus NPK fertiliser. J. Am. Sci. 6, 456–460.

Ojeniyi, S.O., Ezekiel, P.O., Asawalam, D.O., Awo, A.O., Odedina, S.A., Odedina, J.N., 2009. Root growth and NPK status of cassava as influenced by oil palm bunch ash. Afr. J. Biotech. 8, 4407–4412.

Page, A.L., Miller, R.H., Keeney, D.R., 1982. Methods of Soil Analysis: Chemical and Microbiological Properties. American Society of Agronomy Inc Soil Science Society of America Inc, Madison, Wisconsin, USA.

Peoples, M.B., Craswell, E.T., 1992. Biological nitrogen fixation: investments, expectations and actual contributions to agriculture. Plant Soil. 141, 13–39.

Rao, P.L., Jayasree, G., Prakash, T.R., 2017. Effect of soil amendments on texture, porosity of soil and chlorophyll content in maize. J. Pharmacogn. Phytochem. 6, 435–437.

Saarsalmi, A., Mälkönen, E., Piirainen, S., 2001. Effects of wood ash fertilisation on forest soil chemical properties. Silva Fennica. 35, 355–368.

Safo, E.Y., Ankomah, A.B., Branford-Arthur, J., 1997. Palm bunch ash effects on growth of cowpea and the characteristics of a Ghanaian soil. Afr. Crop. Sci. J. 5, 303–308.

Schlecht, E., Buerkert, A., Tielkes, E., Bationo, A., 2006. A critical analysis of challenges and opportunities for soil fertility restoration in Sudano-Sahelian West Africa. Nutr. Cycl. Agroecosys. 76, 109–136.

Serraj, R., Adu-Gyamfi, J., 2004. Role of symbiotic nitrogen fixation in the improvement of legume productivity under stressed environments. West Afr. J. Appl. Ecol. 6, 95–109.

Sinclair, T.R., Vadez, V., 2002. Physiological traits for crop yield improvement in low N and P environments. Plant Soil. 245, 1–15.

van der Maesen, L.J.G., 1980. India is the native home of pigeonpea. In: Arends, J.C., Boelema, G., de Groot C.T., Leeuwenberg, A.J. (Eds.), Liber Gratulatorius in Honorem HCD de Wit, Land Bouwhoge School Miscellaneous Paper No 19. pp. 257–262.