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Growth and yield responses of cowpea genotypes to soluble and rock P fertilizers on acid, highly weathered soil from humid tropical West Africa

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ABSTRACT

Soils in tropical regions have inadequate levels of phosphorus and this apparently leads to reduced cowpea yield in Africa. Identifying phosphorus-efficient cultivars have the potential to reduce the demand for phosphorus fertilizer and increase the productivity of cowpea. This study was conducted to identify cowpea genotypes that maintain high yields under low soil phosphorus condition. A green-house experiment was conducted at the International Institute of Tropical Agriculture, Ibadan, Nigeria. Fifteen cowpea genotypes were used with two sources of phosphorus fertilisers: rock phosphate (60, 90 and 120 mg P kg^{-1} soil) and mono potassium phosphate (30, 60 and 90 mg P kg^{-1} soil) and compared to the control. The experiment was laid out in a strip plot arrangement with three replications. The findings suggested that large geneticvariability exist among the tested cowpea genotypes. IT90K-59 was identified as best phosphorus responder genotype for biomass production and IT90K-76 for grain yield at a rate of 60 mg P kg^{-1} soil as mono potassium phosphate .Danila and IT89KD-288 were identified as promising genotypes under no or minimal external P application. Five genotypes were identified as good responders to rock phosphate based on their grain yield production. The differential response of the genotypes to low soil phosphorus implies that these traits warrant effective selection for further improvement. Thus, identifying genotypes that can grow well in low phosphorus condition has the potential to reduce the quantity of mineral fertilizersand cost of production.

Keywords: Rock phosphate, mono potassium phosphate, Alfisol soil.

INTRODUCTION

Cowpea (*Vigna unguiculata* L. Walp) is one of the most ancient crops and it is widely cultivated around the world especially in the tropics and subtropics basically for seed and vegetable (Ali et al., 2004 cited by Basaran et al., 2011). The grain crop is used and grown predominately in Sub-Saharan

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Africa because it produces seed with high protein content (20% to 25%) as well as considered as nutritional supplement to cereals for human consumption which is more economical than animal protein for smallholder farmers and rural dwellers (Singh et al 2003). The crop also plays an important role in biological nitrogen fixation, by fixing considerable amounts of nitrogen (N) biologically in the range of 3-254 kg Nha^{-1} per year (Sanginga et al., 2000) with subsequent residual effect of nitrogen on succeeding crops.

One of the constraints to high productivity of cowpea is poor soil fertility, notably the low level of available phosphorus (P) such that cowpea responses to P fertilizer are widespread (Sanginga et al., 2000). Phosphorus deficiency is usually the most determining factor for poor yield of legume crops on most of the tropical soils because apart from playing an essential role in root development, phosphorus is needed for growth of rhizobium bacteria responsible for nitrogen fixation. Atmospheric nitrogen fixed by cowpea improves soil fertility (Krasilnikoff et al., 2003) but only in conjunction with the synergistic effect of P. However, the efficient use of soluble P Different management systems involving the use of low-input strategies have been identified to address P fertilization problems in tropical acidic soils through the direct application of rock phosphate (PR) and also the selection of crops with a high potential to absorb and use partially soluble fertilizers (Sanchez and Uehara, 1980 cited by Ankomah et al., 1995). Apart from PR being a cheaper source per kg of P, phosphate fertilizer from PR is effective under acidic conditions in tropical soils. In order to mitigate the growing shortage of phosphate fertilizers in the near future and to save costs for small-scale farmers, exploring the genetic resource of crops is an alternative way to utilize the small amounts of less available P in soils more efficiently(Gweyi-onyango et al., 2011). Strategies to overcome P deficiency demand better understanding of genotypic differences in adaptation to low P environments in order to upsurge the production of cowpea (Nwoke et al., 2005). The implication is that any promising genotype identified can be crossed with another to transfer the gene controlling factor for high capability for using P in low-P soils (Polle and Konzack, 1990 cited by Saidou et al., 2012). While genotypic differences in the efficiency of P uptake from soils and varying phosphorus sources (PR and superphosphate) have been studied for some crop species, these studies are scanty in cowpea production on highly acidic soils from the humid tropics. The objective of this study was to determine growth and yield responses of different cowpea genotypes to P fertilizer in acidic, low P soils from the humid tropics and quantify their response with respect to soluble P and to rock P fertilizers.

MATERIALS AND METHODS

Site description and experimental set up

The study was conducted in a greenhouse at the International Institute of Tropical Agriculture (IITA), Ibadan-Nigeria between (March–July, 2014). The mean daily temperature in the green house during the period of this study was 30.4 °C and average relative humidity was70.7%. Top soil of 0–30 cm depth was collected from a highly weathered, acidic Alfisol (Oxic Paleustalf) at Fashola village (Oyo State; southwestern Nigeria for the pot experiment. The soil was air dried and sieved with 2 mm mesh size before filling 5 kg into each pot having a dimension of 18cm top diameter and 20 cm height. Four (4) soil samples were randomly taken from the soil lot and mixed homogenously. The sieved samples were then subjected to chemical and physical analysis. Soil pH was measured with 1:2.5 soils: water suspension using a HI 9017 microprocessor pH meter. The Walkley and Black procedure as modified by Nelson and Sommers (1982) was used to assess the organic C content in the soils. Total N was determined by Kjeldahl digestion method (Bremner and Mulvaney, 1982). The available P and K were extracted with a HClNH4F mixture method as described by Bray and Kurtz (1945) and P determined calorimetrically using the molybdenum blue at the wavelength of 636nm. Available K was determined using a Gallenkamp flame analyzer (Black, 1965). Soil particle size (texture) was determined by using the hydrometer method (Bouyoucos, 1962). Fifteen (15) cowpea lines were used for the pot experiment**.** The cowpea genotypes IT89KD-288, IT98K-311-8-2, IT03K-351-1, IT90K-76, IT98K-205-8, IT97K-390-2, Danila, IT98K-131-2, IT90K-59, Sanzi, IT97K-499-38, IT00K-1263, IT99K-1122, TVu7778, IT96D-610 were selected from the Cowpea Breeding Program of IITA, based on a previous evaluation of their ability to acquire P from less available sources. A strip plot design was used with two factors. The first factor comprised 15 cowpea genotypes and the second factor was P fertilizer application with seven treatment levels of phosphorus, three treatment levels of mono potassium phosphate (30, 60, 90 mg P kg soil^{-1}), three treatment levels of Togo rock phosphate (60, 90, 120 mg P kg soil^{-1})and the control treatment. All pots received basal dressing of 2.78 g (H_3BO_3), 0.94 g ($MnSO_4$ H_2O), 0.21 g ($ZnSO_4$ $7H_2O$), 5.12 g (Na_2MoO_4 $2H_2O$), 3.00 g ($FeCl_3$) , 0.0043 g ($CoSO_4$ $7H_2O$), and 60 mg P kg soil^{-1} (KCl) (Vincent, 1970). To ensure uniformity, the fertilizers were thoroughly mixed with the soil and water was supplied to field capacity. All pots were irrigated with deionized water throughout the experiment. Three seeds of each line were sown in each pot and thinned to two plants per pot two weeks after emergence. No nitrogen fertilizer, mycorrhizal fungi or rhizobia inoculums were applied. All cowpea seeds were surface sterilized with 95% ethanol (1 min) and 3% H_2O_2 (5 min), and then rinsed with distilled water before sowing. A mixture of Karate, 2.5 E.C. (25 g lambda-cyhalothrin per liter; 4 ml in 1 liter of water) and Vertimec, (1.8% w/v abamectin (18 g/liter; 1.5 ml in 1 liter of water) (Kolawole et al., 2002) insecticides were sprayed twice (third and fifth weeks) to control insect pests. Harvesting of plant samples was done 70 days after planting. The shoots were cut at 1.5 cm above ground level with the help of secateurs. The pods were separated from the shoot during harvesting and were put in separate envelops.

Determination of aboveground biomass

All harvested shoots and pods for each pot were oven-dried at 60 °C-65 °C for 72 hrs to determine dry matter content. The number of seeds per pod was determined by hand threshing of each pod per pot. Seeds in each pod were counted and weighed. The average number of seeds per pot was calculated. The shoot and grain samples were grinded with a ball mill. Analyses of P in the shoot and grain were done using the vanado-molybdate yellow method, and total N was determined by an automatic N analyzer following wet acid digestion (IITA, 1989).

Statistical analysis

Data were analyzed using SAS (version 9.3). Generalized Linear Model procedure using the Restricted Maximum Likelihood method was performed for ANOVA. Treatment means were separated by least significant differences (LSD) at $p < 0.05$.Microsoft Excel software 2007 was used to calculate the correlations between grain yield, N-uptake and P-uptake

RESULTS

Soil characteristics

The result of physical and chemical analysis of the soil used for the experiment is presented in Table 1. The soil pH in H_2O (5.50) was acidic. Total nitrogen, organic carbon content and exchangeable potassium were low and the level of available phosphorus (2.44 ppm) was below the deficiency threshold for most food crops. Generally, the availability of P was low and response to P fertilizer was expected. According to the particle size analysis, the soil was classified as sandy loam.

Grain yield response of cowpea genotypes to low soil P under no P fertilization

Genotypic variations in the cowpea cultivars under investigation showed highly significant differences in grain yield in the control without P application (Figure 1). The cowpea genotypes exhibited different abilities in producing grain yield under low soil P conditions. Danila and IT89KD-288 produced the highest grain yield ranging from 7.2 to 6.8 g representing 64% increase in grain yield compared to TVu7778, IT00K-1263 and IT97K-390-2 which produced the lowest grain yield of 4 to 5 g pot^{-1}.

Aboveground biomass response of cowpea genotypes to low soil P under no P fertilization

Figure 2 shows differences in aboveground biomass response of cowpea genotypes to low soil P conditions in the control (no fertilizer application). Danila recorded the highest aboveground biomass of 16 g representing 53% increase compared to the cultivarsTVu7778, Sanzi, IT99K-1122, IT98K-205-8, and IT97K-390-2 which recorded the lowest aboveground biomass production.

Effect of different P fertilizer treatments on cowpea grain yield

There were differences in the average responses of cowpea over all genotypes to the different fertilizer treatments on grain yield (Figure 3).Cowpea yield was highest at fertilizer level 60 mg P kg^{-1} soil as MP with up to 42% increase compared to the control. There were no significant differences between fertilizer treatment levels at 60 mg Pkg^{-1} soil as RP, 90 mg Pkg^{-1} soil as RP and the control treatment in grain yield production. It was observed that 120 mg Pkg^{-1} soil of RP recorded the lowest grain yield with 19% reduction.

Effect of different P fertilizer treatments on aboveground biomass

Figure 4 shows the effect of different P fertilizer treatments on cowpea aboveground biomass production. Cowpea genotypes did not differ in response to rock phosphate levels and control treatments in terms of aboveground biomass production. The fertilizer treatment level with highest biomass production was 60 mg P kg^{-1} of mono potassium phosphate.

Interaction between cowpea genotypes and P fertilizer application on grain yield

Table 2 indicates that, interaction between genotypes and phosphorus fertilizer applications was significant ($p< 0.0259$) on grain yield production at the different fertilizer application rates. Over all P treatments, IT90K-76 and IT89KD-288 produced the highest mean grain yield of 7.70 g and 7.50 g respectively representing 64% increment compared with IT97K-390 and TVU778 which had the lowest grain yield of 4.70 g and 4.58 g respectively as shown in Table 2. The present study shows that an increase in soluble fertilizer application rate led to an increase in grain yield production at 30 mg P kg^{-1} soil and 60 mg P kg^{-1} soil but declined at treatment level 90 mg P kg^{-1} soil. However, there were differences in the responses of the individual genotypes. Genotypes that showed the same behavior as the overall trend are Sanzi, IT89KD-288 and IT98K-131-2. Grain yields produced at fertilizer levels of 30 mg P kg^{-1} soil and 60 mg P kg^{-1} soil of MP were higher than the grain yield produced at fertilizer level of 90 mg Pkg^{-1} soil. On the other hand, it was observed that two genotypes, IT98K-311-8-2 and IT97K-390-2 did not follow the general pattern and produced the same grain yield in the control and in the different MP treatments. Regarding the application effects of RP, there were genotypes which produced higher grain yield when no fertilizer was applied than at all three rock phosphate levels. These include Danila and IT90K-59. Yield response of cowpea genotypes was higher with all treatment levels of mono potassium phosphate than rock phosphate

Interaction between cowpea genotypes and P fertilizer applications on aboveground biomass at harvest

Interaction between genotypes and the fertilizer levels show significant difference ($P<0.0483$) on total aboveground biomass (Table 3). Over all P treatments, the genotype IT90K-59 had the highest mean biomass production of 17.09 g representing 39% more biomass than TVu7778 which recorded the lowest total biomass of 10.41 g. The cowpea genotypes responded more positively to mineral P application on aboveground biomass production compared to RP application. The results indicated that Danila recorded biomass of 16.16 g in the control treatment which is more than all the fertilizer treatments levels except at 60 mg P kg^{-1} soil as mineral P which recorded a biomass of 17.13 g.

Clustering cowpea genotypes according to their response to fertilizer type and rate

The significant increase in grain yield compared to the control was used for the clustering of cowpea genotypes into responsive and non-responsive. Genotypes which showed no significant difference in grain yield between treatment levels and control treatment were clustered under non-responsive while those that showed significant difference in grain yield between treatments were clustered under responsive genotypes. Each genotype was treated separately with reference to the control.

Classification of cowpea genotypes on the basis of their grain yield production response to Togo rock phosphate

It was observed that five genotypes were responsive to RP (Table 4) even though it has lower P_2O_5 content (34%) and lower solubility compared to MP with 52% P_2O_5. Genotypes that were responsive to RP at either 60 or 90 mg P kg^{-1} soil were IT90K-76, Sanzi, IT96D-610, IT99-1122 and IT00K-1263. IT90K-76 showed the strongest responses at a rate of 60 mg P kg^{-1} soil as RP having the highest grain yield of 7.63 g pot^{-1}. While genotype IT96D-610 showed the strongest responses at P fertilization rate of 90 mg kg^{-1} soil .Ten genotypes (IT89KD-288, IT98K-205-8, IT97K-499-38, IT98K-131-2, IT03K-311-8-2, IT90K-59, IT97K-390-2, TVu7778, IT03K-351-1 and Danila) were non-responsive to RP applications. Among the responsive genotypes, there was a progressive increase in grain yield as the RP fertilizer rates increased from 60 mg P kg^{-1} soil to 90 mg P kg^{-1} soil except IT90K-76. At 120 mg P kg^{-1} soil as RP all genotypes had lower or same grain yield compared to the control.

Classification of cowpea genotypes on the basis of their grain yield production response to mono-potassium phosphate

There was significant difference in the response of the genotypes to the MP fertilizer rates on grain yield based on the clustering shown in Table 5. Thirteen (13) out of fifteen genotypes were responsive to MP (Table 5) either at the rate of 30 mg or 60 mg P kg^{-1} soil. Table 5 indicates a progressive increase in grain yield of all responsive genotypes as the fertilizer rate increased at 30 mg P kg^{-1} soil and 60 mg P kg^{-1} soil, but in most cases declined at a rate of 90mg P kg^{-1} soil except the genotype IT03K-351-1.IT89KD-288 which showed the strongest response at the rate of 60 mg P kg^{-1} soil with 54% increase in grain yield compared to the control. It was interesting to notice that two genotypes were non-responsive to MP fertilizer application with no significant difference in grain yield when MP was applied. Genotypes that showed such characteristics were IT97K-390-2 and IT98K-311-8-2. IT98K-311-8-2 showed lowest grain yield between 4.23 g and 4.45 g at all treatment levels.

Table 1: Physico-chemical characteristics of the top soil (0–30 cm depth) used for the pot experiment

Properties	**Value**
Sand (%)	74.50
Silt (%)	13.00
Clay (%)	12.50
pH (H_2O) (H_2O:soil 1:1)	5.50
Organic C (%)	0.69
Total N (%)	0.037
Available P (Bray) mgkg^{-1})	2.44
Exchangeable cations (cmolkg^{-1})	
Ca	1.50
Mg	0.52
Mn	0.03
K	0.15
Na	0.08
Total Acidity (cmolkg^{-1})	0.01

Table 2: Effects of interaction between no P application (0P), mono potassium phosphate (MP), rock phosphate (PR) on grain yield of cowpea genotypes at harvest

	Cowpea lines	**P application (mg P kg soil^{-1})**								
Obs	Genotypes	0P	30MP	60MP	90MP	60RP	90RP	120RP	Mean	P(0.05)
1	IT90K-76	6.27	8.50	9.64	9.46	7.63	6.33	6.32	7.74	a
2	IT89KD-288	6.75	9.35	9.88	7.93	6.94	6.61	4.01	7.35	ab
3	Sanzi	5.92	8.80	8.11	5.59	6.88	6.53	6.00	6.83	bc
4	IT96D-610	5.47	8.07	7.56	7.96	6.39	6.47	5.13	6.72	bcd
5	Danila	7.21	8.77	8.88	7.75	5.12	5.87	2.83	6.63	bcd
6	IT98K-205-8	5.84	7.12	8.34	6.28	6.13	6.33	5.72	6.54	cd
7	IT98K-131-2	5.12	6.91	8.33	7.81	5.09	5.14	5.27	6.24	cde
8	IT99K-1122	5.10	6.10	8.68	7.17	5.40	5.98	5.01	6.21	cdef
9	IT97K-499-38	5.82	7.27	6.61	6.86	5.95	4.58	5.03	6.02	def
10	IT90K-59	5.16	7.20	7.11	6.64	4.94	4.87	2.70	5.52	efg
11	IT00K-1263	4.29	6.43	7.56	5.68	4.93	6.26	3.27	5.49	fgh
12	IT03K-351-1	4.66	3.90	5.90	6.34	5.04	4.87	3.11	4.83	ghi
13	IT98K-311-8-2	4.71	4.27	4.67	4.54	4.68	4.54	4.81	4.77	hi
14	TVu7778	4.55	5.21	6.26	4.64	5.04	5.01	2.20	4.70	i
15	IT97K-390-2	4.23	4.27	4.45	4.42	4.67	4.61	3.93	4.58	i
	Mean	5.41	6.94	7.66	6.75	5.65	5.60	4.37	6.03	
	PROB	0.2632	0.0014	0.0008	0.0184	0.0173	0.1972	<.0001	<.0001	
	SE	0.78	0.89	0.72	0.86	0.59	0.67	0.46	0.27	
	CV%	24.92	21.10	15.57	20.97	18.01	20.77	18.33	19.99	
	LSD	0.74								
	G*P Prob	0.0259								

Obs=Observations

SE= Standard Error ;CV = Coefficient of variation

Table 3: Effects of interaction between no P applications (0P), mono potassium phosphate (MP), rock phosphate (PR) on the total aboveground biomass of cowpea genotypes at harvest.

Cowpea lines		**P application (mg P kg soil^{-1})**								
Obs	Genotypes	0P	30MP	60MP	90MP	60RP	90RP	120RP	Mean	P(0.05)
1	IT90K-59	15.21	18.15	24.08	18.41	15.33	15.21	13.20	17.09	a
2	IT89KD-288	13.66	19.21	22.95	16.24	15.89	16.79	14.61	17.05	a
3	IT03K-351-1	12.93	17.26	17.06	17.72	14.95	14.14	11.87	15.13	b
4	IT00K-1263	12.05	18.21	19.13	18.43	13.23	12.08	12.21	15.05	b
5	Danila	16.16	12.81	17.13	14.89	14.16	15.20	13.54	14.84	bc
6	IT98K-311-8-2	13.61	18.08	20.08	15.99	12.11	11.64	11.92	14.78	bc
7	IT97K-499-38	13.67	15.66	17.85	15.96	12.07	11.69	13.31	14.32	bcd
8	IT90K-76	13.01	14.43	15.89	15.29	13.35	12.01	12.58	13.79	cde
9	IT96D-610	14.18	14.93	15.71	13.38	14.55	11.88	11.38	13.72	cde
10	Sanzi	10.84	15.41	17.38	16.42	12.01	11.01	10.83	13.41	de
11	IT98K-131-2	12.35	13.73	15.42	13.91	11.55	12.23	11.86	13.01	ef
12	IT98K-205-8	9.85	14.23	17.29	13.91	10.80	11.35	12.09	12.79	ef
13	IT99K-1122	10.32	12.27	15.64	13.37	11.73	10.78	10.86	12.14	fg
14	IT97K-390-2	9.55	14.34	14.32	11.82	10.04	9.18	9.65	11.27	gh
15	TVu7778	8.86	13.81	12.44	11.29	9.15	8.93	8.41	10.41	h
	Mean	12.42	15.50	17.49	15.14	12.73	12.28	11.89	13.92	
	PROB	0.0046	0.0053	0.0015	0.0051	0.0001	<.0001	0.0001	<.0001	
	SE	1.21	1.23	1.59	1.24	0.89	0.86	0.68	0.43	
	CV%	16.85	13.79	15.77	14.24	12.10	12.12	9.87	13.99	
	LSD	1.19								
	G*P(Prob)	0.048								

Obs=Observations ; SE=Standard Error; CV= Coefficient of variation

Table 4: Classification (clustering) of cowpea genotypes based on their response to Togo rock phosphate in terms of grain yield production at harvest.

Responsive Genotypes	**P application (mg P kg soil^{-1})**				**Non-responsive Genotypes**	**P application (mg P kg soil^{-1})**			
	0P	60RP	90RP	120RP		0P	60RP	90RP	120RP
IT90K-76	6.27	8.50	9.64	9.46	IT89KD-288	6.75	6.94	6.61	4.01
Sanzi	5.92	6.39	6.47	5.13	IT98K-205-8	5.84	6.13	6.33	5.72
IT96D-610	5.47	6.39	6.47	5.13	IT97K-499-38	5.82	5.95	4.58	5.03
IT99-1122	5.10	5.40	5.98	5.01	IT98K-131-2	5.12	5.09	5.14	5.27
IT00K-1263	4.93	6.26	3.27	5.68	IT03K-311-8-2	4.71	4.68	4.54	4.81
					IT90K-59	5.16	4.94	4.87	2.70
					IT97K-390-2	4.23	4.67	4.61	3.93
					TVu7778	4.55	5.04	5.01	2.20
					Danila	7.21	5.12	5.87	2.83
					IT03K-351-1	4.665.04	5.04	4.87	3.11
LSD	0.74								

LSD= least significant difference

RP=Rock phosphate

Table 5: Classification (clustering) of cowpea genotypes based on their response to mono-potassium phosphate in terms of grain yield production (g pot-1) at harvest

Responsive Genotypes	**P application (mg P kg soil^{-1})**				**Non-responsive Genotypes**	**P application (mg P kg soil^{-1})**			
	0P	30MP	60MP	90MP		0P	30MP	60MP	90MP
IT90K-76	6.27	8.50	9.64	9.46	IT97K-390-2	4.23	4.27	4.45	4.42
Sanzi	5.92	8.80	8.11	5.59	IT98K-311-8-2	4.71	4.27	4.67	4.54
IT96D-610	5.47	8.07	7.56	7.96					
IT99-1122	5.10	6.10	8.68	7.17					
IT00K-1263	4.29	6.43	7.56	5.68					
IT89KD-288	6.75	9.35	9.88	7.93					
IT98K-205-8	5.84	7.12	8.34	6.28					
IT97K-499-38	5.82	7.27	6.61	6.86					
IT90K-59	5.16	7.20	7.11	6.64					
	4.66	3.90	5.90	6.34					
TVu7778	4.55	5.21	6.26	4.64					
Danila	7.21	8.77	8.88	7.75					
LSD	0.74								

LSD= least significant difference
MP=Mono potassium phosphate

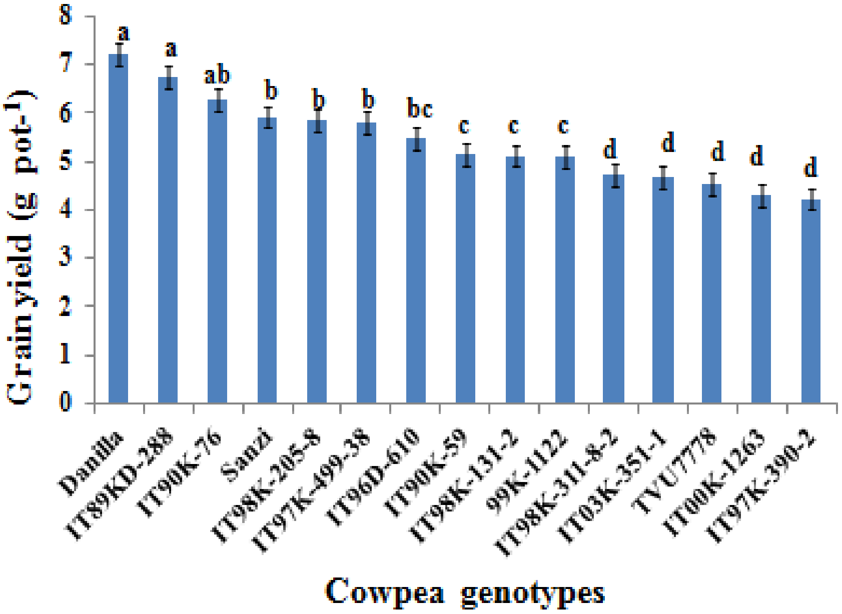

Figure 1: Grain yield, at harvest of fifteen cowpea genotypes without P-fertilizer application in an acidic low P soil**.** Vertical bars represent ±S.E. of the mean (n=3). Different letters above the columns indicate significant differences at P (≤ 0.05).

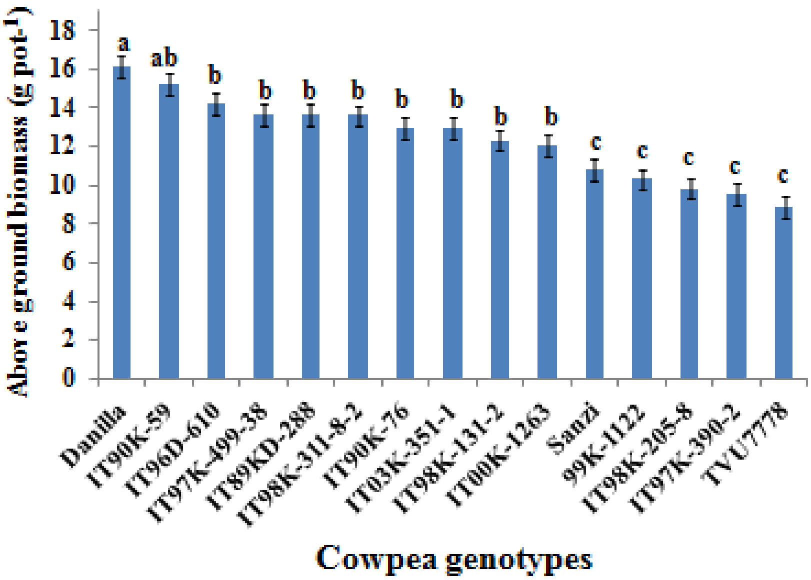

Figure 2: Aboveground biomass at harvest of fifteen cowpea genotypes without P-fertilizer application in an acidic low P soil. Vertical bars represent ±S.E. of the mean (n=3). Different letters above the columns indicate significant differences at P (≤ 0.05).

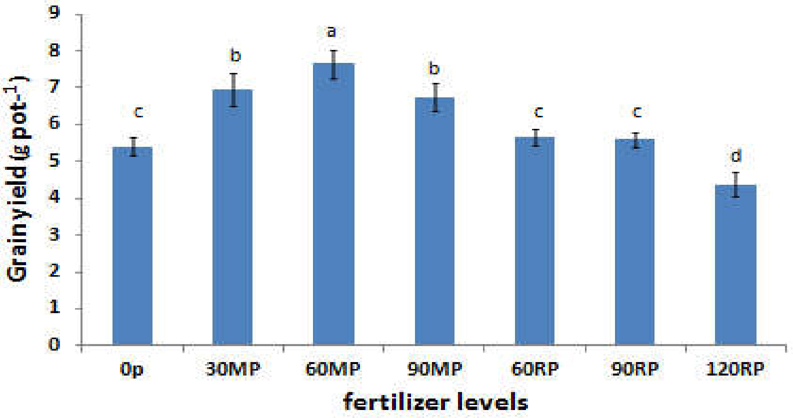

Figure 3: Effect of P-fertilizer treatments on grain yield of cowpea genotypes at harvest in an acidic low P soil. Vertical bars represent ±S.E. of the mean (n=45). Different letters above the columns indicate statistical significance at the P ≤ 0.05 levels.

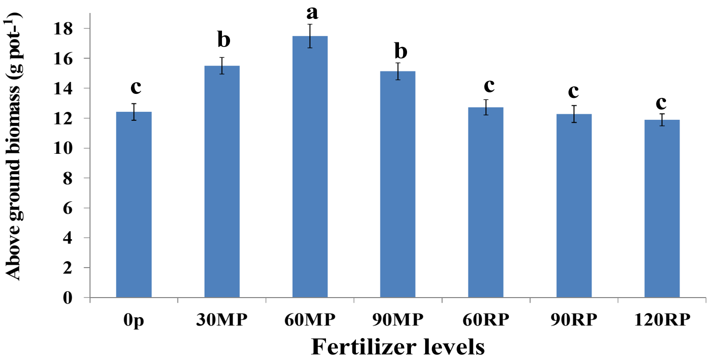

Figure 4: Aboveground biomass of cowpea genotypes of seven different fertilizers treatment levels at harvest in an acidic low P soil. Vertical bars represent ±S.E. of the mean (n=45). Different letters above the columns indicate significance difference at the ($P \leq 0.05$) levels.

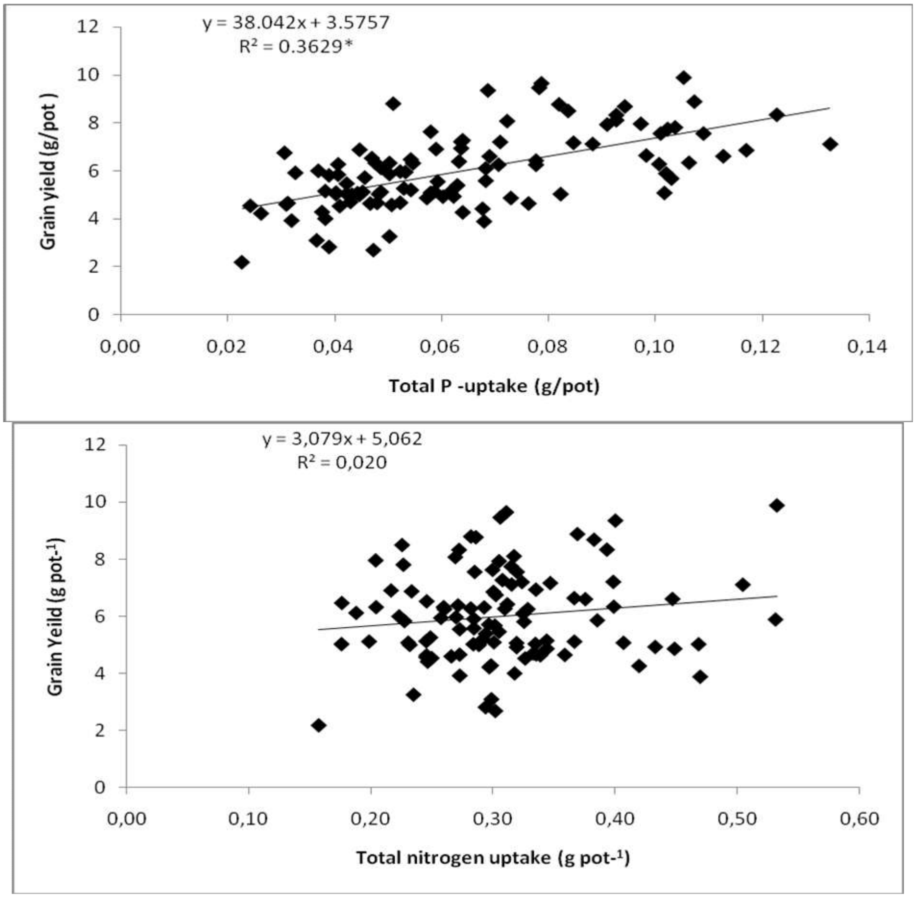

Figure 5: Relationships between grain yields, total N-uptake and total P-uptake described in a linear regression function.

N= nitrogen; P=phosphorus ; g=grams

DISCUSSION

Soil characteristics

According to USDA (1998), the pH value of the soil in the pot experiment was strongly acidic (Table 1) and was similar to those reported for some Ghanaian soils by Adu and Tenadu (1979). Strong leaching of the basic cations out of the top soil contributed to low pH values. It is expected that this factor will affect the dynamics of all nutrients and especially phosphate because the available P depends to a large extent on interactions with constituents carrying a variable charge like iron and aluminum oxides (Quang et al., 1996). The very low organic carbon content and low exchangeable bases (particularly calcium) reflected the generally highly weathered soils in the semi deciduous forest zone of tropical Africa (Owusu-Bennoah et al., 2000).

Grain yield and aboveground biomass responses of cowpea genotypes to low soil P under no P fertilization

In this study, we observed significant variability in grain yield production of genotypes under no P fertilizer application (control) (Figure 1). The genotype Danila and IT89K-D-288 recorded 59% higher yield than the genotype IT97K-390-2which produced the lowest yield. A similar trend was observed by Saidou et al., (2012) where Danila was identified as good performer under no or minimal external P application. This implies, Danila has the ability to utilize inherent soil P more efficiently than the other genotypes engaged in this study. Danila adapts to low P availability by expanding its root system (root and root hairs) to explore a relatively greater volume of soil (Krasilnikoff et al., 2003). This reason may account for Danila's ability to produce higher yields under low soil P conditions. The observed differential performances of the cowpea lines under no P application has practical implications, since such information is vital in identification of potential high-yielding genotypes for P-deficient soils and thus for reducing fertilizer cost.

Effect of different P fertilizer treatments on cowpea grain yield and aboveground biomass

Averaged over all cowpea genotypes, variations in the response to the seven different P-fertilizer treatments in terms of aboveground biomass, and grain yield were observed (Figure 3 and 4). Cowpea responded more to MP fertilizer than to RP application in terms of aboveground biomass production (Figure 4). These results are in accordance with the work reported by Akande et al. (2010). In their work in south western Nigeria using two different types of soils (Arenic Haplustalf (loamy sand) and Udipsament (sandy loam)), the authors observed that dry matter production of maize and cowpea grown without P application were significantly lower than dry matter recorded in P-treated plants and that application of water soluble fertilizer (single super phosphate) gave significantly higher dry matter than both rock phosphate and control treatments.

In our pot experiment, it was observed that the grain yield of cowpea genotypes responded poorly to treatments with the highest P-concentrations, such as 90 mg P kg^{-1} soil of MP and 120 mg P kg^{-1} soil of RP. In the case of 120 mg of RP kg^{-1} soil the average grain yield over all genotypes decreased (Figure 3). This may imply that cowpea genotypes have a threshold at which they can utilize fertilizer incorporated in the pot. Decrease in grain yield at 90mg P kg^{-1} soil of MP maybe attributed to P toxicity but this phenomenon maybe excluded in the case of rock phosphate because of its slow dissolution. The decline in growth and productivity of cowpea genotypes that received high RP (120 mg of RP kg^{-1} soil) may also be attributed to the inhibitory effects of heavy metals (mercury, lead, cadmium etc) present in Togo PR. This is corroborated by Oancea et al (2005) who observed a reduced growth and lower photosynthetic pigments in the presence of heavy metals in a tomato experiment resulting in decreased yield by mercury and cadmium. The fertilizer treatment that produced the highest aboveground biomass was 60 mg P kg^{-1} soil of MP. Similar trend was observed in grain yield where 60 mg P kg^{-1} soil of MP produced the highest grain yield. Based on the findings in this study, it appears to be less economical to apply higher rates than 60 mg kg^{-1} soil in the form of mineral P fertilizers in order to obtain higher grain yield or biomass production. The use of RP to increase grain yield in the first year of application is not justifiable except for a few genotypes (IT90K-76, IT96D-610, IT99-1122, Sanzi and IT00K-1263) (Table 3).

Interaction between cowpea genotypes and P fertilizer application on grain yield and aboveground biomass

Cowpea plays an important role in replenishing of soil fertility especially by N_2 fixation, hence identification of the genotypes with high N_2 fixation potential and high biomass production like IT90K-59 and IT89KD-288 may be of immense interest to farmers. Due to their ability to produce more biomass they can promote the supply of available nitrogen to the soil after decomposition and mineralization of the crop residues (Martins et al., 2003). In line with our observations Jemo et al. (2006) reported similar trends in their study conducted in southern Cameron, where IT90K-59 obtained the highest biomass among all genotypes in a field experiment with low soil P (Rhodic Kandiudult according to USDA classification) with three fertilizer levels 0 and30 kg P ha^{-1} as Triple Super Phosphate and 90 kg P ha^{-1}as Togo rock phosphate. This observation shows that besides the environmental condition of growth, inherent genotypic characteristics of individual cowpea genotypes play an important role in dry matter production. Cowpea genotypes showed increase in aboveground biomass as P-fertilizer was applied as soluble mineral P compared to no P application, except for Danila. However, in most cases 60 mg P kg^{-1} soil gave the highest aboveground biomass production. All the genotypes produced more biomass with MP application compared to RP application, except for Danila at a rate of 60 mg kg^{-1} soil compared to 30 mg MP kg^{-1} soil. This result follows a similar trend documented by Gweyi-onyango et al. (2011) in their field experiment conducted in western Kenya where they found variations in dry matter production in Bambara nut and cowpea under phosphorus (P) supply (50 kg P ha^{-1} in a form of Triple Super Phosphate) as compared to when P was omitted at 55 days after planting.

The present study showed positive correlations between grain yield and total P-uptake ($R^2 = 0.3629^*$) but there was very weak correlation between of grain yield and total N-uptake ($R^2 = 0.0203$) in cowpea genotypes used for this study (Figure 5). This implies increase in P-uptake resulted in corresponding increase in grain yield while increase in N-uptake did not result in an increase in grain yield. This observation suggests that, for this study the limiting nutrient for grain yield production was P and not N since grain yield is independent of N taken up by the seed.

Classification of cowpea genotypes on the basis of their response of grain yield production to P fertilizers

Five genotypes (IT90K-76, IT96D-610, IT99-1122, Sanzi and IT00K-1263) out of the fifteen used were responsive to RP (Table 4) and resulted in significantly higher grain yield than the control treatment. The most responsive out of the five was IT90K-76at the fertilizer level 60 mg P kg^{-1} soil of RP. This observation is very promising given that RP has low solubility rate and is usually not available for short season plant but has residual effect in succeeding crops. Legumes mostly acidify their rhizospheres more than non-legumes and absorb their dissolution products because of their demand for Ca and the acidifying effect of nitrogen (N) fixation in the soil near the root system (rhizosphere). This implies legumes are usually more effective than non-legumes at using rock phosphate (Kamh et al., 1999; Lambers et al., 2006). Such scenario may apparently explain the underlying mechanism driving responsiveness of some genotypes to RP as observed in the current study. The lower response of the other cowpea genotypes to RP may be due to the lower P_2O_5 content (18%) of Togo rock phosphate used in this study, which is considered to be low compared to other rock phosphate such as Ogun rock phosphate from Nigeria (20.2%P_20_5) Tilemsi rock phosphate from Mali (29.7%P_2O_5) and Gafsa rock phosphate from Tunisia (37.8%P_2O_5) (FAO, 2004).

Conclusion

The results of this study revealed that substantial genotypic variability exists among cowpea genotypes to utilize soil P or P applied as fertilizer on strongly acidic tropical soils. We identified Danila and IT89KD-288 as promising genotypes for acidic soils under no or minimal external P application. Out of the seven different levels of P-fertilizer rates applied, cowpea genotypes responded best to P fertilizer level of 60 mg P kg^{-1} soil of mono potassium phosphate. The genotype IT90K-59 was the most P-efficient genotype in terms of biomass production. Five genotypes IT90K-76, IT99K-122, IT96D-610, Sanzi and IT00K-1263 were identified as responsive to rock phosphate, but the genotype IT90K-76 was the most responsive at RP-fertilizer level of 60 mg P kg^{-1} soil.

The differential response to low soil P implies that these traits warrant further selection trials under field conditions on acidic soils. Investigating further into the genotypes that exhibited significant responses to rock phosphate application will be worthwhile with special emphasis on their performance at different locations and rock phosphate types.

COMPETING INTERESTS

There are no competing interests in this research.

AUTHORS' CONTRIBUTIONS

GA was the principal investigator; he carried out the research work. TG supervised the work, corrected the musucript in addition to other important inputs to the work. OB and CF supervised the field work, assited in laboratory analysis of samples at the research sation (International istitute of tropical agricultuer, Ibadan-Nigeria), corrected the musucript.

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