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Journal of Agricultural and Crop Research
Vol. 2(10), pp. 202-210, October 2014
ISSN: 2384-731X
Research Paper

Evaluation of cowpea genotypes for phosphorus use efficiency

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Accepted 1st September, 2014

Abstract. Cowpea (*Vigna unguiculata* L.) yields in West Africa are low primarily due to low available soil phosphorus (P) status. Phosphorus efficient cowpea genotypes with great ability to utilize P from P-deficient soils are important in soils with low nutrient availability. This study was conducted to evaluate the P efficiency of cowpea genotypes under limiting P conditions. Fifty cowpea genotypes were planted in PVC tubes and harvested 5 days after planting (DAP). Data collected on shoot and root parameters showed significant difference ($P < 0.05$) among the genotypes studied. Among the 50 genotypes, 6 were further selected and evaluated in pots under different levels of P application (0, 20 and 40 kg P/ha). The cowpea genotypes varied significantly ($P < 0.05$) in shoot growth, nodulation and P uptake after growing for 40 days. Using principal component analysis (PCA) and phosphorus efficiency index (PEI), cowpea genotypes were grouped into three P efficiency categories. The study concluded that differential growth of cowpea under low P was observed.

Keywords: Phosphorus, cowpea, phosphorus efficiency index.

INTRODUCTION

Cowpea (*Vigna unguiculata* L.) is an important leguminous crop which has the potential of providing the nutritional requirements of developing countries, especially for women and children, as a cheap source of protein and an important source of iron (Welch and Johansen, 2002). Cowpea is adapted to a wide range of soils and does relatively well in the Sahelien soils of West Africa, the region with the highest production. However grain yields are very low. In Ghana, the estimated researcher-managed on-farm yields of 1.8 t ha^{-1} is more than double the average farm level yields (SARI, 1999). Low soil availability of phosphorus (P) has been identified as one of the major limiting factors to crop production in large parts of the tropics (Vesterager et al., 2006) and account for low productivity in legumes (Sanchez et al.,1997) including cowpea (Bationo et al., 2002). Phosphorus limiting conditions also reduces nitrogen fixation, and lowers the nutritional quality of grain and fodder of legumes.

Root systems are important for water and nutrient uptake particularly P. P is absorbed mainly by diffusion through gradients created by root uptake, which means that plant roots mainly take up P from immediate area surrounding the roots system. A larger root system provides greater root-soil contact and thereby higher uptake of soluble P especially under low P availability (Lynch and Brown, 2001). There has been some success in identifying cowpea varieties which can tolerate low P in soils (Singh et al., 2002). However, varietal differences in cowpea with respect to P uptake and utilization, have mainly focused on above ground traits such as yield (Kolawole et al., 2002) and biomass production and to some extent on variation in P uptake, P use efficiency and nodulation at final harvest (Sanginga et al., 2000).

Genotypic variation for roots system has however been associated with substantial variation in the acquisitions of P (Lynch and Brown, 2001). Root traits that enhance P uptake under low P availability include extensive lateral roots (Lynch and Brown, 2012), numerous root hairs (Bates and Lynch, 2001) and adventitious roots (Zhu et al., 2002).

A better understanding of root physiological traits that improve P acquisition especially under low P stress would facilitate selection of more P efficient crop genotypes which would be important in P deficient soils (Lynch, 2007). It would therefore be desirable to discover crop genotypes which can access a greater proportion of the total soil nutrient that may otherwise be unavailable (Sanginga et al., 2000).

The objectives of this study were therefore to:

a) Characterize root and other traits of cowpea which contribute to efficient P uptake in low P soils using established analytical protocols at the seedling stage.

b) Evaluate the phosphorus efficiency of cowpea genotypes with different root traits under limiting P conditions.

MATERIALS AND METHODS

The study was conducted at the Department of Crop Science, University of Ghana (UG), Legon. Fifty cowpea (*Vigna unguiculata* L.) genotypes were evaluated. The 50 cowpea genotypes included 18 early maturing, 6 medium maturing, 10 Striga resistant and 6 dual purpose genotypes obtained from Institute of Tropical Agriculture (IITA), and 10 from the Crop Science Department, UG. The latter from UG were improved varieties which have been released and grown extensively in most of the agro-ecological zones of Ghana. Seeds of each genotype were surface sterilized in 0.5% NaOCl for one minute rinsed and sown into PVC tubes of length 15.0 cm and 3.4 cm in diameter. The tubes contained a mixture of sawdust and rice husk in the ratio of 1:1 by volume. The tubes were placed in aluminium troughs containing 0.5 mM $CaSO_4$ solution. Each genotype was replicated six times. The set-up was placed in a screen house and watered daily with tap water. Five days after planting (DAP) the seedlings were removed from the medium and shoots cut from roots. The roots were washed free of the substrate and growth parameters including primary root length, number of lateral roots on the primary root and total root length were evaluated. Root length was determined using a modified line-intersect method (Tennant, 1975). Counts were made on the intercept of roots with 2 cm vertical and horizontal grid lines with the aid of a tally counter. Counts were converted to length measurements using the formula:

Root length (R) = Number of intercepts × Length conversion factor

Where length conversion factor for the 2 cm grid square was 1.5714.

Data were also collected for shoot growth parameters and subjected to Analysis of Variance (ANOVA) with the differences between means compared using the least significant difference (LSD).

Three (3) genotypes viz., IT03K-351-1, IT00K-901-5 and IT93K-452-1, which obtained the highest number of lateral root number and 3 genotypes viz., IT98K-1263, IT97K-819-118 and Asontem with the lowest number of lateral roots were randomly selected from the first experiment and further evaluated in a pot experiment. The soil used for the study was Toje series (Ghanaian classification), or Alfisol (FAO classification). A sample of the soil was obtained from 0 to 15 cm depth from an uncultivated area at the UG, Legon, and characterized for its physical and chemical properties. Six litre capacity pots were filled with 5 kg P deficient soil, which was previously sieved with a 2 mm sieve. Three P treatments, as Triple Super Phosphate, were administered; no P (P_0), P at 20 kg ha^{-1}(P_{20}) and P at 40 kg ha^{-1}. The experimental design was a factorial randomized complete block with four replications. Because of the laborious nature of root harvest and analysis, the experiment was divided into two plantings. A basal N application of ammonium sulphate at a rate of 50 kg−N ha^{-1} was applied before planting. Hoagland’s plant nutrient solution (full strength), not containing P, was prepared by dissolving 0.4925 g $CaCl_2.2H_2O$, 1.875 g K_2SO_4, 3.075 g $MgSO_4.7H_2O$, 0.8043 g Fe (III) Na EDTA, 0.0155 g H_3BO_3, 0.009 g $MnCl_2.4H_2O$, 0.0008 g $CuSO_4.5H_2O$ and 0.0002 g $H_2MoO_4.H_2O$ in 1 L of distilled water. The solution was adjusted to pH 5.5-6.0 with 0.1N NaOH and 20 ml applied to each pot 8 DAP. This was repeated weekly together with application of tap water three times a week.

Plants were harvested after 40 DAP by cutting the shoot at the soil surface. Leaves were separated, counted and leaf area measured using an AM 100 leaf area meter (Delta-T Devices Burwell, Cambridge). Roots were retrieved by washing under running water. Nodules were counted dried and weighed. All plant parts were dried at a temperature of 65°C for 48 h and milled for determination of N and P. N determination was done by colorimetric analysis and P concentration was determined by spectrophotometry using molybdo-phosphoric blue method.

Phosphorus efficiency of cowpea genotypes was determined by phosphorus efficiency index (PEI) (Pan et al., 2008), and assessed using principal component analysis (PCA) of standardized values of plant biomass and nodulation at low P, and relative values at low P to

Table 1. Physical and chemical characteristics of soils.

Parameter	Classification and properties
FAO Classification	Alfisol
Ghanaian Classification	Toje Series
Sand: Silt: Clay (%)	70: 4: 26
Bulk density (Mg m^{-3})	1.22
pH (KCl: H_2O)	5.0
Organic C (g kg^{-1})	6.5
N (%)	0.08
Total P (mg kg^{-1})	201
Available P (mg kg^{-1})	7
Al Saturation (%)	16.0
Fe Saturation (%)	6
CEC (cmol kg^{-1})	2.8

Table 2. Root and shoot characteristics of cowpea genotypes 5 DAP.

Trait	Mean	Range	CV (%)
Tap root length (cm)	13.1**	5.1 - 18.0	22.7
Number of lateral roots	41**	9 - 66	36.0
Total root length (cm)	103.6*	6.2 - 258.6	56.2
Lateral root length (cm)	100.3*	2.0 - 240.5	56.4
Lateral root density (number of roots/cm)	3.3 ns	1.3 - 5.3	40.2
Root fresh weight (g)	0.30ns	0.10 - 0.50	56.1
Shoot fresh weight (g)	0.67**	0.2 - 1.2	18.6
Root: shoot ratio	0.45ns	0.1 - 1.3	43.5
Total biomass (g)	0.96***	0.52 - 1.36	23.9

*; $P < 0.05$, **; $P < 0.01$, ***; $P < 0.001$

those obtained under high P supply. PCA was computed with XLSTAT (2010) statistical software.

RESULTS

Characterization of soil for evaluation of cowpea genotypes for phosphorus efficiency

Characterization of the soil used for the study is shown in Table 1. Most soils in Ghana, including the one used in this study had very low levels of available P.

Shoot and root characteristics of cowpea at early growth stage

Fifty genotypes of cowpea evaluated at early stage for root and shoot characteristics have shown significant differences for parameters like total root length, root number, root weight, shoot weight and root: shoot ratio within each group of cowpea genotypes (Table 2). The number of lateral roots varied from 9 to 66. Tap root length varied between 5.1 and 18 cm. The average tap root length of cowpea genotypes was 13.1 cm. The lateral root density was obtained by dividing the tap root length by the number of lateral roots counted. There were no significant differences found among the cowpea genotypes for lateral root density and root biomass.

The study also provided an opportunity to compare newly developed genotypes of cowpea [early maturing (EM), medium maturing (MM), Dual purpose (DP) and Striga resistance (SR) genotypes] with earlier released genotypes (ER). There were significant differences in root length among the genotypes. In general, EM genotypes had the greatest tap root length followed by the SR and the DP genotypes (Table 3). The ER genotypes had the least taproot length.

The EM genotypes, which had the greatest tap root length, also had the highest root dry weight while DP genotypes had the least root dry weight (Table 3). The root dry weight was however not significantly different among the genotypes. The DP genotypes had the greatest number of lateral roots, followed by the SR genotypes while the ER genotypes had the least number of lateral roots. The DP and SR genotypes of cowpea,

Table 3. Means of root traits of dual purpose, early maturing, earlier released, medium maturing and striga resistant genotypes of cowpea.

Cowpea group†	Number of lateral roots	Root length (cm)			Lateral root density	Root weight	
		Tap	Total	Lateral	(roots cm^{-1} taproot)	Fresh (g)	Dry (mg)
Dual purpose (DP)	50^{a}	13.6	141.5^{a}	127.9^{a}	3.8	0.34^{a}	17.6
Early maturing (EM)	44^{b}	13.8	122.9^{a}	109.1^{a}	3.2	0.33^{a}	22.6
Earlier released (ER)	30^{c}	11.5	66.3^{b}	55.3^{b}	3.0	0.20^{c}	19.2
Medium maturing(MM)	34^{c}	12.1	85.0^{b}	72.9^{b}	3.4	0.27^{b}	22.4
Striga resistant (SR)	47^{ab}	13.6	131.7^{a}	118.2^{a}	3.5	0.34^{a}	19.0

† Number of genotypes within each classification; Dual purpose, n = 6; Early maturing, n = 18; Earlier released, n = 10; Medium maturing, n = 6; Striga resistant, n = 10. Means within a column followed by the same letter are not significantly different among the groups at $P<0.05$

Table 4. Means of shoot traits of dual purpose, early maturing, earlier released, medium maturing and striga resistant genotypes of cowpea.

Cowpea group†	Shoot fresh weight (g)	Shoot dry weight (mg)	Plant height (cm)	Root: shoot ratio	Total biomass (mg)
Dual purpose	0.77^{a}	112.5^{a}	6.2^{a}	0.16^{b}	130.1^{a}
Early maturing	0.70^{b}	98.8^{a}	5.7^{b}	0.25^{ab}	121.4^{a}
Earlier released	0.43^{c}	57.2^{b}	5.0^{c}	0.35^{a}	74.1^{b}
Medium maturing	0.73^{ab}	112.0^{a}	6.0^{ab}	0.19^{ab}	134.4^{a}
Striga resistant	0.72^{b}	103.1^{a}	5.9^{ab}	0.19^{ab}	122.1^{a}

† Number of genotypes within each classification; Dual purpose, n = 6; Early maturing, n = 18; Earlier released, n = 10; Medium maturing, n = 6; Striga resistant, n = 10. Means within a column followed by the same letter are not significantly different among the groups at $P < 0.05$.

which had the greatest number of lateral roots, also showed the highest lateral root densities of 3.8 and 3.5, respectively but differences were not significant.

The shoot dry weight among genotypes in ascending order was ER < EM < SR < MM < DP (Table 4). However, the shoot dry weight among the following DP, MM, SR and EM was not significant. Plant height varied significantly ($P < 0.01$) among the cowpea genotypes. The DP genotypes obtained the highest plant height whilst the least plant height was obtained by the and ER genotypes. Total biomass followed the same trend as the shoot dry weight. The root: shoot ratio varied significantly among the cowpea genotypes. The DP which had obtained the highest shoot dry weight had the least root: shoot ratio whilst the ER genotypes which had obtained the least shoot dry weight had the highest root: shoot ratio.

Phosphorus efficiency the selected among cowpea genotypes

Shoot biomass

Shoot biomass increased significantly under moderate and high P limiting conditions. Among the six genotypes there was an average increase of 56% of shoot biomass under moderate P and 36% increase of shoot biomass under high P conditions (Table 5).

Shoot biomass varied significantly ($P < 0.01$) from 2.0 to 3.2 g. Genotype IT98K-1263 showed the highest shoot biomass while Soronko the least (Table 6). Genotypic variation in shoot dry weight was related to differences in area per leaf and number of leaves (Table 5), which accordingly affected total leaf area.

In general, smaller leaves and lower leaf numbers were observed in plants grown in low P treatments (P0, P20) as compared to those with high P treatment (P40).

Nodulation, P uptake and P efficiency

Nodule number and nodule dry weight (NDW) increased significantly under moderate and high P conditions (Table 5). Generally, NDW increased 24% under moderate P and a further rise of 11% under high P conditions. Significant variation was observed in nodulation of cowpea genotypes under P limiting conditions.

Similarly, there were significant differences in root to shoot ratio, shoot P concentration, total P uptake, and P uptake efficiency amongst the genotypes and the P treatments. However, with the exception of leaf area and root to shoot ratio no significant interaction was observed (Table 5).

NDW varied from 3 mg in IT93K-452-1 to 42 mg produced by IT98K-1263 under low P conditions (Table 6). It is worth

Table 5. Means and level of significance for growth parameters of 6 cowpea genotypes with low p (0 kg ha^{-1}) moderate p (20 kg ha^{-1}) and high p (40 kg ha^{-1}) availability.

Parameter	Mean for 6 cowpea genotypes			P0/P20 (%)	P0/P40 (%)	Statistical analysis for 6 cowpea genotypes		
	P0	P20	P40			P	G	P × G
Leaf area(cm^2 plant^{-1})	322	556	786	57.9	41.0	***	***	*
Leaf dry weight (g pot^{-1})	1.03	1.94	3.08	53.1	33.4	***	*	ns
Leaf number	28	36	52	77.8	53.9	***	*	ns
OLA	11.5	15.4	19.9	74.7	57.8	**	***	ns
Shoot dry weight (g pot^{-1})	2.41	4.33	6.39	55.7	37.7	***	ns	ns
Root dry weight (g pot^{-1})	0.79	1.38	1.77	57.3	44.6	***	*	ns
Root : shoot ratio	0.46	0.30	0.32	153.3	143.8	***	*	***
Nodule number	22	40	47	55.0	46.8	***	***	ns
Nodule dry weight (mg pot^{-1})	0.016	0.067	0.136	23.9	11.8	***	**	ns
P uptake (mg g^{-1})	10.9	23.7	42.8	46.9	25.5	***	**	ns
N uptake (mg g^{-1})	0.26	0.45	0.63	57.8	41.3	***	ns	ns
P utilization efficiency	0.21	0.61	1.08	34.4	19.4	***	*	ns
P uptake efficiency	14.30	9.70	9.28	147.4	154.1	***	*	ns

*, P < 0.05; **, P < 0.01; ***, P < 0.001; ns, not significant

noting that genotype IT98K-1263 was consistently the highest nodulation under all three P treatments.

The PEI value generated for the genotypes were positive for IT03K-351-1, IT00K-901-5, IT93K-452-1and IT98K-1263 (Table 7). On the other hand, PEI values generated were negative for genotypes IT97K-819-118 and Soronko. Based on the PEI cowpea genotypes were classified under three levels of P efficiency of low, moderate and high (Table 7). Genotype Soronko was low, IT97K-819-118 moderate and IT03K-351-1, IT00K-901-5, IT93K-452-1 and IT98K-1263 were highly efficient.

Based on PEI generated from PCA and growth potential of shoot dry weight, nodule dry weight and P uptake efficiency at high P, two categories were identified (Figure 1). Genotypes 11 (IT 00K-901-5, early maturing), 14 (IT93K-452-1, early maturing), 8 (IT03K-351-1, early maturing) and 22 (IT98K-1263, medium maturing) were identified as efficient and responders (ER). On the other hand genotypes 27 (IT97K-819-118, Striga resistant) and 48 (Soronko, released variety) were classified as non-efficient and responders. Genotypes were consistent in their classification by shoot dry weight, NDW and P uptake efficiency. However genotype 22 (IT98K-1263, medium maturing) was highly efficient in NDW and P uptake. Genotype 8 (IT03K-351-1, early maturing) was consistently highly efficient in shoot biomass, NDW and P uptake.

Correlation analysis between P efficiency and plant growth parameters

P efficiency was positively correlated with leaf area, single leaf area, dry weights of leaf stem, shoots and roots, root to shoot ratio, nodule number, NDW, shoot N and P uptake and P utilization efficiency, and negatively correlated to leaf number and P utilization efficiency at P0 (Table 8). At P40, P efficiency was positively correlated with all parameters measured but negatively correlated with leaf number. Likewise, P efficiency was positively correlated the relative indices at P0 as a % of those at P40, except leaf area, single leaf area, leaf dry weight and P uptake efficiency.

DISCUSSION

Shoot and root growth at early growth stage

Similarly, the total N levels were also very low and consistent with the relatively low OM status of the soil.The low OC, total N, and available P, and CEC values, are also reflections of a soil with low fertility. The soil would therefore require some fertilization from external source if it is to sustain crop growth and cultivated continuously (Darko, 2007). Cowpea is mostly grown in areas where nutrient stress especially P stress exist and this particularly affects forage and grain production. The cost of applying P is not within the economic reach of farmers in these areas, therefore an alternative is to screen for genotypes which are best suited to these nutrient depleted areas (Adu-Gyamfi et al., 2002).

The significant differences found among genotypes within cowpea for root fresh weight, shoot fresh and dry weights and root: shoot ratio were similar to the findings of Mia et al. (1996) who found significant differences in several root traits among legumes they studied during

Table 6. Shoot, root, nodulation, p uptake and p utilization efficiency characteristics of 6 cowpea genotypes grown under 0, 20 and 40 kg p ha^{-1}.

Parameter	IT03K-351-1			IT00K-901-5			IT93K-452-1			IT98K-1263			IT97K-819-118			Soronko		
	0	20	40	0	20	40	0	20	40	0	20	40	0	20	40	0	20	40
Leaf area (cm^2 pot^{-1})	201	446	649	319	492	624	371	526	822	433	565	864	295	362	467	189	859	905
Leaf number	27	37	59	32	41	53	34	31	70	27	32	37	36	43	63	17	34	29
Single leaf area (cm^2)	7.51	11.85	12.92	11.31	13.17	14.76	11.12	17.22	13.07	15.88	18.45	24.82	9.56	9.27	8.51	15.19	25.72	42.58
Leaf DW (g pot^{-1})	0.83	1.95	3.24	0.88	1.91	2.18	1.05	1.74	3.57	1.55	2.11	4.19	1.08	1.53	2.47	0.78	2.39	2.83
Stem DW (g pot^{-1})	1.56	2.66	5.06	1.40	2.58	3.26	1.50	2.53	4.61	1.61	2.60	3.00	1.02	1.95	3.03	1.24	2.12	2.99
Shoot DW	2.39	4.61	8.30	2.28	4.49	5.44	2.55	4.27	8.18	3.16	4.71	7.19	2.10	3.48	5.50	2.02	4.51	5.82
Root DW	0.86	1.39	1.77	0.78	1.56	2.07	0.95	1.29	1.88	0.97	1.68	1.87	0.54	1.11	1.28	0.65	1.24	1.76
Root to shoot ratio	0.62	0.29	0.22	0.48	0.40	0.41	0.42	0.32	0.29	0.31	0.37	0.27	0.27	0.24	0.26	0.62	0.24	0.32
Nodule number	24	40	47	27	42	50	8	23	31	41	59	67	25	29	45	8	50	42
Nodule DW (mg pot^{-1})	25.82	79.7	156.8	19.53	73.1	159.7	3.07	43.3	89.7	42.41	100	183.7	19.24	43.8	110.5	9.65	64.4	115.3
Shoot N uptake (mg g^{-1})	8.58	28.69	74.38	7.85	36.24	61.58	13.95	30.43	59.90	15.69	38.91	63.95	4.95	22.53	43.26	5.60	26.53	58.52
Shoot P uptake (mg g^{-1})	0.84	1.90	4.46	0.80	2.12	3.48	0.97	2.03	5.18	1.11	1.84	3.45	0.63	1.25	2.41	0.57	1.65	2.57
P uptake efficiency	0.97	1.36	2.52	1.03	1.36	1.68	1.02	1.58	2.76	1.14	1.09	1.84	1.17	1.12	1.88	0.87	1.33	1.46
P utilization efficiency	0.21	0.71	1.42	0.18	0.62	0.76	0.23	0.51	1.26	0.37	0.80	1.31	0.18	0.42	0.72	0.17	0.59	0.98

NB: Statistical analysis for cowpea genotypes represented in table 5.

early growth. Interestingly, they reported that cowpea showed the widest genotypic variability for root traits, and formed an extensive root system by producing a large number of lateral roots, comparable to the findings in this study. Extensive lateral rooting systems have been shown to be important adaptive traits that enhance P uptake from low P soils (Zhu and Lynch, 2004).

Genotypic differences were also observed in cowpea for lateral rooting at 5 DAP. This has been reported in early growth stage in both chickpea and cowpea (Mia et al., 1996). The deployment of root architectural traits in plant breeding programs has great potential to alleviate P deficiency, a primary constraint to crop production in world agriculture (Lynch, 2007). The significant differences found in cowpea at the seedling stage provide an opportunity for screening a large number of genotypes for important root traits such as an extensive lateral root system.

Phosphorus efficiency in cowpea

Cowpea, like most legumes in Ghana, is grown under little or no nutrient application. In common with most soils found in Ghana, the levels of available P in the soils used for the study were low. Similarly, the total N was also low, consistent with the relatively low OM status of the soil. The most common stress that affects grain and forage production in Ghana is nutrient stress, particularly low P. The soil would therefore need some fertilization from an external source to sustain crop growth and permit continuous cultivation (Darko, 2007). However, this is beyond the economical reach of most Ghanaian farmers and has prompted genotype screening and selection for tolerance to low soil P conditions as an important strategy to increase productivity (Adu-Gyamfi et al., 2002).

Genotypic variation was observed in 6 cowpea genotypes studied under P limiting and high P conditions. Genotypic evaluation of crops should be under both low and high availability P since P efficiency is a complex quantity trait involving growth parameters (Pan et al., 2008). Genotypic variation in P efficiency has been identified in cowpea (Ankomah et al., 1996; Sanginga et al., 2000; Kolawole et al., 2002).

The method used for P efficiency analysis was the PCA which is relatively new multiple-parameters

Table 7. Categorising 6 cowpea genotypes into low efficiency (LE), moderate efficiency (ME) and high efficiency (HE), according to p efficiency index (PEI) generated from PCA using parameters under low p (0 kg ha^{-1}) and high p availability (40 kg ha^{-1}).

ID	Genotype	Cluster	PEI
8	IT03K-351-1	HE	0.059
11	IT00K-901-5	HE	0.064
14	IT93K-452-1	HE	0.121
22	IT98K-1263	HE	0.225
27	IT97K-819-118	ME	-0.345
48	Soronko	LE	-0.094

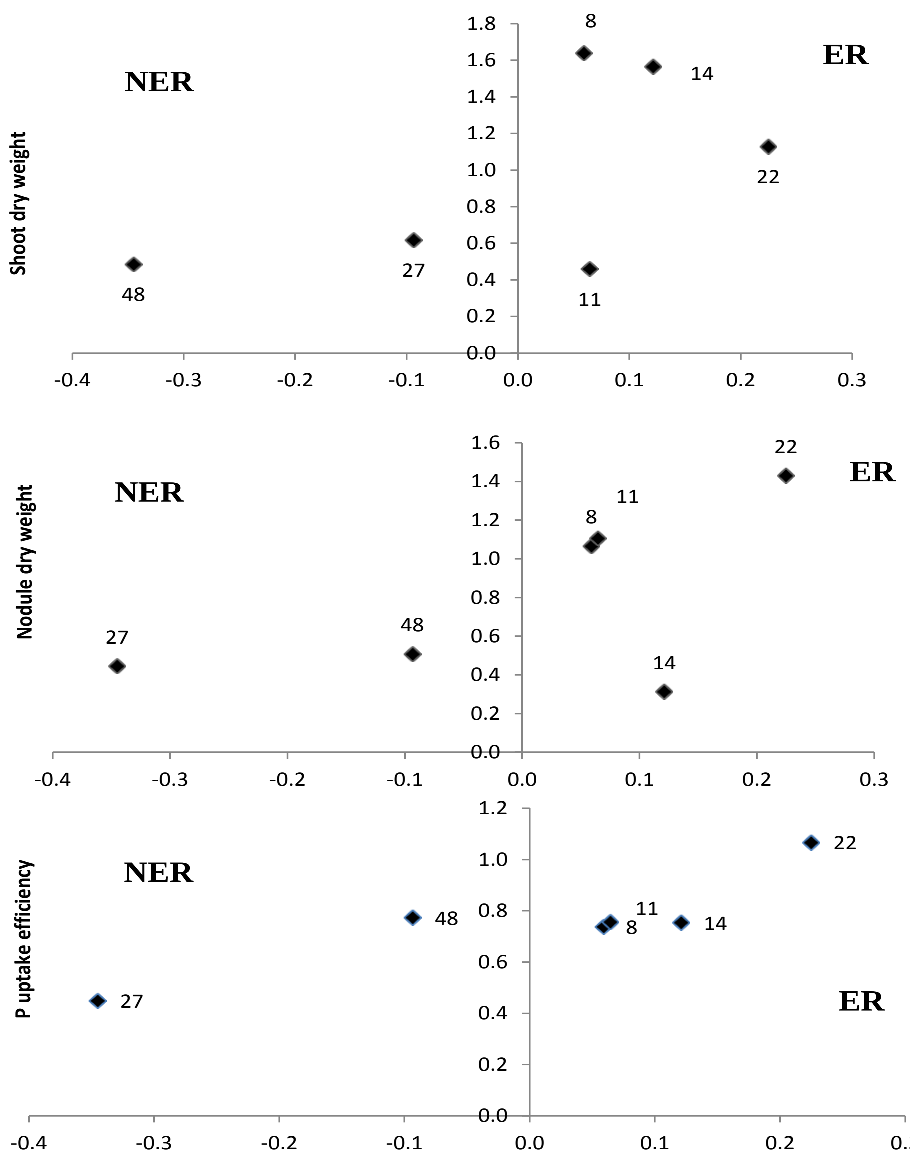

Figure 1. Classification of cowpea genotypes into 2 distinct responsive groups (NER-non efficient and responsive: ER- efficient and responsive) according to P efficiency index and standardized values of shoot biomass, nodule dry weight and P uptake efficiency under high P availability.

Table 8. Correlations between p efficiency and parameters of 6 cowpea genotypes grown in a p-deficient soil without (P0) or with p addition (P40) and parameters at P0 AS % of those AT P40 (P0/P40).

Parameter	Correlation coefficients (*r*)		P0/P40
	P0	P40	
Leaf area (cm^2 pot^{-1})	0.48	0.61	-0.21
Leaf number	-0.16	-0.15	0.16
Single leaf area (cm^2)	0.31	0.11	-0.43
Leaf dry weight (g pot^{-1})	0.37	0.67	-0.40
Stem dry weight (g pot^{-1})	0.96**	0.33	0.46
Shoot dry weight	0.77	0.60	0.09
Root dry weight	0.95**	0.85*	0.58
Root to shoot ratio	0.15	0.10	0.13
Nodule number	0.26	0.33	0.05
Nodule dry weight (mg pot^{-1})	0.33	0.52	0.03
Shoot N uptake (mg g^{-1})	0.84*	0.77	0.72
Shoot P uptake (mg g^{-1})	0.85*	0.66	0.07
P uptake efficiency	–0.12	0.31	-0.33
P utilization efficiency	0.67	0.69	0.01

*, $P < 0.05$; **, $P < 0.01$

screening method used in evaluating P efficiency. Due to the sensitive nature of parameters such as shoot biomass and P uptake to P availability, multiple-parameter screening methods are ideal. Unlike single-parameter screening methods, PCA take into account the relative contributions of all parameters measured to P efficiency (Pan et al., 2008). Utilizing the same method, the cowpea genotypes were also grouped under three categories of P efficiency. Consistent with the findings of others (Pan et al., 2008; Bayuelo-Jimenez et al., 2011), as well as the findings from this study, PEI generally places genotypes into three main categories of P efficiency of low, moderate and high. The 6 cowpea genotypes were further classified into two P responsive groups using the standardized values of shoot dry weight at high P and P efficiency. In contrast, the 50 soybean genotypes were classified under four P responsive categories. The categories obtained for cowpea were (i) efficient and responsive (ER); (ii) inefficient and responsive (NER). This grouping indicates that even though all 6 genotypes were good responders to P application, genotype was either efficient or inefficient.

IT03K-351-1, IT 00K-901-5, IT93K-452-1 and IT98K-1263 genotypes were more P efficient than IT97K-819-118 and Soronko. According to Sanginga et al. (2000), genotypes which increased in shoot dry weight with increasing levels of P, as observed in this study, are distinguished as P-responders. Genotype 48 (Soronko) was identified as low efficiency under PEI, but was very responsive to P application. For instance, it had the highest leaf area when P was applied at 40 kg ha^{-1} and produced the highest percentage increase when P was applied. It is a typical cowpea variety which was produced during earlier breeding programmes by IITA to respond well to P application. In earlier IITA breeding programmes, yield parameters were predominantly targeted, while factors such as P use and uptake efficiency and root traits may not have been deliberately included.

P application significantly increased leaf dry weight, stem dry weight, root dry weight, leaf area, nodulation, P uptake and P uptake efficiency of all 6 cowpea genotypes. Increased shoot growth of cowpea genotypes in response to P application in low P soils has also been reported by several researchers (Ankomah et al., 1996; Kolawole et al., 2002; Bationo et al., 2002; Owolade et al., 2006; Nwoke et al., 2007). The enhancing effects of P application on nodulation have been associated with increased nodule mass and number in cowpea as shown by this study and detailed by the other researches (wan Othman et al., 1991; Sanginga et al., 2000; Kumata et al., 2008). In contrast, Kolawole et al. (2002) found a decrease in nodule number when P was applied in cowpea production.

Correlation among parameters

With the exception of root and shoot biomass no significant correlation was found between PEI and most of the parameters studied in cowpea genotypes. The study also indicated little correlation between the plants harvested at 5 DAP and shoots and yield parameters in the field. One possible explanation for the differences between the field and greenhouse results is that the field environment may have presented other environmental variables and stresses that could have difference observed in the plants. Lack of correlation between root traits and yield per plant under low P in the field could have been caused by the uncertainty associated with yield estimates from small plots in a single location and season.

CONCLUSION

The study concluded that there were significant genotypic variation for root traits at an early growth stage and genotypic differences for cowpea growth under low P. All 6 cowpea genotypes used in the P efficiency study, were good responders to P application, but IT03K-351-1, IT 00K-901-5, IT93K-452-1 and IT98K-1263 were more P efficient than IT97K-819-118 and Soronko.

ACKNOWLEDGEMENTS

The research work was financially supported by the International Atomic Energy Agency (Vienna, Austria; Project No. 13800/RO). The authors also thank International Institute of Tropical Agriculture (IITA) and for the cowpea seed used in the study.

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