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Effect of Phosphorus Fertilizer Application on Yields of Cowpea (*Vigna unguiculata*) Varieties across Sites of Differing Soil Fertility in western Kenya

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Abstract
Phosphorus deficiency remains a key constraint to cowpea productivity in Kenya. Continuous cultivation of smallholder farms confounded with inadequate use of fertilizer and use of poor local cowpea (*Vigna unguiculata*) seed varieties, has led to decreased cowpea yields in western Kenya. Earlier studies have indicated that application of phosphorus fertilizer at recommended rates as well as growing of improved cowpea varieties may result to increased grain yield. Against this background, improved cowpea varieties were screened under different phosphorus (Triple Super Phosphate) fertilizer rates to investigate their response on grain yield production, at sites of differing soil fertility status (Bonjoge and Koibem) in western Kenya. Field experiments were conducted during the short rain (SR) seasons in 2019. The experiments were factorially arranged and laid out in a RCBD with three replications at both sites. P was applied at three levels of 0, 15, and 30 kg P/ha. Six cowpea varieties; one local check (Khaki) and five improved varieties (ICV1, 1CV12, CB46, IT92K-282-2 and IT83D-442) were tested. Grain yield data collected was subjected to analysis of variance using SAS statistical software, release 8.2. Least Significant Difference test separated means of parameters whenever significant difference was detected at ≥ 95% confidence level. Phosphorus application resulted to insignificant ($p<0.05$) increase in cowpea grain yield across varieties. Highest and least average yields were from variety CB 46 (325 kg/ha) and variety Khaki (216 kg/ha) and IT 90K-284-2 (216 kg/ha), respectively. At Bonjoge, cowpea grain yields varied from 206 to 434 kg/ha and were significantly ($p<0.05$) higher than the yields at Koibem which ranged from 127 to 342 kg/ha. The results of this study show that while cowpea productivity is influenced by soil fertility status, application of P was not essential for grain yield production. Interaction of fertilizer and varieties in Bonjoge resulted to a positive grain yield response, hence suitable site for cowpea.

Key words: Phosphorus, cowpea, grain yield, soil fertility

Introduction

About 1.25 million people in Kenya are severely food insecure with 25% of the children being underweight (FAOSTAT, 2019). Cultivation of land has been left to smallholder farmers, who cultivate small plots of land to sustain their immediate family (Odendo et al., 2011). Nearly 75% of the rural households in western Kenya are engaged in unproductive low input/low output subsistence farming (Odendo et al., 2011). The farmers grow mainly subsistence crops such as maize, beans etc. and one or more cash crops. This has increasingly threatened the food and nutritional security of rural smallholder communities in western Kenya and Kenya as a whole. Cowpea is a multipurpose legume that provides both leaves and grains and thus widen the farmer's food preference and security. Cowpea is an annual or biannual grain legume ranked among the topmost important legumes in the world, second in Africa and third in Kenya (Awurum and Enyiukwi 2013). It is suitable for sub-Saharan Africa due to its ability to grow in adverse climatic conditions where other legumes cannot flourish well. Cowpea provides a cheap source of quality protein. The protein content of cowpea leaves ranges from 27 to 43% and protein concentration of the dry grain range from 21 to 33% (Abudulai et al., 2016). Although they have a high nutritional value, cowpea grains are a minor component of food diet. That is the reason why efforts have been made to introduce cowpea in the food habits and farmer activities of western Kenya.

Cowpea is grown for both leaves and grain in western Kenya. Average yield of dry cowpea seed of 175 kg ha^{-1} and 400 kg ha^{-1} of leaves has been reported in Kenya against the global average grain yield of 500 kg ha^{-1} and 750 kg ha^{-1} of leaves (FAOSTATS, 2019). The main constraints to high productivity of cowpea in smallholder farms, is the low level of available phosphorus in western Kenya soils which is widely spread (Keino et al., 2015) and use of local varieties. Phosphorus losses of 3 – 13 kg/ha/yr in western Kenya have been documented (Woomer et al., 1997), contributing to low crop yields. Although it is well recognized that application of mineral fertilizers plays an important role in the intensification of crop production (Ndungu et al., 2015), prohibitive and variable costs of mineral P fertilizers have discouraged their continued use by the resource-poor smallholder farmers to replenish soil fertility (Odendo et al., 2011). Triple Super Phosphate is one of the inorganic fertilizers that replenishes the soil with nutrient P. It has the highest P content of dry fertilizers that do not contain N. Over 90 % of the total P in TSP is water soluble, so it becomes rapidly available for plant uptake (IITA 2015). TSP also contains 15 % calcium (Ca), providing an additional plant nutrient and liming effect in the long run. Poor local cowpea seed varieties are susceptible to major pests and diseases, and have greatly led to decreased cowpea grain yields in smallholder farms in western Kenya. This compels cowpeas farmers to apply inorganic basal fertilizers such as TSP every season to sustain production and meet their subsistence and market requirements. Among the solutions towards reducing low yields due to low levels of P in the soil is determination of the best level of P application and selection of best performing varieties to maximise returns from cowpea and yield. This study seeks to identify improved cowpea varieties that positively respond to fertilizer P application to provide high in smallholder farms of western Kenya.

Materials and methods

A field study was conducted during the short-rains cropping season between August and November in the year 2019, on smallholder farms in Bonjoge and Koibem, western Kenya (Figure 1). The experimental sites had differing soil fertility status according to earlier studies by Kimetu et al., (2009). Bonjoge lies between latitude E 034° 54' 42.6"and longitude N 00° 06' 52.2", elevated at 1674 m above sea level that receives an annual average of 2000 mm while Koibem lies between latitude E 024° 54' 31.9".and longitude N 00° 09' 28.2", elevated at 1700 m above sea level. Mean monthly temperatures of the two study areas ranges between 18°C and 19°C (Meteorological Station, Kakamega, (2019).

The study adopted a Randomized Complete Block Design (RCBD) with 3 x 6 factorial arrangement of treatments, replicated three times at both sites. Phosphorus fertilizer was applied at three levels of 0, 15, and 30 kg P/ha tested on six cowpea varieties; one local check (Khaki) and five improved varieties (ICV1, 1CV12, CB46, IT92K-282-2 and IT83D-442).

Initial soil characterization was done by taking 15 samples randomly at each site. Soil sample weighing about 500 g was taken to the laboratory for analysis. The soil was air dried and lumps crushed gently to separate the soil from foreign matter. The soil was later sieved (< 2 mm) and analyzed for pH (determined with water 2.5:1 H_2O), extractable P (determined calorimetrically, Murphy and Riley 1962), particle size (hydrometer method) and through (<0.75 mm) for organic carbon and total N analysis. The procedures followed Okalebo *et al.,* (2002) manual.

Cowpea seeds sown and spaced at 45 cm by 15 cm. Routine agronomic management practices were done. Data collected included grain yield. Grain samples were oven dried at 65^0C until it maintained constant weight. Grain yield determination was calculated using the relationships;

Yields per plot = Total Fresh Weight x Sample Dry Weight / Sample Fresh Weight,

Yield (Kg/ha) = Yields per plot x 10,000 / Effective Area Harvested

Data was analyzed using SAS Statistical software; release 8.2 SAS Institute Inc., (2011). Least Significant Difference (LSD) test was used to separate means of parameters significant at 95% confidence level. The models employed in the analysis were:

$$Y_{ij} = \mu + A_i + B_j + AB_{ij} + \sum_{ij}$$

where;

Y: Plot observations, µ: Overall mean of plot observations, A_i: Effect due to P fertilizer, B_j: Effect due to cowpea varieties, AB_{ij}: Interaction between P fertilizer and cowpea varieties, $\sum_{ijkl}$: Overal experimental error.

Results

Initial soil chemical and physical characterisation of study sites in Nandi South County

Initial soil characterization confirmed a clear decline in soil nutrient level i.e. percent soil organic carbon (SOC), percent total N and extractable P, from Koibem to Bonjoge (Table 1). According to Okalebo *et al.*, 2002, soils were acidic in all sites, i.e. less than soil pH value 7.0 and showed limiting P levels (< 10 ppm extractable P) (Table 1). Due to the acidic nature of the soils, soluble sources of P, such as those in fertilizers may have been fixed, and in time, form highly insoluble compounds of Fe and Al compounds (Sanchez *et al.,* 2015). Koibem showed highest values of both percent SOC and total N at 3.91 and 0.38 respectively. The values were above critical threshold levels considered adequate for crop production (Okalebo *et al.,* 2002). Moderate levels of C:N ratio may have resulted from residual effects of maize stover incorporation, a common land management practice by smallholder farmers in these sites, perceived to be a means of replenishing soil fertility (Nekesa et al., 1999).

***Table 1*: Initial soil chemical and physical characteristics of surface soils (0-20cm) taken at study sites**

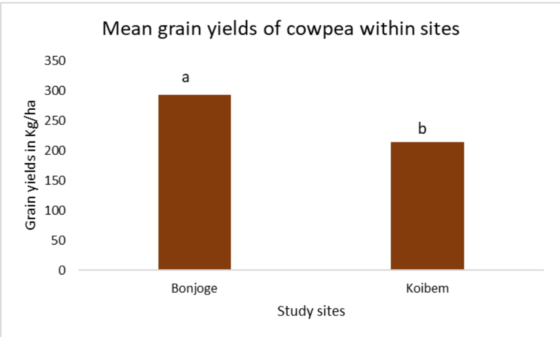
Soil Parameters	*Experimental sites*	
	Bonjoge	Koibem
pH_w (1:2.5 H_2O)	5.81	6.12
Organic Carbon (%)	3.53	3.91
% Nitrogen	0.31	0.38
Olsen P (mg /kg)	9.25	9.38
C: N	11.39	10.29

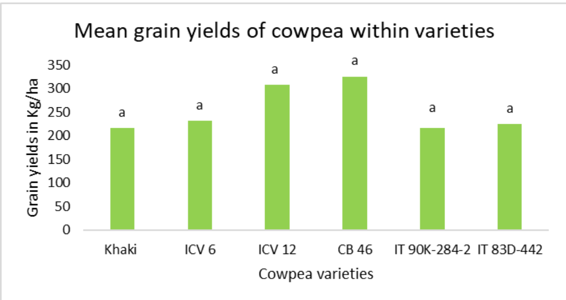
% Sand	71	67
% Silt	22	24
% Clay	7	9

Effect of Site, varieties and fertilizer application on cowpea grain yield (kg/ha)

Effect of site significantly (p<0.05) influenced mean grain yield of cowpea varieties studied. At Bonjoge, cowpea grain yields varied from 206 to 434 kg/ha and were significantly (p<0.05) higher than the yields at Koibem which ranged from 127 to 342 kg/ha (Figure 1). Averaged across varieties, mean grain yield increase of 37% was observed at Bonjoge compared to Koibem. Highest and least average yields were from variety CB 46 (325 kg/ha) and variety Khaki (216 kg/ha) and IT 90K-284-2 (216 kg/ha), respectively (Figure 1).

While the yield from 15 kg P/ha treatment was slightly higher than the 0 kg P/ha and 30 kg P/ha treatments, the difference was not statistically significant (p<0.05).





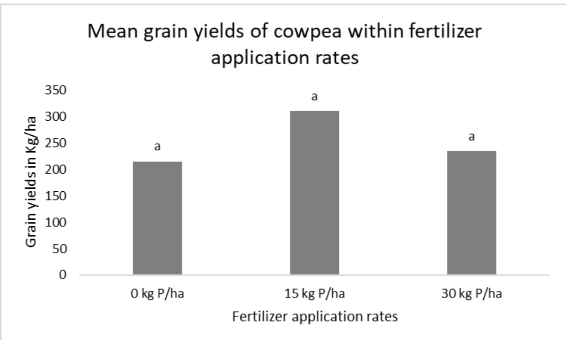


Figure 2: Effects of Site, cowpea and P fertilization on cowpea grain yields.

Means within a location followed by the same letter are not significantly different at P < 0.05 according to LSD.

Comparison between varieties showed that, P application significantly (p<0.05) influenced grain yield production in Koibem but not in Bonjoge (Table 2). However, in both sites, more increase on mean grain yield was observed at 15 kg P/ha rate than at 30 kg P/ha when compared to the no P rate. At 15 kg P/ha rate, mean grain yield increase of 33% (Bonjoge) and 62% (Koibem) was observed relative to no P rate (Table 2) while at 30 kg P/ha rate, grain yield increase of 8% (Bonjoge) and 10% (Koibem) was observed relative to no P rate. Mean grain yield was significantly (p<0.05) influenced by varietal differences at both sites. (Table 2).

Yields from variety CB 46 at Bonjoge (434 kg/ha) was statistically higher (p<0.05) than varieties ICV 6 (206 kg/ha) and IT90K-284-2 (217 kg/ha) at Bonjoge and IT 83D-442 (128 kg/ha) and Khaki (127 kg/ha) at Koibem, but was statistically similar (p>0.05) in yields to other lines at both sites.

***Table 2*: Effect of P application on mean grain yield (kg / ha) at study sites during SR 2009 experiment**

		P rates (kg P/ha)			
Site	Cowpea varieties	0	15	30	**Means**
(a) Bonjoge (MHFS)	Khaki	228b	182b	506a	**306**
	ICV 6	170b	151b	295ab	**206**
	ICV 12	319ab	335ab	160b	**272**
	CB 46	544a	540a	219b	**434**
	IT 90K-284-2	161b	228b	262ab	**217**
	IT 83D-442	121b	615a	229b	**322**
	Means	**257**	**342**	**278**	
(b)Koibem (HFS)	Khaki	171b	134b	76b	**127**
	ICV 6	256ab	299ab	196b	**256**
	ICV 12	214ab	347a	466a	**342**
	CB 46	92b	381a	173b	**215**
	IT 90K-284-2	210ab	319ab	114b	**214**
	IT 83D-442	88b	188b	108b	**128**
	Means	**172**	**278**	**189**	
	Grand mean	253			
	SED $_{(phosphorus)}$	49			

SED $_{(variety)}$	66
SED $_{(Phosphorus\ x\ variety)}$	104

Mean values with the same letters in the column are not significantly different from one another at P<0.05

Effect of interaction between Fertilizer and varieties on cowpea grain yield (kg/ha)

Highest average yields at statistically significant (p<0.05) values were from variety IT 83D-442 (615 kg/ha) at 15 kg P/ha application rate in Bonjoge and ICV 12 (466 kg/ha) at 30 kg P/ha application rate in Koibem.

Discussions

Soil chemical and physical characteristics of the field study sites in Nandi South County

Initial soil chemical characteristics exhibited a trend of declining soil fertility (N and P) and soil organic carbon (SOC) stock. The two sites showed low available P levels (less than 10 mg/kg considered critical for extractable P in soils) suggesting the need for supplemental P addition. Continuous cultivation of these sites without or with minimal fertilizer replenishment partly resulted to gradual depletion of soil P (Kinyagi *et al.*, 2008), hence the low available P levels.

Effect of phosphorus fertilizer application on grain yield

Phosphorus application did not influence grain yield production. At 15 and 30 kg P/ha, mean grain yield increase was statistically (p>0.05) similar. The results were inconsistent with the findings reported by Okalebo *et al.*, (1997) and Vanlauwe *et al.*, (2007), that soils from smallholder farms in western Kenya are predominantly P deficient and therefore requires modest applications of P fertilizers at recommended rates (FURP, 2020), for increased and sustained crop yields. This finding partly confirms the beneficial effect of nutrient P on cowpea grain production (Vance, 2001).

Conclusions

Results from this study show that extractable P and total N were limiting at all sites. While productivity is influenced by soil fertility status, application of P was not essential for increasing grain yield. There were no significant differences in the cowpea grain yield with varying rates of fertilizer application.

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