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Effects of Phosphorus Fertilizer Sources and Application Time on Grain Yield and Nutrient Composition of Cowpea (*Vigna unguiculata* L., Walp)

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Authors' contributions

This work was carried out in collaboration between the both authors. Author OJA designed the study, performed the statistical analysis and wrote the first draft of the manuscript. Author AAO carried out edited corrections and facilitated all e-mail correspondences. Both authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

The appropriate time to apply water-soluble phosphate fertilizer sources for the production of cowpea (IT84E-2246-4) was evaluated in an Oxic Paleustalf at the Teaching and Research Farm, Ekiti State University, Ado-Ekiti. Cowpea growth and yield were significantly improved by single superphosphate (SSP) and triple superphosphate (TSP), each applied to supply 45 kg $P_2O_5.ha^{-1}$. The increase in vegetative growth and nodulation enhanced earliness to flowering and the combined effects produced significantly higher grain yield from TSP and SSP compared to NPK 15-15-15 and the control (0kg $P.ha^{-1}$) treatments. P fertilizer applied at sowing enhanced early vegetative growth and produced the highest number of nodules, flowers and $pods.plant^{-1}$ which ensured significantly higher grain yield than withholding the application till 3 and 5 weeks after sowing. The low grain yields obtained from application of P fertilizer at 3 and 5 weeks after sowing were not significantly different which favour applying P fertilizer at sowing time as the recommended practice.

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1. INTRODUCTION

The deficiency of phosphorus (P) is widespread in most of the soils in Nigeria. The soils are highly-weathered Alfisols, Ultisols and associated Entisols [1] in which native and applied P are converted, through fixation reactions, to forms not readily available to crops such that this deficiency constitutes one of the soil fertility constraints to high yields in cowpea. Thus, P fertilizer is vital to output maximization as its application stimulates root and shoot growth, nodulation and general efficiency of the Rhizobium-legume symbiosis [2] as well as flowering, pod and seed formation [3]. The cumulative effects of these benefits is grain yield response to P fertilizer application from which the optimum requirements between 13 and 40 kg $P.ha^{-1}$ have been obtained and so indicated in several extension bulletins and cowpea production guides [4- 6].

Once the rate of nutrient to apply has been determined, there remains the need to resolve the issue of the right type(s) of fertilizer that would be used to supply the nutrient for the best results. There are several commercial P fertilizers out of which single superphosphate (SSP; 18% P_2O_5), triple superphosphate (TSP; 45% P_2O_5) and a number of nitrogen (N)-containing P sources: nitrophosphates, ammonium phosphates (di-ammonium phosphate, DAP, 18-46-0; mono-ammonium phosphate, MAP, 11-48-0) and compound NPK fertilizers have been used as P sources in Nigeria [6]. These sources contain mainly water-soluble form of P, being 90 and 95-98% in SSP and TSP respectively [7] and they have been recommended for cowpea production. Unfortunately, these sources are scarce in Nigeria, especially at the beginning of the cropping season and so farmers are unable to sow seeds timely, are compelled to establish cowpea farms without applying fertilizer or do so late.

The search for alternative P fertilizer sources has necessitated the evaluation of rock phosphate and basic slag- a by-product of the iron and steel industry. These sources contain water-insoluble phosphate which has been found suitable for acid soils and give best results when the sources are finely-ground, broadcast and incorporated with the top layer of soil during land preparation [8]. Rock phosphate leaves high residual P in the soil which may not benefit a cowpea crop that matures in 60-90 days, more so as it is grown during the late season when unreliable rainfall can affect solubilisation of the phosphate mineral [9]. In these circumstances, water-soluble sources which give superior performances during the year of application but leave less residual P in the soil than rock phosphate [10] would be the choice. This experiment was carried out to evaluate the performances of some water-soluble phosphate fertilizer sources and also determine the time of P fertilizer application after planting that can be applied without suffering significant cowpea grain yield losses.

2. MATERIALS AND METHODS

This study was conducted in the late seasons of 2010 and 2011 on the Teaching and Research Farm, Ekiti State University, Ado-Ekiti (long. 7º47'N and lat. 5º13'E). Ado-Ekiti is located in the dry forest zone and experiences a warm sub-humid tropical climate with long-term mean annual rainfall of 1,367 mm received in 112 days between March and November. Table 1 shows the characteristics of the surface layer (0-15 cm) soil samples as slightly acid sandy loams containing low organic matter, total N, available P and exchangeable cations.

Table 1. Characteristics of the surface layer (0-15 cm) of soils in the study sites

Soil characteristics	2010	2011
Sand, %	71.5	71.1
Silt, %	18.2	10.6
Clay, %	10.6	18.3
Textural Class	SL	SL
pH (Water)	6.0	5.8
Organic Matter, %	1.99	2.24
Total N, %	0.07	0.09
Available P, mg.kg-1	5.90	3.10
Exchangeable cations		
K, cmol.kg-1	0.19	0.23
Ca, cmol.kg-1	2.24	2.56
Mg, cmol.kg-1	0.45	0.52
Na, cmol.kg-1	0.09	0.06
Exchangeable acidity	0.76	0.68
Effective CEC	3.73	4.05
Base Saturation, %	79.6	83.2

SL = Sandy Loam

The land was ploughed, harrowed and a fairly level portion measuring 17x30 m marked out into four blocks, each subdivided into four 3x6 m plots separated by 1m paths. In the first experiment, SSP, TSP and NPK 15-15-15 fertilizers were used to supply the 45kg $P_2O_5.ha^{-1}$ optimum rate [11] and compared to a control treatment without P (0kg $P.ha^{-1}$) in the presence of 20 kg N and 50 kg $K_2O.ha^{-1}$ as urea (46%N) and muriate of potash (MOP, 60% K_2O) respectively. In the second experiment, 45kg $P_2O_5.ha^{-1}$ as SSP was applied at different times: At planting, 3 weeks after sowing (WAS) and 5 WAS. The control and all the treatments received basal 20kg N and 50kg $K_2O.ha^{-1}$.

Seeds of IT84E-2246-4 variety of cowpea were sowed at 60x30 cm spacing and seedlings thinned to $two.stand^{-1}$ to attain the recommended population of 111, 110 $plants.ha^{-1}$ [5]. Data of vegetative characters (plant height, number of leaves and branches, leaf area) and reproductive parameters (number of flowers and pods) were collected weekly from randomly selected plants in each plot beginning at 3 WAS. At 46 days after sowing (DAS), sample plants were carefully uprooted for the determination of nodulation count and weight. Index leaf samples were taken and oven-dried at 70ºC for 48 hours. Mature pods that had dried were harvested twice weekly, bulked for each plot into polypropylene bags and shelled by beating with heavy wooden sticks. The seeds were recovered by winnowing, further sun-dried and weighed.

The oven-dried index leaf samples were ground in a micro-hammer mill and digested in a ternary mixture of concentrated nitric-sulphuric-perchloric acids (25-5-5 v/v). Total P in the digest was determined using the vanado-molybdate yellow method, total K, Ca and Na by flame photometry and Mg by atomic absorption spectrophotometry while total N was determined with the micro-Kjeldahl digestion method using standard laboratory procedures described in IITA [12] Laboratory Manual.

Growth and yield data were subjected to statistical analysis using the variance ratio method described in Steel et al. [13]. The treatment means were separated with the Least Significant Difference (LSD) at 5% level of probability.

3. RESULTS

The effects of P application at the optimum 45kg P_2O_5.ha^{-1} on cowpea growth parameters are shown in Table 2. Cowpea plants increased in height with age but most growth was recorded in NKP 15-15-15 treatment (11.5cm) while the least was from SSP application (0.9 cm). P application produced significantly (P=0.05) taller plants than those in the control and NPK15-15-15 treatments at 4 WAS with plants in SSP taller than TSP treatment. At 5 WAS, SSP still produced the tallest plants but the height did not differ from TSP and NPK 15-15-15 treatments. NPK 15-15-15 gave tallest plants at 6 WAS but the height did not differ from SSP treatment. TSP and SSP produced the highest number of branches.plant^{-1} which differed significantly from the control treatment only. The control treatment gave 35 leaves. Plant^{-1} which was significantly different from NPK 15-15-15 and SSP which produced 30 and 28 leaves. Plant^{-1} respectively. TSP and control treatments gave largest leaf area.plant^{-1} which differed significantly from SSP and NPK 15-15-15. Nodulation as indicated by number of nodules.plant^{-1} was highest in TSP treatment followed by SSP while the difference between control and NPK 15-15-15 was significant. The number of flowers was highest in TSP and SSP followed by NPK 15-15-15 and least in the control treatment.

Table 2. Effect of different P sources on growth performance of cowpea

Parameters		**Treatments**				**SE**
		Control	**SSP**	**TSP**	**NPK-15-15-15**	
Plant height	4 WAS	26.7	36.0	28.5	25.6	0.48
	5WAS	31.0	36.4	35.8	36.0	0.35
	6WAS	31.8	36.9	36.1	37.1	0.50
Number of branches		3.5	4.0	4.5	3.8	0.34
Number of leaves		35	28	34	30	1.27
Leaf area, cm^2		3213	2838	3414	1232	216.79
Number of flowers		7.8	24.0	28.0	17.0	0.90
Number of nodules		10.0	16.5	22.8	5.0	1.34

WAS= Weeks after sowing; Number of branches, number of leaves and leaf area determined at 4 WAS; Number of flowers and nodules determined at 6 WAS; SSP= Single superphosphate TSP= Triple superphosphate

Table 3 shows the influence of P fertilizer sources and stage of development on biomass yield of cowpea. The pattern of biomass yield differed among the treatments at the various stages of development with highest yield produced as follows: control followed by NPK 15-15-15 before flowering; TSP and SSP at flowering; SSP and control at pod setting; and TSP and SSP at harvesting.

The nutrient concentrations of cowpea index leaves over the four-week period are shown in Table 4. Leaf P was least in the control treatment (1.4% P) before flowering (3 WAS), increased to 2.0% at flowering and decreased progressively until harvesting. The trend was similar for the P sources but with SSP containing the highest index leaf P at pod setting. NPK 15-15-15 contained 1.9% leaf P before flowering, increased to 2.1% at flowering and decreased to 1.0 and 1.6% at pod setting and harvesting respectively. Cumulative leaf P was 7.8, 6.7, 6.5 and 6.4% for TSP, SSP, control and NPK 15-15-15 respectively. Leaf Ca and Mg were not affected whereas application of the P sources increased mean index leaf N.

Table 3. Effect of different P sources on dry matter yield of cowpea

Treatment	Sampling periods			
	Before flowering	At flowering	Pod setting	Harvesting
	Biomass yield($g.plant^{-1}$)			
Control	48.8	70.5	89.3	120.5
SSP	27.4	77.6	102.6	187.5
TSP	36.3	76.4	83.2	265.0
NPK 15-15-15	39.0	70.6	79.3	116.0
SE	0.44	0.95	1.26	1.55

SSP= Single superphosphate; TSP=Triple superphosphate

Table 4. Effect of different P sources on index leaf nutrient composition of cowpea

Parameters	Treatments				
Nutrient content	Control	SSP	TSP	NPK 15-15-15	SE
N%	1.79	1.97	2.34	1.76	0.048
P,% Before Flowering	0.28	0.32	0.36	0.56	0.002
After Flowering	0.40	0.41	0.43	0.42	0.013
Pod Setting	0.18	0.50	0.40	0.20	0.023
Harvesting	0.12	0.13	0.38	0.32	0.032
Total	1.22	1.34	1.56	1.30	0.049
K,%	3.60	4.13	4.17	4.43	0.102
Ca,%	0.41	0.50	0.48	0.51	0.015
Mg,%	0.58	0.35	0.31	0.50	0.011

SSP= Single superphosphate; TSP=Triple superphosphate

Table 5 shows the grain yield and yield components of cowpea as influenced by application of P sources. The effects of the P sources were significant on grain yield (P=0.05) with the performance being in the order: TSP>SSP>NPK 15-15-15>control. The trend was similar for number of pods. $Plant^{-1}$, 100-seed weight, and pod length and seeds pod^{-1}.

Table 5. Effect of different P sources on yield components of IT84E-2246-4 variety of cowpea

Treatments	No of $pods.plant^{-1}$	Pod length(cm)	No of seeds. pod^{-1}	100- seed weight (gm)	Grain yield ($MT.ha^{-1}$)
Control	10.0	10.3	11.5	15.93	0.381
SSP	11.5	10.3	11.0	17.38	0.575
TSP	12.8	11.3	12.0	19.33	0.798
NPK 15-15-15	10.5	10.0	11.3	16.10	0.453
SE	0.82	0.34	0.52	0.57	0.064

SSP= Single superphosphate; TSP= Triple superphosphate

The effects of different times of P fertilizer application on cowpea growth parameters are shown in Table 6. P application at planting enhanced early vegetative growth in terms of plant height, number of leaves and leaf $area.plant^{-1}$. The control treatment gave the least values of these growth parameters which did not differ significantly (P=0.05) from withholding P fertilizer application until 3 and 5 WAS. The same trend was observed for number of nodules, flowers and $pods.plant^{-1}$ and biomass dry matter yield.

Table 6. Effect of time of P fertilizer application on cowpea growth performance

Parameters	Treatments				SE
	Control	T0	T1	T2	
Plant height(cm) 4 WAS	26.1	33.4	29.4	29.8	0.40
5WAS	28.4	34.0	32.9	30.1	0.41
6WAS	27.8	34.2	33.3	31.7	0.37
Number of branches	4.0	4.2	3.3	4.1	0.85
Number of leaves	41.5	58.5	48.5	47.0	3.77
Leaf area, cm^2	1820.0	2100.0	2201.0	2504.0	64.63
Number of flowers	18.0	25.0	16.4	16.9	0.69
Number of nodules	24.3	38.9	30.3	25.6	0.52
Biomass yield ($g.plant^{-1}$)	30.0	35.2	32.5	31.6	0.64

T0= P application at planting time; T1= P application 3 weeks after sowing; T2= Papplication 5 weeks after sowing; WAS= weeks after sowing

Table 7 shows the dry grain yield and yield components of cowpea as influenced by the different times of P fertilizer application. Grain yield and components of yield- number of $pods.plant^{-1}$, average pod length, number of $seeds.pod^{-1}$ and 100-seed weight were best with P applied at planting, 3 and 5 WAS did not differ significantly while the control treatment gave least values.

Table 7. Effect of P fertilizer application times on cowpea yield components

Parameters	Treatments				SE
	Control	T0	T1	T2	
No of $pods.plant^{-1}$	10.5	12.5	10.1	10.0	0.99
Pod length	9.8	10.8	10.2	10.1	0.28
No of $seeds.pod^{-1}$	9.6	10.8	10.2	10.1	0.19
Grain yield ($MT.ha^{-1}$)	0.33	0.73	0.16	0.57	0.02
100-seed weight (gm)	15.4	16.3	15.7	15.4	0.15

T0= P application at planting time; T1= P application 3 weeks after sowing;T2= P application 5 weeks after sowing

The effects of different times of P fertilizer application on index leaf nutrient composition of cowpea are shown in Table 8. The control treatment gave lower index leaf %N, K, Ca and Mg contents whereas P application increased %P by 68-78% with the highest value obtained when P fertilizer was applied at planting.

Table 8. Index leaf nutrient content as influenced by time of P fertilizer application

Treatments	Nutrient content					
	N	P	K	Ca	Mg	Na
Control	1.8	0.34	2.4	0.43	0.25	0.086
T0	2.2	0.61	2.8	0.52	0.27	0.096
T1	2.1	0.57	2.6	0.50	0.27	0.090
T2	2.0	0.58	2.5	0.49	0.26	0.092
SE	0.1	0.06	0.1	0.011	0.012	0.002

T0= P application at planting time; T1= P application 3 weeks after sowing; T2= P application 5 weeks after sowing

4. DISCUSSION

The vegetative response to P application is not surprising given the available P content of the soil which was below the 7.0mg.kg^{-1} critical level established for cowpea [14]. Similar responses of cowpea to P fertilizer application in soils deficient in available P have been reported [15,3,16,17,11]. Although cowpea can be more tolerant of the P stress associated with the soils in the sub-humid zone of Nigeria than other legumes like soyabean, the recommended 45 kg P_2O_5.ha^{-1} rate applied significantly improved plant growth performance and gave optimum grain yield.

The increase in nodulation is one of the advantages of P application to cowpea and this was shown by the TSP and SSP treatments [14,16]. On the other hand, reduced nodulation from NPK treatment confirms earlier reports of the suppression of nodulation when NPK fertilizer was used as a P source for groundnut production [18]. The explanation is that NPK lowers the N-fixation potential of cowpea by reducing the population of rhizobium bacteria in the rhizosphere and hence the lower number of root nodules.

Cowpea performed better with the application of TSP and SSP, in terms of vegetative growth and reproductive characters, probably on account of the differential solubility of the phosphate forms and possible interactions with other soil nutrients. Since application of TSP and SSP increased index leaf N, then the choice of P sources to enhance N-fixation would be a strategy for N nutrition and balance of cowpea. The use of compound NPK fertilizers is widespread in Nigeria where NPK 15-15-15 has become the most popular product slate. However, the claim of its suitability for all crops and soil conditions has been criticized, especially for cowpea where the use to provide the required P would surreptiously increase N supply. NPK 10-20-10 as the appropriate recommended slate for grain legumes [6] has not been produced by the local fertilizer industry. The choice will be to use the straight P sources (TSP, SSP which contain water-soluble phosphates) in addition to basal N+K for optimum grain yield of cowpea.

Data reported from the second experiment indicate the importance of applying the P at the early stages of cowpea growth, particularly to stimulate root elongation and proliferation, nodule formation and development of vegetative structures as well as uptake of other plant nutrients. Since P plays vital roles in the reactions involving energy transfer, cowpea which depends on fixed N for growth would require large amounts [19]. N-fixation is usually optimum between flowering and early pod-fill stages which coincides with demand for high P levels needed in the energy transfer for the development of reproductive structures and seed formation. For a P-deficient soil, delaying P application till 3 and 5 WAS (closer to flowering stage) would have starved the plants and the applied P not effectively utilized. A major consideration in P fertilizer management is the fear of high P fixation in soils of the tropics for which initial heavy dosages needed to satisfy the fixation capacity and divert the excess for plant use is a control measure [6]. Thus, the recommendation to broadcast P fertilizer before splitting the ridges or at seed bed preparation conforms to this measure. However, in view of the low P fixation capacity of coarse-textured soils developed on basement complex granitic rocks in Western Nigeria [20], P applied at planting would remain available to enhance efficient P use, as indicated by the higher percentage of P in the index leaf. P applied at 5 WAS gave better grain yield than the control treatment but would not be recommended given that this cowpea variety matures in 65-75 days.

5. CONCLUSION

Application of superphosphate fertilizers increased vegetative growth and nodulation, enhanced earliness to flowering and grain yield of cowpea compared to npk 15-15-15 fertilizer as a p source. P fertilizer applied at sowing enhanced early vegetative growth and nodulation, produced the highest of flower and pods.plant^{-1} and grain yield than the delayed application at 3 and 5 weeks after sowing. The application of superphosphate fertilizer at sowing time would be the recommended practice for cowpea cultivation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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