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Phosphorus Uptake and Balance in a Soyabean-Maize Rotation in the Moist Savanna of West Africa

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Abstract
This study investigated the effect of maturity class on phosphorus (P) balance in a soyabean-maize rotation in the West African moist savanna. Four soyabean varieties of different maturity classes were grown with or without P fertilizer followed by a maize crop. Soyabean stover P content averaged 1.77 kg ha^{-1} compared with 5.13 kg ha^{-1} in the grain. The late soyabean variety TGx1670-1F accumulated a significantly higher P in the grain (6.56 kg ha^{-1}), and stover (2.57 kg ha^{-1}) than the others. While P harvest index averaged 79%, P application increased grain P by 63-81% and stover P by 100% or more. When either soyabean grain or grain+stover was exported, P balance was negative and was not statistically different for varieties when no P was applied. At 30 or 60 kg P ha^{-1}, P balance was negative but significantly lower in TGx1670-1F compared with other varieties. Increasing P rate applied to soyabean significantly ($p < 0.01$) increased maize grain P by 35-66% in the second year. When P was exported only in soyabean grain, cumulative P balances after maize grain harvest (with no P or 30 kg ha^{-1} applied previous year) were not significantly different for previous soyabean crops. At 60 kg ha^{-1}, however, P balance in previous TGx1670-1F plot was significantly lower than for other varieties. A further export of soyabean stover reduced P balance. Significant residual P effect was observed emphasizing the need to focus P fertilizer application in the cropping system rather than on the single crop. Also with more P in soyabean grain, a reduction in the extent of P depletion will be achieved by returning soyabean stover to the field after threshing.

Keywords: phosphorus balance, soyabean, moist savanna, maize, rotation

1 Introduction

The moist savanna make up to 80% of the land area in West Africa. With a precipitation/evaporation ratio of between 0.40 and 0.10 (Isichei and Akobundu, 1995), this ecological zone is well suited to annual crops of medium duration such as groundnut,

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maize and soyabean (Jagtap, 1995). Low levels of soil available phosphorus (P) are, however, common in this ecological zone and this has been attributed to the low levels of clay and organic matter (Manu *et al.*, 1991). Under low soil P status, P fertilizer application to legume and its management are of importance in attaining high yields. Not the entire nutrient element applied in fertilizers, however, is absorbed and incorporated into crop plant tissues. Phosphorus for instance, is immobile in the soil. Only 10-30% of the P applied in fertilizers in tropical areas is recovered by crop plants (Baligar and Bennett, 1986). From their work on cowpea, Ankomah *et al.* (1995) reported that the crop was able to recover 8 to 9.4% of the P applied as triple superphosphate. Much of the unabsorbed P remains in soil as fertilizer reaction products. These fertilizer reaction products are only slowly available to the crop and carry some residual value to the succeeding crop in the cropping sequence (Fixen and Ludwick, 1982).

Where cereals follow grain legumes in rotation, Pandey and McInttosh (1990) have hypothesized that adequate P fertilization of the legume may eliminate or considerably reduce the amount of P fertilizer needed for the cereal. A fertilization practice in which P is first applied to the legume component in a legume-cereal rotation is premised on the importance of P in biological nitrogen fixation (BNF). When BNF is maximized by non-limiting P supply, a greater amount of residual N is available to the subsequent cereal crop. In their work on pigeon pea, Ae *et al.* (1991) reported that the crop can convert $Fe - P$ into available form of P, thus making P more available to subsequent crop. The farmer can, therefore, appropriate the benefits of residual P on subsequent cereal crop in a legume-cereal rotation system. As crops are harvested, however, the nutrient elements accumulated in the harvested biomass are consequently removed from the system. According to Kumari *et al.* (1992) available P under soyabean showed a positive balance where no P fertilizer was added, and negative balance where P was added. They attributed this to the greater amounts of P removed in the higher yields obtained with fertilizer treatments. Such exports lead to reduction in total nutrient balance (Stoorvogel and Smaling, 1990; Bationo and Mokwunye, 1991). In the moist savanna of West Africa, the resulting nutrient balances in crop fields are generally negative because crop nutrients are derived from the already low soil stock which is usually not supplemented with inorganic fertilizer because of high costs and availability. As this negative nutrient balance becomes recurrent, soils of low nutrient status are further depleted (Rhodes *et al.*, 1996). There is, therefore, the need for P management practices that will optimize yield and economic returns as well as nutrient and water use efficiency (Davis *et al.*, 1994). In order to establish the appropriate P fertilizer practice, this study was carried out to determine the amount of P loss in a soyabean-maize rotation, and consequently determine the P balance in the system.

2 Materials and Methods

Field studies were carried out during the growing seasons of 1996 and 1997 at Mokwa (9°18'N, 5°04'E), Fashola (7°56'N 3°45'E), Gidan Waya (9°28'N, 8°22'E) and Kasuwan Magani (10°24'N, 7°42'E) in the moist savanna ecological zone of Nigeria where the length of growing period is 151-270 days. Varying amounts of rainfall are, therefore, received across this zone. Distribution and average amount of rainfall at experimental sites in the 1996 and 1997 cropping seasons are presented in Table 1. The site at Mokwa had been variously planted to cowpea and maize until 1995. Maize, sorghum and groundnut were planted at Kasuwan Magani until 1995. At Gidan Waya, the land was planted to soyabean in 1995 after being fallowed for over 20 years. The site at Fashola had been fallowed for over 20 years before clearing in 1996. Although information on previous soil fertilization practices for the sites were not available, the available soil P determined using Bray II according to the procedures outlined by OKALEBO *et al.* (1993), was 16.2 mg kg^{-1} at Mokwa while the values at the other sites were less than 7 mg kg^{-1}. Other chemical and physical characteristics of the soils at the time of sowing in 1996 are shown in Table 2.

Table 1: Distribution and average amount of rainfall at experimental sites in the 1996 and 1997 cropping seasons

Month	*Amount of Rainfall (mm)*			
	Mokwa	*Fashola*	*Gidan Waya*	*Kasuwan Magani*
May	211	147	48	172
June	242	256	241	258
July	126	102	368	266
August	185	120	363	419
September	80	215	142	319
October	87	99	100	90
Total Rainfall	931	939	1262	1524

Table 2: 1996 pre-planting soil chemical and physical properties at the experimental sites

Properties	*Site*			
	Mokwa	*Fashola*	*Gidan Waya*	*Kasuwan Magani*
pH (1:1 soil/H_2O)	6.1	6.1	4.9	5.6
Organic Matter (g kg^{-1})	0.88	1.02	1.50	1.30
Total N (g kg^{-1})	0.60	0.69	1.13	0.78
Bray-II P (mg kg^{-1})	16.2	5.2	6.2	5.7
Sand (g kg^{-1})	770	860	650	590
Silt (g kg^{-1})	190	110	210	260
Clay (g kg^{-1})	40	30	140	150
Textural Class	Loamy Sand	Loamy Sand	Sandy Loam	Sandy Loam

Four soyabean varieties: TGx1670-1F and TGx923-2E, maturing in 115-120 days; TGx536-02D (Medium), maturing in 100 days; and TGx1485-1D (Early), maturing in 95 days were sown at all sites in 1996. The soyabean varieties as main plot treatments received P (sub-plot treatment) which was applied as triple superphosphate (20% P) at the rates of 0, 30 and 60 kg P ha^{-1}. Treatments were assigned in a split-plot arrangement in a randomised complete block with three replications. P was applied and mixed with soil in furrows made at the top of ridges to the depth of 6-8 cm. The ridges were 75 cm apart and soyabean seeds were drilled along the ridges after the application of triple superphosphate. Soyabean seedlings were thinned to 8 cm within row spacing three weeks after planting. Late soyabean varieties were sown three weeks before the early and medium varieties at all sites. In 1997, ridges in each plot were re-made and the maize variety, TZEComp4C2, was sown in all plots at all sites.

At harvest in 1996, soyabean plants within 2 m length of three central rows were cut at the base. Pods were separated from each aboveground harvest, dried and shelled for grain. Soyabean litter was collected at grain harvest using 0.5 x 0.5 m quadrat within each sub-plot, air-dried and cleaned of soil. In 1997, maize grain yield was determined by harvesting the 2 m length of the three central rows in each plot. The soyabean stover (which included haulm and the pod wall obtained after shelling), grain, litter, and maize grain were oven-dried for 48 h and milled to pass through 1 mm sieve. The P contents were then determined by digestion with H_2SO_4 and subsequently colorimetry (Okalebo *et al.*, 1993). The amount of P left in the field after grain harvest depends on the total amount of P accumulated. Soyabean phosphorus harvest index (PHI) was determined as a ratio of grain P to total plant P in standing biomass at harvest. P balance after soyabean crop was determined for when: (i) only soyabean grain was exported; and (ii) soyabean grain with stover was exported. In both cases, the amount of P exported in the biomass was subtracted from the amount of P applied in fertilizer. P balance after maize grain harvest was determined by subtracting the P in maize grain from the previous P balance after the soyabean crop when either soyabean grain or grain with stover is exported. Data were analyzed using the Generalized Linear Model Procedures of the Statistical Analysis System Institute Inc. (1992).

3 Results and discussion

3.1 Soyabean Grain P content

Grain P content at harvest was significantly different for soyabean varieties at $p < 0.01$. Table 3 shows that soyabean grain P content increased with duration. The late variety TGx1670-1F accumulated a significantly larger amount of P in the grain (6.56 kg P ha^{-1}), this was at least 48% higher compared to the other varieties. The amount of P accumulated in the grain of the other late variety TGx923-2E was, however, not significantly different from that in Early and Medium. The interaction of site by P rate had a significant effect on soyabean grain P at $p < 0.01$. Increasing P rate significantly increased grain P in soyabean at all sites except Mokwa where the initial available soil P was 16.2 mg kg^{-1}. Enwezor *et al.* (1989) have classified available P status as low when less than 15 mg kg^{-1}, medium if within the range of 15-25 mg kg^{-1}, and high if greater than 25 mg kg^{-1}. They have noted that while low availability is below critical level, at medium availability is above critical level and response to fertilization is expected. Response is unlikely and fertilization may not be necessary at high soil available P level. Grain P in this study showed no significant response to P application at Mokwa where soil available P was 16.2 mg kg^{-1} and may, therefore, be classified as high. WEBB *et al.* (1992) have also reported that increases in soyabean grain yield (from which grain P content is derived) due to P fertilizer application are small or non-existent when soil test P is high. At other sites available soil P was <7 mg kg^{-1} and the responses to an initial 30 kg P ha^{-1} application was observed to have increased grain P by 94-130%. A second increment in P application of 30 kg ha^{-1} at these sites was observed to have significantly increased grain P content (by about 83%) only at Gidan Waya. The soil at this site was strongly acidic with pH of 4.9 (1:1 soil/H_2O). This must have given rise to a greater degree of P fixation compared to other sites. As the fixation sites are saturated, the effect of additional P applied in fertilizer became apparent. The differences observed in grain P among the sites were significant ($p < 0.01$). Although grain P was not affected by P application at Mokwa, the amount of P (6.24 kg P ha^{-1}) accumulated in soyabean grain at this site was higher than at other sites by at least 54% (Table 3). Averaged over sites and varieties, soyabean grain P was significantly ($p < 0.01$) increased by 62% when 30 kg P ha^{-1} were applied. A second 30 kg P ha^{-1} application did not result in a significant increase in the amount of P accumulated in soyabean grain. These results show that above 30 kg P ha^{-1}, no significant response was observed in soyabean. When soil test P is low, therefore, applying P to soyabean at the rate of 30 kg ha^{-1} may be enough to build up soil available P to a sufficiency level.

Soyabean grain P was also significantly ($p < 0.01$) affected by the interaction of variety by P rate. Increasing P rate significantly increased grain P content in the varieties (Table 3). Without P amendment, the amount of P accumulated in soyabean grain was not different for all the varieties. This shows that the soyabean varieties used in this study were not different in their abilities to utilize soil P at low available P levels. The larger response to P application was observed in the late varieties that also accumulated significantly more P in the grain compared to the Early and Medium. With an initial application of 30 kg P ha^{-1}, grain P was higher by 38-40% in Early and Medium, and 79-95% in late varieties. In only one late variety TGx1670-1F the additional 64% increase in grain P resulting from a second 30 kg P ha^{-1} increment was significant. Apart from varietal characteristics, nutrient accumulation is a function of growth duration, hence, the larger amount of grain P in the late varieties.

3.2 Soyabean stover P content

The interaction of site by P rate was significant on soyabean stover P content at $p < 0.01$. At all sites, more P was accumulated in soyabean stover with increasing P rate (Table 3). Significantly more P was accumulated in soyabean stover at Mokwa compared to other sites and while least amount of P was accumulated in stover at Gidan Waya. More P was accumulated in soyabean grain than stover at each P level and at each

Table 3: Effects of site, variety, and phosphorus on soyabean grain and stover P content, and phosphorus harvest index (PHI).

	P rate (kg P ha^{-1})			*Mean*
	0	*30*	*60*	
		Grain P (kg ha^{-1})		
Site				
Mokwa	6.32	6.70	5.69	6.24
Fashola	2.43	4.72	4.97	4.04
Gidan Waya	2.14	4.92	6.70	4.58
Kasuwan Magani	3.12	6.41	7.92	5.82
Variety				
TGx1485-1D	3.43	4.73	5.10	5.10
TGx536-02D	3.72	5. 19	5.18	5.18
TGx923-2E	3.30	5.91	5.79	5.79
TGx1670-1F	3.55	6.92	9.21	9.21
Mean	3.50	5.68	6.32	
		Stover P (kg ha^{-1})		
Mokwa	2.84	4.75	6.11	4.57
Fashola	0.26	1.10	1.38	0.91
Gidan Waya	0.22	0.77	0.83	0.61
Kasuwan Magani	0.49	0.94	1.52	1.02
Mean	0.95	1.89	2.46	
		PHI (%)		
Mokwa	71	59	49	59
Fashola	90	81	79	83
Gidan Waya	89	86	88	88
Kasuwan Magani	85	87	81	84
Mean	84	78	74	

Standard Error (grain P): site = 0.294, variety = 0.293, P rate = 0.261, site × P rate = 0.520, variety × P rate = 0.520

Standard Error (stover P): site = 0.160, P rate = 0.135, site × P rate = 0.269

Standard Error (PHI): site = 0.012, P rate = 0.010, site × P rate = 0.020

site. Although increasing P rate had no significant effect on grain P at Mokwa, results show that it significantly increased stover P at this site (Table 3). Averaged over sites and varieties, the application of 30 kg P ha^{-1} significantly increased stover P content twofold and a second 30 kg P ha^{-1} application resulted in a further 60% increase. Stover P content was significantly ($p < 0.01$) affected by soyabean variety. Evidently due to duration, significantly more P was accumulated in the stover of late varieties with the larger amount in TGx1670-1F (Table 3). Stover P contents in Early and Medium were not different. Stover P content was not significantly different in the varieties when no P was applied.

3.3 Soyabean litter P content

The effect of site was significant ($p < 0.01$) on soyabean litter P content. More P (4.11 kg P ha^{-1}) was accumulated in soyabean litter at Mokwa and this was 72-83% higher than at other sites (Table 4). The lower litter P contents observed at Fashola, Gidan Waya and Kasuwan Magani are attributable to the low initial available P content which was =6.2 mg kg^{-1} at any of this sites. CHIEZEY *et al.* (1992), have similarly reported varying responses to P due to soil P status. Soyabean variety significantly affected litter P content at $p < 0.05$. Table 4 shows that the late variety, TGx1670-1F, accumulated at least 76% more P in the litter although this was not significantly different from litter P contents of the other late variety (TGx923-2E), and the Medium. The application of P to soyabean significantly ($p < 0.01$) increased litter P, and compared to no P amendment 30 kg P ha^{-1} increased litter P by 95% while a second 30 kg P ha^{-1} increment gave no significant increase (Table 4). Significant site by P rate, and variety by P rate interactions were not observed on litter P.

3.4 Soyabean P Harvest Index (PHI)

While PHI in soyabean at final grain harvest averaged 79% in this study, IMAIL (1991) reported that 75% of the P in soyabean is accumulated in the grain. Significant differences were observed for sites, P rates, and their interaction at $p < 0.01$, but not for varieties. The significant effect of site by P rate interaction on PHI observed in this study was due to the responses at Mokwa and Fashola (Table 3). PHI was significantly reduced by 13% at Mokwa when 30 kg P ha^{-1} was applied with another 22% reduction due to a second 30 kg P ha^{-1} increment. Also at Fashola, 30 kg P ha^{-1} significantly reduced PHI by 9%, but a further 11% reduction in PHI by a second 30 P ha^{-1} application was not significant. Averaged over varieties and P rates, PHI was lowest at Mokwa (69%) where available soil P was highest. Reduction in PHI with increased P may be attributed to the enhanced dry matter accumulation resulting from improved P nutrition. Over sites and varieties, there was a significant reduction in PHI as P rate increased. Compared to no P treatment, PHI was significantly lower by 6-10% when P was applied.

Table 4: The effect of site, variety, and P rate on soyabean stover and litter P contents.

	Stover P content (kg P ha^{-1})	*Probability level for significant difference*				
Variety			1	2	3	4
TGx1485-1D	1.36	1	·			
TGx536-02D	1.30	2	0.7792	·		
TGx923-2E	1.84	3	0.0366	0.0191	·	
TGx1670-1F	2.57	4	<0.0001	<0.0001	0.0022	·
Standard Error	0.155					

	Litter P content (kg P ha^{-1})	*Probability level for significant difference*				
Site			1	2	3	4
Mokwa	4.11	1	·			
Fashola	1.13	2	<0.0001	·		
Gidan Waya	0.73	3	<0.0001	0.1940	·	
Kasuwan Magani	0.71	4	<0.0001	0.1680	0.9346	·
Standard Error	0.214					
Variety			1	2	3	4
TGx1485-1D	1.21	1	·			
TGx536-02D	1.65	2	0.1551	·		
TGx923-2E	1.70	3	0.1146	0.8717	·	
TGx1670-1F	2.13	4	0.0037	0.1150	0.1556	·
Standard Error	0.214					
P rate (kg P ha^{-1})			1	2	3	
0	0.92	1	·			
30	1.79	2	0.0018	·		
60	2.30	3	<0.0001	0.0565	·	
Standard Error	0.185					

Numbers 1 to 4 represent the effects tested for significant differences for either stover or litter P content.

3.5 Maize grain P

Results from three sites in this study show that while previous soyabean crop had no significant effect on maize grain P content at harvest, there was a significant effect of site ($p < 0.05$), previous year P rate, and site by previous year P rate interaction ($p < 0.01$). Within site, P application in the previous year had no significant effect on maize grain P at Mokwa and Fashola (Table 5). However, among the sites, maize grain P was significantly higher at Mokwa (3.34 kg P ha^{-1}) and less than 1 kg ha^{-1} at Fashola. The non-significant effect of previous year P application on maize grain P at Mokwa may be attributed to the high level of soil available P. Before the application of P at this site, initial soil test P was adequate (16.2 mg kg^{-1}). P application at Mokwa increased available P further to 33.7 and 42.8 mg kg^{-1} when 30 and 60 kg P ha^{-1} were applied, respectively (OGOKE, 1999). At this sites, therefore, P was not limiting on maize at any of the previous year P rates. Although initial soil test P was low (5.2 mg kg^{-1}) Fashola, P application only increased soil available P in the year following application to 9.8 and 13.6 mg kg^{-1} when 30 and 60 kg P ha^{-1} were applied, respectively. As a result soil P was not adequate for maize at Fashola even when 60 kg P ha^{-1} were applied previous year. In fact purple streaks were observed on maize leaves at all previous year P rates at this site and at Gidan Waya and Kasuwan Magani when no P was applied the previous year. The small P build-up at Fashola may be attributable to the low clay content (3%) of the soil. The application of P in the previous year had no significant effect on maize grain P at Mokwa because initial soil available P was high. Similarly at Fashola, ABDELGADIR (1998) and SANGINGA *et al.* (2000) have reported lack of response to P application by soyabean and cowpea lines, respectively. Increasing P rate applied previous year significantly increased grain P in maize at the third site (Kasuwan Magani). At this site, initial soil available P was low (5.7 mg kg^{-1}) but the relatively higher clay content (15%) may have enhanced P build-up in the soil. Averaged over sites and variety, maize grain P was increased by 35% when 30 kg P ha^{-1} were applied previous year to soyabean, and 66% by 60 kg P ha^{-1} previous year application. This is consistent with the already reported significant residual effect of P on maize grain yield in this study (OGOKE *et al.*, 2001).

3.6 P Balance

With only soyabean grain exported, P balance was negative and not significantly different for all soyabean crop without P amendment (Table 6). This is consequent upon the fact that regardless of duration, the amount of P accumulated in grain when no P was applied was not significantly different for soyabean varieties tested in this study. CASSMAN *et al.* (1993) have similarly reported a negative P balance due to soyabean when there was no P input. The application of P gave positive P balance for all soyabean crop. P balance was not different for the two late varieties of soyabean, or for the early and medium varieties when 30 kg P ha^{-1} were applied. At P rate of 60 kg ha^{-1}, P balance was not different in the plots of Early, Medium, and one of the late varieties (TGx923-2E). The other late variety TGx1670-1F accumulated the larger amount of P in grain and, therefore, gave the significantly least P balance for all soyabean crops.

Table 5: Effects of site and previous year P rate on maize grain P content.

Site	P *rate (kg P ha^{-1})*			*Mean*
	0	*30*	*60*	
Mokwa	3.04	3.75	3.23	3.34
Fashola	0.86	0.80	1.11	0.92
Kasuwan Magani	0.83	1.88	3.52	2.08
Mean	1.58	2.14	2.62	

Standard Error: P rate = 0.170, site = 0.170, site × P rate = 0.290

Table 6: Effect of soyabean crop on P balance in a soyabean-maize rotation.

Soyabean variety	*P Input (kg P ha^{-1})*	*P Balance (kg P ha^{-1})*			
		Soyabean grain exported	*Soyabean grain + stover exported*	*Soyabean grain P + maize grain P exported*	*Soyabean (grain + stover) P + maize grain P exported*
TGx1485-1D	0	-3	-4	-5	-6
	30	+25	+24	+24	+22
	60	+55	+53	+53	+51
TGx536-02D	0	-4	-4	-5	-5
	30	+25	+23	+22	+20
	60	+55	+53	+52	+50
TGx923-2E	0	-3	-4	-6	-7
	30	+24	+22	+22	+20
	60	+54	+51	+53	+50
TGx1670-1F	0	-4	-5	-5	-7
	30	+23	+20	+22	+18
	60	+51	+47	+48	+45

Table 6 also shows that the export of soyabean stover along with grain when soyabean plots received no P treatment resulted in negative P balances in all soyabean plots. P balances were also not significantly different for the soyabean crops at this control P treatment. At both 30 and 60 kg P ha^{-1}, significantly more P was accumulated in aboveground soyabean biomass at harvest in TGx1670-1F. Consequently, the resulting P balances in TGx1670-1F plots at these P treatments were lower. P balances in the plots of Early and Medium soyabean were not significantly different when 30 or 60 kg P ha^{-1} were applied.

In all previous year soyabean plots where P was not applied, whether P was exported only in soyabean grain or in grain with stover, the harvest of maize grain of the following year resulted in negative P balances (Table 6). P balances were not significantly different after the harvest of maize grain in previous soyabean plots that received 30 kg P ha^{-1} when only soyabean grain was exported. When both soyabean grain and stover were exported, P balance was highest in previous Early plots at this same P rate. When 60 kg P ha^{-1} were applied to soyabean previous year, and soyabean grain or grain with stover exported, the harvest of maize grain in previous plots of TGx1670-1F gave a significantly lower P balance compared with the plots of the other soyabean varieties.

4 Conclusions

In this study a significant residual P effect was observed. The application of 30 kg P ha^{-1} in soils where available P was low ($\leq$6.2 mg kg^{-1}) was able to bring soil P to high levels of availability, in the year following application, especially where the clay content was comparatively high. This emphasizes the need to focus P fertilizer application in the cropping system rather than on the single crop. Also with about 79% of the P in the above ground biomass at harvest partitioned in the grain of soyabean, a reduction in the extent of P depletion will be derived from the litter which remain and by returning soyabean stover to the field after threshing.

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References

Abdelgadir, A. H.; *The role of mycorrhizae in soyabean growth in P-deficient soil in the humid tropics*; Ph.D. thesis; Cornell University; 1998.

Ae, N., Arihara, J. and Okada, K.; Phosphorus uptake mechanisms of pigeon pea grown in Alfisols and Vertisols; in: *Phosphorus Nutrition of Grain Legumes in Semi-Arid Tropics*, edited by Johansen, C., Lee, K. K. and Sahrawat, K. L.; ICRISAT, Patancheru, India; 1991.

Ankomah, A. B., Zapata, F., Danso, S. K. A. and Axmann, H.; Cowpea varietal differences in uptake of phosphorus from Gafsa phosphate rock in a low-P Ultisol; *Fertilizer Research*; 41:219–225; 1995.

Baligar, V. C. and Bennett, O. C.; NPK fertilizer efficiency - a situation analysis for the tropics; *Fertilizer Research*; 10:147–164; 1986.

Bationo, A. and Mokwunye, A. U.; Alleviating soil fertility constraints to increased crop production in West Africa; *Fertilizer Research*; 29:95–115; 1991.

Cassman, K. G., Singleton, P. W. and Linquist, B. A.; Input/output analysis of the cumulative soyabean response to phosphorus on an ultisol; *Field Crops Research*; 34:23–36; 1993.

Chiezey, U. F., Yayock, J. Y. and Shebayan, J. A. Y.; Response of soyabean (*Glycine max* (L.) Merrill) to N and phosphorus fertilizer levels; *Tropical Science*; 32:361–368; 1992.

Davis, J. G., Manu, A., Hossner, L. R. and Persaud, N.; Phosphorus management of a millet/cowpea intercrop system in sandy dunal soils of western Nigeria; *Journal of Plant Nutrition*; 17:899–910; 1994.

Enwezor, W. O., Udo, E. J., Usoroh, N. J., Ayotade, K. A., Adepetu, J. A., Chude, V. O. and Udegbe, C. I., (Eds.) *Fertilizer Use and Management Practices for Crops in Nigeria (Series No. 2)*; Fertilizer Procurement and Distribution Division, Federal Ministry of Agric., Lagos; 1989; 163p.

Fixen, P. E. and Ludwick, A. E.; Residual available phosphorus in near-neutral and alkaline soils: II, Perspective and quantitative estimation; *Soil Science Society American Journal*; 46:335–338; 1982.

Imail, H.; Nutrient dynamics in tropical cropping systems involving legumes; in: *Phosphorus Nutrition of Grain Legumes in Semi-Arid Tropics*, edited by Johansen, C., Lee, K. K. and Sahrawat, K. L.; pages 195–211; ICRISAT, Patancheru, India; 1991.

Isichei, A. O. and Akobundu, I. O.; Vegetation as a resource: Characterization and management in the moist savannas of Africa; in: *Moist savannas of Africa: Potentials and constraints for crop production*, edited by Kang, B. T., Akobundu, I. O., Manyong, V. M., Carsky, R. J., Sanginga, N. and Kueneman, E. A.; pages 31–48; International Institute of Tropical Agriculture, Ibadan; 1995.

Jagtap, S. S.; Environmental characterization of the moist lowland savanna of Africa; in: *Moist savannas of Africa: Potentials and constraints for crop production*, edited by Kang, B. T., Akobundu, I. O., Manyong, V. M., Carsky, R. J., Sanginga, N. and Kueneman, E. A.; pages 9–30; International Institute of Tropical Agriculture, Ibadan; 1995.

Kumari, C. N. N., Thimmegowda, S., Devakumar, N. and Paramesh, R.; Effect of phosphorus management practices on balance sheet of available phosphorus of soyabean; *Indian Agriculturist*; 36:61–63; 1992.

Manu, A., Bationo, A. and Geiger, S. C.; Fertility status of selected millet producing soils of West Africa with emphasis on phosphorus; *Soil Science*; 152:315–320; 1991.

Ogoke, I. J.; *Response of soyabean to phosphorus fertilizer and its residual effects on subsequent maize performance in the Nigerian moist savanna*; Ph.D. thesis; University of Ibadan; Ibadan, Nigeria; 1999.

Ogoke, I. J., Carsky, R. J., Togun, A. O. and Dashiell, K.; Maize yield following phosphorus-fertilized soyabean in the Nigerian Guinea savanna; in: *Impact, Challenges and Prospects of Maize Research and Development in West and Central Africa*, edited by Badu-Apraku, B., Fakorede, M. A. B., Ouedraogo, M. and Carsky, R. J.; pages 205–213; WECAMAN/IITA, IITA-Cotonou, Benin Republic; 2001.

Okalebo, J. R., Gathua, K. W. and Woomer, P. L.; *Laboratory Methods of Soil and Plant Analysis: A working Manual*; TSBF Programme, UNESCO-ROSTA, Nairobi, Kenya; 1993.

Pandey, R. K. and McInttosh, J. L.; Phosphorus requirements and management of grain legumes; in: *Phosphorus Requirements for Sustainable Agriculture in Asia and Oceania*; pages 361–370; IIRI; 1990.

Rhodes, E. R., Bationo, A., Smaling, E. M. A. and Visker, C.; Nutrient stocks and flows in West African soils; in: *Restoring and Maintaining the Productivity of West African Soils: Key to Sustainable Development*, edited by Mokwunye, A. U., de Jager, A. and Smaling, E. M. A.; Miscellaneous Fertilizer Studies No. 14; pages 22–32; 1996.

Sanginga, N., Lyasse, O. and Singh, B. B.; Phosphorus use efficiency and nitrogen balance of cowpea breeding lines in a low P soil of the derived savanna zone in West Africa; *Plant and Soil*; 220:119–128; 2000.

Statistical Analysis System Institute Inc.; *SAS/STAT User's guide*; SAS; Cary, NC; 1992.

Stoorvogel, J. J. and Smaling, E. M. A.; Assessment of soil nutrient depletion in sub-Saharan Africa, 1983-2000; Report 28, DLO Winand Staring Centre for Irrigated Land, Soil and Water Research (SC-DLO), Wageningen, Netherlands; 1990.

Webb, J. R., Mallarino, A. P. and M., B. A.; Effect of residual and applied phosphorus on soil test values and yields of corn and soyabean; *Journal of Production Agriculture*; 5(1):148–152; 1992.