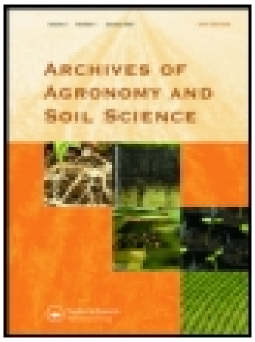

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Influence of phosphorus application on growth and yield of soybean genotypes in the tropical savannas of northeast Nigeria

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Abstract
The cultivation of soybean is increasing in the savannas of Nigeria due to its widespread use in the food and feed industry. Production is, however, constrained by low soil phosphorus (P) levels in northeast Nigeria. This study evaluated four soybean varieties for their response to three rates of P in two agro-ecozones in 2004 and 2005. Experimental design was a split-plot arrangement of treatments with three replications. The main plots were assigned the P treatments and subplots were soybean cultivars randomised within the main plots. The studies found that soybean responds to P application but differences between 20 and 40 kg P/ha were not significant, despite low test P levels. This may be due to limitations in other nutrients. More studies are needed to determine the synergistic effect of P and other nutrients on soybean growth and yield. Soybean growth and seed yield were lower in 2004 than in 2005 because trials were established comparatively late in 2004 and crops were therefore affected by late season moisture stress. There is, therefore, a need to establish the appropriate time for planting soybean in these zones. Late maturing varieties produced higher yields than early maturing varieties in 2005 probably due to early planting which allowed full use of the growing season.

Keywords: *Phosphorus, soybean genotypes, nitrogen fixation, grain yield*

Introduction

The cultivation of soybean is increasing in the savannas of Nigeria for several reasons. It is becoming a major food and cash crop and is widely used in the food and feed industry (Brader 1998; Sanginga et al. 2002). It contributes to improving soil fertility and reducing *Striga* infestation on farmers' fields (Sanginga et al. 2002; Franke et al. 2004). Farmers have adopted new varieties developed at IITA (Okogun et al. 2004) that store well and, unlike cowpea, do not need expensive pesticides. They also nodulate freely with native rhizobia strains and take care of a large proportion of their nitrogen (N) fertilizer requirement through biological N fixation once the plants are established (Okogun et al. 2004) without depleting soil N reserves (Singh et al. 2003). Some of the soils in the savannas of northeast Nigeria with organic carbon below 0.5% can hardly supply the quantities of N required for reasonable crop

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yields (Carsky & Iwuafor 1995). Soybean grows well in soil of pH 6.0 or higher, but can also tolerate a pH of 4.3–4.8. Available phosphorus (P) levels critical for soybean production range from 10–15 mg kg^{-1} soil (Aune & Lal 1997). Although the development and introduction of several varieties of soybean have resulted in a tremendous increase in production in the Nigerian savannas, sustainable production is constrained by prevailing soil low P levels (Ogoke et al. 2003). Pal et al. (1989) observed that the grain yield of soybean responded to P fertilizer in 10 of 11 trials in northern Nigeria. The process of biological N_2 fixation by nodules of legumes requires large amounts of P, and its availability is a primary constraint to N_2 fixation and therefore to the N economy of many tropical ecosystems (Danso 1992). Deficiencies of soil nutrients, especially P, may restrict the development of a population of free-living rhizobia in the rhizosphere, limit the growth of the host plant, restrict nodulation itself, and cause an impaired nodule function (Danso 1992). Low levels of soil available N and P and large crop responses to application of N and P fertilizer are common for both cereals and legumes in the moist savanna of west Africa (Batiano et al. 1986). Apart from increases in yield, the application of P to soybean enhances the amount of N derived from the atmosphere by the soybean-rhizobium symbiotic system (Sanginga et al. 1996) resulting in an increase in the N content of the roots, haulms, and leaves. These residues, when left on the soil, will mineralize and add to the soil part of the N derived from the atmosphere. Soil P levels are very low in the Sudan and Guinea savannas of northeast Nigeria. Kwari (2005) found P levels ranged from 0.3–10.4 mg kg^{-1} in the southern Guinea savanna (SGS), from 1.4–9.5 mg kg^{-1} in the northern Guinea savanna (NGS) and from 0.3–7 mg kg^{-1} in the Sudan savanna (SS). He further reported that P levels were lower (below the critical values for the Nigerian savanna; < 7 mg kg^{-1}) in 78% of fields surveyed in the SGS, in 92% in the NGS, and in 93% in the SS. He attributed this low P status to the suboptimal amounts of P applied by farmers and/or P-sorption particularly in the SGS and NGS where the soils are derived from basalt. Such soils are rich in Fe and Al oxides and generally exhibit high P sorption (Singer 1987). Kwari (2005) concluded that the poor soil-P status would have implications for the production of legumes, such as cowpea and soybean, which would require P for their root development and N fixation. Their effectiveness in soil improvement can be hindered by P deficiency (Giller & Cadisch 1995).

Through the project, Promoting Sustainable Agriculture in Borno State (PROSAB), in northeast Nigeria, IITA has introduced and disseminated four varieties of improved soybean for use by farmers in rotation with cereals to improve soil fertility and reduce *Striga* infestation on their fields. Field observations showed that most fields were showing symptoms of P deficiency, despite the application of starter fertilizer (15 kg ha^{-1} each of N, P, and K). Little information is available on the magnitude of response to the P fertilization of soybean varieties currently being introduced in the agriculturally productive ecological zones of Borno State. There are species and varietal differences in tolerance to low soil P and in the ability to utilise poorly soluble P sources. Thus, crop selection has promise for increasing crop P efficiency (Johanssen et al. 1995). This study evaluated the four soybean varieties for their response to application of P in the NGS and SS. Results will form the basis for P fertilizer recommendation for soybean production in this zone.

Materials and methods

Sites and treatments

Field experiments evaluating the response of four soybean cultivars to P application were conducted in 2004 and 2005 in Miringa (10°73′N, 12°14′E) in the NGS and Azir

(12°87.78′N, 11°1.8′E, altitude 444 m asl) in the SS zone. The soils in both experimental sites were Alfisols formed on basalt in Miringa and on argillaceous sediments in Azir (Kwari et al. 1999). To avoid confounding residual effects from applied P, separate but adjacent plots within each site were used in each year. Composite topsoil samples (0 – 15 cm) were collected from each experimental site with an auger at the beginning of the trials. Each topsoil sample contained 15 subsamples taken along three transects across the field and mixed together. The soil samples were crushed using a pestle and mortar and passed through a 2-mm sieve and stored in sealed polythene bags for analysis. The soil samples were analysed for texture, pH, organic carbon, and total N (Van Reeuwijk 1992). Exchangeable potassium (K), available P, zinc (Zn) and copper (Cu) were extracted with Mehlich-3 extracting solution (Mehlich 1984). Potassium was determined on a flame photometer and P on a spectrophotometer. Zinc and Cu were determined on an atomic absorption spectrophotometer. Available sulphur (S) was extracted with 0.01 M mono calcium phosphate and determined by the turbidimetric method (Tabatabai 1982).

The experimental design was a split-plot arrangement of treatments with three replications. The main plots were assigned the P treatments (0, 20, and 40 kg P ha^{-1}) and subplots were assigned soybean cultivars (TGX 1448-2E and TGX 1904-6F were late maturing; TGX 1485-ID and TGX 1830-20E were early maturing) randomised within the main plots. Sizes of the subplot experimental units were four-row plots, having a row spacing of 0.75 m and 5 m row length. Before the trials were established, the land was cleared, tilled with a disc harrow, and ridges prepared using work-bulls mounted with mouldboard ploughs. In 2004, plots were sown on 5 July in Miringa and 8 July in Azir. In 2005, planting was carried out on 12 June in Miringa and 26 June in Azir. In each plot five seeds of soybean were planted/hill at a spacing of 0.20 m to give a population of 333,333 plants ha^{-1}. Each plot received a basal application of 30 kg K ha^{-1} as muriate of potash. No N fertilizer was applied. To obtain a localised P fertilizer effect, single super phosphate was applied manually in furrows made at the top of ridges to a depth of 6 – 8 cm before the seeds were planted on the same day. Immediately after sowing, paraquat (1:1-dimethly-4, 4′-bipyridinium dichloride) was applied at the rate of 276 g a.i/litre to control weeds. This was followed by hand weeding three weeks later.

Measurements

Data collected during the two years were days to 50% flowering (DTF, growth stage R_1), at $R_{3.5}$ growth stage for total shoot biomass, nitrogen content and proportion of N derived from atmosphere, days to physiological maturity (growth stage R_8), dry matter accumulation (DTM), number pods/plant, number of seeds/pod, 100 seed weight, Harvest Index (HI), and seed yield. At the $R_{3.5}$ growth stage, the xylem ureide assay method (Peoples et al. 1989) was used to measure N_2 fixation in soybean varieties. The stems and petioles of three dried plants were finely ground, and a subsample of 0.5 g was used to extract the xylem solutes in boiling water. Concentration of ureide in the extract was measured according to the procedure of Young and Conway (1942); concentration of nitrate by the procedures of Cataldo et al. (1975). The relative ureide-N abundance (RUA) of the sample was calculated, based on the molar concentrations of ureides and nitrate with the assumption of 4 N atoms per ureide molecule, using the following equation:

$$\mathrm{RUA} = 4\ \mathrm{N_1}/(4\ \mathrm{N_2} + \mathrm{N_1}) \times 100$$

where N_1 is the concentration of ureide and N_2 the concentration of nitrate in the stem and petiole extracts in nmol. Ground plant samples were digested in concentrated hot H_2SO_4 and the total N content was determined colorimetrically using automated analysis (Technicon™ Autoanalyzer™ II System) by the method of Novozamsky et al. (1983).

At physiological maturity, a 1 × 0.75 m quadrat was placed at one end of the two middle rows and all plants within the quadrat, together with leaves on the ground, were sampled. The plants collected from the quadrat were separated into leaves, stems, pods, and seeds. Samples were oven-dried at 60°C to a constant weight to determine dry matter yield. Total aboveground dry matter was the sum of all plant parts. Five plants were randomly selected from the two middle rows at physiological maturity to determine the number of pods/plant. Pods on the five plants were counted and threshed and the total number of seeds in each pod was counted. Individual seed weight was determined by counting, drying and weighing 100 seeds from plants in each plot. At harvest maturity, plants within a 4 m length of two central rows in each plot were cut at the base just above the ground. The pods were separated from the haulms and shelled for grain. After shelling, moisture contents of grain samples were determined using Dickey-John moisture meter (Dickey-John Co., Auburn, IL, USA). Seed yield was corrected to 12% moisture content.

Data analysis

All data were subjected to an ANOVA using the PROC Mixed procedure (Littell et al. 1996) of SAS (SAS Institute 1995) with the variety analysed as subplot and P level as main plot. Block was treated as a random effect; P levels and soybean varieties were treated as fixed effects in determining the expected mean square and appropriate F test in the analysis of variance. Variability of means is presented as a standard error of the difference between means (SED). Pearson's correlation coefficient between grain yield and the other traits was also computed using PROC CORR of SAS (SAS Institute 1995).

Results

Some physical and chemical properties of the topsoil (0 – 15 cm) before experimentation are presented in Table I. The soils have a loamy surface texture in Azir and clay loam in Miringa and are within the medium texture category (18.00 – 35.00% clay) (Food and Agriculture Organization [FAO] 1974). Soil reaction was slightly acid (6.1 – 6.5) in Azir and moderately acid (6.1 – 6.5) in Miringa. In Azir organic carbon (<1.05%), total N (<0.10%), and

Table I. Characteristic of soils of two experimental locations in Borno State, northeast Nigeria.

Soil properties	Azir	Miringa
Sand (%)	46.20	26.20
Silt (%)	32.50	4.25
Clay (%)	21.30	31.30
Textural class	L	CL
pH 1:2.5 (H_2O)	6.06	5.67
Organic C (%)	0.94	1.58
Total N (mg/kg)	0.08	0.15
Available P (mg/kg)	2.40	1.70
Exchangeable K (meq/100 g)	0.46	0.31
Available S (mg/kg)	10.84	7.01
Available Zn (mg/kg)	0.17	0.08
Available Cu (mg/kg)	0.10	0.13

available P (<3.0–7.0 mg/kg) were low. In Miringa, organic carbon was high (1.5–2.0%), total N was medium (0.15–0.20%) (Aduayi et al. 2002) and available P was low (Nathan & Sun 1997). Exchangeable K (0.30–0.60 meq/100 g) (Nathan & Sun 1997) and available S (6.00–12.00 mg/kg) were moderate (Tabatabai 1982) in both locations. Available Zn (<0.60–0.80 mg/kg) and Cu (<0.20 mg/kg) were deficient (Garcia et al. 1997). The soil in Miringa was better endowed with organic matter. However, P, Zn, and Cu are major limiting nutrients in both locations.

Weather was a dominant factor controlling grain yield and yield components of soybean in the two sites. Year effects were, therefore, highly significant for most traits measured. Total rainfall was higher in Miringa than in Azir (Table II). It was also higher in 2005 than in 2004 due to early cessation of the rains in 2004. The F ratios of the combined analysis of variance for measure parameters are presented (Table III). Mean values for most traits including %Nda were lower in 2004 than in 2005. Year × location, year × P rates, and year × variety interactions were highly significant for most traits (Table III). Data are therefore reported separately for each year. Location × P rate, location × variety, and P rate × variety interactions were not significant for all traits. Although location effects were not significant for most traits, the number of pods plant^{-1} was significantly higher in Miringa than in Azir in 2004, but significantly higher in Azir than in Miringa in 2005. Location effects were also not significant for %Nda even though %Nda was significantly higher at Azir than at Miringa in 2004. However, the growth conditions of 2004 significantly reduced %Nda and this was more pronounced at Miringa than at Azir. Total nitrogen derived from N_2 fixation was highly significantly influenced by both year and location.

Application of P significantly influenced soybean growth and yield (Table III). In 2004, P application significantly influenced N uptake and N_2 fixation (Table IV) but not in 2005. The response to P was significant only at 20 kg/ha; a higher P rate did not lead to corresponding increase in N_2 fixation. There was however, no consistent response to P for TDM, HI, number of pods plant^{-1}, and seeds pod^{-1} (Table V). Mean seed yield over the two years did not significantly differ among P rates. One hundred seed weight was, however, significantly higher at 40 kg P ha^{-1} than at 0 and 20 kg P ha^{-1}. In 2005, TDM was 49%

Table II. Monthly mean minimum and maximum temperature and total rainfall in 2004 and 2005 growing season at Miringa and Azir.

	Miringa						Azir					
	Min temp (°C)		Max temp (°C)		Rainfall (mm)		Min temp (°C)		Max temp (°C)		Rainfall (mm)	
Month	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
January	15.68	25.82	31.87	33.56	0.00	0.00	14.00	20.00	30.90	30.55	0	0.00
February	16.50	26.54	31.57	34.52	0.00	0.00	15.79	22.00	32.29	32.45	0	0.00
March	19.48	27.85	33.97	37.45	0.00	0.00	19.68	24.12	35.00	34.55	0	0.00
April	25.87	26.15	38.03	40.65	0.00	67.00	24.57	25.00	41.13	35.65	0.05	17.50
May	22.29	27.55	34.68	31.55	113.50	240.00	24.25	25.45	38.97	33.42	89.3	50.00
June	20.40	28.83	31.2	32.62	180.50	110.60	22.77	25.88	35.23	34.56	156.8	169.00
July	20.29	29.50	30.29	32.62	94.00	238.00	21.03	23.90	31.84	33.14	228.7	153.00
August	20.29	29.58	29.42	35.03	276.00	302.30	20.87	21.19	31.71	38.86	179.05	310.00
September	20.11	24.53	31.61	36.06	132.10	157.00	21.93	22.67	33.70	37.83	103.2	97.10
October	20.53	20.05	34.77	36.71	15.80	94.00	20.19	21.80	36.52	36.90	0	37.80
November	17.77	23.99	34.33	37.31	0.00	0.00	17.53	22.18	35.33	33.62	0	0.00
December	16.43	23.19	33.60	40.35	0.00	0.00	14.06	21.12	32.16	32.51	0	0.00

Table III. F ratios for the combined analysis of variance for total dry matter (TDM), harvest index (HI), days to flowering (DTF), total N in shoot (TNBIO), proportion on N derived from atmosphere (%Nda) total N derived from atmosphere (Nda) pod number, seed weight, seed per pod, and seed yield for four soybean genotypes evaluated under three P treatments at two locations in Borno State, northeast Nigeria.

Source of variation	df	TDM	HI	DTF	TNBIO	%Nda	Nda	Pod number	Seed weight	Seed per pod	Seed yield
Year (Y)	1	203.77**	5.25*	30.27**	94.97**	17.26**	96.33**	132.21*	435.08**	25.55**	175.16**
Location (L)	1	2.77ns	1.14ns	33.65*	17.06**	2.96ns	15.17**	1.25ns	3.22ns	1.37ns	2.21ns
Y × L	1	53.10**	74.26**	6.02*	9.93**	6.89**	1.99ns	36.93**	0.11ns	0.02ns	5.40*
P-fertilizer rate (P)	2	25.68**	6.34ns	0.50ns	12.42**	4.45**	14.33**	10.23**	14.98**	0.24ns	60.70**
Y × P	2	25.38**	1.97ns	0.45ns	13.45**	0.70ns	8.33**	10.60**	6.46**	1.25ns	52.12**
L × P	2	0.51ns	0.72ns	1.54ns	5.31**	5.50**	0.60ns	1.09ns	0.44ns	1.07ns	0.90ns
Variety (V)	3	18.10**	8.59**	243.73**	2.67*	2.25ns	2.95*	5.97**	7.79ns	3.80*	0.86ns
Y × V	3	11.72**	5.06*	27.97**	2.72*	0.19ns	2.33ns	4.59**	1.57ns	0.23ns	12.94**
L × V	3	0.09 ns	0.10ns	5.88**	1.10ns	0.19ns	0.67ns	2.17ns	0.96ns	0.50ns	0.92ns
P × V	6	0.97 ns	0.85ns	0.14ns	0.71ns	1.34ns	0.82ns	0.76ns	0.55ns	1.33ns	1.10ns
L × P × V	6	0.59 ns	0.65ns	0.32ns	3.45**	0.85ns	2.44*	0.66ns	1.94ns	0.65ns	1.33ns

ns, not significant at $p < 0.05$; *significant at $p < 0.05$; **significant at $p < 0.01$.

Table IV. Total shoot nitrogen, proportion of N derived from atmosphere and total N derived from atmosphere of four soybean varieties under three P treatments at two locations in Borno State, northeast Nigeria.

	TNBIO (kg ha^{-1})		Nda (%)		TNda (kg ha^{-1})	
Location	2004	2005	2004	2005	2004	2005
Miringa	106.0	152.7	46.76	60.35	48.8	93.1
Azir	112.9	204.2	55.47	58.54	61.9	121.1
P-fertilizer rate						
0	111.0	128.5	45.55	56.56	50.5	72.4
20	100.6	201.1	53.20	61.92	53.0	124.8
40	116.7	205.8	54.60	59.86	62.6	124.0
Variety						
TGX 1448-2E	108.3	152.6	50.25	56.89	55.5	88.0
TGX 1904-6F	107.1	200.6	48.03	57.085	49.2	114.2
TGX 1485-1D	111.5	195.3	55.78	62.96	60.8	125.9
TGX 1830-20E	110.9	165.4	50.40	60.85	56.0	100.2
SED (Location)	7.5		2.13		5.6	
SED (P)	9.15		2.61		6.8	
SED (Variety)	10.65		3.00		8.0	
SED (Year)	7.51		2.13		5.6	
SED (Y × L)	10.62		3.00		7.9	
SED (Y × P)	13.05		3.69		9.8	
SED (Y × V)	15.0		4.25		11.3	

higher, HI was 26% higher, number of pods plant^{-1} was 77% higher, 100 seed weight was 11% higher and seed yield 108% higher at 20 kg/ha than at 0 kg P ha^{-1}. Differences between P rates of 20 and 40 kg/ha were not significant in most of the parameters measured. Mean values for DTF and number of seeds/pod did not significantly differ among P rates in both years. In both locations, soybean seed yield response to P followed the same pattern (Table V). At 20 kg P ha^{-1} seed yield was 47% higher in Miringa, and 56% higher in Azir than at 0 kg P ha^{-1}. In both locations, seed yield did not significantly differ between P rates of 20 and 40 kg P ha^{-1}.

Except for seed yield and 100 seed weight, all other traits were significantly influenced by soybean variety (Table V). In both years, %Nda in TGX 1485-1D was significantly ($p \leq 0.05$) higher, compared with TGX 1448-2E but not when compared with TGX 1904-6F and TGX 1830-20E. In 2004, TDM, and number of pods/plant did not significantly differ among soybean varieties. HI of TGX 1448-2E was significantly lower than that of the other varieties. Seed weight and seed yield were significantly lower in TGX 1448-2E than in the other varieties. In 2005, the two late maturing varieties (TGX 1448-2E and TGX 1904-6F), recorded TDM and number of pods per plant which were significantly higher than those of the two early maturing varieties (TGX 1485-ID and TGX 1830-20E). DTF were similar and longer in TGX 1448-2E and TGX 1904-6F than in the early maturing varieties. Seed weight did not significantly differ among varieties except TGX 1904-6F which recorded 5% higher seed weight than the average of the other varieties. Seed yield of the two late maturing varieties did not significantly differ from each other but was 18% higher than the seed yield of the early maturing varieties.

Although soybean seed yield response to P application was significant at 20 kg P ha^{-1}, differences between varieties were significant only at 40 kg P ha^{-1} (Table VI). At this P rate, the early maturing variety (TGX 1830-20E) had a lower grain yield than the other varieties. Across locations and P rates, grain yield was strongly associated with TDM

Table V. TDM, HI, DTF, pod number, 100 seed weight, seed per pod, and seed yield for four soybean varieties under three P treatments at two locations in Borno State, northeast Nigeria.

	TDM		HI		DTF		Pod number		100 seed weight (g)		Seed per pod		Seed yield (Kg/ha)	
Location	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
Miringa	12.77	16.51	0.37	0.47	47.47	47.94	52.23	82.14	10.86	14.44	2.22	1.94	1250	1880
Azir	10.65	22.21	0.53	0.36	45.68	46.92	24.88	121.85	10.61	14.08	2.28	2.01	1410	2310
P-fertilizer														
0	11.97	14.13	0.43	0.35	46.61	47.63	39.40	66.34	10.53	13.21	2.26	1.93	1290	1190
20	10.57	21.01	0.48	0.44	46.63	47.29	33.69	117.12	10.57	14.71	2.31	1.97	1280	2480
40	12.59	22.95	0.44	0.44	46.50	47.38	42.56	122.52	11.10	14.88	2.19	2.03	1420	2610
Variety														
TGX 1448-2E	11.50	22.96	0.35	0.38	49.70	50.83	47.15	116.48	10.05	14.17	2.17	1.88	1040	2410
TGX 1904-6F	12.70	22.79	0.46	0.48	45.84	48.89	34.91	129.26	11.34	14.78	2.36	2.00	1430	2140
TGX 1485-1D	11.45	16.24	0.47	0.41	45.31	44.89	35.02	82.46	11.17	14.28	2.21	1.88	1440	1910
TGX 1830-20E	11.19	15.46	0.51	0.38	45.46	45.11	37.13	79.79	10.38	13.83	2.27	2.15	1410	1930
SED (Location)	1.08		0.03		0.24		5.52		0.17		0.05		200	
SED (P)	0.66		0.02		0.19		6.68		0.21		0.07		70	
SED (Variety)	0.75		0.02		0.22		7.78		0.24		0.08		80	
SED (Year)	0.54		0.02		0.15		5.52		0.17		0.05		60	
SED (Y × L)	1.11		0.03		0.26		7.78		0.24		0.08		210	
SED (Y × P)	0.93		0.03		0.27		9.55		0.29		0.10		100	
SED (Y × V)	1.07		0.03		0.31		11.03		0.34		0.11		120	

Table VI. Grain yield of four soybean varieties under three P treatments for two locations in Borno State, northeast Nigeria, in 2004 and 2005.

	Phosphorus levels (Kg/ha)		
Variety	0	20	40
TGX 1448-2E	1200	1850	2110
TGX 1904-6F	1280	1890	2180
TGX 1485-1D	1190	1870	1960
TGX 1830-20E	1280	1910	1810
Mean	1240	1880	2020
SED (Phosphorus)		70	
SED (Variety × Phosphorus)		140	

($r = 0.82$, $p \leq 0.001$), number of pods per plant ($r = 0.67$, $p \leq 0.001$) and seed weight ($r = 0.66$, $p \leq 0.001$). Grain yield was also weakly but significantly associated with HI (Table VII).

Discussion

Weather significantly influenced yield and yield components in the 2 years. Mean values for most traits were either lower in 2004 or showed no consistent trends among P rates or varieties compared to 2005. Consequently significant interactions between years and treatments were recorded. This was due to the late establishment of the trials in 2004 when plots were sown on July 5 in Miringa and on July 8 in Azir. These dates turned out to be too late for planting soybean in both locations since the rains stopped when the soybean crops were in the grain filling stage. Moisture stress in 2004 significantly reduced growth, biological N fixation, yield and other yield components of the soybean varieties. There is, therefore, a need to establish a correct planting date for soybean in these zones. Cultivar adaptability to a region and its influence on soybean yield and yield components can be affected by growth habit and planting date. Planting soybean late in a season results in less branched vegetative growth, lower branch yields, and lower total yields/plant (Board et al. 1990). Yield decreases resulting from drought stress depend both on the phenological timing of the stress and degree of yield component compensation (Pedersen & Lauer 2004). Drought or moisture stress suppress nodulation and consequently N_2 fixation in soybean and other crops (Sinclair et al. 1987; Lecoeur & Sinclair 1996) and reduces soybean seed yield when it occurs between flowering and earlier seed filling (Frederick et al. 2001). Pedersen and Lauer (2004) reported that the early planting date produced 10% more seeds/m^2 and a higher number of pods than the late planting date. Total nitrogen derived from N_2 fixation was highly significantly influenced by both year and location, which could be a reflection of shoot dry matter accumulation but also suggest differences in the effectiveness of indigenous rhizobia populations in the two locations.

Although location effects were not significant for most traits, the number of pods/plant was significantly higher in Miringa than in Azir in 2005. Azir is located in the SS zone with a characteristic lower rainfall (600 – 800 mm) and higher temperatures than the NGS. Beatty et al. (1982) showed that early planted soybean would take advantage of favourable soil moisture conditions and seed yield would decrease consistently with later planting.

In 2005, when experiments were established considerably earlier, most traits responded well to P application. Application at 20 kg P ha^{-1} gave a yield advantage of 108% over no application of P and corroborates a previous report of high P requirements of some soybean

Table VII. Rank correlation coefficients for total dry matter (TDM), harvest index (HI), days to flowering (DTF), pod number, seed weight, seed per pod and seed yield of four soybean genotypes across two locations and two years.

	TDM	HI	DTF	Pod number	Seed weight	Seed per pod	Seed yield	Total shoot nitrogen	% N-derived from atmosphere	Total N derived from atmosphere
TDM										
HI	0.08 (−0.6351)									
DTF	0.45 (−0.0057)	−0.43 (0.0084)								
Pod number	0.72 (<.0001)	0.21 (0.2141)	0.43 (0.0083)							
Seed weight	0.48 (−0.0033)	0.49 (0.0026)	−0.12 (0.4737)	0.37 (0.0258)						
Seed per pod	0.34 (−0.0415)	0.28 (0.0968)	−0.06 (0.7174)	0.33 (0.0493)	0.14 (0.4035)					
Seed yield	0.70 (<.0001)	0.50 (0.0018)	−0.04 (0.8221)	0.63 (<.0001)	0.50 (0.0019)	0.27 (0.1123)				
Total shoot nitrogen	−0.12 (0.4870)	−0.22 (0.1963)	0.01 (0.9710)	−0.02 (0.9049)	−0.32 (0.0568)	0.09 (0.5919)	−0.18 (0.2836)			
% N-derived from atmosphere	0.13 (0.4571)	0.32 (0.0585)	−0.07 (0.6891)	0.16 (0.3505)	0.31 (0.0620)	−0.03 (0.8425)	0.43 (0.0089)	−0.13 (0.4394)		
Total N derived from atmosphere	0.004 (0.9798)	0.09 (0.6057)	0.01 (0.9402)	0.14 (0.4022)	−0.02 (0.9024)	−0.02 (0.9107)	0.17 (0.3088)	0.60 (<0.0001)	0.68 (<0.0001)	

genotypes (Abdelgadir 1998). The variability in P response among the soybean varieties used in the study was, however very narrow. Differences between rates of 20 and 40 kg P ha^{-1} were generally not significant for all traits. The lack of differences in response to rates of 20 and 40 kg P ha^{-1} is noteworthy, given the generally P deficient status of the soils of the experimental sites (Table I) and is an indication of an interaction with other limiting nutrients. Similar results have been reported for the NGS of Nigeria. In research involving high-yielding soybean cultivars in Nigeria, responses of up to 26.4 kg P ha^{-1} have been reported by Pal et al. (1989) and Chiezey et al. (1992). Wendt (2002) reported a lack of response of groundnut to P and K in southern Cameroon, although soil P was deficient. He attributed this to probably low levels of other nutrients, which may limit yield. In the present study, available Zn and Cu were deficient in the trial sites. Therefore, the use of fertilizers containing these micronutrients may probably improve the response of crops to major nutrients. Elsewhere, Abdelgadir (1998) and Slaton et al. (2005) also reported a lack of response by soybean to P application in soils which had tested low for soil P levels. They concluded that soybean efficiently uses residual fertility and is often less responsive to fertilization. It is, therefore, a common practice to grow soybean in rotation with a cereal whereby fertilizer is applied to the cereal (Javaheri & Baudoin 2001). Part of this residual fertility is organic P made available during the growing season through mineralization. The soil at Miringa site was high in organic matter (1.58%) and the organic carbon value (0.94%) at Azir was close to the critical value (1.05%) suggesting that an appreciable amount of P could have been released from organic P mineralization. Adepetu and Corey (1976) have confirmed that mineralization was an important source of available P in tropical environments and its formation through mineralization was not inhibited by the application of P fertilizer (Sharpley 1985). Application of P may enhance the release of organically bound P by stimulating microbial biomass in the soil which, in turn, plays a major role in the redistribution of P derived from both fertilizer and plant residues (McLaughlin et al. 1988).

There was no significant interaction between variety and P rate, suggesting that the varieties responded similarly to P application. Few interactions were, however, observed between year and variety for some traits (Table III) indicating that the varieties responded differently in 2004 and 2005. Late planting particularly reduced the grain yield of the late maturing variety TGX 1448-2E by 27% in 2004 compared to the early maturing varieties. It also reduced HI by 29%. These yield reductions emphasize the need to plant late maturing varieties earlier in the season to make full use of the season. The higher yield of the early maturing varieties despite the late planting in 2004 was due to the fact that the early maturing varieties had flowered and grain had filled before the rains stopped. The other late maturing variety, TGX 1904-6F, recorded grain yield similar to that of the early maturing varieties, suggesting that this variety may be moderately tolerant to drought stress. In 2005, when the crops were planted earlier to take advantage of the full season, the two late maturing varieties recorded higher yields than the early maturing varieties because they had accumulated higher dry matter and produced significantly higher numbers of pods plant^{-1}. This is expected because the duration of water and nutrient uptake as well as of photosynthesis is a function of the number of days between emergence and senescence. Giller and Wilson (1991) have similarly noted that grain yield increases with days to maturity.

Correlation analysis also showed strong relationship between seed yield and total dry matter and number of pods plant plant^{-1}. The accumulation of dry matter from R_5 stage is an important factor in attaining high yields (Koutroubas et al. 1998). Our result also agrees with Specht et al. (1986) who stated that achieving a high total biomass through adequate vegetative growth is a prerequisite for high reproductive growth and a high seed yield in soybean. Liu et al. (2005) reported that, irrespective of maturity, high yield genotypes generally exhibited significantly higher numbers of pods and seed than low yielding genotypes. This indicates that the numbers of pods and seeds/plant are still the most important components in selecting for high grain yield. Total N accumulation at $R_{3.5}$ growth stage correlated significantly with Ndfa but not with %Ndfa. There was no significant correlation between the N_2 fixation parameters with the yield parameters such as TDM, harvest index, pod numbers and number of seeds per pod, and 100 seed weight. The lack of correlation between %Ndfa and total N uptake indicates that the genotypes vary in their total N uptake potential and also have varying capacity to support their N requirements at the $R_{3.5}$ growth stage by assessing soil available N.

Conclusions

This two-year study found that soybean responds to P application in the savannas of northeast Nigeria. However the response to 40 kg P ha^{-1} was not different from 20 kg ha^{-1} despite low test P levels in the two study locations. This may be due limitations in other nutrients. More studies are needed to determine the synergistic effect of P and other nutrients on soybean growth and yield. Late planting in 2004 affected growth and yield of the soybean varieties particularly the late maturing varieties, because of late season moisture stress. Planting at the beginning of the rainy season (late June) would increase soybean grain yield but the appropriate time of plating of soybean in this zone needs to be established. Late maturing varieties produced higher yields than early maturing varieties in 2005, probably due to early planting which allowed the plants to make full use of the growing season.

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