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Biological nitrogen fixation potential by soybeans in two low-P soils of southern Cameroon

M. Jemo · C. Nolte · M. Tchienkoua ·
R. C. Abaidoo

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Abstract Biological nitrogen fixation (BNF) potential of 12 soybean genotypes was evaluated in conditions of low and sufficient phosphorus (P) supply in two acid soils of southern Cameroon. The P sources were phosphate rock (PR) and triple superphosphate (TSP). The experiment was carried out during two consecutive years (2001 and 2002) at two locations with different soil types. Shoot dry matter, nodule dry matter, and nitrogen (N) and P uptake were assessed at flowering and the grain yield at maturity. Shoot dry matter, nodule dry matter, N and P uptake, and grain yield varied significantly with site and genotypes ($P < 0.05$). On Typic Kandiuult soil, nodule dry matter ranged from 0.3 to 99.3 mg plant⁻¹ and increased significantly with P application ($P < 0.05$). Total N uptake of soybean ranged from 38.3 to 60.1 kg N ha⁻¹ on Typic Kandiuult and from 18 to 33 kg N ha⁻¹ on Rhodic Kandiuult soil. Under P-limiting conditions, BNF

ranged from -5.8 to 16 kg N ha⁻¹ with significantly higher values for genotype TGm 1511 irrespective of soil type. Genotype TGm 1511 can be considered as an important companion crop for the development of smallholder agriculture in southern Cameroon.

Keywords Biological nitrogen fixation (BNF) · P-uptake · Soybean

Introduction

Soybean (*Glycine max* L. Merr) is a relatively new crop for smallholder farming communities in most African countries, gaining popularity as a consequence of the increasing need for food and fodder (Sanginga et al. 2002). In the humid forest zone (HFZ) of southern Cameroon, soybean is also being conserved as an important component of cropping systems through soil fertility restoration and provision of dietary proteins to small-scale farmers (Maesen and Somaatmadja 1992). However, many soils in humid forest ecosystems have low level of available P due to high phosphorus (P) sorption by Fe and Al oxides (Ssali et al. 1996; Menzies and Gillman 1997). Growth and biological nitrogen fixation (BNF) of legumes such as soybean are hampered by P deficiency (Giller 2001). Soil-P availability during plant seedling development is an important determinant for plant growth, N₂ fixation,

M. Jemo (✉) · C. Nolte
International Institute of Tropical Agriculture, Humid
Forest Ecoregional Centre (HFC), BP 2008 (Messa),
Yaounde, Cameroon
e-mail: m.jemo@cgiar.org; mjemo2001@yahoo.com

M. Tchienkoua
Institut de la Recherche Agricole pour le Développement
(IRAD), Yaounde, Cameroon

R. C. Abaidoo
International Institute of Tropical Agriculture (IITA), Oyo
Road, PMB 5320, Ibadan, Nigeria

and grain formation of legumes (Vance 2001). Low P availability in soils results in a decrease in shoot growth, affects the photosynthetic activity, and limits the transport of photosynthates to nodules (Jakobsen 1985) with a significant decline in N_2 fixation by the plant (Israel 1987).

Successful integration of grain legumes into the cropping system of humid forest ecosystems will depend on alleviation of the soil constraints such as those mentioned above. This may be difficult in areas where the supply of P is limited or where added P may be fixed into forms unavailable to plants (Sample et al. 1980). Selection of plant species or genotypes efficient in acquiring P from sparingly available sources or that make better use of P applied to the soil and fix N_2 from the atmosphere will benefit subsequent crops and represent keys elements of sustainable cropping systems in such regions (Horst et al. 2001).

Wide genotypic differences in BNF potential under P-deficient soil conditions have been documented among and within many legumes, including soybean (Alves et al. 2003; Sanginga 2003). However, no attempt has been made so far to select soybean genotypes for southern Cameroon that grow and fix N_2 , and contribute to N inputs under low-P soil conditions or in response to limited P application.

Low-P-tolerant plants have been shown to develop several physiological mechanisms to acquire P from the soil system. Among the mechanisms described are the development of specific root morphological system that permit the exploration of a large soil volume (Krasilnikoff et al. 2003), mycorrhizal associations (Smith and Read 1997), acidification of the soil rhizosphere that helps solubilize less-labile P pools (Gahoonia et al. 1992), and excretion of organic acid anions to solubilize inorganic P (Raghothama 1999) or by secreting phosphatase enzymes making P bound to organic matter available (Li et al. 1997).

The present study was carried out to evaluate the potential of 12 soybean genotypes for BNF in two acid soils of southern Cameroon.

Materials and methods

Site characteristics

The field experiments were conducted during two consecutive years (2001 and 2002) at two locations

of southern Cameroon. The first location Abang ($3^{\circ}24'$ N, $11^{\circ}47'$ E) at 660 m asl was situated 50 km south of Yaounde. Mean annual rainfall was 1,513 mm with a bimodal distribution. The second location was Minkoameyos ($3^{\circ}51'$ N, $11^{\circ}25'$ E), 10 km west of Yaounde at an altitude of 780 m asl with mean annual rainfall of 1,643 mm. The soils were classified as Typic Kandudult and Rhodic Kandudult (USDA soils classification system) for Abang and Minkoameyos, respectively. Selected physicochemical properties for surface horizons (0–10 cm) are shown in Table 1. The two sites were selected on the basis of their low P availability (between 3 and 5 μg by the Bray1-P method) and soil acidity ($\text{pH} < 5.50$). The soybean genotypes tested in the field were provided by the breeding program of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. Some morphological and growth characteristics of the genotypes are presented in Table 2.

Field experiment

The field experiment was carried out with a split-block design with four replications. Phosphorus treatments were applied on the main plots at rates of 0 and 30 kg P ha^{-1} in the form of triple superphosphate (TSP) and 90 kg P ha^{-1} with phosphate rock (PR). Subplots, measuring 4×4 m, comprised the soybean genotypes. The PR was a granulated powder from Hahotoe mine in Togo, sieved at 0.15 mm. The PR contained 17.5% P of which 3% was citrate soluble. No N fertilizer or *Bradyrhizobia* inoculation was applied. Soybean seeds were drilled along a ridge with 75 cm between rows and 5 cm separation within the row and were thinned to one plant 1 week after emergence. All the soybean plants were sprayed with the insecticide Thiodan[®] (endosulfuran organochlorine insecticide) at the rate of 0.33 mg l^{-1} (corresponding to approximately 2 kg ha^{-1}) at 14 and 28 days after sowing (DAS) and hand weeded at 14, 28, and 48 DAS.

Plant sampling and analysis

Plants were sampled at mid-pod fill stage, i.e., 56 DAS for shoot growth, nodulation, and shoot N and P concentrations. Six plants were chosen from the middle rows of each plot, their shoots cut at

Table 1 Physical and chemical properties of the topsoil (0–10 cm) used in the field experimental sites in southern Cameroon (Mean \pm SE, $n = 36$)

Soil properties	Sand (%)	Silt (%)	Clay (%)	pH ^a	OC (g kg ⁻¹)	TN (g kg ⁻¹)	Ca (cmol (+) kg ⁻¹)	Mg (cmol (+) kg ⁻¹)	K (cmol (+) kg ⁻¹)	Al (cmol (+) kg ⁻¹)
Rhodic Kandiudult	40.8 (5.3)	10.2 (1.8)	48.9 (7.1)	4.5 (0.10)	22.5 (1.9)	2.1 (0.1)	1.1 (0.10)	0.33 (0.01)	0.08 (0.01)	0.65 (0.13)
Typic Kandiudult	50.6 (1.58)	9.7 (0.85)	39.7 (1.2)	5.4 (0.10)	16.0 (1.1)	1.6 (0.05)	1.3 (0.17)	0.64 (0.06)	0.06 (0.04)	0.12 (0.02)
	P sorption (%) ^b FeOx (%) ^c P (Bray 1) (mg kg ⁻¹) ^d NaOH-Pi (mg kg ⁻¹) ^e HCl-P (mg kg ⁻¹) ^f H ₂ SO ₄ -P (mg kg ⁻¹) ^g									
Rhodic Kandiudult	88.3 (3.2)	0.69 (0.04)	2.50 (0.95)		1.7 (0.29)	25.4 (3.2)	1.0 (0.5)	154.1 (2.3)		
Typic Kandiudult	77.5 (0.30)	2.3 (0.07)	5.0 (1.20)		3.2 (0.50)	29.2 (1.2)	0.86 (0.38)	190.9 (12)		

Values in parentheses represent the standard error of the mean

^a pH, measured in water

^b P sorption, percentage of P sorbed into Fe and Al ions

^c FeOx, oxalate-extractable Fe

^d NaHCO₃-Pi, NaHCO₃-extractable inorganic P

^e NaOH-Pi, NaOH-extractable inorganic P

^f HCl-Pi, concentrated HCl-extractable inorganic P

^g H₂SO₄-Pi, H₂SO₄-extractable inorganic P

Table 2 Characteristics of the soybean genotypes used for the field experiments in 2001 and 2002

Genotype	Mature pod color	Lodging score	Plant height (cm)	Days to 50% maturity	Origin geographic code
TGX-1456-2E	Brown	Unknown	Unknown	86	IITA
TGm 1511	Tan	Moderate	49	86	USA
TGm 1196	Brown	Moderate	65	89	Puerto Rico
TGm 1293	Brown	Severe	70	89	Unknown
TGm 1420	Brown	Slight	54	89	USA
TGm 1419	Tan	Severe	49	89	USA
TGm 1039	Brown	Slight	67	92	Taiwan
TGm 1251	Brown	Unknown	51	92	Unknown
TGm 1566	Brown	Moderate	85	94	USA
TGm 1576	Brown	Moderate	85	94	USA
TGm 944	Brown	Severe	72	96	Nigeria
TGm 1360	Brown	Moderate	62	96	USA
TGm 1540	Brown	Moderate	77	104	USA

0.05 m above ground level, and their fresh weight recorded. A representative subsample of about 500 g per plot was oven-dried at 70°C for 72 h for shoot biomass determination. To minimize the damage to the root system, the soil around the plant was loosened using a fork and the roots were carefully removed from the soil. Fresh nodules were cautiously removed from the roots, their number determined, and oven-dried at 70°C for 72 h for their dry matter determination. At grain maturity (84 DAS), a subplot of 1.5 × 1.5 m was harvested. The fresh weights of shoot biomass and grain yield were determined in the field. A subsample of about 500 g fresh biomass and 100 g fresh grain yield were retained and oven-dried at 70°C for 72 h and the respective dry weights were measured. Total P in plant samples was determined by the vanadomolybdate-yellow method (Motomizu et al. 1983) and total N was determined by the colorimetric method after sample ashing in concentrated sulfuric acid (Powers et al. 1981).

BNF of soybean genotypes

The BNF from soybean genotypes was estimated using the plant N uptake and nodule dry matter. We assumed that genotypes with nodules dry matter less than 20 mg plant⁻¹ were a non-N₂ fixing control and their means were calculated, being 44 and 27 kg N ha⁻¹ for the Typic and Rhodic Kandudult, respectively. Differences in N accumulation between the mean of non-N₂ fixing controls and each genotype

with nodule dry matter more than 20 mg plant⁻¹ were considered as the N contribution from BNF.

Statistical analysis

Statistical analyses of the data were carried out using the Statistical Analysis System (SAS) software version 8.2 (2001). Analysis of variance (ANOVA) was performed using the general linear procedure (GLM). Regression analysis was used to establish the relationship between pairs of variables.

Results

Nodulation, N uptake, BNF, and N contribution of soybean

Nodule dry matter and N uptake of soybean differed significantly in all soils (Table 3), with genotypes in the Typic having better values than those in the Rhodic Kandudult soil.

Significant genotypic variation in nodule dry matter and N uptake among the soybean genotypes was observed on both soils ($P < 0.05$). Five soybean genotypes (TGm 1566, TGm 1511, TGm 1293, TGm 1540, and TGm 0944) produced higher nodule dry matter than other cultivars on both soils (Table 4). With respect to N uptake, soybean genotypes TGm 1511 and TGm 1566 had higher N uptake than other on both soils. The BNF and N contribution of soybean was

Table 3 Nodule dry matter and N uptake (kg N ha^{-1}) of the soybean genotypes grown on Typic and Rhodic Kandudult soils of southern Cameroon at mid-pod filling (56 DAS)

P application	Nodule dry matter (mg plant^{-1})		N uptake (kg N ha^{-1})	
	Typic Kandudult	Rhodic Kandudult	Typic Kandudult	Rhodic Kandudult
OP	27.4 b	15.8 b	37.6 c	27.3 b
PR	30.8 ab	24.5 b	47.8 b	31.3 b
TSP	54.8 a	44.0 a	56.8 a	36.4 a
<i>F</i> value				
Year	ns		ns	
Soil type (S)	14.9***		97.6***	
P application (P)	3.0**	4.6**	18.6***	13.0***
Genotype (G)	4.5***	3.4***	2.0*	2.0*
S × P	ns		ns	
S × G	1.9*		ns	
P × G	ns		ns	
S × P × G	ns		ns	

Means across genotypes, 2001 and 2002, $n = 96$

Numbers followed by the same lower-case letter are not significantly different between genotypes at $P > 0.05$, LSMEANS/PDIFF. ns, not significant; *, **, ***, significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$, respectively

Table 4 Nodule dry matter, N uptake, and N_2 fixation indicator of the soybean genotypes grown on Typic and Rhodic Kandudult soils of southern Cameroon at mid-pod filling (56 DAS)

Genotype	Nodule dry matter (mg plant^{-1})		N uptake (kg N ha^{-1})		Biological nitrogen fixation potential (kg N ha^{-1})	
	Typic Kandudult	Rhodic Kandudult	Typic Kandudult	Rhodic Kandudult	Typic Kandudult	Rhodic Kandudult
TGm 1196	0.3 c	2.5 b	40.7 c	29.6 b	-3.3	2.6
TGm 1360	3.3 c	0.0 b	47.1 b	31.2 b	3.1	4.2
TGm 1039	3.6 c	1.7 b	44.9 b	26.2 bc	1.9	-0.8
TGm 1251	6.5 c	8.6 b	41.1 c	30.1 b	2.9	3.1
TGx 1465-2E	7.6 bc	3.5 b	38.3 c	18.8 d	-5.8	-8.2
TGm 1419	13.5 bc	24.5 b	52.1 b	28.8 b	8.1	1.8
TGm 1420	15.0 bc	9.8 b	46.5 b	27.1 bc	2.5	0.1
TGm 1566	52.5 bc	28.8 b	51.5 b	33.0 b	7.5	6.0
TGm 1511	69.4 ab	25.5 b	60.1 a	41.4 a	16.1	14.4
TGm 1293	82.2 ab	64.6 ab	46.6 b	33.0 b	2.6	6.0
TGm 0944	98.6 a	78.8 ab	52.0 b	32.4 b	8.0	5.4
TGm 1540	99.3 a	88.7 a	48.1 b	23.3 cd	4.1	-3.7

Means across P rates, and 2001 and 2002, $n = 24$

Numbers followed by the same lower-case letter are not significantly different between genotypes at $P > 0.05$, LSMEANS/PDIFF. Forty-four and 27 kg N ha^{-1} were the mean N uptakes of genotypes with nodule mass less than 20 mg plant^{-1} , used to separate the N contribution efficiency of the soybean genotypes

higher in soybean genotypes TGm 1511, TGm 0944, and TGm 1293 than the others in the Typic and Rhodic Kandudult soils, respectively, while the genotype

TGx1456-2E had a negative BNF and N contribution ($-5.8 \text{ kg N ha}^{-1}$), suggesting poor N_2 input from the atmosphere. Under field conditions this genotype

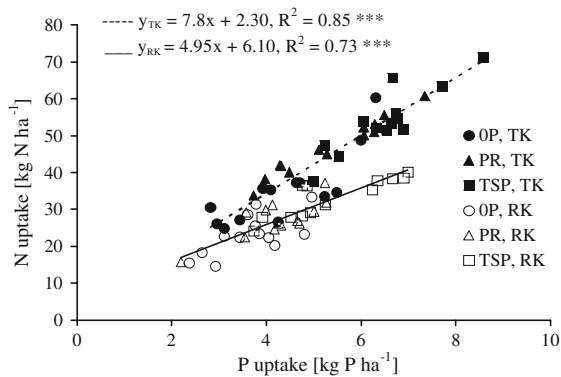


Fig. 1 Relationship between N and P uptake (in plants) of the soybean genotypes at mid-pod filling (56 DAS) grown on a Typic and Rhodic Kandiudult soils of southern Cameroon. $n = 8$. TK, Typic Kandiudult; RK, Rhodic Kandiudult; 0P, without P application; PR, phosphate rock (90 kg P ha⁻¹); TSP, triple superphosphate (applied at 30 kg P ha⁻¹)

presented symptoms of N deficiencies in older leaves, which was recognized by a yellowish color in old leaves a few weeks after plant sowing.

Phosphorus application significantly increased nodule dry matter and N uptake ($P < 0.05$) on both soils, with TSP being more effective than PR in general (Table 3). The soil \times phosphorus interaction

was significant for plant N uptake on the Typic Kandiudult soil. The soil \times genotype interaction was only significant for the nodule dry matter in the Typic Kandiudult soil. However, the interactions phosphorus \times genotype and soil \times genotype \times phosphorus were not significant for either nodule and plant N uptake in the Typic or the Rhodic Kandiudult soil.

The individually calculated regressions between plant P uptake and N uptake of the soybean genotypes were significant irrespective of the soil type (Fig. 1).

Shoot biomass production, P-uptake, and grain yield

The effects of soil types, P application, and genotype differences on soybean biomass, P-uptake, and grain yield differed significantly ($P < 0.001$). The soybean TGm 0944, TGm 1511, and TGm 1566 produced significantly higher shoot dry matter than other genotypes irrespective of the soil. With respect to the P-uptake, soybean genotypes TGm 0944, TGm 1511, TGm 1566, and TGm 1540 had significantly higher P uptake than the other (Tables 5 and 6). The genotypes TGm 1039, TGm 1566, and TGm 1511

Table 5 Shoot dry matter, P uptake at mid-pod filling (56 DAS), and grain yield at maturity (84 DAS) of the soybean genotypes grown on Typic and Rhodic Kandiudult soils of southern Cameroon

P application	Shoot dry matter (kg ha ⁻¹)		P uptake (kg P ha ⁻¹)		Grain yield (kg ha ⁻¹)	
	Typic Kandiudult	Rhodic Kandiudult	Typic Kandiudult	Rhodic Kandiudult	Typic Kandiudult	Rhodic Kandiudult
0P	1822 c	1284 c	3.9 c	3.7 c	715.0 b	237.7 b
PR	2074 b	1503 b	4.7 b	4.3 b	871.9 a	258.9 ab
TSP	2379 a	1678 a	5.5 a	5.1 a	904.4 a	286.3 a
<i>F</i> -value						
Year (Y)	ns		ns		8.7**	
Soil types (S)	198.7***		32.0***		666.9***	
P application (P)	27.5***	29.0**	19.6***	23.8***	10.9***	5.7**
Genotypes (G)	5.0***	8.0**	3.3*	5.3**	15.5***	8.9**
S \times P	4.1**		ns		11.5**	
S \times G	ns		2.3**		8.3**	
P \times G	ns		ns		ns	
S \times P \times G	ns		ns		ns	

Means across genotypes, and 2001 and 2002, $n = 96$

Numbers followed by the same lower-case letter are not significantly different between genotypes at $P > 0.05$, LSMEANS/PDIFF. ns, not significant; *, **, ***, significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$, respectively

Table 6 Shoot dry matter and P uptake at mid pod filling (56 DAS) of the soybean genotypes grown on a Typic and Rhodic Kandiudult soils of southern Cameroon

Genotype	Shoot dry matter (kg ha ⁻¹)		P uptake (kg P ha ⁻¹)	
	Typic Kandiudult	Rhodic Kandiudult	Typic Kandiudult	Rhodic Kandiudult
TGm 1196	1401 e	1375 cd	3.5 c	3.5 bc
TGm 1360	1748 cd	1748 ab	4.2 bc	4.0 b
TGm 1039	2223 bcd	1317 cd	4.6 bc	5.3 ab
TGm 1251	1353 e	1364 cd	3.4 c	3.1 c
TGx 1465-2E	1472 e	821 e	3.4 c	3.0 c
TGm 1419	2178 bc	1550 bc	4.3 b	4.2 b
TGm 1420	2269 bc	1343 cd	4.4 b	4.1 bc
TGm 1566	2776 a	1878 a	6.4 a	5.6 a
TGm 1511	2559 ab	1722 ab	6.7 a	4.6 b
TGm 1293	2085 cd	1360 cd	4.7 b	3.6 bc
TGm 0944	2574 a	1772 ab	5.3 ab	5.7 a
TGm 1540	2326 bc	1609 ab	4.9 bc	5.5 ab

Means across P rates, and 2001 and 2002, *n* = 24

Numbers followed by the same lower-case letter are not significantly different between genotypes at *P* > 0.05, LSMEANS/PDIFF

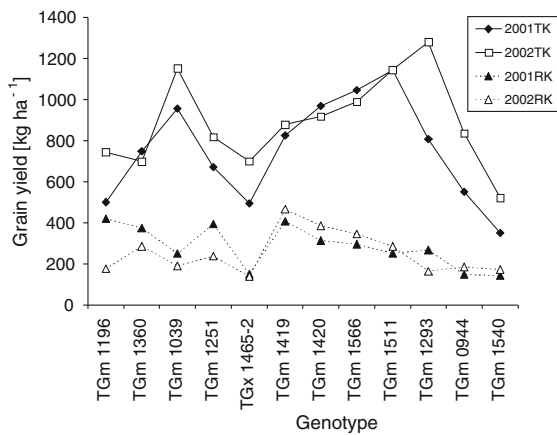


Fig. 2 Grain yield at maturity (84 DAS) of the soybean genotypes grown on Typic (TK) and Rhodic (RK) Kandiudult soils (southern Cameroon) in 2001 and 2002. Means across P rates, and 2001 and 2002, *n* = 12

were among the highest yielding on both soils across P rates.

Soybean grain yield of the genotypes significantly varied over the year and soil types with the highest values from the Typic Kandiudult soils (Fig. 2). There were significant correlations between grain yield and shoot dry matter (Fig. 3a), and plant N uptake (Fig. 3b) at low level of available P for both soils combined.

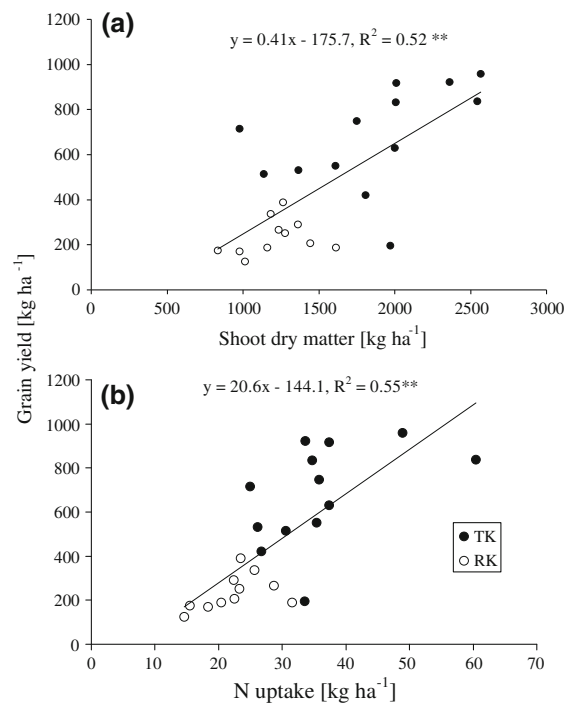


Fig. 3 Relationship between shoot dry matter (a), and N uptake (b) at mid-pod filling (56 DAS) and grain yield at maturity (86 DAS) on low-available P soils of southern Cameroon. Means at 0P and across soils. Open and filled symbols represent data points for the Typic (TK) and Rhodic Kandiudult (RK) soils, respectively. *n* = 8

Discussion

The present results show a positive response in shoot dry matter and P uptake in soybean genotypes to P application. The positive effects of P nutrition on plant growth were generally observable a few weeks after P application. Jakobsen (1985) related positive response to increased photosynthetic surface area, root growth, and nodulation. Results from our study are comparable with those obtained by several other authors on the effects of P application in bean (Christiansen and Graham 2002), in cowpea (Othman et al. 1991), and in pigeon pea (Adu-Gyamfi et al. 1989). Significant genotypic variations among the soybean genotypes were also observed. Assuming that only seeds of the soybean are to be removed from the plots, genotypes such as TGm 1511 and TGm 1566 will be of great interest to farmers because they will supply nutrients, particularly N and P, to the associated and/or rotational crops after decomposition and mineralization of shoot and leaf organs. In a parallel study, it was observed that maize grain yield production significantly increased after the genotypes TGm 1511 and TGm 1566 were grown as preceding crops (Jemo et al. 2006).

Significant genotypic variation for grain yield was observable depending on the soil used. Although such significant differences between the sites can be partly attributed to the variation in cropping history and the soil's chemical composition, such as high P fixation capacity and Al toxicity, the difference among genotypes is of practical interest in a low inputs agricultural system of southern Cameroon. In general grain yields of soybean were low compared to that produced in many other regions such as Argentina and Brazil (Alves et al. 2003). Although soybean cultivation in these areas is highly dependent on inputs, the low grain yield obtained in this present study might indicate that the rate of P application used was not optimal to allow sufficient nodulation and thus highest N₂ fixation of soybean. Additional research work will be conducted to support this hypothesis. Grain yield of the soybean genotypes TGm 1566, TGm 1511, and TGm 1039 was particularly higher compared to other genotypes previously grown on these soils (Wendt and Atemkeng 2004). Such findings provide useful information to farmers to increase yield production and to breeders for the possibility of improving soybean grain yield on soils with low available P in southern Cameroon.

P application significantly increased nodulation and grain yield, indicating that P was a limiting factor to nodulation and yield formation. Enhanced nodulation and plant growth after application of P have been reported by various authors (Othman et al. 1991; Adu-Gyamfi et al. 1989) with positive plant response to P applied under P-deficiency conditions.

The BNF potential of the soybean genotypes varied from -5.8 to 16.1 kg N ha⁻¹ in the Typic Kandiudult and from -8.2 to 14.4 kg N ha⁻¹ in the Rhodic Kandiudult soil with superior ability of the genotypes TGm 1566, TGm1511, and TGm 0944 over the others. Studies conducted in the southern Guinea Savanna zone of Nigeria with soybean-maize rotation indicated that the N contribution of soybean were in the range of -8 to 47 kg N ha⁻¹ (Sanginga et al. 1997). However, the method of estimation of N₂ fixation was based on N isotope dilution. The superior ability of the genotypes TGm 1566, TGm1511, and TGm 0944 could be attributed to their efficient strategies for acquiring P under limited-P conditions of soils in southern Cameroon, a process which requires large amounts of P for each atom of N₂ fixed (Vance 2001). The possibility that these genotypes rapidly contact root symbiosis with the indigenous population of *Bradyrhizobium japonicum* strains at earlier stages of their growth than others could also not be excluded. It was generally observed that these genotypes were forming nodules only 8 DAS under the field conditions at both sites (data not shown). However, the question of whether the bacteria populations of these soils are large and diverse enough to allow these genotypes to optimize their BNF will need further investigation.

In most tropical areas, such as in southern Cameroon, previous research studies have shown that soils supporting maize, the commonly grown cereal, must supply 50 to 60 kg N ha⁻¹ for each ton of grain produced per hectare (Weber et al. 1995). From our study, it was observed that the BNF will only contribute to 15 and 16 kg N ha⁻¹, respectively from genotypes TGm 1511 and TGm 1566. Although the observed BNF contributions are still insufficient to cover the total maize N need, the obtained N contribution remains important to smallholder farmers in order to reduce part of the N inputs to agronomically and economically support maize yield in soils of southern Cameroon. In addition, the soybean genotypes produce grain important for food or fodder and

extra income for farmers in the local market or in neighboring countries. It was generally observed that, even when the stovers are exported, maize grain yield increased following soybean cultivation (Carsky et al. 1997), implying that the benefit from the incorporation of soybean into cropping system may go beyond the N contribution. Such benefits may include a suppression of root nematodes (Bagayoko et al. 2000), efficient P use by the subsequent maize crops (Carsky et al. 1997), and possibly the belowground-N contribution from legumes (Wichern et al. 2008).

Conclusion

The present study identified two soybean genotypes (TGM 1511 and TGM 1566) that thrive well under low-P conditions with potential to obtain part of their N from atmospheric fixation in the humid regions of southern Cameroon. These genotypes can be considered important and may be introduced into smallholder agriculture in Cameroon. However, at the present state of the study further work will need to be undertaken to improve their nodulation efficiency and effectiveness of *Bradyrhizobium* nodulating by the genotypes as well as the contribution from BNF to cropping systems in the humid forest of southern Cameroon.

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