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RESEARCH

Integrating inorganic NP application and *Bradyrhizobium* inoculation to minimize production cost of peanut (*Arachis hypogea* L.) in eastern Ethiopia

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Abstract

Background: Integrated application of inorganic NP and inoculation of *Bradyrhizobium* sp. exhibits various effect on nodulation and productivity of peanut in different locations. Therefore, this field experimental was set up in Fedis and Babile to investigate the effect of nitrogen, phosphorus and *Bradyrhizobium* inoculation on nodulation and yield of peanut.

Methods: Fourteen treatments were laid out in randomized complete block with three replications.

Results: ANOVA revealed that the main effect of *Bradyrhizobium* inoculation, N and P and their two and three ways interaction had significant effect on most of the investigated traits of peanut. Applying 20 kg N ha^{-1} significantly enhanced the nodule number (NN) and nodule dry weight (NDW) at Fedis but reduction of nodulation was found at Babile site. Phosphorus application at 60 and 30 kg P_2O_5 ha^{-1} significantly increased the NDW by 88.4 and 34% over the P control at Babile and Fedis site, respectively. A significant increase in grain yield at 60 and 30 kg P_2O_5 ha^{-1} was also observed at Babile and Fedis, respectively. Although *Bradyrhizobium* increased the nodulation at Fedis site, this effect was not observed on yield of peanut. A significant increase in NN and NDW by inoculation was found with only when N was not applied either of the locations. However, inorganic N application increased plant N accumulation at Babile site.

Conclusions: According to the results from the field experiments, the yield of peanut at Babile and Fedis can be enhanced by applying 60 and 30 kg P_2O_5 ha^{-1}, respectively, with background rhizobia. Although P application increase the yield of peanut, the yield is still far below the potential yield of peanut reported elsewhere. Hence, further investigation of other yield limiting factors in the study sites is needed.

Keywords: Babile, Fedis, Nodulation

Background

Nitrogen (N) and phosphorus (P) are two important soil nutrients affecting the N_2-fixing process [1]. The majority of the soils in sub-Saharan Africa are deficient in both N and P [2]. Nitrogen is considered to be the most limiting nutrient for plant growth, at least in most soils of Ethiopia [3]. To alleviate N deficiency, *Rhizobium* inoculation is not alone sufficient to boost crop yield increase [4, 5]. Soil conditions, and especially the nutrient content of the soil, should be at optimum level.

Peanut is one of the most importance oil crops cultivated in eastern part of Ethiopia. Peanut plants grow best in well-drained sandy soils and sunny warm temperatures with moderate rainfall. Cultivated fields with a peanut cultivation history contained (as estimated by most probable numbers) an average of 1.6×10^3 rhizobia g^{-1} of soil [6]. Field studies conducted by Nambiar et al. [7] showed

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87% N_2 fixation which is 183–190 kg N ha^{-1} by N difference method by using non-nodulating groundnut and nodulating isolines. This study found N_2 fixation ranging from 53 to 63% when higher N rates (100–150 kg ha^{-1}) were applied. The ability of symbiotic N_2 fixation and nodulation (nodule weight and numbers) has been detected among cultivars of peanut [8]. Differences were also found among peanut cultivars in terms of response to *Bradyrhizobium* inoculation and N fertilizer application [9].

A small amount of combined N at the beginning of growth is needed for N_2-fixing plants [10, 11]. A low concentration of nitrate favors the initial establishment of the nodules, perhaps as an additional source of nitrogen [12]. Application of small amounts of fertilizer N has been shown to increase seedling vigor [13], through correcting possible N deficiency during early growth stage [14]. In chickpea, Namvar et al. [15] found the significant increase in plant growth, N_2 fixation, and yield of was found when N was applied with *Rhizobium*. A significant increase in chickpea grain yield production as a result of 100 kg N ha^{-1} application was obtained [16], despite chickpea is able to fix up to 80% of its N requirement from symbiotic N2 fixation [17]. In common bean, Hungria et al. [18] found a significant increase in nodulation and grain yield when a small amount of inorganic N was applied with *Rhizobium*.

At high concentrations of nitrate in the growing medium, both nodulation and N_2 fixation in almost all legume species is inhibited [19–23]. In common bean, there was no further increase in grain yield and reduction of nodulation and N_2 fixation with N rates above 12.5 mg N kg^{-1} soil [24]. Reduction in plant dry weight of soybean has also been noted when plants were treated with the high amount of N (128 kg N ha^{-1}) at planting [22].

Legume plants require a high amount of P for nodulation and N_2 fixation, and N_2-fixing legumes will require more P than those supplied with combined nitrogen [25–27]. An increase in the total plant dry matter (DM), nodule number and the N_2-fixation rate was found with increased P, for example, cowpea [28], soybean [29] and chickpea [30]. High P levels counteracted the negative effect of high N on nodulation [31]. Phosphorus application increased the effect of N application and rhizobia inoculation on the grain yield of common bean [32]. This could be because of the fact that nitrogen fixation is a very expensive process in energy terms, exceeding 16–18 mol ATP per mol N_2 fixed [33]. Therefore, the hypothesis of this work has been stated that whether the crop is inoculated with suitable *Rhizobium* or not, N fertilizer is required for maximum growth and yield of peanut in the study site. Therefore, the aim of this study was to evaluate the effect of inorganic fertilizer (NP fertilizer) application and effective *Bradyrhizobium* inoculation on nodulation and yield of peanut in major growing areas of eastern Ethiopia.

Methods

Description of the study sites

The field experiment was carried out at Babile [09°13.234′N and 042°19.407′E at 5478 ft above sea level (asl)] and Fedis (09°06.941′N and 042°04.835′E at an altitude of 5476 ft asl) experimental sites during the rainy season of May to October of 2014 cropping season. The experimental site has a bimodal rainfall pattern with the major season occurring between July and October and the minor season between March and May. Climatically, Fedis site is the semiarid area with mean annual maximum and a minimum temperature of about 27.8 and 8.8 °C, respectively, and mean annual rainfall of 714.3 mm. While the mean maximum and minimum temperature at Babile site are 20 and 9 °C with mean rainfall of 540 mm. Agriculture in Fedis and Babile sites is characterized by smallholder mixed farming activities, which include cash crops (Khat and fruits), food crops (peanut solely and intercropped with sorghum) and livestock (dairy and beef cattle, goats and poultry).

Initial soil properties

The soil of the Babile site is reddish brown gravelly sandy loam with sandy clay loam texture (18% clay, 6% silt and 79% sand), near neutral in reaction (pH = 6.6), 0.04 mS/cm electrical conductivity, 0.56% organic carbon, 0.06% total N, 2.22 mg/kg available P, 4.18 cmol(+)kg exchangeable Ca, 3.5 cmol(+)kg exchangeable Mg, 0.15 cmol(+)kg exchangeable Na, 0.34 cmol(+)kg exchangeable K and 6.59 cmol(+)kg cation exchange capacity.

The top layer (0–20 cm) soil fertility at Fedis site is considered silty clay loam (36% clay, 45% silt, 19% sand) with an organic C content of 1.32%, pH of 7.76, electric conductivity of 0.06 mS/cm, total N of 0.12%, available P of 1.78, cation exchange capacity of 32.22 cmol(+)kg and exchangeable Ca, Mg, Na and K of 23.12, 12.87, 0.12 and 1.09 cmol(+)kg, respectively.

Source of peanut variety and inocula

The peanut variety used in the experiments was *BaHagudo*, kindly supplied by Peanut Improvement Project, Haramaya University. Botanically, this variety is erect growth habit and large seeded [34]. They have found up to 2.1 and 1.1 ton ha^{-1} productivity at Fedis and Babile, respectively. Native and effective isolate of *Bradyrhizobium* was obtained in the form of filter cake-based inoculants from Haramaya University, Biofertilizer Research and Development Laboratory.

Experimental design and treatments

A factorial combination of the following treatments was used in triplicate: N fertilizer applied at rates of 0, 20 and 40 kg ha^{-1}; three doses of P fertilizer application: 0, 30 and 60 kg P_2O_5 ha^{-1} and two levels of *Bradyrhizobium* inoculation: inoculated and uninoculated. The experiment was laid out in a randomized complete block design with the size of each plot being 6 m × 6 m, while the sample plot was 3 m × 2.2 m. Peanut variety *BaHa-gudo* was planted at a spacing of 0.40 and 0.1 m inter- and intra-row, respectively. Urea and tri-superphosphate fertilizer were used as source of N and P, respectively.

Agronomic data

At the R_2 stage of peanut, five plants from the central three rows were uprooted. The nodulation status (nodule number dry eight) and shoot dry weight were recorded. At harvest, the pod weight, the total biomass yield and kernel weight were measured. Shelling % was calculated based on the pod and kernel weight following the formula indicated in Pattee et al. [35].

Statistical data analysis

Data were tested for normality using the Shapiro–Wilk test, and all non-normal data were log transformed. A mixed-model three-way analysis of variance was performed based on a randomized complete block design with N rates, P rates and inoculation as fixed effects. Treatment means in interactions were compared using Tukey-adjusted least significant (LS) means, and treatment means in simple main effects were compared by performing post hoc Tukey honestly significant difference (HSD) test. The data were analyzed with analysis of variance (ANOVA) using SAS version 9.2 statistical software.

Result

Analysis of variance showed that *Bradyrhizobium* inoculation (I), nitrogen (N) and phosphorus (P) application and their two and three ways interaction, except the main effect of inoculation, had significant effect on the nodule number (NN) at Babile site (Table 1). At Fedis site, the NN of peanut was significantly influenced by the main effect of N and I, and N × P and I × N × P (Table 2). The NN increased with increasing N and P application rates, but inoculation did not have a significant effect on the NN at Babile site (Table 3). At Fedis site, only *Bradyrhizobium* inoculation significantly increased the NN when compared to the uninoculated plants, but the reduction of NN was found due to inorganic N application. Higher mean NN was recorded at Babile site than Fedis site.

Inoculation along with 60 kg P_2O_5/ha and N unfertilized plants resulted in significantly higher NN than the same rates of N and P without inoculation at Babile site (Fig. 1a, b). At Fedis site, inoculation without P application was found to increase significantly the NN over P unfertilized without inoculation (Fig. 2a). In addition, inoculation along with inorganic N at 0 and 20 kg N ha^{-1} gave significantly higher NN than the same rates of N without inoculation (Fig. 2b).

The effect of P, I × N and N × P was significant on nodule dry weight at Babile site (Table 1), while the main effect of I, N, P, and two and three ways interaction except I × P had significant influence on the NDW at Fedis site (Table 2). As it has been found in NN, inorganic N application significantly decreased the NDW at Fedis, but a slight increase in NDW was found at Babile (Table 3). However, P application significantly improved the NDW and the highest NDW was found to have at 60 kg P_2O_5 ha^{-1}. Inoculation of *Bradyrhizobium* significantly increased the NDW at Fedis but not observed at Babile.

Table 1 Analysis of variance of measures traits of peanut as affected by the main effect of *Bradyrhizobium* inoculation, nitrogen and phosphorus application and their two and three ways interaction at Babile experimental site

Source of variation	*F* value							
	df	NN	NDW	TPW	TBY	GY	Plant N	Shelling %
Inoculation	1	0.10 ns	3.19 ns	5.10*	0.11 ns	0.39 ns	12.78**	8.38**
Nitrogen	2	5.97**	2.22 ns	1.84 ns	5.99**	8.20**	27.72***	1.90 ns
Phosphorus	2	17.82***	18.43***	4.13*	2.52 ns	9.19***	5.13*	0.30 ns
I × N	2	12.67***	21.24***	0.30 ns	0.34 ns	6.70**	5.47**	0.76 ns
I × P	2	16.89***	1.07 ns	1.15 ns	0.16 ns	0.07 ns	1.77 ns	0.91 ns
N × P	4	2.85*	2.77*	1.43 ns	7.29***	12.37***	11.71***	0.67 ns
I × N × P	4	6.31***	2.45 ns	0.92 ns	2.28 ns	4.57**	9.92***	0.46 ns

ns nonsignificant; *NN* nodule number per plant, *NDW* nodule dry weight (g/plant), *TPW* total pegs weight (kg/ha), *TBY* total biomass yield (kg/ha), *GY* grain yield (kg/ha), *Plant N* plant tissue N accumulation at late flowering stage

* Significant at 0.05; ** significant at 0.01; *** significant at 0.001

Table 2 Analysis of variance of measures traits of peanut as affected by the main effect of *Bradyrhizobium* inoculation, nitrogen and phosphorus application and their two and three ways interaction at Fedis experimental site

Source of variation	*F* value							
	df	NN	NDW	TPW	TBY	GY	Tot N	Shelling %
Inoculation	1	5.12*	4.94*	1.08 ns	0.34 ns	0.18 ns	10.57**	2.38 ns
Nitrogen	2	11.06***	31.59***	0.89 ns	27.89***	1.72 ns	18.13***	0.42 ns
Phosphorus	2	0.64 ns	13.84***	5.87**	3.38*	8.46**	4.17*	2.73 ns
I × N	2	2.17 ns	33.19***	4.77*	21.53***	1.38 ns	9.84***	1.86 ns
I × P	2	3.08 ns	0.94 ns	9.48***	0.48 ns	11.54***	3.25 ns	0.65 ns
N × P	4	3.55*	8.77***	7.55***	4.62**	13.89***	19.37***	10.72***
I × N × P	4	2.88*	11.71***	4.50**	5.31**	11.10***	8.67***	1.55 ns

ns nonsignificant, *NN* nodule number per plant, *NDW* nodule dry weight (g/plant), *TPW* total pegs weight (kg/ha), *TBY* total biomass yield (kg/ha), *GY* grain yield (kg/ha), *Plant N* plant tissue N accumulation at late flowering stage

* Significant at 0.05; ** significant at 0.01; *** significant at 0.001

Table 3 Effect of nitrogen, phosphorus and *Bradyrhizobium* application on nodulation, total pegs weight and total biomass yield of peanut at Babile and Fedis experimental sites

Treatment	Nodule number		Nodule dry weight		Total pegs weight		Total biomass yield	
	Babile	Fedis	Babile	Fedis	Babile	Fedis	Babile	Fedis
Nitrogen (kg N/ha)								
0	102.4b	67.0a	0.1825a	0.1788a	1759.5a	3013.7a	6583.3ab	7406.5b
20	119.0ab	67.8a	0.1723a	0.1655a	1682.7a	3078.6a	6937.0a	7444.7b
40	133.6a	47.5b	0.2115a	0.1078b	1567.0a	3137.9a	6151.9b	9237.0a
LSD ($P < 0.05$)	22.0	12.0	0.0472	0.0232	246.85	228.0	555.3	684.57
P value	**	***	ns	***	ns	ns	**	***
Phosphorus (kg P_2O^5/ha)								
0	92.39c	59.50a	0.1323c	0.1219b	1608.7ab	3140.73a	6333.3a	7613.0a
30	116.56b	58.89a	0.1848b	0.1633a	1565.1b	3194.63a	6503.7a	8287.5a
60	146.17a	63.94a	0.2493a	0.1669a	1835.4a	2894.81a	688.2a	8187.6a
LSD ($P < 0.05$)	22.06	11.96	0.0472	0.0232	246.85	228.03	555.34	684.57
P value	***	ns	***	***	*	**	ns	*
Bradyrhizobium inoculation								
Inoculated	119.6a	65.30a	0.2029a	0.1593a	1576.6b	3116.4a	6527.2a	8095.8a
Uninoculated	117.2a	56.26b	0.1747a	0.1421b	1762.9a	3077.1a	6587.7a	7963.0a
LSD ($P < 0.05$)	14.94	8.10	0.032	0.0157	167.24	154.48	376.3	463.78
P value	ns	*	ns	*	*	ns	ns	ns
Mean	118.4	60.8	0.1888	0.1507	1669.7	3076.7	6557.4	8029.4
CV (%)	22.87	24.15	30.67	18.92	18.15	9.10	10.39	10.46

Means in the same column followed by the same letter are not significantly different at the 5% probability level by Tukey's test

ns nonsignificant, *NN* nodule number per plant, *NDW* nodule dry weight (g/plant), *TPW* total pegs weight (kg/ha), *TBY* total biomass yield (kg/ha)

* Significant at 0.05; ** significant at 0.01; *** significant at 0.001

At Babile, *Bradyrhizobium* inoculation did not influence the NDW with P application rates when compared to the same rates without inoculation (Fig. 3a). Among the N application rates, the positive effect of inoculation found only in N unfertilized plant (Fig. 3b). At Fedis, the higher NDW by inoculation was recorded at 30 kg P_2O_5 ha^{-1} than the same rate without inoculation (Fig. 4a). However, the better NDW with inoculation was recorded in plants N control when compared to N control without inoculation (Fig. 4b).

The main effect of I and P significantly affected the total pod's weight (TPW) at Babile (Table 1). At Fedis, the two and three ways interaction, and the main effect of P significantly ($P < 0.05$) influenced the TPW (Table 2). The

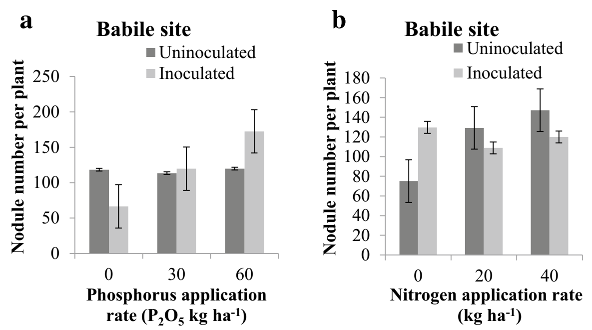

Fig. 1 Nodule number of peanut as affected by **a** phosphorus and **b** nitrogen rates of application at Babile sites

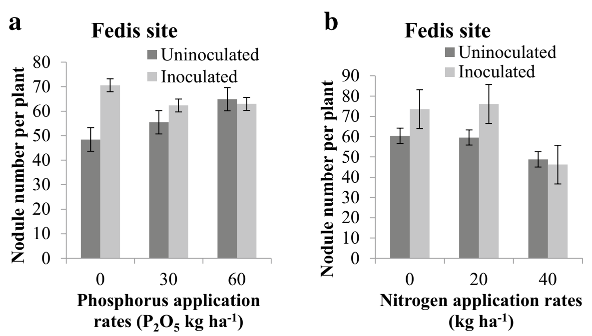

Fig. 2 Nodule number of peanut as affected by **a** phosphorus and **b** nitrogen rates of application at Fedis sites

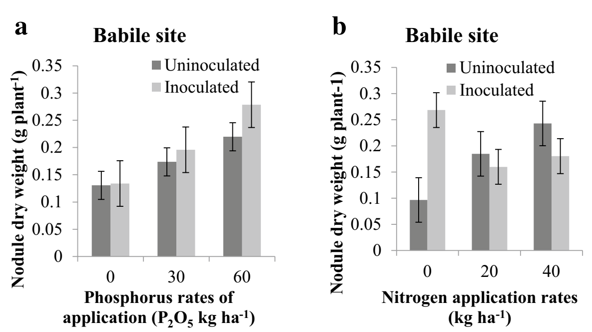

Fig. 3 Nodule dry weight of peanut as affected by **a** phosphorus and **b** nitrogen rates of application at Babile sites

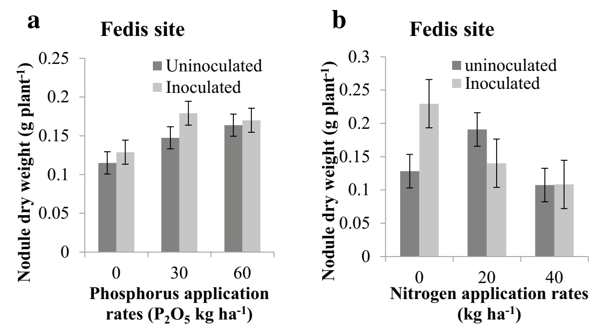

Fig. 4 Nodule dry weight of peanut as affected by **a** phosphorus and **b** nitrogen rates of application at Fedis sites

effect of inorganic N application on TPW was not significant in both experimental sites (Table 3). A significant increase in TPW due to P application was obtained only at Babile. Inoculation did not improve significantly the TPW in both locations.

ANOVA showed the significant effect of N and N × P on total biomass yield (TBY) at Babile site (Table 1). At Fedis site, except for the main effect of I and I × P, the main effect of N and P and their two and three ways interaction significantly influenced the TBY. The highest TBY at Babile and Fedis sites was recorded at 20 and 40 kg N ha^{-1}, respectively (Table 2). However, there was no significant effect of P application and *Bradyrhizobium* inoculation on TBY at both locations.

ANOVA revealed that only the main effect of *Bradyrhizobium* inoculation significantly influenced shelling % at Babile site (Table 1). Inoculation caused a significant increase in the shelling % over the uninoculated plant (Table 4). At Fedis site, there was a significant effect of two-way interaction of N × P on shelling % (Table 2). Relatively, higher shelling % was found at Fedis than Babile site.

The grain yield of peanut was significantly influenced by the main effects and two and three ways interaction of I, N and P at both locations, except the main effect of I and I × P at Babile site (Table 1). The main effect of P and I × P, N × P and I × N × P was found to be significant on GY at Fedis site (Table 2). The highest GY at Babile and Fedis sites was found to have at 20 and 40 kg N ha^{-1}, respectively, but the effect was not significant when compared to N control at both sites (Table 4). At 60 and 30 kg P_2O_5 application, GY was increased significantly over the P control at Babile and Fedis sites, respectively. However, the effect of inoculation did not influence the GY at both locations. Higher GY was recorded at Fedis than Babile site.

At Babile site, *Bradyrhizobium* inoculation did not improve the GY of peanut regardless of P and N rates of application (Fig. 5a, b). The better effect of P at 30 kg P_2O_5 ha^{-1} on GY was found at the uninoculated plant when compared to the same rate with inoculation (Fig. 6a). Inoculation, however, increased the GY when applied with 20 kg N ha^{-1} (Fig. 6b).

Except for I × P, the main effect of I, N and P and their interaction was significant on plant N accumulation at both locations (Table 1). Significantly higher plant N

Table 4 Effect of nitrogen, phosphorus and *Bradyrhizobium* application on grain yield, plant tissue N accumulation and shelling percentage of peanut at Babile and Fedis experimental sites

Treatment	Grain yield		Plant N		Shelling %	
	Babile	Fedis	Babile	Fedis	Babile	Fedis
Nitrogen (kg N/ha)						
0	1148.14ab	2242.87a	2.7817b	2.7128a	67.31a	75.02a
20	1222.12a	2351.68a	2.7694b	2.6433b	74.54a	76.94a
40	1088.71b	2318.00a	2.9700a	2.5750c	70.08a	74.77a
LSD ($P < 0.05$)	80.67	146.76	0.0738	0.0559	9.14	6.29
P value	**	ns	***	**	ns	ns
Phosphorus (kg P_2O^5/ha)						
0	1116.64b	2245.88b	2.7933b	2.6617a	71.57a	72.11a
30	1107.83b	2446.05a	2.8378ab	2.6640a	71.37a	77.16a
60	1234.50a	2220.62b	2.8900a	2.6056b	68.98a	77.45a
LSD ($P < 0.05$)	80.67	146.76	0.0738	0.0559	9.14	6.29
P value	***	**	*	*	ns	ns
Bradyrhizobium inoculation						
Inoculated	1161.41a	2293.71a	2.8844a	2.6133b	75.06a	73.96a
Uninoculated	1144.57a	2314.65a	2.7963b	2.6741a	66.22b	77.20a
LSD ($P < 0.05$)	54.65	99.43	0.05	0.0379	6.19	4.26
P value	ns	ns	**	***	**	ns
Mean	1152.99	2304.18	2.8404	2.6437	70.64	75.58
CV (%)	8.59	7.82	3.19	2.60	15.88	10.21

Means in the same column followed by the same letter are not significantly different at the 5% probability level by Tukey's test

ns nonsignificant, *GY* grain yield (kg/ha), *Plant N* plant tissue N accumulation at late flowering stage (%)

* Significant at 0.05; ** significant at 0.01; *** significant at 0.001

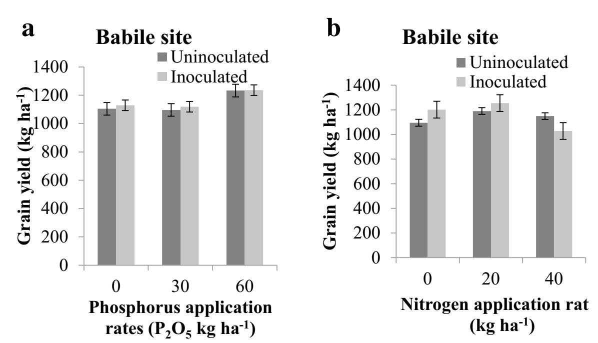

Fig. 5 Grain yield of peanut as affected by **a** phosphorus and **b** nitrogen rates of application at Babile sites

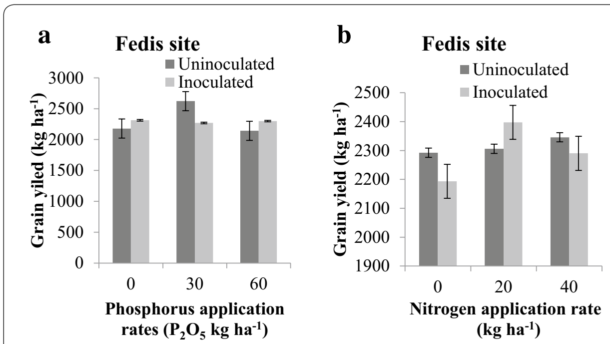

Fig. 6 Grain yield of peanut as affected by **a** phosphorus and **b** nitrogen rates of application at Fedis sites

accumulation was recorded at 40 kg N ha^{-1} and N control plants at Babile and Fedis site, respectively (Table 4). The highest plant N accumulation was found at 60 and 30 kg P_2O_5 ha^{-1} in Babile and Fedis site, respectively. A significant increase in plant N accumulation at Babile site was found to record by *Bradyrhizobium* inoculation, but an opposite effect was observed at Fedis site.

Discussion

The addition of starter N and inorganic P is vital for improving the food legumes production in degraded soils in sub-Saharan Africa. However, further study to know appropriate rates of N and P in combination with *Bradyrhizobium* inoculation is needed to improve the productivity of peanut. Hence, the two and three ways interaction effect of N, P and *Bradyrhizobium* inoculation on nodule number (NN) and nodule dry weight (NDW) was significant at $P < 0.05$. This suggests the need for different rates of N and P, and *Bradyrhizobium* inoculation requirement at Babile and Fedis site. Although the Babile and Fedis soil had the native rhizobia population nodulating peanut > 10^3, *Bradyrhizobium* inoculation significantly increased the NDW at both locations. This might be because of the less competitiveness of native rhizobia as compared to the inoculated isolates [36]. Kishinevsky et al. [37] found appreciable nodulation increase in peanut by inoculation of *Bradyrhizobium*. However, *Bradyrhizobium* inoculation failed to show a significant increase in plant N accumulation at Babile site.

The present findings show that inorganic N application at Fedis site significantly suppressed the NN and NDW and reduced the plant accumulated N. However, N application increased significantly the total biomass yield of peanut with no effect on grain yield and shelling %. These results are in agreement with those obtained in previous studies [24, 38] in which it was shown that significant reduction of nodulation and nitrogenase activity by N application did not decrease the biomass yield of alfalfa and common bean. However, reduction of grain yield by N application without inoculation was found as compared to inoculated soybean [39]. The present study shows a significant increase in NN, NDW and grain yield of peanut by 20 kg N ha^{-1} application in Babile indicates the need of starter N for peanut production at this site [40].

The NN and NDW at 60 kg P_2O_5 ha^{-1} and N control with *Bradyrhizobium* inoculation were found to be higher than the same rates without inoculation. This indicates the need of P application for enhancing the competitiveness and infectiveness of inoculation at Babile site. It has been reported on bean by Leidi and Rodriguez-Navarro [41] that an increase in nodulation and symbiotic N_2 fixation with increasing P application occurs only at lower N concentration in the soil. Given the low available P status of the Fedis soil, better effectiveness of *Bradyrhizobium* on NN and NDW was found with NP control checks. The non-response of peanut to P at this site when *Bradyrhizobium* was inoculated could be associated with less effectiveness of the inoculated isolate against the indigenous isolate. On top of this, the deficiency of other nutrients rather than NP might be found in Fedis site which may reduce the responsiveness of peanut to NP application.

When the rates of NP application increased, the *Bradyrhizobium* inoculation effect on NN and NDW was decreased. The data would rather have showed that the NN and NDW in uninoculated plants improved better than that of inoculated plants. Less effectiveness and competitiveness of inoculated isolate when compared to the native rhizobia probably became more obvious at higher NP application rates. It is not clear how the nodules formation suppresses in inoculated plants. Nitrogen application may promote or suppress the nodulation. When nitrate was applied above starter amount, the nodules formation had reduced [37, 42] besides high N applied did not improve the productivity of food legume such as chickpea [15].

Although inoculation increased the NN and NDW at Fedis site, inoculation had no discernible effect on total pods weight, total biomass yield and grain yield of peanut at both locations. This unpredictable result has been reported on peanut by Kishinevsky et al. [37]. Van Rossum [43] found that an increase in nodule weight was not always associated with increased yield of peanut, but it was determined by peanut cultivar. Several studies showed that peanut has a low response to P fertilizer because it is able to utilize P from non-labile P sources such as Ca–phytate [44], Fe–P [45] and Al–P [46].

In this study, it is shown that usage of 60 and 30 kg P_2O_5 ha^{-1} increased significantly the grain yield of peanut at Babile and Fedis sites, respectively. In contrast to this, peanut has been considered as less responsive for P applications [47, 48] due to the fact that critical soil P levels for peanut may be lower than for other crops [49]. It is also evident from the present results that N application did not increase significantly the yield of peanut at both locations, though N is relevant for enhancing photosynthesis leading to higher dry matter production and partitioning of the assimilated products [50, 51]. These results compare well with those reported in the literature for peanut [36]. This less effect of N application on yield might be due to high N_2 fixation potential of peanut-rhizobia symbiosis [52].

In this study, it has been demonstrated that *Bradyrhizobium* inoculation did not increase the grain yield when compared to the indigenous rhizobia without inoculation at both sites. The result also revealed that the grain yield of inoculated plants showed the decreasing trends as the rates of N and P increased. This implies that the NP application increases the effectiveness of indigenous rhizobia rather than the inoculated isolate. It is not clear how high rates of NP application reduce the effectiveness of inoculated isolate. In contrast to this, Namvar et al. [15] found that grain yield of inoculated plants in all N rates was higher than uninoculated plants at the same rate of N application. Other studies reported that the effect of P application on nodulation and yield of lentil has been more pronounced when it was applied with *Rhizobium* [53]. The present research output could be due to the presence of competent and effective rhizobia of peanut in soils of the study site [54].

A significant reduction in plant N concentration of peanut with increasing N and P application and *Bradyrhizobium* inoculation was recorded at Fedis site. These results support the findings of several authors concerning inhibition of N_2 fixation reduction at high NP rate of application [41, 55]. Overall, P increased the nodulation and grain yield of peanut in both study sites more than *Bradyrhizobium* and N did; by inference, P must have limited peanut growth more than N. Low N and inoculation responses were obtained because there were enough effective indigenous peanut rhizobia, as shown by the good nodules and grain yield production.

Conclusion

This study shows the need of different rate of N and P fertilizer, and *Bradyrhizobium* inoculation requirement for peanut production in different locations in eastern Ethiopia. Native rhizobia are better effective when compared to the inoculated isolate and *Bradyrhizobium* inoculation effect can be determined by the native rhizobia population. Phosphorus application at the rate of 60 and 30 kg P_2O_5 ha^{-1} can be used to increase the grain yield and effectiveness of the native rhizobia of peanut at Babile and Fedis soils, respectively. Long- and short-term research work to enhance the effectiveness of native rhizobia and NP application and insure food security using balanced nutrient managements in sandy and degraded soil of eastern Ethiopia is needed.

Abbreviations

GY: grain yield; I: inoculation; N: nitrogen; NN: nodule number; NDW: nodule dry weight; P: phosphorus; TBY: total biomass yield; TPY: total pod weight.

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Competing interests

The author declare that they have no competing interests.

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References

1. Wall LG, Hellsten A, Huss-Danell K. Nitrogen, phosphorus, an d the ratio between them affect nodulation in *Alnus incana* and *Trifolium pratense*. Symbiosis. 2000;29:91–105.
2. Mafongoya PL, Barak P, Reed JD. Carbon, nitrogen and phosphorus mineralization of tree leaves and manure. Biol Fertil Soils. 2000;30:298–305.
3. Tadesse G. Land degradation: a challenge to Ethiopia. Environ Manag. 2001;27:815–24.
4. Vincent JM. Nitrogen fixation in legumes. New York: Academic Press Inc; 1982.
5. Tufenkci S. Effect of different strains of *Rhizobium Japonicum* and nitrogen-phosphorus fertilization on yield and quality of soybean. Unpublished PhD thesis, Yuzuncu Yil University, Van, Turkey; 1995.
6. Boonkerd N, Wadisirisuk P, Meromi G, Kishinevsky BD. Population size and N_2-fixing activity of native peanut rhizobia in soils of Thailand. Biol Fertil Soils. 1993;15:275–8.
7. Nambiar PTC, Rego TJ, Srinivasa Rao B. Comparison of the requirements and utilization of nitrogen by genotypes of sorghum (*Sorghum bicolor* (L.)Moench), and nodulating and non-nodulating groundnut (*Arachis hypogeal* L.). Field Crops Res. 1986;15:165–79.
8. Wynne JC, Elkan GH, Isleib TG, Schneeweis TJ. Effect of host plant, *Rhizobium* strain and host x strain interaction on symbiotic variability in peanut. Peanut Sci. 1983;10:110–4.
9. Delfini R, Belgoff C, Fernández E, Fabra A, Castro S. Symbiotic nitrogen fixation and nitrate reduction in two peanut cultivars with different growth habit and branching pattern structures. Plant Growth Regul. 2010;61:153–9.
10. Wassermann VD, Heyns G, Kruger AJ. Effect of nitrogenous fertilizer on the yield of various annual fodder legumes nodulated by effective rhizobia. Proc Ann Congr Grassl Soc South Afr. 1983;18(1):55–60.
11. Daba S, Haile M. Effects of rhizobial inoculant and nitrogen fertilizer on yield and nodulation of Common bean under intercropped conditions. J Plant Nutr. 2002;25:1443–55.
12. Moreau D, Voisin AS, Salon C, Munier-Jolain N. The model symbiotic association between *Medicago truncatula* cv. Jemalong and *Rhizobium meliloti* strain 2011 leads to N-stressed plants when symbiotic N_2 fixation in the main N source for plant growth. J Exp Bot. 2008;59(13):3509–22.
13. Osborne SL, Riedell WE. Impact of low rates of nitrogen applied at planting on soybean nitrogen fixation. J Plant Nutr. 2011;34(3):436–48.
14. Selamat A, Gardner FP. Growth, nitrogen uptake, and partitioning in nitrogen-fertilised nodulating and non nodulating peanut. Agron J. 1985;77:862–7.
15. Namvar A, Seyed Sharifi R, Khandan T, Jafari Moghadam M. Seed inoculation and inorganic nitrogen fertilization effects on some physiological and agronomical traits of chickpea (*Cicer arietinum* L.) in irrigated condition. J Central Eur Agric. 2013;14(3):28–40.
16. McKenzie BA, Hill GD. Growth and yield of two chickpea (*Cicer arietinum* L.) varieties in Canterbury, New Zealand. NZ J Crop Horticul Sci. 1995;23(4):467–74.
17. Mahler RL, Saxena MC, Aeschlimann J. Soil fertility requirements of pea, lentil, chickpea and faba bean. In: Summerfield RJ, editor. World crops: cool season food legumes. Dordrecht: Kluwer Academic Publishers; 1988. p. 278–89.
18. Hungria M, Campo RJ, Mendes IC. Benefits of inoculation of the common bean (*Phaseolus vulgaris*) crop with efficient and competitive *Rhizobium tropical* strains. Biol Fertil Soils. 2003;39:88–93.
19. Valladares F, Villar-Salvador P, Domínguez S, Fernández-Pascual M, Peñuelas JL, Pugnaire FI. Enhancing the early performance of the leguminous shrub *Retama sphaerocarpa* (L.) Boiss.: fertilisation versus *Rhizobium* inoculation. Plant Soil. 2002;240:253–62.
20. Voisin AS, Salon C, Munier-Jolain NG, Ney B. Quantitative effects of soil nitrate, growth potential and phenology on symbiotic nitrogen fixation of pea (*Pisum sativum* L.). Plant Soil. 2002;243:31–42.
21. Muller S, Pereira PAA, Martin R. Effect of different levels of mineral nitrogen on nodulation and N_2 fixation of two cultivars of common bean (*Phaseolus vulgaris* L.). Plant Soil. 1993;152:139–43.
22. Abdel Wahab AM, Abd-Alla MH. Effect of different rates of N-fertilizers on nodulation, nodule activities and growth of two field grown cvs. of soybean. Fertil Res. 1996;43:37–41.
23. La Favre AK, Eaglesham ARJ. The effects of a high level of N, applied at planting, on nodulation of soybean (*Glycine max* (L.) Merr.) by diverse strains of *Bradyrhizobium*. Plant Soil. 1987;102:267–70.
24. Rai R. Effect of nitrogen levels and *Rhizobium* strains on symbiotic N_2 fixation and grain yield of *Phaseolus vulgaris* L. genotypes in normal and saline-sodic soils. Biol Fertil Soils. 1992;14:293–9.

25. Cassman KG, Munns DN, Beck DP. Phosphorus nutrition of *Rhizobium japonicum*: strain differences in phosphate storage and utilization. Soil Sci Soc Am J. 1981;45:517–20.
26. Cassman KG, Witney AS, Fox RL. Phosphorus requirements of soybean and cowpea as affected by mode of N nutrition. Agron J. 1981;73:17–22.
27. Gill MA, Ali N, Nayyar MM. Relative effect of phosphorus combined with potash and *Rhizobium phaseoli* on the yield of *Vigna aureus* (mung). J Agric Res. 1985;23:279–82.
28. Abaidoo RC, Okogun JA, Kolawole GO, Diels J, Randall P, Sanginga N. Evaluation of cowpea genotypes for variations in their contribution of N and P to subsequent maize crop in three agro-ecological zones of West Africa. In: Bationo A, editor. Advances in integrated soil fertility management in Sub-Saharan Africa: challenges and opportunities. Berlin: Springer; 2007. p. 401–12.
29. Mullen MD, Israel DW, Wollum AG. Effects of *Bradyrhizobium japonicum* and soybean (*Glycine max* (L.) Merr.) phosphorus nutrition on nodulation and dinitrogen fixation. Appl Environ Microbiol. 1988;54:2387–92.
30. Shahzad SM, Khalid A, Arif MS, Riaz M, Ashraf M, Iqbal Z, Yasmeen T. Co-inoculation integrated with P-enriched compost improved nodulation and growth of Chickpea (*Cicer arietinum* L.) under irrigated and rainfed farming systems. Biol Fertil Soils. 2013. https://doi.org/10.1007/s00374-013-0826-2.
31. Hellsten A, Huss-Danell K. Interaction effects of nitrogen and phosphorus on nodulation in red clover (*Trifolium pratense* L.). Acta Agric Scand Sect B. 2000;50:135–42.
32. Pacheco RS, Brito LF, Straliotto R, Pérez DV, Araújo AP. Seeds enriched with phosphorus and molybdenum as a strategy for improving grain yield of common bean crop. Field Crops Res. 2012;136:97–106.
33. Bergersen FJ. Physiological control of nitrogenase and uptake hydrogenase. In: Dilworth MJ, Glen AR, editors. Biology and biochemistry of nitrogen fixation. Amsterdam: Elsevier; 1991. p. 76–102.
34. Kebede A, Bushra F. Registration of BaHa-jidu and BaHa-gudo Groundnut (Arachis hypogaea L.) varieties. East Afr J Sci. 2012;6(1):79–80.
35. Pattee HE, Wynne JC, Young JH, Cox FR. The seed hull weight ratio as an index of peanut maturity. Peanut Sci. 1977;4:47–50.
36. Kvien CS, Pallas JE. Response of peanut to strains of bradyrhizobium and n fertilizer. Commun Soil Sci Plant Anal. 1986;17(5):497–513.
37. Kishinevsky B, Strijdom BW, Otto CJ, Lochner HH, Kriel MM. Response to inoculation of groundnuts grown under irrigation in soil containing indigenous rhizobia. S Afr J Plant Soil. 1987;4(2):75–8.
38. Cherney JH, Duxbury JM. Inorganic nitrogen supply and symbiotic dinitrogen fixation in alfalfa. J Plant Nutr. 1994;17:2053–67.
39. Albareda M, Rodríguez-Navarro DN, Temprano FJ. Soybean inoculation: dose, N fertilizer supplementation and rhizobia persistence in soil. Field Crops Res. 2009;113:352–6.
40. Biswas P, Hosain D, Ullah M, Akter N, Bhuiya MAA. Performance of groundnut (*Arachis hypogaea* L.) under different levels of bradyrhizobial inoculums and nitrogen fertilizer. SAARC J Agric. 2003;1:61–8.
41. Leidi E, Rodriguez-Navarro DN. Nitrogen and phosphorus availability limit N_2 fixation in bean. New Phytol. 2000;147:337–46.
42. Gan Y, Stulen I, van Keulen H, Kuiper PJC. Low concentrations of nitrate and ammonium stimulate nodulation and N_2 fixation while inhibiting specific nodulation (nodule DW g^{-1} root dry weight) and specific N_2 fixation (N_2 fixed g^{-1} root dry weight) in soybean. Plant Soil. 2004;258:281–92.
43. Van Rossum D, Muyotcha A, Van Verseveld HW, Stouthamer AH, Boogerd FC. Effects of *Bradyrhizobium* strain and host genotype, nodule dry weight and leaf area on groundnut (*Arachis hypogaea* L. ssp. fastigiata) yield. Plant Soil. 1993;154:279–88.
44. Shibata R, Yano K. Phosphorus acquisition from non-labile sources in peanut and pigeonpea with mycorrhizal interaction. Appl Soil Ecol. 2003;24:133–41.
45. Ae N, Arihara J, Okada K, Yoshihara T, Johansen C. Phosphorus uptake by pigeon pea and its role in cropping systems of the Indians subcontinent. Science. 1990;248:477–80.
46. Otani T, Ae N, Tanaka H. Phosphorus (P) uptake mechanisms of crops grown in soils with low P status". II. Significance of organic acids in root exudates of pigeonpea. Soil Sci Plant Nutr. 1996;42:553–60.
47. Bronson KF, Trostle CL, Schubert AM, Booker JD. Leaf nutrients and yields of irrigated peanut in the southern high plains: influence of nitrogen, phosphorus, and zinc fertilizer. Commun Soil Sci Plant Anal. 2004;35:1095–110.
48. Aulakh MS, Pasricha NS, Baddesa HS, Bahl GS. Long-term effects of rate and frequency of applied P on crop yields, plant available P, and recovery of fertilizer P in a peanut-wheat rotation. Soil Sci. 1991;151:317–22.
49. Cope JT, Starling JC, Ivey HW, Mitchell CC Jr. Response of peanuts and other crops to fertilizers and lime in two long term experiments. Peanut Sci. 1984;11:91–4.
50. Satapathy MR, Sen H, Chattopadhyay A, Mohapatra BK. Dry matter accumulation, growth rate and yield of sweet potato cultivars as influenced by levels of nitrogen and cutting management. J Root Crops. 2005;31:129–32.
51. Ramana S, Biswas AK, Singh AB, Yadava RBI. Relative efficacy of different distillery effluents on growth, nitrogen fixation and yield of groundnut. Biores Technol. 2002;81:117–21.
52. Elkan GH. Biological nitrogen fixation. In: Lederberg J, editor. Encyclopedia of microbiology, vol. 1. San Diego: Academic press; 1992. p. 285–96.
53. Al-Karaki GN. *Rhizobium* and phosphorus influence on lentil seed protein and lipid. J Plant Nutr. 1999;22(2):351–8.
54. Denton MD, Coventry DR, Bellotti WD, et al. Distribution, abundance and symbiotic effectiveness of *Rhizobium leguminosarum* bv. *trifolii* from alkaline pasture soils in South Australia. Aust J Exp Agric. 2000;40:25–35.
55. Unkovich MJ, Pate JS. Symbiotic effectiveness and tolerance to early season nitrate in indigenous populations of subterranean clover rhizobia from S.W. Australian pastures. Soil Biol Biochem. 1998;30:1435–43.