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Response of Field Pea (*Pisum sativum* L.) to *Rhizobium* Inoculation and NPS Fertilizer Applications in Western Ethiopia

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ABSTRACT
Background and Objective: The low attention of smallholders and low soil fertility are the main reasons for the low productivity of field peas in Western Ethiopia. Thus, a study was conducted to investigate the effects of *Rhizobium* inoculation and NPS fertilizer rates on nodulation, yield and yield components of field peas and to identify economically profitable treatments that can maximize the productivity of field peas in the study area. **Materials and Methods:** Two levels of *Rhizobium* inoculation (No inoculation and EAL301), two field pea varieties (Jidha and Lammiif) and five rates of NPS fertilizer (0, 25, 50, 75, 100 kg NPS ha^{-1}) were arranged in Randomized Complete Block Design (RCBD) with three replications and all collected yield and yield related parameters were analyzed using R statistical software. **Results:** Phenological and growth parameters were influenced by the main effects of varieties whereas harvest index was influenced by varieties and NPS fertilizer rates. On the other hand, pod numbers per plant and seed yield were significantly affected by the three-way interaction of *Rhizobium*, varieties and NPS fertilizer rates. The highest grain yield (2800 kg ha^{-1}) was obtained from the application of 100 kg NPS ha^{-1}+*Rhizobium* inoculation which was followed the by application of 100 kg NPS ha^{-1} for the lammiif variety. The highest net benefit (93490 and 82290 Birr ha^{-1}) and MRR (1596.0 and 1593.3%) were recorded from the application of 100 and 100 kg NPS ha^{-1}+EAL301 strain. **Conclusion:** Thus, the application of 100 kg NPS ha^{-1} only or the application of 100 kg NPS ha^{-1}+EAL301 strain inoculation is recommended for field pea production in western highlands of Oromia and similar agro-ecologies.

KEYWORDS
Inoculation, *Rhizobium*, strain, yield, *Pisum sativum* L., NPS fertilizer

INTRODUCTION

Field pea is an essential leguminous plant that serves as a source of high-quality protein and its importance in crop sequence to replenish soil fertility is driving interest in it[1]. It is the third most important food legume cool-season pulses[2] and it is an important source of protein and calories in Ethiopia. In Ethiopia, field pea is grown at altitudes ranging from 1800 to 3000 m a.s.l with an annual rainfall of 600-700 mm[2]. Field pea was cultivated on approximately 220×10^3 ha of land and 3762×10^4 tons of production in the 2020/21 main cropping season with an average productivity of 1.7 ton ha^{-1}[3], which

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is far below the potential yield as recorded at research plot yield of 2.5-3.5 ton ha^{-1} [4]. The major yield-limiting problems in the country are low soil fertility and inadequate agronomic practices[5]. Particularly, inadequate fertilizer rates and low soil fertility are the major constraints for field pea production in Western Ethiopia[5].

As outlined in the United Nations' Sustainable Development Goals (SDGs), agriculture is expected to contribute to ending hunger, achieving food security and improving nutrition through sustainable agriculture, avoiding land use changes and biodiversity loss, combating climate change and shifting crop production paradigms[6]. As a result, incorporating legumes into cropping systems with integrated nutrient management has been shown to boost sustainable crop production in the face of climate change. Legumes can create symbiotic relationships with rhizobia to convert atmospheric nitrogen into ammonia (NH^+) via biological nitrogen fixation (BNF)[7,8]. Integrated application of inputs enhances the production and productivity of field pea[6]. As a result, using *Rhizobium* strains in conjunction with low rates of synthetic fertilizer is one strategy for increasing sustainable legume productivity for resource-poor farmers who cannot afford the cost of inorganic fertilizers. Field peas have an inbuilt ability to obtain a considerable percentage of their nitrogen (N) requirement from the atmosphere via a symbiotic connection with *Rhizobium* bacteria in the soil[4]. However, the effectiveness in nitrogen fixation depends on the genotypes of legumes and requires host-specific *Rhizobium* strain for effective nodulation to boost the productivity of legumes.

Soil acidity[9] and low soil fertility are two main issues limiting productivity in Western Ethiopia[10,11]. Therefore, using effective rhizobia strains that tolerate soil acidity and selecting field pea genotypes or varieties are options for increasing yield and BNF in field peas. Inoculating food legumes with *Rhizobium* strains is not a common practice in Western Ethiopia, but it could provide an option for increasing seed yield in low nitrogen acidic soils[12].

Low soil fertility is one of the key yield loss issues for field pea cultivation in Western Oromia. Recently, the government of Ethiopia has introduced blended fertilizers for farmers based on soil tests for different agro-ecologies. As a result, the response of field peas to *Rhizobium* inoculation and blended NPS rate applications in the study areas has not been examined. Thus, because rhizobia inoculation and the addition of blended NPS fertilizers raise nitrogen and phosphorus levels in the soil, their use may have a significant impact on the yield and economic benefits of field peas produced in very deficient acidic soils of Western Ethiopia. Therefore, this study was initiated with the objectives of evaluating the effects of *Rhizobium* inoculation and NPS fertilizer rates on nodulation, growth, yield and yield components on field peas and identifying economically advantageous treatments that can enhance field pea productivity in the study area.

MATERIALS AND METHODS

Description of the study area: Throughout the main cropping seasons of 2018 and 2019, the field experiment was carried out at Shambu and Gedo. Shambu is located at an elevation of 2400 m a.s.l between 9°34'N Latitude and 37°06'E Longitude and receives a mean annual rainfall of 1,695 mm[5]. The mean minimum, mean maximum and average air temperatures are 8.15, 15.72 and 11.94°C, respectively, thus it has a cool, humid environment. Gedo receives a mean annual rainfall of 1,026 mm[5] and is located between 9°03'N Latitude and 37°26'E Longitude at an Altitude of 2,500 m. With mean minimum, mean maximum and average air temperatures of 8.51, 18.48 and 13.49°C, respectively, it has a cool, humid climate. Both sites have nitisols soil and the properties were listed in Table 1.

Experimental materials: Jidha and Lammiif varieties were used for the study. The varieties were released by Bako Agricultural Research Center (BARC) in 2017. Jidha and Lammiif varieties were characterized by

Table 1: Selected soil physico-chemical properties of the experimental site before planting

	Value			
Soil characters	Shambu	Gedo	Rating	Reference
Textural class	Clay	Clay		
Soil pH (1:2.5 (H_2O) suspension	5.07	5.02	Strongly acidic	Hazelton and Murphy[13]
Organic carbon (%)	1.06	1.59	Medium	Walkley and Black[14]
Organic matter (%)	1.83	2.74	Medium	Walkley and Black[14]
Total nitrogen (%)	0.09	0.14	Low	Hazelton and Murphy[13]
Available P (mg kg^{-1} soil)	8.58	8.23	Low	Hazelton and Murphy[13]

kik (white seed color) and shiro (brown seed color) types, respectively. Currently, the Ethiopian field pea breeding program has been categorized into two parts based on seed color and marketability (Kik and Shiro Types). Jidha and Lammiif varieties take 110-140 and 105-130 days to maturity having white and brown seed colors and yield potential of 2.7-3.6 and 2.8-3.5 ton ha^{-1} at a research station, respectively. They are highly adaptable to highland areas of Western Oromia. The NPS fertilizer containing 19% N, 38% P_2O_5 and 7% S was applied in the row as per the treatment and mixed with soil just at the time of field pea planting. Carrier based *Rhizobium* strain *leguminosarum* bv. *Viciae,* EAL301 was obtained from Managasha Biotechnology Private Limited Company, Addis Ababa, Ethiopia.

Soil sampling and analysis: Prior to planting, a representative soil sample was taken from the entire experimental field using an auger at a depth of 0-30 cm, randomly in a zigzag pattern. The physicochemical characteristics of the soil at the experimental site were finally determined by preparing one composite soil sample per site for analysis. For the examination of total N, soil pH, organic carbon and accessible phosphorus, the collected soil samples were air dried, crushed and sieved using a 2 mm mesh size sieve. The selected soil physico-chemical properties were analyzed at Bako Agricultural Research Center Soil Laboratory. Using a pH meter (BASIC 20) and combined glass electrode in a suspension of 1:2.5 soil-to-water supernatant, soil pH was calculated potentiometrically[13]. Walkley and Black[14] procedure was used to calculate the amount of organic carbon in the soil. According to Hazelton and Murphy[13] soil total nitrogen was measured using the Kjeldahl method utilizing a micro-Kjeldahl distillation apparatus and Kjeldahl digesting stand. The Bray II method[15] was used to extract the available soil phosphorus and a spectrophotometer (UV-1280) was used to measure it calorimetrically.

Treatments and experimental design: The treatment consisted of five NPS fertilizer rates (0, 25, 50, 75 and 100 NPS kg ha^{-1}), two levels of *Rhizobium* inoculation (Un-inoculated and EAL301) and two field pea varieties (Jidha and Lammiif). The treatment was arranged as 5×2×2 in factorial combinations in Randomized Complete Block Design (RCBD) with three replications. Each plot comprised seven rows of 3 m length (7×0.2×3 m = 4.2 m^2) and was used for data collection as a net plot.

Experimental procedure: The land was ploughed by a tractor, disked and harrowed. The 30 seeds were planted per each row at a spacing of 20 and 10 cm between rows and within rows, respectively. The spacing between blocks and plots was 1.5 and 0.8 m, respectively. Two seeds were sown per hill and then thinned to one plant after seedling establishment. All other management practices were done as per the recommendations. Carrier-based inoculant of EAL301 strain was applied at the rate of 10 g inoculants per kg of seed[16]. The inoculants were mixed with sugar with the addition of some water in order to facilitate the adhesion of the strain on the seed. To ensure that the applied inoculants stick to the seed, the required quantities of inoculant were suspended in a 1:1 ratio in a 10% sugar solution. The thick slurry of the inoculants was gently mixed with the dry seeds so that all the seeds received a thin coating of the inoculants. To maintain the viability of the cells, inoculation was done under the shade and allowed to air dry for 30 min and sown at the recommended spacing. Seeds were immediately covered with soil after sowing to avoid the death of cells due to the sun's radiation. A plot with un-inoculated seeds was planted first to avoid contamination.

Measurements and observations

Phenological and growth parameters: The number of days from sowing to the date on which 50 % of plants on the net plot produced at least their first flower and days to physiological maturity were recorded as the number of days from sowing to the stage when 90% of the plants in a plot have reached physiological maturity, i.e. the stage at which pods lost their pigmentation and begin to dry. The plant height was measured from five randomly taken plants from each of the four middle rows was measured in centimeters (cm) from the ground level to the tip of the plant at harvest maturity and expressed as an average of five plants per plot.

Yield and yield components: The number of pods per plant was determined by counting the average of five randomly chosen plants from each of the four middle rows at harvest maturity. In contrast, the number of seeds per pod was determined by counting the average of ten randomly chosen pods from the net plot. A sensitive balance was used to weigh 100 seeds that were sampled from each plot and the weight was adjusted to a 10% standard moisture content.

After the crop was taken from the net plot area, grain yield was calculated. The harvested produce was sun-dried, threshed by hitting with sticks and winnowed. The grain's moisture content was adjusted to 10%. Harvest index was calculated by dividing grain yield by above-ground biomass.

Statistical analysis: All collected phenological, growth, yield and yield components parameters were subjected to analysis of variance using R Statistical software version 4.2.2. The treatment means were compared using the Tukey's Honest Significance Difference (Tukey HSD) test at a 5% level of significance. Pearson correlation coefficients were computed among field pea grain yield and yield components to know the degree of relationship between yield and yield components.

Partial budget analysis: Partial budget analysis was used to assess the gross value of the grain yield by using the adjusted yield[13] at the market value of the grain and inputs throughout the cropping period to establish the economically acceptable treatment(s). To compute costs, only total costs that changed (TCV) were used. Current prices of field pea, inoculant, NPS fertilizer and inoculant and NPS application costs were deemed variable. The costs of land preparation, field management, harvest, transportation and storage were not included in the analysis. To match the field pea grain yield with what a farmer would get, the yield was reduced by 10%. Both the expenditures and benefits were converted to Ethiopian currency. Dominance analysis was used to compare treatment net benefits (NB) with TCV. All treatments that had net benefits less than or equal to treatment with lower TCV were marked with a letter "D" since they were dominated and eliminated from any further analysis. Un-dominated treatments were subjected to marginal rate of return (MRR) analysis[13] in a stepwise manner, moving from lower TCV to the next as shown below:

$$\text{MRR (\%)} = \frac{\text{Change in NB (NBb - NBa)}}{\text{Change in TCV (TCVb - TCVa)}} \times 100$$

RESULTS AND DISCUSSION

Pre-planting soil characteristics: Laboratory analysis of the pre-planting soil of the experimental sites was presented in Table 1. The results showed that the soil pH of the experimental sites is 5.07 at Shambu and 5.02 at Gedo. The results showed that the soil pH of the experimental sites is strongly acidic. The organic carbon content of Shambu (1.06%) and Gedo (1.59%) and rated medium according to rating done by Hazelton and Murphy[13]. Organic carbon in soils influences physical, chemical and biological properties of soils, such as soil structure, water retention, nutrient contents and retention and micro-biological life and activities in the soils. The analysis further indicated that the total N content of the experimental sites is 0.09% at Shambu and 0.14% at Gedo and rated as low[13]. The low total nitrogen might have been caused by soil acidity that tends to reduce microbial-mediated process that results in poor crop residue decomposition, mineralization of nitrogen from organic sources, N uptake by plants and denitrification[11]. Phosphorus levels in the soil can be used as a guide to indicate whether phosphate fertilizer is required for plant growth. The available P in the experimental soil was 8.58 mg kg^{-1} of soil at Shambu and 8.23 mg kg^{-1} of soil at Gedo (Table 1). According to Hazelton and Murphy[13] rating, the available soil P is rated as low.

Phenological parameters

Days to 50% flowering and physiological maturity: The main effect of *Rhizobium* strain and NPS rates and two or three-way interaction effect of varieties, *Rhizobium* strain and NPS rates did not significantly influence days to 50% flowering and days to physiological maturity. On the other hand, the main effect of field pea varieties revealed a significant difference in days to 50% flowering and days to physiological maturity (Table 2). Days to 50% flowering and days to physiological maturity were influenced by the main effect of varieties only. Jidha variety having indeterminate growth habits took a considerably longer period of time (77 and 136 days) to reach days to 50% flowering and physiological maturity while the variety lammif took 76.4 and 133.8 days to reach 50% flowering and physiological maturity indicating that lammif matured earlier than Jidha variety (Table 2). Days to 50% flowering and physiological maturity were influenced by field pea varieties (Table 2). This might be because indeterminate varieties produce additional nodes after initial flowering as a result, the physiological maturity becomes longer and their genetic differences influence the phenological periods of the field pea varieties. In conformity to these results Argaw and Mnalku[4] and Tirfessa and Lamessa[17], reported significant differences in the number of days to reach 50% flowering and days to reach physiological maturity among common bean varieties in Ethiopia.

Yield and yield components: Plant height, number of seeds per pod and hundred seed weight were significantly influenced by the main effect of field pea varieties only (Table 3). The difference in genetic potential of field pea varieties may be the cause of the variation in plant height, number of seeds per pod and 100-seed weight. Non-significant main and interaction effect of variety by *Rhizobium* inoculation and NPS rates in the number of seeds per pod indicated that the varietal seed per pod responses were similar under different *Rhizobium* inoculation and NPS fertilizer rates. Non-significant effects of studied

Table 2: Main effect of varieties, *Rhizobium* inoculation and NPS fertilizer application on days to 50% flowering and days to physiological maturity

	Parameters	
Treatment	Days to 50% flowering	Days to physiological maturity
Variety		
Lemmif	76.37	133.8
Jidha	77.03	136.1
LSD (0.05)	0.56	2.93
Inoculation		
Un-inoculated	76.79	138.3
EAL301	76.6	135.6
LSD (0.05)	NS	NS
NPS rate (kg ha^{-1})		
0	76.81	135.3
25	76.94	135.5
50	76.65	143
75	76.67	135.6
100	76.42	135.5
LSD (0.05)	NS	NS
CV (%)	2.9	17

CV: Coefficients of variation, NS: Non-significant and LSD: Least significant differences

Table 3: Main effects of field pea variety, *Rhizobium* strains and NPS fertilizer rates on plant height

	Parameters			
Treatment	Plant height (cm)	No of seeds/pod	HSW (g)	Harvest index (%)
Variety				
Lammiif	133.1	4.27	21.32	37.64
Jidha	146.9	4.04	19.63	33.77
LSD (0.05)	4.07	0.04	0.41	3.2
Inoculation				
Uninoculated	139.3	4.1	20.56	34.3
EAL301	140.7	4.1	20.38	37.11
LSD (0.05)	NS	NS	NS	NS
NPS fertilizer rate				
0	135.1	4.117	20.75	31.0
25	139.7	4.154	20.23	35.1
50	140.7	4.208	20.31	36.0
75	140.7	4.162	20.88	38.4
100	143.8	4.121	20.19	38.2
LSD (0.05)	NS	NS	NS	4.5
CV (%)	11.4	12.3	7.9	13.5

HSW: Hundred seed weight, CV: Coefficient of variation and LSD: Least significant difference

Table 4: Interaction effects of variety ×*Rhizobium*×NPS rates on number of pods per plant

		Rhizobium Inoculation	
NPS rate (kg ha^{-1})	Variety	Uninoculated (-R)	Inoculated (+R)
0	Jidha	10.3^{abc}	10.4^{abc}
	Lemmif	7.6^{c}	8.1^{c}
25	Jidha	11.9^{ab}	10.5^{abc}
	Lemmif	8.7^{c}	8.5^{c}
50	Jidha	9.7^{abc}	11.9^{ab}
	Lemmif	7.6^{c}	9.6^{abc}
75	Jidha	10.8^{abc}	12.5^{a}
	Lemmif	9.87^{abc}	9.6^{abc}
100	Jidha	10.1^{abc}	10.8^{abc}
	Lemmif	8.7^{bc}	8.7^{c}
LSD (0.05)		1.7	
CV (%)		16.0	

CV: Coefficient of variation, LSD: Least significant difference, Means followed by the same letter are not significantly different at 5% level of significance

treatments on the number of seeds per pod might be due to more effects of genetic factors in controlling this trait than environmental and management factors. Lammiif variety produced significantly heavier seed weight which was about 21.32 g compared with the Jidha variety (19.63 g) (Table 3). Among various NPS fertilizer levels, the maximum harvest index (38.4 and 38.2%) was recorded at the rate of 75 and 100 kg NPS ha^{-1}, respectively whereas the lowest harvest index was recorded at 0 kg NPS ha^{-1} (Table 3). The result might indicate that seed weight was less likely to be affected by the external application of fertilizers compared to the genetic effect. Similarly, the increased mean harvest index with the increase of NPS fertilizer rate might be due to the influence of P for greater fruit and seed setting than above-ground biomass yield. In line with this result Tarekegn and Kibret[18] obtained the maximum mean harvest index of soybean from the application of 46 kg P_2O_5 ha^{-1}, which resulted in a 19.1% increase over the control.

The number of pods per plant was significantly influenced by the interaction effects of variety ×*Rhizobium*×NPS rates. A greater number of pods per plant was recorded from the application of NPS fertilizer supplied with *Rhizobium* inoculant (Table 4). The positive effects of the inoculants might be due to a better amount of nitrogen rendered through nitrogen fixation which promoted vegetative growth

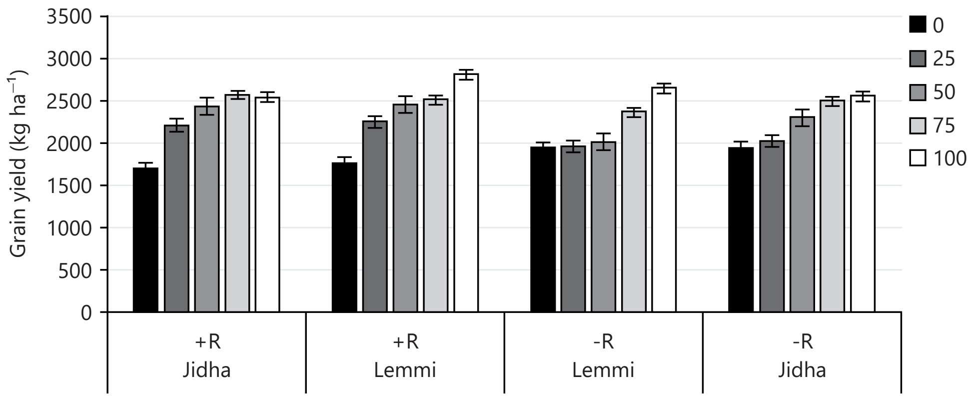

Fig. 1: Interaction effects of *Rhizobium* strain ×NPS fertilizer rates on grain yield of field pea varieties

and plant height thus improving the number of pods per plant. This could again be attributed to the availability of phosphorus that would have increased the intensity of photosynthesis, nitrogen fixation, root development, flowering, seed formation and fruiting.

Field pea grain yield was significantly influenced by the interaction effects of variety ×*Rhizobium*×NPS fertilizer rates application. Results in Fig. 1 revealed the performance of field pea varieties with the application of different rates of NPS fertilizer with and without *Rhizobium* strain. Both varieties (Jidha and Lammiif) showed positive yield increment with increasing rates of NPS fertilizer both under *Rhizobium* inoculation and uninoculated plots but the performance of the varieties was better under *Rhizobium* inoculation compared to uninoculated conditions (Fig. 1). The highest grain yield (2800 kg ha^{-1}) was obtained from the application of 100 kg NPS ha^{-1}+*Rhizobium* inoculation which was followed by the application of 100 kg NPS ha^{-1} for lammiif variety. The differential response of field pea varieties to the application of *Rhizobium* strain and NPS fertilizer might be due to their variable growth habit and the genetic potential of the two varieties. The positive effects of the inoculants might be due to a better amount of nitrogen rendered through nitrogen fixation which promoted vegetative growth and plant height thus improving the number of pods per plant. This could again be attributed to the availability of phosphorus that would have increased the intensity of photosynthesis, nitrogen fixation, root development, flowering, seed formation and fruiting. An increased number of pods per plant of soybean due to the combined application of phosphorus up to 46 kg P_2O_5 ha^{-1} and inoculation was reported by Dabesa and Tana[11]. *Rhizobium* inoculation with inorganic fertilizer applications enhanced the grain yield of legume crops. As a result, using *Rhizobium* strains with inorganic fertilizer boosts field pea productivity in Western Ethiopia. This study was done on the response of field peas to inorganic fertilizer (NPS) and *Rhizobium* inoculations only. Thus, future studies should be focused on the response of field peas to integrated nutrient management to reduce the adverse effects of chemical fertilizer on the environment and to enhance sustainable agriculture practices.

Pearson correlation: The pearson correlation coefficient was used to calculate a correlation among the response variables of field peas. A correlation coefficient was performed among field pea grain yield and yield components (Fig. 2). A significant positive correlation was found between field pea grain yield, biomass yield, harvest index, 100-seed weight, number of nodules per plant height, days to 50% flowering and number of pods per plant. The results from this study suggest that biomass yield, harvest index, 100-seed weight, number of nodules, plant height, days to 50% flowering and number of pods per plant are important parameters to monitor the grain yield of field pea. But, field pea grain yield was negatively correlated with the number of seeds per pod and days to physiological maturity. The non-significant negative correlation between field pea grain yield, number of seeds per pod and days to physiological maturity indicated that the number of seeds per pod and days to physiological maturity

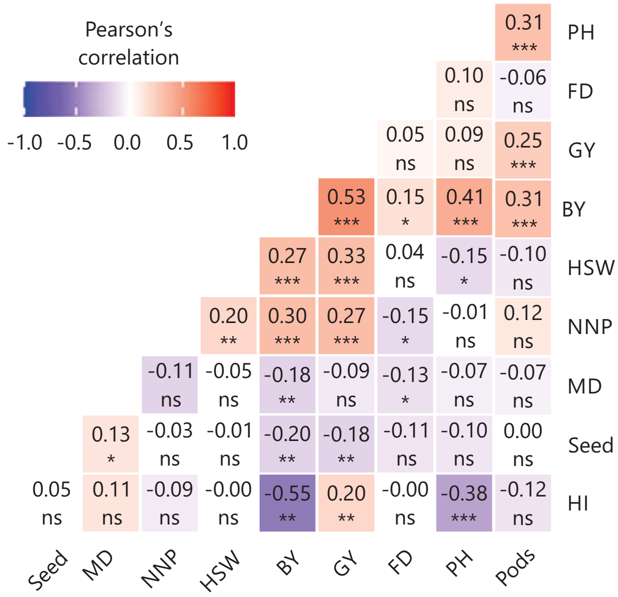

Fig. 2: Pearson correlation among yield and yield components of field pea with their p-values

Seed: Number of seeds per pod, MD: Maturity date, NNP: Number of nodules per plant, HSW: Hundred seed weight, BY: Biomass yield, GY: Grain yield, FD: Days to 50% flowering, PH: Plant height and Pods: Number of pods per plant, ns: p>0.05, *p<0.05, **p<0.01 and ***p<0.001

Table 5: Partial budget analysis of the effects of *Rhizobium* strain and NPS rates on the productivity of field pea varieties

Variety	Inoculation	NPS (kg ha^{-1})	Yield	TVC	Gross benefit	Net benefit	MRR (%)
Jidha	-R	0	1949	0	66266	66266	0
Lemmi	-R	0	1947	0	66198	66198	0
Jidha	EAL301	0	1700	235	57800	57565	-3673.6
Lemmi	EAL301	0	1769	235	60146	59911	-2675.3
Jidha	-R	25	2018	425	68612	68187	468.0
Lemmi	-R	25	1958	425	66572	66147	D
Lemmi	EAL301	25	2248	660	76432	75772	1450.6
Jidha	EAL301	25	2216	660	75344	74684	D
Jidha	-R	50	2300	775	78200	77425	1448.6
Lemmi	-R	50	2013	775	68442	67667	D
Lemmi	EAL301	50	2450	1010	83300	82290	1593.3
Jidha	EAL301	50	2434	1010	82756	81746	D
Jidha	-R	75	2500	1125	85000	83875	1571.3
Lemmi	-R	75	2376	1125	80784	79659	D
Jidha	EAL301	75	2570	1360	87380	86020	1457.5
Lemmi	EAL301	75	2522	1360	85748	84388	D
Jidha	-R	100	2553	1475	86802	85327	D
Lemmi	-R	100	2650	1475	90100	88625	1520.5
Lemmi	EAL301	100	2800	1710	95200	93490	1596.0
Jidha	EAL301	100	2534	1710	86156	84446	D

-R: Without inoculation, 14 birr: Cost of NPS kg^{-1}, 1 kg of field pea: 34 Birr, one sachets of inoculant: 40 birr, TCV: Total costs that vary, MRR: Marginal rate of return and D: Dominated

are not important parameters to affect the grain yield of field pea. A significant positive correlation observed among field pea grain yield and yield components suggests that biomass yield, harvest index, 100-seed weight, number of nodules, plant height, days to 50% flowering and number of pods per plant are important parameters to monitor grain yield of field pea. Likewise, Epie *et al.*[19] found a significant and positive correlation between soybean grain yield and yield components.

Partial budget analysis: Table 5 presents an analysis of the net benefits, variable costs that vary and marginal rate of return. Farmers must have information on the costs and advantages of treatments before they will adopt technical innovation. The study looked at the economic benefits of the treatments in order to offer recommendations based on the agronomic data. This improves farmers' ability to choose the best combination of resources in the study area. The cost of NPS, inoculant and fertilizer application cost, as well as the cost of mixing inoculant with seeds, were evaluated in the partial budget analysis.

The highest net benefits (93490 Birr ha^{-1}) and marginal rate of return (1596.0 %) were obtained from the application of 100 kg NPS ha^{-1} inoculated with EAL301 strain. Similarly, the application of 100 and 50 kg NPS ha^{-1}+EAL301 gave the highest net benefit and marginal rate of return (Table 5). This implies that farmers would be better off inoculating their field peas in combination with the application of 50 kg NPS ha^{-1} or the farmers can use 100 kg NPS ha^{-1} only if the inoculants are not available. These can increase field pea yields and thus increase farmer's income. Thus, the application of 100 or 50 kg NPS ha^{-1}+EAL301 is profitable and recommended for the farmers in the study areas and other areas with similar agro-ecological conditions.

CONCLUSION

The decline of soil fertility due to the monoculture of cereal crops is one of the major constraints of field pea production in Western Ethiopia in general and particularly in highland areas where wheat and barley are major crops. The highest grain yield (2800 kg ha^{-1}) of field pea was obtained from the application of 100 kg NPS ha^{-1}+*Rhizobium* inoculation which was followed by the application of 100 kg NPS ha^{-1} for the Lammiif variety. The highest net benefit (93490 Birr ha^{-1}) and MRR (1596.0%) were recorded from the application of 100 kg NPS ha^{-1} which was followed by 50 kg NPS ha^{-1} supplied with EAL301 strain. From this study, it can be concluded that the application of 100 kg NPS ha^{-1} only or 50 kg NPS ha^{-1} supplied with EAL301 inoculation resulted in higher net benefit and it is recommended for use in the study areas. However, as this study was done under acidic soil (problematic soil), the experiment has to be repeated under reclaimed soil in the study area to reach a conclusive recommendation.

SIGNIFICANCE STATEMENT

Integrated use of *Rhizobium* strains with inorganic fertilizer is one of the methods to boost legume productivity. This experiment was conducted to determine the effects of *Rhizobium* inoculation and NPS fertilizer rates on yield and yield components of field peas as well as to find economically profitable treatment that can maximize the productivity of field peas in the study areas. Application of NPS fertilizer with *Rhizobium* strain improved field pea grain yield compared to the application of NPS fertilizer alone.

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