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Yield and Fiscal Benefits of *Rhizobium* Inoculation Supplemented with Phosphorus (P) and Potassium (K) in Climbing Beans (*Phaseolus vulgaris* L.) Grown in Northern Tanzania

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Abstract

Both field and green house experiments were intended to investigate and evaluate the outcome of rhizobial inoculation supplemented with P and K on climbing beans production in northern Tanzania. The results obtained indicated that, inoculation using *Rhizobium* inoculants supplemented with fertilizers significantly ($p \leq 0.001$) improved both vegetative and yield parameters of climbing beans varieties compared with control treatment. The economic analysis in rhizobium alone revealed a profit of US$ 2350 compared with control treatment with US$ 1558 profit, which was finally reflected in higher percentage increase over control and higher marginal rate of return (MRR). Thus, the use of *Rhizobium* inoculants supplemented with P and K increased climbing beans yield and the economic analysis performed based on total revenue and variable costs reflected an improvement in economic well being of a small hold farmer of northern Tanzania.

Keywords

Variable Cost, Total Revenue, Biological Nitrogen Fixation, Nodulation, Marginal Rate of Return (MRR) and Marginal Net Return (MNR)

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1. Introduction

Common bean is a major grain legume in Tanzania, but smallholder farmers' yields are far below potential, the

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main reasons being the low soil fertility due to lack of essential nutrients such as N, P and K [1]-[5]. It is important source of income to farmers in East and sub Saharan African and the efforts at improving their yield have been increasing over the year [6] [7]. Despite the attractive market of pulses, the yield of grain legumes has remained very low under farmer's condition in Africa. Studies revealed that the low yields of legumes in Africa is sought to be associated with low soil fertility, low native *Rhizobium* and thus reduced N_2 fixation as a results of various abiotic factors such as N and P [3] [4] [7]. The use of rhizobial inoculants is less expensive than industrial fertilizer for small scale agriculture which is practiced in most sub-Saharan Africa and cover majority of the people of which, chemical fertilizers are unaffordable because of increasing prices in each year [8]. Thus, to these farmers Biological Nitrogen Fixation which is enhanced by inoculation to the compatible host legume is recommended as it is considered to have ecological and high economic benefits.

Limiting factors such as diversity or scarcity of native *Rhizobium* population in soil can affect the legume performance and grain yield [4] [9]. Supplementing climbing legumes with nutrients has great potential for increasing yield as it is not only promoting growth but also enhance symbiotic establishment for increased nitrogen fixation [10]-[12].

Bambara and Ndakidemi [13] [14] reported that legumes that are exogenously supplied with mineral nutrients tend to double plant growth, nitrogen fixation and grain yield relative to their unfertilized counterparts.

Nitrogen is a very important macro-nutrient largely involved in metabolic actions and protein synthesis, resulting to increased vegetative and reproductive growth and ultimately leads to yield of the crops [15] [16]. It is the most limiting nutrients to plant physiological requirement and amendment of nitrogen to plants has been commonly accomplished by application of industrial fertilizer in various places in Africa [17] [18]. This common solution of nitrogen adjustment is very expensive and untenable to small holder farmers and it is environmental unfriendly [19]. The solution to nitrogen deficiency in East and sub Saharan Africa is suggested to be through *Rhizobium* inoculation of legumes [4] [13]. Rhizobial inoculation of legumes will maximize the inherent trait of legume plant species which are capable of solely obtain nitrogen required by plant for growth and development from Biological Nitrogen Fixation [20].

Nyoki and Ndakidemi [21] [22] reported that *Rhizobium* inoculation significantly improved the yield and yield components of legumes such as number of pods per plant, number of seeds per pod, number of seeds per plant, 100-seed weight, and seed yield relative to control. The increase in seed yield could be due to high nodulation which results in high N_2 fixation and hence higher Dry Matter yield and Seed yield.

Phosphorus deficiency is also a chief contributing factor limiting BNF in legumes [23] [24]. Phosphorus is required in large quantities in juvenile cells, such as shoots tips and root tips, where metabolism is high and cell division is quick [25]. Phosphorus aids in root expansion and flower commencement, and it also plays role in seed and fruit development [26] [27]. Yield of beans can be reduced by as much as 60% - 75% in soils that are unable to release sufficient P levels during the growing season [28]. Many researchers have reported a significant performance of legumes when supplied with phosphorus [8] [20] [29]. In the study by [30], they revealed that phosphorus significantly increased dry matter yield, yield components and growth parameters such as leaf area and number of branches per plant and finally the seed yield. Phosphorus use is also reported to significantly improve number of nodule, nodules dry weight and nitrogen and phosphorus uptake of the cowpea [31] [32]. Thus phosphorus application in legume based system is a vital undertaking.

Potassium regulates the opening and closing of the plant stomata, thus helping to prevent water loss through transpiration and hence affecting growth and yield [33] [34]. K^+ is highly mobile and can aid in balancing the anion charges within the plant. Studies of potassium application in corn and soybean increased average yields of both crop when applied at higher rate based on soil potassium test recommendations as compared with lower rates [35]. Like nitrogen, the importance of potassium in legume production has to be considered and taken into action for proper yield.

The very low nitrogen, phosphorus and potassium status of many soils in East African highlands suggests that availability of these elements will be an emerging limitation to crop productivity in the near future. Therefore, *Rhizobium* inoculation supplemented with recommended amount of phosphorus and potassium may play a crucial role in enhancing legume productivity in poorly depleted soils of East Africa; therefore, help to reduce the problem of hunger, poverty and poor health of most rural population of sub-Saharan Africa (SSA) who cannot afford high price of inorganic nitrogenous fertilizers.

Studies by [8] [22] [36] on economic analysis of rhizobial inoculation and phosphorus supplementation on cowpea, soybean and common beans grown under field conditions in Kilimanjaro region Tanzania, revealed greater financial benefits from rhizobial inoculation compared with un-inoculated control. For example, inoculation on cowpea has resulted into greater income of 495 US$ as profit relative to un-inoculated treatments which produced a profit of 307 US$ and ultimately resulted into higher percentage increase over control and marginal rate of return. However, phosphorus supplementation at the rate of (40 kg P/ha) gave greater revenue as profit over all other treatments. Therefore, inoculation with effective *Rhizobium* strains and supplementation with recommended amount of phosphorus and potassium in African highlands soils is essential for obtaining profitable and sustainable yield. Thus inoculation with rhizobial inoculants and supplementation of newly release climbing bean varieties with P and K recommended for growing in highlands of East Africa will supply enough nitrogen, phosphorus and potassium and thus enhance the grain yield and finally resulting into higher economic benefits to the growers.

Paper Outline

This paper titled Yield and Fiscal Benefits of Rhizobium inoculation supplemented with Phosphorus (P) and Potassium (K) in Climbing Beans (*Phaseolus vulgaris* L.) Grown in Northern Tanzania is a results of the experimental study performed in Tanzania. The study aimed to investigate and evaluate the outcome of inoculating Climbing beans varieties with rhizobial inoculant supplemented with some fertilizer P and K and its economic implication to small holder farmers.

Material and Methods, this part covers:

- Description of the study Area—Location;
- Experimental design—The setup of the experiments and parameters involved in the experiments.

Statistical Analysis Method used, here the following is displayed:

- Results for Root and Shoot Biomass (Field and Green house);
- Analyzed Yield Results for Field and Green house Experiment;
- Marginal Net Return (MNR), Total Variable Cost (TVC) and Marginal Rate of Return (MRR) of Climbing Beans (*Phaseolus vulgaris* L.) under field conditions.

Results and Discussion, this part is enriched with:

- Effects of Rhizobium inoculation on Shoot Biomass and Root Biomass of three climbing beans varieties tested (*Phaseolus vulgaris* L.);
- Effects of Fertilizer (P and K) on Shoot Biomass and Root Biomass of three climbing beans varieties tested (*Phaseolus vulgaris* L.);
- Effects of Rhizobium inoculation on nodules number, Grain yield and Yield parameters of three climbing beans varieties tested (*Phaseolus vulgaris*);
- Effect of fertilizer (P and K) supplementation on nodulation, yield and yield components of three climbing beans varieties (Cheupe, Selian 2005 and Selian 2006);
- The profitable aspects of Rhizobium inoculation supplemented by Phosphorus and Potassium in production of climbing legumes (*Phaseolus vulgaris* L.);
- Interactive effect between Rhizobium inoculation and varieties on the shoot biomass and number of nodules on climbing bean (*Phaseolus vulgaris*).

Conclusion:

- This study has revealed a positive outcome of the rhizobial inoculation when used together with fertilizer K and P supplementation. The economic analysis on this study has shown a benefit to the small farmers of northern Tanzania thus, the technology is highly recommended to put in use.

2. Material and Methods

Description of the Study Area—Location

The field experiment was laid down at—Tanzania Coffee Research Institute (TACRI) located at 1390 m above sea level, latitude (3˚14'44") S and longitude (37˚14'48") E. The maximum temperature ranges from 22.7˚C - 23.5˚C and the minimum temperature ranges from 12.4˚C - 13.7˚C with the (RH) Relative humidity of about 94%. The green house experiment was conducted at NM-AIST located at Tengeru compass along the old Moshi-Arusha road. The coordinates of NM-AIST lies between latitude (3˚3'83") S and longitude (36˚83'3") E, at an altitude of about 1250 m above sea level. The mean maximum temperature ranges from 23.6˚C to 27.5˚C whiles the mean minimum temperature ranges from 13˚C to 15.5˚C with RH of 96%. The field site is characterized with bimodal precipitation pattern with mean annual rainfall of 1200 mm, the experiment was conducted between Aprils to end of August 2014.

3. Experimental Design

Experiments were conducted in Lyamungo (Field) and Nelson Mandela African Institution of Science and Technology (Green house). The experiment was laid out in factorial arrangement. Factor I comprised of three climbing bean varieties (Cheupe, Selian 2005 and Selian 2006). Factor II involved two inoculation treatments, viz 1) inoculation with *Rhizobium spp.* and 2) without inoculation. Factor III included four fertilizer levels (0 $\text{Kg}\cdot\text{ha}^{-1}$ 20 $\text{Kg K}\cdot\text{ha}^{-1}$, 30 $\text{Kg P}\cdot\text{ha}^{-1}$ and 20 kg K + 30 $\text{Kg P}\cdot\text{ha}^{-1}$). The experiment was replicated four times in both sites and *Rhizobium tropici* CIAT899 strain with a peat carrier supplied by Legume Technology United Kingdom was used to inoculate targeted seeds. The climbing beans were obtained from the breeder based at Selian Agricultural Research Institute, Northern zone Arusha, Tanzania. Land clearing was properly done and all the required land management practices such as ploughing, harrowing and field layout were performed first before embarking on planting. Few minutes before sowing, seeds were carefully mixed with *Rhizobium* inoculants to supply (10^9 cells/g seed), following procedure predetermined by products producer. Uninoculated seeds were sown first followed by inoculated seeds so as to avoid contamination. Seeds were sown at a spacing of 50 cm by 20 cm. The size of the plot was 4 m by 3 m, and the plant population density was 200,000 plants per hectare. Each plot had a total of 6 rows, two border rows which were left untouched and four middle rows from which the observation was made and samples were taken for analysis.

Three seeds were sown per hole and after full germination and establishment thinning was done leaving only two healthy plants per hill.

The field trial was performed at TACRI-Lyamungo. The trial was conducted during the long rainy season of Northern Tanzania. The field and green house trials were both planted on 7th and 14th of April, 2014 respectively and were harvested on 9th July 2014 for green house trials and 25th August 2014 for the field trials.

For the green house experiment, 4 kg soil pots were used. In order to ensure uniformity the soil used was collected from Lyamungo the same place where the field experiment was laid down; and each pot was planted with four seeds, and then thinned to two strong plants per pot after germination. In the field site the land was tractor ploughed and harrowed before planting. Sowing was done at a spacing of 50cm by 20cm starting with uninoculated plots followed by inoculated ones to avoid contamination. The plot size was 4m by 3m.

The weeding management was done three times one after every two weeks; however, the last one was done precautionary because plants were initiating flower buds.

3.1. Yield and Yield Constituent of Climbing Beans (*Phaseolus vulgaris*)

The yield and yield component data was collected and recorded. The parameters recorded were seed yield per hactre, number of pods per plant, number of seeds per pod and weight of 100 seeds grain. At 50% flowering the number of nodules were determined, this was done by selecting ten plants randomly from every sub plot; these plants were uprooted using a hand garden spade and number of nodules counted. This was done twice in the field at 2WAP and 6WAP while in the green house it was performed only once at 6WAP.

At harvesting stage, the plants in the two middle rows of every plot were counted and harvested for assessing grain yield. All the plant found in the border within each row was excluded. When estimating yield components, ten plants were selected from each plot to determine targeted parameters such as number of pod per plant and number of seeds per pod. All pods were hand threshed and allowed to dry to below 13% moisture content. Grain yield was determined for each plot and the seed yield per hactre computed based on the number of plant net plot harvested versus an equivalent of one hactre. Lastly, the 100-seed weight were weighed for each plot and recorded for analysis.

3.2. Fiscal Benefit of the Tested Treatments

To assess the profitability of *Rhizobium* technology in climbing beans production, simple economic analysis was done and marginal net return (MNR) was calculated for every treatment using the formula:

$$\mathbf{PROFIT}(\mathbf{MNR}) = (\mathbf{Y} \times \mathbf{P}) - \mathbf{TVC}$$

where every letter denotes specific meaning as follows: Y is total yield of climbing bean grain (kg/ha), P denote the selling price at farm gate (USD/kg) and TVC is the total variable costs being the cost of all the inputs involved in the experiment. That is all costs which vary with production levels related to the treatment such as labour, fertilizers, seeds etc.

The selling price at farm gate was estimated to be Tsh.1500/= which is equivalent to US$ 0.91/kg of climbing beans. Thus the marginal rate of return (MRR) was computed using the formula:

$$\mathbf{MRR = MNR/TVC}$$

4. Statistical Analysis Method Used

The 3 ways analysis of variance (ANOVA) in Factorial arrangement was the statistical package used and the computation was performed by means of STATISTICA soft ware program. Then the treatment means was compared at ($p = 0.05$) significance level using fisher's least significance difference (L.S.D).

5. Results

5.1. Effects of *Rhizobium* Inoculation on Shoot Biomass and Root Biomass of Three Climbing Beans Varieties Tested (*Phaseolus vulgaris* L.)

Results show that rhizobial inoculation significantly ($p \le 0.01$) increased shoot biomass at 6 WAP in the green house experiment relative to the control treatment. On the other hand in the field experiment rhizobial inoculation significantly ($p \le 0.001$) increased shoot biomass 4 and 6 WAP relative to uninoculated control treatment. For example, rhizobial inoculation increased shoot biomass by 10% in the greenhouse experiment. Likewise, in the field experiment inoculation by *Rhizobium* increased root biomass 4 and 6 WAP by 63% and 5% respectively. Also shoot biomass increased by 31% and 14% in the field trials 4 and 6 WAP respectively (**Table 1**).

5.2. Effects of Fertilizer (P and K) on Shoot Biomass and Root Biomass of Three Climbing Beans Varieties Tested (*Phaseolus vulgaris* L.)

Application of fertilizer (P + K) significantly ($p \le 0.5$), increased shoot biomass relative to control treatment in both field and green house experiments. Phosphorus increased shoot biomass in the field experiment at 4 WAP by 18% while the combination of P and K increased shoot biomass by 6% relative to the control treatment (**Table 1**).

Likewise, the study revealed significantly ($p \le 0.001$) increase in root and shoot biomass of the 3 tested varieties in both field and green house experiments. For example, shoot and root biomass significantly increased at 4 and 6WAP relative to control treatment. Climbing bean variety Cheupe produced the highest root biomass in the green house compared with Selian 2005 and Selian 2006. Cheupe had mean root biomass of 2 g and 4 g in the field and green house respectively for the data collected 6WAP. However, Selian 2006 performed better in the field with the highest shoot biomass mean of 26 g and 42 g for the data collected 4 and 6 WAP in the field while in the green house the biomass was 38% and 22% respectively relative to other varieties (**Table 1**).

5.3. Effects of *Rhizobium* Inoculation on Nodules Number, Grain Yield and Yield Parameters of Three Climbing Beans Varieties Tested (*Phaseolus vulgaris*)

The results in **Table 2** indicate that rhizobial inoculation significantly ($p \le 0.001$) increased the number of root nodules collected at 2 and 6 WAP in both field and green house experiments. Specifically, the number of nodules increased by 89% and 55% for data collected at 2 and 6WAP respectively for field experiment and 79% increase in the green house for the count performed at 6WAP relative to the control treatment. **Figure 1(a)** & **Figure 1(b)** and **Figure 2(a)** & **Figure 2(b)** pictures of nodulated and non nodulated climbing legumes uprooted in field plots).

Furthermore, rhizobial inoculation resulted into significant ($p \le 0.001$) increase in yield and yield components of the climbing bean relative to the control treatment in most components measured both in the field and green house. For example, rhizobial inoculation increased number of pods per plant by 5%, number of grain per pod by 26% in the green house trials. The field trials also indicated a significant increase by 20%, 29% and 30% on number of pods per plant, number of grain per pod and yield per hactre 6WAP relative to uninoculated control

Table 1. Results for root and shoot biomass (field and green house).

	GREEN HOUSE RESULTS		FIELD RESULTS			
Treatments	**Shoot biomass 6 WAP**	**Root biomass 6 WAP**	**Roots Biomass 4 WAP**	**Roots Biomass 6 WAP**	**Shoots Biomass 4 WAP**	**Shoots Biomass 6 WAP**
Rhizoium						
−	24.02 ± 2.96b	1.64 ± 0.03a	1.87 ± 0.08a	3.25 ± 0.07a	16.56 ± 0.73a	35.92 ± 1.23a
+	26.63 ± 0.08a	1.57 ± 0.03a	5.06 ± 2.96a	3.42 ± 0.07a	24.00 ± 1.26b	41.71 ± 1.57b
Fertilizer						
Control	25.83 ± 0.15a	1.62 ± 0.03a	1.99 ± 0.15a	3.38 ± 0.14a	19.21 ± 1.78a	38.67 ± 2.18a
20K	24.21 ± 0.10a	1.61 ± 0.05a	1.87 ± 0.10a	3.17 ± 0.08a	18.21 ± 1.23a	37.83 ± 2.15a
30P	26.44 ± 0.12a	1.66 ± 0.04a	2.07 ± 0.12a	3.41 ± 0.09a	23.38 ± 1.92b	39.21 ± 2.14a
30P + 20K	24.79 ± 5.92a	1.54 ± 0.04a	7.93 ± 5.92b	3.38 ± 0.09a	20.33 ± 1.44ab	39.54 ± 1.92a
Varieties						
1: Cheupe	26.69 ± 0.09a	1.76 ± 0.03c	2.24 ± 0.09a	3.66 ± 0.09c	16.06 ± 0.79a	35.16 ± 1.62a
2: Selian 05	24.63 ± 4.45a	1.58 ± 0.04b	6.10 ± 4.45a	3.03 ± 0.05a	19.06 ± 1.20b	36.03 ± 1.31a
3: Selian 06	24.66 ± 0.11a	1.48 ± 0.02a	2.05 ± 0.11a	3.31 ± 0.09b	25.72 ± 1.59c	45.25 ± 1.87b
3 WAY ANOVA (F stat)						
Rhiz	10.41**	3.11 ns	1.16 ns	3.11 ns	43.14***	11.797***
Fert	1.57 ns	1.44 ns	1.01 ns	1.44 ns	03.91*	0.196 ns
Variaties	2.86 ns	16.01***	0.79 ns	16.01***	25.40***	14.664***
Rhiz × Fert	0.41 ns	0.14 ns	0.96 ns	0.14 ns	01.20 ns	0.497 ns
Rhiz × Varieties	4.77*	0.73 ns	0.92 ns	0.73 ns	06.46**	2.425 ns
Fert × Varieties	0.68 ns	0.74 ns	1.03 ns	0.74 ns	0.44 ns	2.446*
Rhiz × Fert × Varieties	0.07 ns	0.23 ns	1.01 ns	0.23 ns	0.40 ns	1.432 ns

R = without rhizobia, **R+** = with rhizobia, **P** = Phosphorus **K** = Potassium, Values shown are for means ± SE; stars indicates significant at $p \leq 0.001$, $p \leq 0.01$ and $p \leq 0.05$ (***, ** and * respectively), **ns** = not significant, **SE** = standard error. Means followed by dissimilar letter(s) in a column are significantly different from each other at p=0.05 according to (LSD) Fischer least significance difference.

treatment (**Table 2**).

5.4. Effect of Fertilizer (P and K) Supplementation on Nodulation, Yield and Yield Components of Three Climbing Beans Varieties (Cheupe, Selian 2005 and Selian 2006)

Generally, fertilizer application showed significant ($p \leq 0.01$) increase in the nodulation of the climbing beans in the green house experiment. The number of nodules significantly ($p \leq 0.01$) increased by 59%, 44% and 8% following addition of P, (P+K) and K respectively based on the count performed 6 WAP (**Table 2**).

Additionally, supplementation of fertilizer revealed a significant increase in number of grain per pod ($p \leq 0.001$) in the green house and number of pods per plant ($p \leq 0.01$) in the field trials for data collected at 6WAP. For example, the number of grain per pod increased by 38%, 22% and 37% following the application of K, P and (P + K) fertilizers respectively relative to the control treatment. Furthermore, the number of pods per plant in the field experiment increased by 14% and 5% 6WAP after addition of K and P in a single doze respectively.

Additionally, rhizobial inoculation supplemented with fertilizer P and K showed significant ($p \leq 0.001$) performance in the varieties tested on nodule formation in both experiments. For example, Selian 06 showed highest nodule number compared with Cheupe and Selian 05. At 6WAP, the mean nodule number recorded was 13,


(a) (b)

Figure 1. (a) & (b) Variety 3-Selian 06 with highest number of nodules in the experiment with *Rhizobium* inoculated plots taken at 50% flowering in Lyamungo field—July, 2014.


(a) (b)

Figure 2. (a) & (b) Variety 2-Selian 05, the variety which produced the least number of nodules in the experiment. Note in the above photo no root nodules and the plants are yellow in colour an indication of low/No nitrogen fixation. The picture taken from uninoculated plot in Lyamungo July, 2014.

10 and 6 respectively in the green house. The number of nodules recorded in the field was 9, 13, 9 for Cheupe, Selian 2006 and Selian 2005 for measurements taken at 2 WAP and 62, 47, 43 for Cheupe, Selian 2006 and Selian 2005 for data recorded at 6WAP in the field experiment.

5.5. The Profitable Aspects of *Rhizobium* Inoculation Supplemented by Phosphorus and Potassium in Production of Climbing Legumes (*Phaseolus vulgaris* L.)

The fiscal computational performed after harvesting revealed that this technology had a greater benefit when used in the production of climbing bean under field condition compared with the control treatment. For example, rhizobial inoculation alone produced a profit of US$ 2350 compared with control treatment which resulted to only US$ 1558 profit, which was finally reflected in higher percentage increase over control and higher marginal rate of return (MRR).

Likewise, the study revealed that application of P and K in combination resulted into highest profit compared with P or K alone. Despite the fact that P had shown highest value of percentage increase over control and

Table 2. Analysed yield results for field and green house experiment—2014, season.

	GREEN HOUSE			**FIELD EXPERIMRNT RESULTS (YIELD)**					
TREATMENT	**No. of nodules 6WAP**	**No. of pods per plant 6WAP**	**No. of grain/pod At Maturity**	**No. of root nodules 2WAP**	**No. of root nodules 6WAP**	**No. pods/plant 6WAP**	**No. of grain/pod AT HAVST**	**100 grain WT(g) AT HARVST**	**Yield/Ha (Kg/Ha)**
Rhizobium									
− (Without)	03.50 ± 0.84a	11.85 ± 0.68a	3.52 ± 0.14b	2.06 ± 0.35 a	31.81 ± 2.32a	6.17 ± 0.34b	4.79 ± 0.13b	34.02 ± 1.48a	1958.99 ± 11337 b
+ (With)	16.88 ± 2.21b	12.48 ± 0.73a	4.77 ± 0.17a	18.88 ± 0.95b	70.25 ± 3.84b	7.75 ± 0.31a	6.75 ± 0.34a	35.31 ± 1.66a	2805.22 ± 240.92a
Fertilizer									
Control	06.46 ± 1.47a	12.08 ± 0.90a	3.04 ± 0.19b	9.21 ± 1.69a	51.96 ± 7.18a	6.75 ± 0.40b	5.83 ± 0.50a	34.92 ± 2.28a	2243.97 ± 307.88a
20K	07.00 ± 1.87a	11.17 ± 1.11a	4.88 ± 0.24a	11.38 ± 2.28a	50.46 ± 5.68 a	7.83 ± 0.56a	5.38 ± 0.19a	35.00 ± 2.26a	2319.67 ± 225.08a
30P	15.75 ± 4.11b	12.63 ± 0.93a	3.88 ± 0.17c	11.21 ± 2.18 a	48.42 ± 6.35 a	7.08 ± 0.54ab	6.21 ± 0.61a	34.46 ± 2.27a	2438.67 ± 207.35a
30P + 20K	11.54 ± 2.35ab	12.79 ± 1.05a	4.79 ± 0.23a	10.08 ± 1.86a	53.29 ± 4.64a	6.17 ± 0.40b	5.67 ± 0.22a	34.29 ± 2.18a	2526.11 ± 361.12a
Varieties									
1:Cheupe	10.75 ± 2.10ab	13.16 ± 0.75a	4.16 ± 0.24a	9.06 ± 1.44a	62.44 ± 6.19b	5.00 ± 0.26b	5.94 ± 0.34a	34.94 ± 0.45b	1612.88 ± 078.38c
2:Selian 2005	06.47 ± 1.29a	14.47 ± 0.88a	4.09 ± 0.19a	9.13 ± 1.40a	43.19 ± 4.32a	8.00 ± 0.48a	6.09 ± 0.49a	22.00 ± 0.16c	2164.28 ± 188.87b
3:Selian 2006	13.34 ± 3.18b	8.88 ± 0.61b	4.19 ± 0.24a	13.22 ± 2.18 b	47.47 ± 4.21a	7.88 ± 0.26a	5.28 ± 0.16a	47.06 ± 0.96a	3369.15 ± 291.03a
3 WAY ANOVA (F stat)									
Rhiz	39.13***	86.27***	59.34***	362.95***	86.270***	23.04***	32.17 ***	3.10 ns	16.72***
Fert	3.43*	0.26 ns	28.37***	1.339 ns	0.256 ns	4.45**	1.02 ns	0.22 ns	0.37 ns
Varieties	4.47**	7.95***	0.12 ns	9.712***	7.954***	35.30***	2.08 ns	388.54***	25.11***
Rhiz × Fert	1.251 ns	1.25 ns	2.27 ns	1.224 ns	1.250 ns	2.40 ns	2.57 ns	0.89 ns	1.53 ns
Rhiz × Varieties	2.62 ns	2.23 ns	0.94 ns	6.927***	2.231 ns	2.75 ns	2.23 ns	2.82 ns	8.29***
Fert × Varieties	1.07 ns	1.57 ns	0.93 ns	0.869 ns	1.567 ns	2.09 ns	1.14 ns	0.18 ns	0.99 ns
Rhiz × Fert × Variety.	1.86 ns	0.66 ns	1.05 ns	0.889 ns	0.656 ns	0.68 ns	1.51 ns	0.47 ns	0.86 ns

R = without rhizobia, **R+ =** with rhizobia, **P =** Phosphorus **K =** Potassium, Values shown are for means ± SE; stars indicates significant at $p \le 0.001$, $p \le 0.01$ and $p \le 0.05$ (***, ** and * respectively), **ns** = not significant, **SE** = standard error. Means followed by dissimilar letter(s) in a column are significantly different from each other at $p = 0.05$ according to (LSD) Fischer least significance difference.

subsequently high value of marginal rate of return, its profit was below the treatment with combined P and K by 2%. Therefore, the combination of P and K produced a profit of US$ 2044, followed by P alone which gave the profit of US$ 2014 compared with control with US$. 1856 profit only. The percentage increase over control for P and its marginal rate of return was 39% and 8 respectively, followed by K with 36% and 7 percentage increases over control and marginal rate of return (MRR) respectively (Table 3).

Similarly, all varieties performed differently despite of being exposed to the same experimental conditions. Selian 2006 performed better among the three varieties with the profit of $ 2,885 followed by Selian 2005 which gave a profit of US$ 1756 per hectare. However, Cheupe produced a profit of US$ 1219 and was the least performer in this study. Furthermore, Selian 2006 had highest percent increase over control (44%) and high marginal rate of return (11) relative to other varieties. Selian 2005 was the second best with 32% and 7, percentage

Table 3. Marginal Net Return (MNR), Total Variable Cost (TVC) and Marginal Rate of Return (MRR) of Climbing Beans (*Phaseolus vulgaris* L.) under field conditions.

Treatment	Profit or MNR (US$/Ha)	% Increase over control (US$/Ha)	Total Variable Cost (US$/Ha)	Marginal Rate of Return (MRR)
Rhizobium				
−	1557.54 ± 106.38a	-	265.34 ± 5.50a	5.93 ± 0.42a
+	2349.56 ± 225.62b	41.40 ± 4.63	280.34 ± 5.28b	8.51 ± 0.82b
Fertilizer				
Control	1856.35 ± 290.16a	-	220.03 ± 1.90a	6.93 ± 0.75a
20K	1901.02 ± 210.67a	36.19 ± 6.11a	273.67 ± 1.45ab	7.36 ± 0.70a
30P	2013.18 ± 194.17a	38.57 ± 7.47a	273.07 ± 1.45ab	8.33 ± 1.26a
30P + 20K	2043.64 ± 338.02a	28.67 ± 9.60a	324.59 ± 1.45b	6.26 ± 1.02a
Varieties				
1:Cheupe	1218.73 ± 072.74a	11.39 ± 5.89a	272.84 ± 6.78a	4.52 ± 0.29a
2:Selian 2005	1756.17 ± 176.21b	−3.23 ± 4.83a	272.84 ± 6.78a	6.48 ± 0.63b
3:Selian 2006	2885.74 ± 271.53c	−5.0 ± 13.84a	272.84 ± 6.78a	10.66 ± 0.99c
3 WAY ANOVA (F stat)				
Rhizobium	16.77^{***}	11.25^{***}	8.39^{***}	13.56^{***}
Fertilizer	0.21 ns	0.26 ns	6.79^{***}	1.53 ns
Variaties	25.80^{***}	1.14 ns	0.0 ns	26.57^{***}

+R: With rhizobia; **−R:** Without rhizobia; **R:** rhizobia; **P:** Phosphorus; K: Potassium, **SE** = standard error; Values presented are means (±SE); Stars indicates significant at $p \le 0.001$, $p \le 0.01$ and $p \le 0.05$ (***, ** and * respectively), **ns** = not significant, Means followed by dissimilar letter(s) in a column are significantly different from each other at $p = 0.05$ according to Fischer least significance difference (LSD).

increase over control and marginal rate of return respectively. Likewise, Cheupe was the least among the three varieties with 11% increase over control and a marginal rate of return of 5. The economic analysis and profitability aspects in this study was established based on revenues and variable costs both for materials and labour as shown in **Table 4** and **Table 5**.

5.6. Interactive Effect between *Rhizobium* Inoculation and Varieties on the Shoot Biomass and Number of Nodules on Climbing Bean (*Phaseolus vulgaris*)

The results in the **Table 2** show interactive effect between rhizobial and varieties in shoot biomass and number of nodules. The significant ($p \le 0.01$) and ($p \le 0.05$) interactive effect was observed with shoot biomass at 4 and 6WAP in the field and green house respectively. Additionally interactive effect was also noted between Fertilizer and varieties ($p \le 0.05$) on nodule numbers and also on yield per hactre ($p \le 0.001$) (**Figures 3-5**).

6. Discussion

The study on rhizobial inoculation and supplementation with fertilizer (TSP and MOP) as source of P and K in production of climbing legumes was conducted in Northern Tanzania. The aim of the study was to determine total yield and economic benefit of climbing beans when supplied with the aforementioned inputs, in single or in combination.

The results obtained revealed that *Rhizobium* inoculation had a significant increase in yield and yield components of three climbing beans varieties tested (Cheupe, Selian 2005 and Selian 2006). The improved results on yield and its component signifies how much *Rhizobium tropici CIAT*899 *strain* with a peat carrier supplied by Legume Technology United Kingdom was effective in causing nodulation and ultimately improved nitrogen

Table 4. The variable cost of inputs used for computing Marginal Net Return (MNR).

Input	Amount/ha	Unit price (T.shs.)	Unit price (US$)	Total cost (T.shs.)	Total cost (US$)
Climbing Beas Seeds	18 kg	2500	1.52	45,000	27.3
Inoculants: (*Rhizobium tropici* CIAT899)	2 packets (100 g @)	1500	0.91	3000	1.82
Fertilizer (TSP)	1	65,000	39.4	65,000	39.4
Fertilizer (MOP)	1	64,000	38.8	64,000	38.8
TOTAL				**177,000**	**107.32**

Table 5. Variable cost involved as labour charges in field activities.

Activities	Unit &/Amount (Mandays)	Unit cost (T.shs.)	Total variable cost (T.shs.)	Total variable Cost in (US$)
Land preparation	Tractor	60,000	60,000	36.4
Planting per hactre	6	10,000	30,000	18.2
Weeding 3 rounds	10	10,000	100,000	60.6
Crop harvesting per hactre	5	10,000	50,000	30.3
Threshing and processing/100 kg	4	10,000	40,000	24.2
***Fertilizer application*:**				
Rhizobial inoculation	2	10,000	20,000	12.12
30 kg P	2	10,000	20,000	12.12
20 kg K	2	10,000	20,000	12.12
Inoculation + 30 kg P + 20 KG K	3	10,000	30,000	18.18
TOTAL			**370,000**	**224.24**

NB: The total Variable cost per hactre stand at US$ **107.32 +224.24 =** US$ **331.56**.

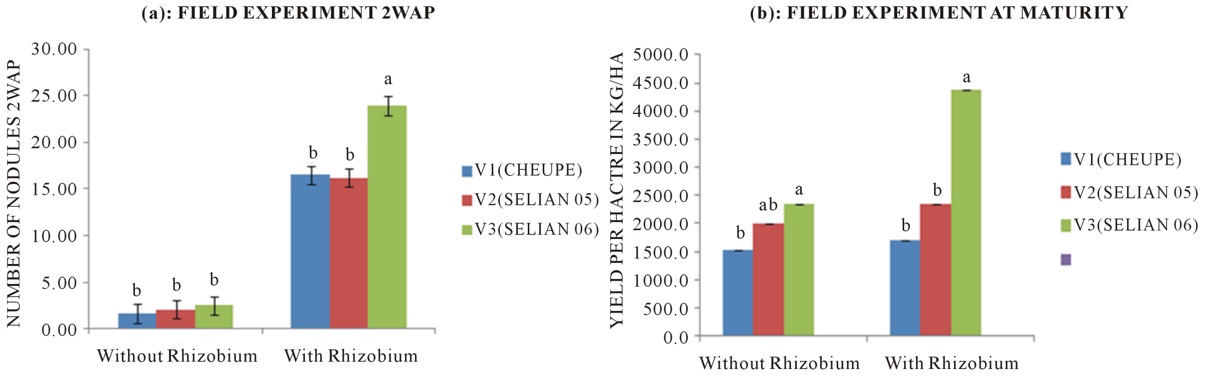

Figure 3. (a) Interactive effects of Rhizobia and Varieties on the number of nodules per plant counted at 2WAP and (b) on Yield per Ha at harvest. V1 = Cheupe, V2 = Selian 05, V3 = Selian 06. Bars followed by similar letter(s) are not significantly different.

fixation, thus, providing adequate nitrogen which would have been supplied with nitrogenous fertilizer responsible for yield and yield components performance relative to control treatment.

Despite the positive outcome observed, the literatures show that such related findings were also reported by [6] [21] [22] [37]-[39]. Their report indicated significant increase in legume grain yield and the related yield

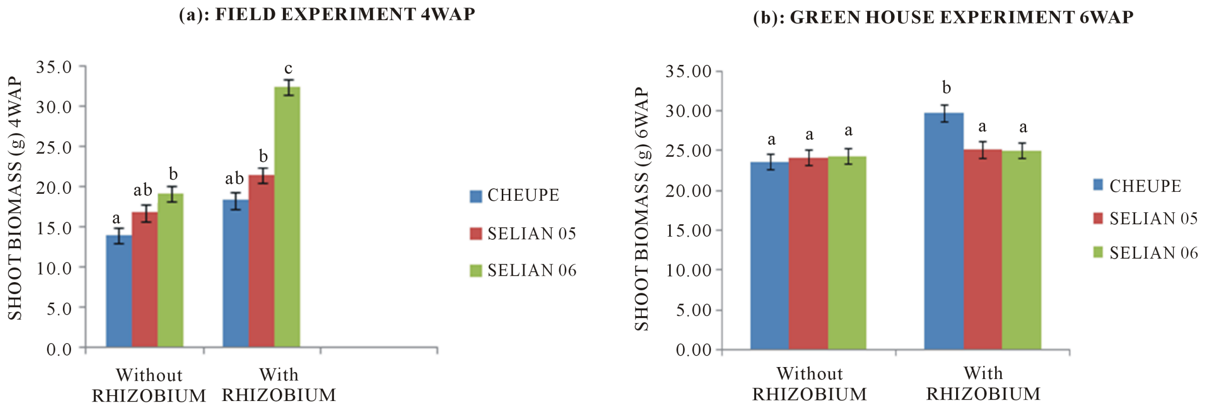

Figure 4. Interactive effects of Rhizobia and Varieties on shoot Biomass at (a) 4WAP field and (b) 6WAP green house. Bars followed by similar letter(s) are not significantly different.

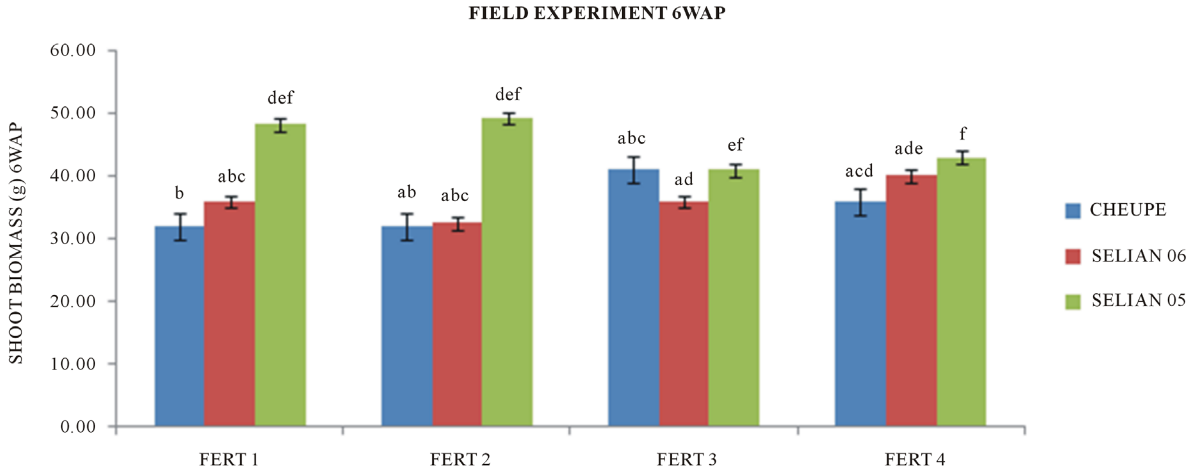

Figure 5. Interactive effects of Fertilizer and Varieties on Shoot Biomass at 6WAP Field experiment. FER 1 = Control (K = 0, P = 0), FER 2 = K-20 kg/ha, FER 3 = P-30 kg/ha, FER 4 = (K-20 + P-30kg/ha), WAP = Weeks after planting. Bars followed by similar letter(s) are not significantly different from each other.

components such as increase in number of nodules per plant, shoot and root biomass, nodule fresh weight, number of seeds per plant, number of pods per plant and 100 seed weight per treatment following inoculation with specific *Rhizobium* strain. The study also showed high rate of nodulation at second week after planting compared with the number observed at 50% flowering. **Figure 6(a)** & **Figure 6(b)**. But very few nodules were observed in the uninoculated plots.

Phosphorus and potassium fertilization resulted in significant effect on number of pods per plant, number of nodules, number of grains per pod, plant dry matter, 100 seed weight and total grain yield relative to unfertilized treatments. The improved yield components of climbing bean over control may be attributed by the availability of adequate P and K which are essential nutrients for nodulation, photosynthesis, pod development, grain filling and improves seed quality in leguminous crops [40] [41].

Higher nodulation is associated with higher nitrogen fixation and ultimately yield and yield parameters. The study by [42]-[44] revealed that fertilizer significantly influence grain yield in legumes. Therefore, the result obtained in this study indicates that fertilization of climbing bean with P and K is important for improved growth and productivity.

Furthermore, the study revealed a significant interaction between *Rhizobium* and varieties on the number of nodules per plant and yield/Ha (**Figure 3(a)** & **Figure 3(b)**). The results in **Figure 4(a)** & **Figure 4(b)** indicated that rhizobial inoculation had interactive effects with varieties on nodulation and yield per hactre. This shows that rhizobial inoculation improved nodulation and ultimately increased the final grain yield. Selian 2006 was


(a) (b)

Figure 6. (a) Plant legume uprooted at 2WAP with small but many root nodules and (b) Plant at 50% flowering with large nodule. Note the size of the nodule, colour and the root canopy developed reflects the activeness of the nodule. (The picture Taken at field experiment-Lyamungo Plots. April-July, 2014).

more responsive to inoculation than other varieties.

Also there were interactive effect between rhizobial and varieties on shoot biomass for both experiment in the field and green house. Inoculations influenced the shoot biomass which is the base for carbohydrates formation and finally yield.

The impact of fertilizer application and subsequently rhizobial inoculation in common beans and its associated grain yield was reflected in economic component of the farmer's income. According to the fiscal analysis of the study which was based on Revenues and Variable costs (**Table 4** & **Table 5**), rhizobial technology resulted into significant profit realization. For example, rhizobial inoculation alone produced a profit of US$ 2350 compared with uninoculated control treatment which resulted into profit of US$ 1558 profit, which was finally reflected in higher percentage increase over control and higher marginal rate of return (MRR) (**Table 3**).

Likewise, this study revealed that application of P and K in combination resulted in to highest profit compared with when P or K was used alone. Despite the fact that P- fertilizer had shown highest value of percentage increase over control and subsequently high value of marginal rate of return, its profit was below the combined P and K treatment by 2%. Therefore, the combination of P and K produced a profit of US$ 2044, followed by P alone which gave the profit of US$ 2014 compared with the zero fertilizer treatment with a profit of US$ 1856. The percentage increase over control for P and its marginal rate of return was 39% and 8 respectively, followed by K with 7 marginal rate of return (MRR). Thus, P application treatment was significantly more profitable compared with the combination of P and K due to its high MRR and low TVC (**Table 3**). The result of this study concurs with [8] [21] who revealed that both inoculation and fertilizer application at the recommended rates resulted in high dollar profit for legume farmers in Tanzania.

7. Conclusion

This study has shown that rhizobial inoculation technology supplemented with fertilizer (P and K) increased number of nodules per plant, number of pods per plant, above and below ground biomass and 100 grain weight of climbing bean varieties grown in glass house and field experiment. The fiscal analysis indicated that *Rhizobium* inoculated plots significantly ($p \leq 0.001$) increased the marginal net return (net profit) over un-inoculated treatments. Such pleasing results were also obtained with fertilizer application especially when P was used alone. For farmers to realize profit in climbing bean production, *Rhizobium* inoculation and supplementation with P and/or K fertilizers are of paramount importance in northern Tanzania.

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