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Effect of Integration of Bio-fertilizers on the Growth and Yield of Mung Bean

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Abstract

Nutrient management is one of the major constraints in the production of mung bean. The experiment was conducted at the agronomy farm of Far Western University, Tikapur, Kailali from April to June 2024 to study the effect of integration of biofertilizers on the growth, yield and yield attributes of mung bean. The field was laid out in a randomized complete block design with seven treatments and three replications. The treatments were control (T_1), Rhizobium (T_2), Azotobacter (T_3), Phosphate Solubilizing Bacteria (T_4), Rhizobium + PSB (T_5), Azotobacter + PSB (T_6) and Rhizobium + Azotobacter + PSB (T_7) along with recommended dose of chemical fertilizers and FYM. Results revealed the significant effect of biofertilizer integrations on plant height, root length, number of branches, effective and non-effective nodules, fresh shoot weight, fresh and dry root weight, root volume, pods plant^{-1}, Seeds pod, pod length, grain yield and biological yield, however, non-significant effect was overlooked on harvest index and 1000 grain weight. The maximum significant values for growth and yield parameters were observed with the combination of Rhizobium + Azotobacter + PSB indicating increased grain yield by 23.94% compared to control. Both single inoculation and combination of biofertilizers outperformed the control. Seed treatment either with Rhizobium or Azotobacter remained economically feasible compared to other treatments and hence is recommended to extrapolate the finding.

***Keywords*:** Azotobacter, Economic analysis, Effective nodules, PSB, Rhizobium

Introduction

Mung bean (*Vigna radiata*) is a major pulse crop in Asia and is an important legume which has high nutritional and pharmacological values (Sehrawat et al., 2021). Because of its atmospheric nitrogen fixing ability, it can adjust to an extensive range of climatic conditions. Mung bean consists of 24.2% protein, 1.3% fat and 60.4% carbohydrates. Furthermore, it is rich in vitamin A and also contains calcium and phosphorus i.e. 118 mg and 340 mg respectively per 100 g of seeds (Ahmad et al., 2011). It is a short duration and warm season crop which can be beneficial for regions where land remains fallow for short period of time (Ranawake et al., 2011). It is extensively grown throughout Southeast Asia with India being the world's largest producer as well as consumer of mung bean which produces about 1.5 to 2.0 million tons from about 3 to 4 million hectares of area having an average productivity of 500 kg ha^{-1} (Pandey et al., 2019). However, this crop contributes only four percent in area and production of grain legumes in Nepal. The area under pulse crop is 334,550 ha, producing 408,371 tons with the productivity of 1.21 t ha^{-1} and there is no separate data available for mung bean (MoALD, 2023). In dry and semi-arid regions of Nepal, it is generally planted as a green manure crop and grain legume during the kharif (July-October) and summer (March-June) seasons.

Biofertilizers are micro inoculants that can change vital nutritional components in the soil through biological processes and transform it from an unusable to a useable state for crops (Fernandes & Bhalerao, 2015). The release of phytohormones like IAA (auxin), cytokinin, ACC deaminase by biofertilizers (Ahmad et al., 2016) assist to uplift overall performance of plant. Biofertilizers can amplify the soil organic matter and soil nutrients. It also minimizes the use of chemical nitrogen and phosphorus by about 30% (Malo, 2020). They convert complex nutrients into simple nutrients and make available to the plants. *Rhizobium* is a symbiotic soil bacterium that can fix 50 to 300 kg N ha^{-1} in mung bean while *Azotobacter* is a free-living bacterium which can fix 0.026 to 20 kg N ha^{-1} in many crops and PSB can solubilize about 50-60% of the fixed phosphorus in the soil in almost all crops (Kumar et al., 2017). Biofertilizers can reduce the biotic and abiotic stress of plants like drought and soil pathogens which lead to uplift the growth, yield and overall performance of crops (Chaudhary et al., 2022).

Mung bean plays a significant role in raising cropping system productivity and soil fertility although both acreage and production are steadily diminishing. Unavailability of quality seeds, lack of mechanization in harvesting, organic manures, irrigation facilities, technical services and nutrient management are some of the constraints of mung bean production in Nepal (Singh & Chauhan, 2012). Hence, biofertilizers incorporation can provide nutrients, protect the plants, increase the productivity, minimize the use of chemical fertilizers and lead to proper nutrient management in a sustainable way. Limited research has been done to study the effect of different biofertilizers on mung bean in Nepal. This experiment was performed to study the effect of biofertilizers on growth and yield of mung bean crop. The study also analyzed economic feasibility of cultivating mung bean in the farming system promoting sustainable agriculture.

Methods and Procedures

Experimental Site

The field trial was conducted at Agronomy Farm, School of Agriculture, Far Western University, Tikapur-1, Kailali, Nepal from March 2024 to June 2024. Geographically, it is located at an elevation of 161 meters above sea level (masl) on the latitude of 28°32’26” N and longitude of 81°7’26” E. The experimental site had a subtropical climate with summer being hot and humid while winter being cold. The site had sandy loam and alkaline soil with pH of 7.69. The soil had 2.10% organic matter, 0.1% nitrogen, 14.84 kg ha^{-1} phosphorus and 89.46 kg ha^{-1} potash. The soil was tested in Soil and Fertilizer Testing lab Sundarpur, Kanchanpur and according to Nepal nutrient standard, all the nutrients contents were low in the soil of research field. The experimental site received 52.74 mm total rainfall during the experimental period with the maximum temperature of 42.07°C at maturity stage and minimum temperature of 17.04°C at germination stage as shown in Figure 2.

Figure 1

GIS Map of Study Area Showing Research Site at Tikapur Municipality-1, Kailali, Nepal

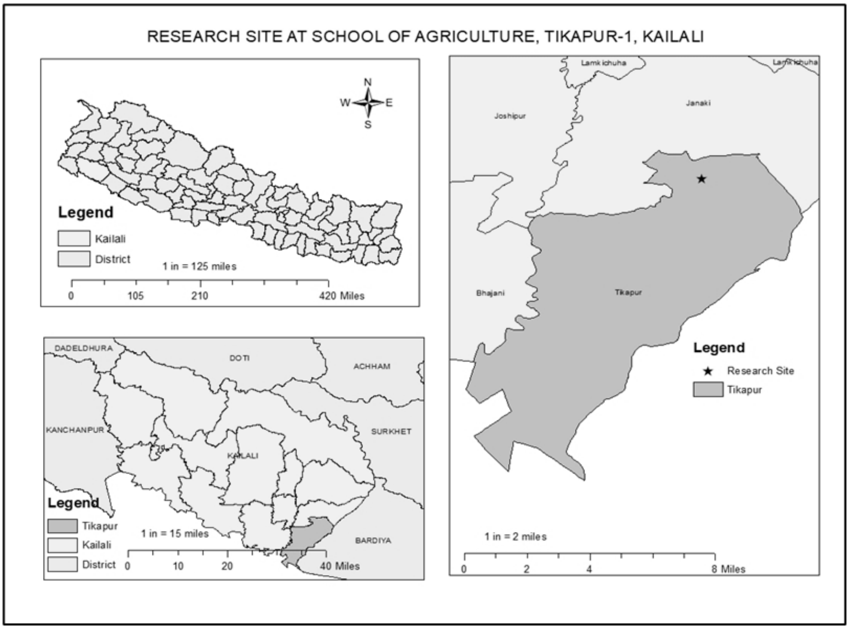
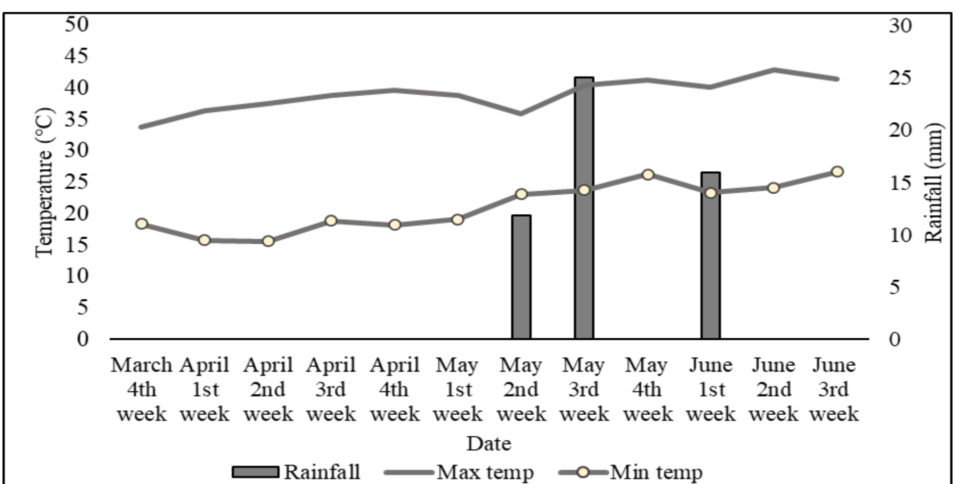


Figure 2

Weather Condition of the Study Site during the Experimental Period in 2024



Experimental Details

The experiment was laid out in a Randomized Complete Block Design (RCBD) with seven treatments and three replications. "Pratigya" variety of mung bean was used for the experiment which was released in 2019 A.D. and recommended by NARC in Terai, inner Terai, and foot-hills of Nepal from 100 to 700 masl having maturity days of 59 DAS (AITC, 2024). The size of each plot was 5.4 m^2 (3 m x 1.8 m) with total area of field being 228.8 m^2 (17.6 m x 13 m). The distance between each plot and each replication were 0.5 m and 1 m respectively. The treatments were T_1: Control, T_2: Rhizobium, T_3: Azotobacter, T_4: PSB, T_5: Rhizobium + PSB, T_6: Azotobacter + PSB, T_7: Rhizobium + Azotobacter + PSB.

Soil Treatment

Soil treatment was done with PSB one day prior sowing @3ml l^{-1} water by mixing it with 2% jaggery solution. The PSB was drenched uniformly on the soil of each treated plot.

Seed Treatment

The seeds were treated with Rhizobium @10g kg^{-1} seed and Azotobacter @25ml kg^{-1} seed by mixing them with 2% jaggery solution. The required quantity of seed was mixed thoroughly to gain uniform seed coating with bacteria. Seeds were soaked overnight and shade drying was done. Then next morning seed treatment was done with Rhizobium and Azotobacter for 15 minutes before 2 hours of sowing and then shade dried on cotton cloth.

Agronomic Practices

Chemical fertilizers and FYM were applied as recommended dose i.e. @ 20:20:20 NPK kg ha^{-1} and 6 t ha^{-1} (AITC, 2024), respectively. FYM was applied one month before seed sowing. Half dose of urea, full dose of DAP and MoP was applied as a basal dose while half dose of urea was applied at 30 DAS. Seeds were sown on 10^{th} Chaitra. Thinning was done 2 weeks after sowing to maintain plant spacing of 30 cm x 10 cm. Weeding was done manually at 30 and 45 days after sowing (DAS). Pre-irrigation was done before sowing and then irrigation was done at flowering and pod formation stages. The total of three harvestings were done manually at 65, 75 and 86 DAS manually.

Biometrical Observations

Plant height and fresh shoot weight were recorded at 30 DAS, 45 DAS, 60 DAS and at harvest. Number of branches per plant, root length, fresh and dry root weight and root volume data were collected at 60 DAS. Effective and non-effective nodules were counted from uprooted plants at 45 and 60 DAS. All the above data were observed from six uprooted plants of each plot present in destructive rows. Pods plant^{-1} were collected from 6 tagged plants of each plot, seeds pod^{-1} and pod length data were collected from 10 randomly selected pods and their values were summed and averaged. Data for seed yield of each plot was taken from the net plot excluding border plants, destructive rows and border rows i.e. 1.68 m^2 and was converted to tons per hectare. Total of three manual harvesting was done from each plot and summed up finally. After final harvest, the harvested shoots of net plot were sun-dried for 2 days and then weighed. The weight of shoot was added to weight of first, second and final harvested pods to get the biological yield. For the thousand seed weight, 1000 seeds were counted from each plot and weighed on an electric weighing balance. The harvest index was calculated by using following formula:

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}}$$

Economic Analysis

The calculation of the cost of cultivation, gross return and net return of all the seven treatments were done and calculated B:C ratio. The cost of cultivation and gross return was determined on the basis of local market price of the study site. B:C ratio was computed as per following formula.

$$\text{B:C ratio} = \frac{\text{Gross Returns}}{\text{Cost of cultivation}}$$

Statistical Analysis

Data was systematically arranged on the basis of various observed parameters. The different statistical tools like MS-Excel and R-Studio were used for the analysis of variance (ANOVA). The significance difference among the treatment means was estimated at 5% level of significance by the Duncan Multiple Range where test package "doe bio-research" was used for the analysis.

Results and Discussion

Growth Attributes

Plant Height

There was no significant effect on plant height due to application of biofertilizers at 30 DAS. But the results showed that the plant height was significantly influenced by biofertilizers at 45 DAS, 60 DAS and at harvest with mean plant height of 51.80 cm as shown in the table 1. The combined application of biofertilizers i.e. RDF+Rhi+Azo+PSB consistently resulted in tallest plant height i.e. 53.77 cm at harvest which was statistically at par with RDF+Rhi+PSB and RDF+Azo+PSB while the smallest plant height was displayed in control (RDF) in all growth stages. Application of biofertilizers contributes in converting nitrogen and phosphorus into readily available forms for the crop which lead to adequate availability of phosphorous and nitrogen and increases the rate of photosynthesis resulting into maximum plant height. These findings are in accordance with (Dixit & Gupta, 2020) which stated that the application of biofertilizers significantly increased plant height of mung bean.

Table 1

Effect of Integration of Biofertilizers on Plant Height at Different Growth Stages of Mung Bean

	Plant height (cm)			
Treatments	30 DAS	45 DAS	60 DAS	At harvest
Control (RDF)	24	34.50[b]	44.77[c]	48.33[b]
RDF+Rhi	24.16	36.61[ab]	47.72[a-c]	52.22[a]
RDF+Azo	25.11	36.16[ab]	46.83[bc]	50.94[ab]
RDF+PSB	24.5	37.44[a]	47.50[a-c]	51.33[ab]
RDF+Rhi+PSB	24.66	38.55[a]	49.72[ab]	53.11[a]
RDF+Azo+PSB	24.33	37.55[bc]	48.33[ab]	52.94[a]
RDF+Rhi+ Azo+PSB	24.94	38.94[a]	50.44[a]	53.77[a]
$CD_{0.05}$	2.03	2.66	3.96	2.32
CV %	4.66	4.04	3.48	3.37
F-test	Ns	*	*	*
P value	0.88	0.04	0.02	0.03
Grand mean	24.53	37.11	47.904	51.8

CV: Coefficient of Variation; CD: Critical Difference; Ns: Non-Significant; *: significant at ≤0.05 level of significance, **: significant at ≤0.01 level of significance, ***: significant at ≤0.001 level of significance; Rhi: Rhizobium, Azo: Azotobacter, PSB: Phosphate Solubilizing Bacteria

Fresh Shoot Weight

Biofertilizers had significant effect on fresh shoot weight of mung bean at 60 DAS and harvesting time. At harvest the maximum fresh shoot weight was displayed by RDF+Rhi+Azo+PSB i.e.14.73 t ha^{-1} which was statistically at par with all other treatments except control. Control exhibited lowest fresh shoot weight i.e. 11.89 t ha^{-1}. The mean fresh shoot weight at 30 DAS, 45 DAS, 60 DAS and at harvest were 2.49

t ha^{-1}, 7.12 t ha^{-1}, 13.97 t ha^{-1} and 13.77 t/ha respectively. The usage of biofertilizers significantly increased the fresh shoot weight of mung bean due to nitrogen fixing and phosphorus solubilizing capabilities of Rhizobium, Azotobacter and PSB which ultimately increases vegetative growth of mung bean. Significantly increased plant height and number of branches of mung bean as shown in table 1 and 4 respectively might have led to significant increase in fresh shoot weight. This result coincides with the findings of (Khan et al., 2022).

Table 2

Effect of Integration of Biofertilizers on Fresh Shoot Weight at Different Growth Stages of Mung Bean

	Fresh shoot weight (t ha^{-1})			
Treatments	30 DAS	45 DAS	60 DAS	At harvest
Control (RDF)	2.35	6.62	12.75^{b}	11.89^{b}
RDF+Rhi	2.4	7.07	13.90^{ab}	13.98^{a}
RDF+Azo	2.68	7.03	13.70^{ab}	13.47^{a}
RDF+PSB	2.35	7.29	13.79^{ab}	13.96^{a}
RDF+Rhi+PSB	2.57	7.07	14.51^{a}	14.20^{a}
RDF+Azo+PSB	2.53	7.4	14.24^{a}	14.53^{a}
RDF+Rhi+ Azo+PSB	2.57	7.35	14.87^{a}	14.73^{a}
$CD_{0.05}$	0.46	1.03	1.2	1.45
CV %	10.5	8.18	4.83	5.92
F-test	Ns	Ns	*	*
P value	0.64	0.71	0.15	0.02
Grand mean	2.49	7.12	13.97	13.77

CV: Coefficient of Variation; CD: Critical Difference; Ns: Non-Significant; *: significant at ≤0.05 level of significance, **: significant at ≤0.01 level of significance, ***: significant at ≤0.001 level of significance; Rhi: Rhizobium, Azo: Azotobacter, PSB: Phosphate Solubilizing Bacteria

Effective and Non-effective Nodules

Data for effective and non-effective nodules were collected at 45 and 60 DAS. Significant variation in number of effective and non-effective nodules due to application of biofertilizers was observed. The effective nodules increased by 24.15% from 45 DAS to 60 DAS. The highest number of effective nodules was exhibited in the treatment RDF+Rhi+Azo+PSB i.e. 22.27 followed by RDF+Rhi+PSB and RDF+Azo+PSB respectively whereas least number of effective nodules was observed in the control i.e.14.44. While the non-effective nodules were decreased by 55.75% in combined application of biofertilizers compared to the control. The effective nodules increased by 54.22% in RDF+Rhi+Azo+PSB compared to the control. The increase in number of rhizobia bacteria in the soil and their ability to inject the host plant, perforate the roots and increase the formation of the root nodules might be the reason to increase the number of nodules (Al-Burki & Al-Ajeel, 2021). Due to the vital role of biofertilizers the highest number of effective nodules per plant was observed on biofertilizer treated plants (Debela et al., 2021).

Table 3

Effect of Integration of Biofertilizers on Effective and Non-Effective Nodules of Mung Bean

Treatments	Effective nodules		Non-effective nodules	
	45 DAS	60 DAS	45 DAS	60 DAS
Control (RDF)	11.33^{c}	14.44^{c}	1.22	4.00^{a}
RDF+Rhi	16.66^{ab}	18.77^{ab}	1.66	3.66^{ab}
RDF+Azo	15.30^{bc}	17.77^{bc}	2.77	3.72^{ab}

RDF+PSB	15.88[bc]	18.27[a-c]	2.27	3.72[ab]
RDF+Rhi+PSB	19.33[ab]	21.27[ab]	1.61	2.55[c]
RDF+Azo+PSB	16.83[ab]	21.27[ab]	1.66	2.61[bc]
RDF+Rhi+ Azo+PSB	21.11[a]	22.27[a]	1.61	1.77[c]
$CD_{0.05}$	4.55	3.76	0.62	1.04
CV %	15.37	11.11	18.4	18.7
F-test	*	*	Ns	**
P value	0.013	0.01	0.05	0.004
Grand mean	16.63	19.04	1.91	3.15

CV: Coefficient of Variation; CD: Critical Difference; Ns: Non-Significant; *: significant at ≤0.05 level of significance, **: significant at ≤0.01 level of significance, ***: significant at ≤0.001 level of significance; Rhi: Rhizobium, Azo: Azotobacter, PSB: Phosphate Solubilizing Bacteria

Root Attributes

Root Length

Root length was significantly increased due to application of biofertilizers as shown in table 4. The longest root length was resulted by applying combination of biofertilizers (RDF+Rhi+Azo+PSB) i.e. 17.05 cm which was statistically at par with all treatments except control. Whereas the shortest root length was observed on control i.e. 13.88 cm. This might be due to the application of biofertilizers which make phosphorus available to the plants, releases phytohormones that triggered elongation of cells, makes better soil environment and helps in vigorous root growth. This conclusion is also upheld by (Shravani et al., 2019).

Fresh and Dry Root Weight

The effect of biofertilizers disclosed the significant difference on both fresh and dry root weight of mung bean. The significant increase in root length and effective nodules ultimately lead to significant increase in fresh root weight per plant with an average value of 2.02 g. The maximum fresh root weight per plant was shown by RDF+Rhi+Azo+PSB i.e. 2.17 g which was statistically similar to all other treatments except control. While control exhibited 1.72 g fresh root weight being lowest among all. In line to this result (Bilal et al., 2021) displayed usage of Pseudomonas had showed the significant increment in root fresh weight. Similarly, with significant increase in fresh root weight led to significant increment in the dry root weight of mung bean. The maximum dry root weight per plant was exhibited by RDF+Rhi+Azo+PSB i.e. 0.86 g which was statistically similar with all treatments except control i.e. 0.70 g. In compliance to this study the application of Rhizobium and PSB showed the statistically high dry root weight as compared to the control (Yadav et al., 2014).

Root Volume

As shown in table 2, root volume was significantly influenced by the application of different biofertilizers. The utmost root volume per plant was noted in the treatment where combination of all biofertilizers were applied (RDF+Rhi+Azo+PSB) i.e. 2.19 ml followed by RDF+Rhi+PSB i.e. 2.13 ml which was statistically at par with RDF+Azo+PSB, RDF+Rhi and RDF+PSB. And the lowest root volume was observed in the treatment without application of any biofertilizers with 1.77 ml volume. The overall effect showed that the root volume increases significantly due to application of biofertilizers as number of nodules, root length and root weight increased significantly. In correspondence to our results the increase in root volume due to application of biofertilizers has also been documented in (Sultana et al., 2016).

Table 4

Effect of Integration of Biofertilizers on Root Length, Fresh Root Weight, Root Volume and Dry Root Weight of Mung Bean

Treatments	Root length (cm)	Fresh root weight (g)	Root volume (ml)	Dry root weight (g)
Control (RDF)	13.88[b]	1.72[b]	1.77[c]	0.70[b]
RDF+Rhi	15.88[a]	2.04[a]	2.05[ab]	0.82[a]
RDF+Azo	15.33[ab]	2.01[a]	1.94[bc]	0.79[a]
RDF+PSB	16.11[a]	2.01[a]	2.02[ab]	0.81[a]
RDF+Rhi+PSB	16.83[a]	2.03[a]	2.13[ab]	0.85[a]
RDF+Azo+PSB	16.38[a]	2.06[a]	2.08[ab]	0.84[a]
RDF+Rhi +Azo+PSB	17.05[a]	2.17[a]	2.19[a]	0.86[a]
$CD_{0.05}$	1.56	0.21	0.19	0.08
CV %	5.52	6.03	5.46	5.94
F-test	*	*	*	*
P value	0.01	0.01	0.01	0.02
Grand mean	15.92	2.02	2.03	0.81

CV: Coefficient of Variation; CD: Critical Difference; Ns: Non-Significant; *: significant at ≤0.05 level of significance, **: significant at ≤0.01 level of significance, ***: significant at ≤0.001 level of significance; Rhi: Rhizobium, Azo: Azotobacter, PSB: Phosphate Solubilizing Bacteria

Yield Attributes

Number of Branches

There was significant change in the number of branches of mung bean at 60 DAS. The highest number of branches were observed in the treatment RDF+Rhi+Azo+PSB i.e. 9.55 which was statistically at par with RDF+Rhi+PSB and RDF+Azo+PSB. The reason might be that number of effective nodules increased at the time of flowering which ultimately increased nutrient uptake and hence number of branches also significantly increased at 60 DAS. In consistency to our result (Mondal et al., 2010) stated that the count of branches escalated due to application of biofertilizers.

Pods Plant^{-1}

The data presented revealed that number of pods plant^{-1} was significantly influenced by the usage of different biofertilizers as shown in the table 5. The highest count of pods was detected in treatment RDF+Rhi+Azo+PSB i.e. 32.05 followed by RDF+Rhi+PSB, it was statistically at par with RDF+Azo+PSB. The least count of pods per plant was witnessed in the control i.e. 25.38. Overall availability of nutrients increases photosynthetic activity of the plant and hence increases the number of pods plant^{-1}. The higher number of branches, better root development and efficient nodulation generally lead to high number of pods plant^{-1}. Similar results were obtained in (Pandey et al., 2019).

Pod Length

The pod length of mung bean was influenced significantly by the application of biofertilizers. The longest pod was shown by the treatment RDF+Rhi+Azo+PSB i.e. 8.26 cm which is followed by RDF+Rhi+PSB i.e. 8.22 cm. Control exhibited significantly shortest pod i.e. 7.46 cm as compared to other treatments. The result is in line with (Bhabai et al., 2019) which conveyed that Rhizobium and PSB significantly increased the pod length.

Seeds Pod^{-1}

The study disclosed that the usage of biofertilizers caused significant variation on seeds pod^{-1}. The combination of biofertilizers (RDF+Rhi+Azo+PSB) had the maximum count of seeds per pod i.e. 10.40. Control had the least count of seeds per pod as compared to all other treatments i.e. 8.86. The treatment without application of any biofertilizers displayed 14.80% decrement in the number of seeds pod^{-1} as compared to RDF+Rhi+Azo+PSB. These findings are aligned with (Barakzai et al., 2019). In contradiction to our findings (Htwe et al., 2019) showed that there was no significant difference in number of seeds after application of biofertilizers.

Thousand Seed Weight

As shown in the given table 5, the implication of biofertilizers did not lead to the statistical difference among the treatments. This might be due to the fact that seed weight is controlled by its genetic factor rather than external factors like nutrient management. In conformity to our findings test weight was not significantly impacted by biofertilizers in mung bean (Htwe et al., 2019). Chaudhary et al. (2024) articulated that test weight of oat was not significantly different due to biofertilizers inoculation.

Table 5

Effect of Integration of Biofertilizers on Yield Attributes of Mung Bean

Treatments	No. of branches	Pods plant^{-1}	Pod length (cm)	Seeds pod^{-1}	Thousand seed weight (g)
Control (RDF)	7.22^{c}	25.38^{c}	7.46^{c}	8.86^{b}	45.74
RDF+Rhi	8.72^{ab}	29.83^{ab}	8.06^{ab}	10.20^{a}	44.58
RDF+Azo	8.05^{bc}	28.44^{b}	7.80^{bc}	9.76^{a}	46.68
RDF+PSB	8.55^{ab}	29.11^{b}	7.91^{ab}	9.83^{a}	44.15
RDF+Rhi+PSB	9.38^{a}	30.10^{ab}	8.22^{ab}	10.24^{a}	46.02
RDF+Azo+PSB	9.27^{a}	30.05^{ab}	8.01^{ab}	10.00^{a}	45.58
RDF+Rhi+ Azo+PSB	9.55^{a}	32.05^{a}	8.26^{a}	10.40^{a}	46.33
$CD_{0.05}$	1.07	2.27	0.41	0.73	2.42
CV %	6.94	4.36	2.92	4.2	2.99
F-test	**	**	*	*	Ns

P value	0.005	0.001	0.01	0.01	0.31
Grand mean	8.68	29.34	7.96	9.9	45.58

CV: Coefficient of Variation; CD: Critical Difference; Ns: Non-Significant; *: significant at ≤0.05 level of significance, **: significant at ≤0.01 level of significance, ***: significant at ≤0.001 level of significance; Rhi: Rhizobium, Azo: Azotobacter, PSB: Phosphate Solubilizing Bacteria

Yield

Seed Yield

Critical review of table 6 showed that the grain yield in mung bean varied significantly at 5% level of significance due to application of biofertilizers. RDF+Rhi+Azo+PSB produced the maximum grain yield i.e. 1.76 t ha^{-1} which was statistically at par with RDF+Rhi+PSB and RDF+Azo+PSB. The least grain yield was exhibited by control i.e. 1.42 t ha^{-1}. The treatment with combination of all biofertilizers appeared to have 23.94 % increment in the grain yield as compared to the control. The combined application of biofertilizers seems to be more effective as compared to single application. The application of biofertilizers displayed significant increment in plant height, number of branches, root length, number of effective nodules, root volume, shoot biomass, pods per plant, seeds per pod and pod length due better uptake of nutrients through nitrogen fixation and phosphorus solubilization which led to significant increase in yield of mung bean as compared to the control. In accordance with our findings the maximum grain yield was obtained under inoculation of Rhizobium which was significantly superior in comparison to other treatments (Mehboob et al., 2019). The grain yield was significantly increased after treating the seed of mung bean with PSB (Mandiwal et al., 2019).

Biological Yield

There was significant variation in the biological yield among different treatments. The utmost biological yield was displayed in the treatment RDF+Rhi+Azo+PSB i.e. 5.66 t ha^{-1} followed by RDF+Rhi+PSB. The least value for biological yield was detected in the treatment without application of any biofertilizers (control) i.e. 4.48 t ha^{-1}. There was 26.33 % increase in biological yield spotted in RDF+Rhi+Azo+PSB over control. This may be due to increased plant height, count of branches, root parameters, pods/plant, pod length and seeds per pod. Due to incorporation of biofertilizers, access to nutrients required by plants triggered the significant variation in biological yield. The findings are in accordance with (Verma et al., 2017).

Harvest Index

The analyzed data showed that there was no significant difference for harvest index due to application of different biofertilizers. However, the highest value of harvest index was observed in the treatment RDF+Rhi+Azo+PSB i.e. 0.31 and the lowest value was observed on control. The proportionate increase in biological and grain yield in spite of significant effects on them as shown in table 6 could be the reason of non-significant harvest index. In line with our result harvest index was not significantly influenced by application of biofertilizers in fenugreek (Mehta & Patel, 2011). In dispute to our result (Yadav et al., 2014) declared that the harvest index of mung bean amplified by the usage of Rhizobium and PSB.

Table 6

Effect of Integration of Biofertilizers on Seed Yield, Biological Yield and Harvest Index of Mung Bean

Treatments	Seed yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index
Control (RDF)	1.42^{b}	4.84^{c}	0.29
RDF+Rhi	1.62^{ab}	5.11^{bc}	0.31
RDF+Azo	1.59^{ab}	5.29^{ab}	0.3
RDF+PSB	1.60^{ab}	5.33^{ab}	0.3

RDF+Rhi+PSB	1.71[a]	5.44[ab]	0.31
RDF+Azo+PSB	1.66[a]	5.39[ab]	0.3
RDF+Rhi +Azo+PSB	1.76[a]	5.66[a]	0.31
$CD_{0.05}$	0.18	0.41	0.02
CV %	6.54	4.37	3.67
F-test	*	*	Ns
P value	0.04	0.01	0.14
Grand mean	1.62	5.29	0.307

CV: Coefficient of Variation; CD: Critical Difference; Ns: Non-Significant; *: significant at ≤0.05 level of significance, **: significant at ≤0.01 level of significance, ***: significant at ≤0.001 level of significance; Rhi: Rhizobium, Azo: Azotobacter, PSB: Phosphate Solubilizing Bacteria

Economic Analysis

The economic analysis of the data showed that the Rhizobium inoculation displayed significantly highest gross return of Rs. 243452.4 and a benefit cost ratio of 1.97 which was statistically at par with Azotobacter i.e. 1.93. The lowest gross return i.e. Rs. 213154.8 and B:C ratio i.e. 1.72 was observed in the absence of all biofertilizers i.e. control as shown in table 7. Although combination of biofertilizers yielded high grain yield it showed low B:C ratio due to additional cost as biofertilizer is added the cost of production increased. Bam et al. (2022) also reported that there was significant difference in B:C ratio when economic analysis of different biofertilizers was done.

Table 7

Economic Analysis of Mung Bean

Treatments	Total Cost (Rs.)	Gross Return (Rs.)	Net Return (Rs.)	B:C ratio
Control (RDF)	123247.5^{g}	213154.8^{b}	89907.29^{b}	1.72^{b}
RDF+Rhi	123547.5^{f}	243452.4^{ab}	119904.91^{a}	1.97^{a}
RDF+Azo	124132.5^{e}	23988.0^{ab}	115748.48^{a}	1.93^{a}
RDF+PSB	164647.5^{d}	241369.0^{ab}	76721.58^{b}	1.46^{c}
RDF+Rhi+PSB	164947.5^{c}	257440.5^{a}	92493.01^{ab}	1.56^{bc}
RDF+Azo+PSB	165532.5^{b}	250000.0^{a}	84467.53^{b}	1.51^{c}
RDF+Rhi +Azo+PSB	165832.5^{a}	264821.4^{a}	98988.96^{a}	1.59^{bc}
$CD_{0.05}$	1.72e-11	28458.35	28458.35	0.19
CV %	6.58e-15	6.54	14.51	6.51
P value	<2e-16	0.04192	0.05143	0.0003871
F test	***	*	Ns	***
Grand mean	147412.5	244302.7	96890.25	1.68

CV: Coefficient of Variation; CD: Critical Difference; Ns: Non-Significant; *: significant at ≤0.05 level of significance, **: significant at ≤0.01 level of significance, ***: significant at ≤0.001 level of significance; Rhi: Rhizobium, Azo: Azotobacter, PSB: Phosphate Solubilizing Bacteria

Conclusion

This experiment showed that the combination of biofertilizers had exhibited better performance as compared to the control treatment in all physiological and yield parameters of mung bean. Biofertilizers whether applied alone or in combination was more effective than the control. Biofertilizers improved the seed yield and other parameters by better uptake of nutrients, releasing growth hormones and protecting plants from different biotic and abiotic stresses. Comparatively, Rhizobium either alone or paired with PSB and Azotobacter displayed better results. Moreover, economic analysis indicated that the seed treatment of mung bean either with Rhizobium or Azotobacter was economically more feasible as compared to other treatments. Hence, biofertilizers are recommended for increasing production of mung bean, minimizing use of chemical fertilizers, increasing income and promoting sustainable agriculture.

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