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Effect of Rhizobium and Molybdenum on Growth, Root Nodulation and Yield of Mung Bean (*Vigna radiata* L.) in Tikapur, Kailali

Laxmi Kumari Awasthi[1], Lalit Pandey[1], Devraj Chalise[2]
[1]Faculty of Agriculture, Far Western University, Tikapur, Kailali
[2] Nepalese Association of Agriculture, Forestry and Environment in Australia, Australia
Corresponding Author's Email: awasthilaxmi2058@gmail.com

Abstract
A field experiment was conducted at Agronomy farm of Far Western University, School of Agriculture, Tikapur, Kailali during spring season of 2024 to study the effect of *Rhizobium* and molybdenum on growth, root nodulation and yield of mung bean. The trial was laid out in two factorial randomized complete block design having four replications and six treatments. Two levels of *Rhizobium* (with and without) and three levels of molybdenum (0, 1 and 2 kg ha^{-1}) were used. Sodium molybdate as a source of molybdenum and seeds of variety SML-668 were used. The experimental results revealed that application of *Rhizobium* + 2 kg ha^{-1} molybdenum provided significantly higher plant height (54.84 cm), root length (17.03 cm), total nodules (21), effective nodules (18), fresh weight of root (2.33 g), dry weight of root (1.02 g), root volume (2.43 ml), fresh weight of shoot (65.18 g), pod length (8.97 cm), seeds/pod (10), pods/plant (34) followed by *Rhizobium* + 1 kg ha^{-1} molybdenum. Similarly, number of branches/plant (13), grain yield (1.7ton ha^{-1}), biomass yield (6.71ton ha^{-1}) and 1000 grain weight (51.45 g) also recorded highest at *Rhizobium* + 2 kg ha^{-1} molybdenum. The effect of sole *Rhizobium*

inoculation and increasing level of molybdenum was significant over control for all these parameters. Number of effective nodules was positively correlated with all the growth, yield and yield attributing parameters with concluding *Rhizobium* + 2 kg ha^{-1} molybdenum as best combination for growth, root nodulation and yield of mung bean in Tikapur, Kailali.

Keywords: Effective nodules, Inoculation, SML-668, Sodium molybdate

Introduction

Mung bean (*Vigna radiata* L.) is generally called as green gram which is related to the Leguminosae family. It is a short-duration crop and has greater tolerance against drought stress (Chattha, et al., 2017). It is widely grown in Asia, and in some parts of Africa and Australia. It is domesticated as almost 8.5% of world pulse area (Khan et al., 2019). Almost 90% of the mung bean production is found in Asia, where India, China, Pakistan and Thailand are among the most important producers (Pataczek, et al., 2018). Globally, India is the largest producer of mung bean. It is gaining more popularity in Nepal as a promising legume due to its high nutritive value (Bam et al., 2022). Mung bean has a high digestibility and is a highly nutritious crop which contains 24.8% protein, 0.6% fat, 0.9% fiber, 3.7% ash, vitamins and minerals (Chattha, et al., 2017). It contains vitamin A (94 mg), iron (7.3 mg), calcium (124 mg), zinc (3 mg) and folate (549 mg) per 100 g dry seed (Chadha, 2010).

Although there is huge production potential of mung bean in Nepal, it has not achieved the targeted level of yield due to imbalanced nutrient management and nitrogen deficient soil. It has been a challenge for farmers to reduce the excessive use of agrochemicals in mung bean farms, which adversely affect the environment and human health. Therefore, nutrient management is a crucial factor for successful and profitable mung bean production. Balanced and efficient fertilizer application, combining inorganic, organic, and bio-fertilizers, is essential for realizing a higher yield and reducing the cost of production as well as improving soil fertility status. *Rhizobium* is a nitrogen-fixing bacteria which is common in soil, especially found in root nodules of leguminous plants. Inoculating mung bean with *Rhizobium* can fix 20–40 kg N ha^{-1} (Bam et al., 2022). It has been observed increased nodulation, nitrogen acquisition, and legume yield through inoculation of *Rhizobium* strains. Studies have shown that inoculating crop roots with bacteria regulates soil water dynamics and improves plant resistance to stress resulting in increased productivity as well as they are environment friendly (Bam et al., 2022). *Rhizobium* inoculation supplements soil nitrogen increasing 57% effective nodule, 77% dry matter production, 64% grain yield and 40% hay yield over un-inoculated control in mung bean (Hossain et al., 2011).

Micronutrient/trace elements play a vital role in achieving higher yield in legumes through biological nitrogen fixation and their positive influence on plant growth. In contrast their deficiency affects plant growth and yield. Molybdenum (Mo), a key trace element necessary for development of plants, animals and other biological organisms, is crucial for nitrogenase enzymatic activity and nitrate reductase in the plants (Ahmad, et al., 2021). As it is a part of nitrogenase enzyme it is required for the conversion of atmospheric nitrogen into ammonium nitrogen. In nutrient deficient soil, molybdenum application enhances formation of nodules and thus for nitrogen fixation. Application of molybdenum into the soils increases the contents of potassium, phosphorus and crude protein. There is increase in flower numbers, pod set improvement and reduction in days to flowering by the application of molybdenum (Ahmad et al., 2013; Ahmad, et al., 2021). Inoculation of legumes with *Rhizobium* is well known practice but there is not much study related to combined effects of molybdenum and *Rhizobium*. Thus, this study was conducted to compare the individual impacts of molybdenum and *Rhizobium* along with their combinations on plant growth, root nodulation and yield parameters of mung bean.

Methods and Procedures

The details of the materials and methods employed during the course of this experiment are presented below.

Study Site

The field experiment of mung bean was conducted during spring season of 2024 at Agronomy farm of Far Western University, School of Agriculture, Tikapur

Municipality-1, Kailali district of Far Western Province. The location of the site falls in Terai region of Nepal. The latitude and longitude of site is 28°32'28.37" N and 81°07'26.72" E, respectively. It lies in Northern hemisphere. The maximum and minimum temperature ranged from 33.33°C to 45.64°C and 19.33°C to 32.26°C respectively and average precipitation ranged from 0.00 mm to 0.27 mm during the whole crop growing period. The soil was sandy loam in texture having bulk density of 1.68 g cm^{-3}**,** pH of 7.61(slightly alkaline), low in organic matter and NPK.

Figure 1

Study Area Map of Experimental Site at Tikapur

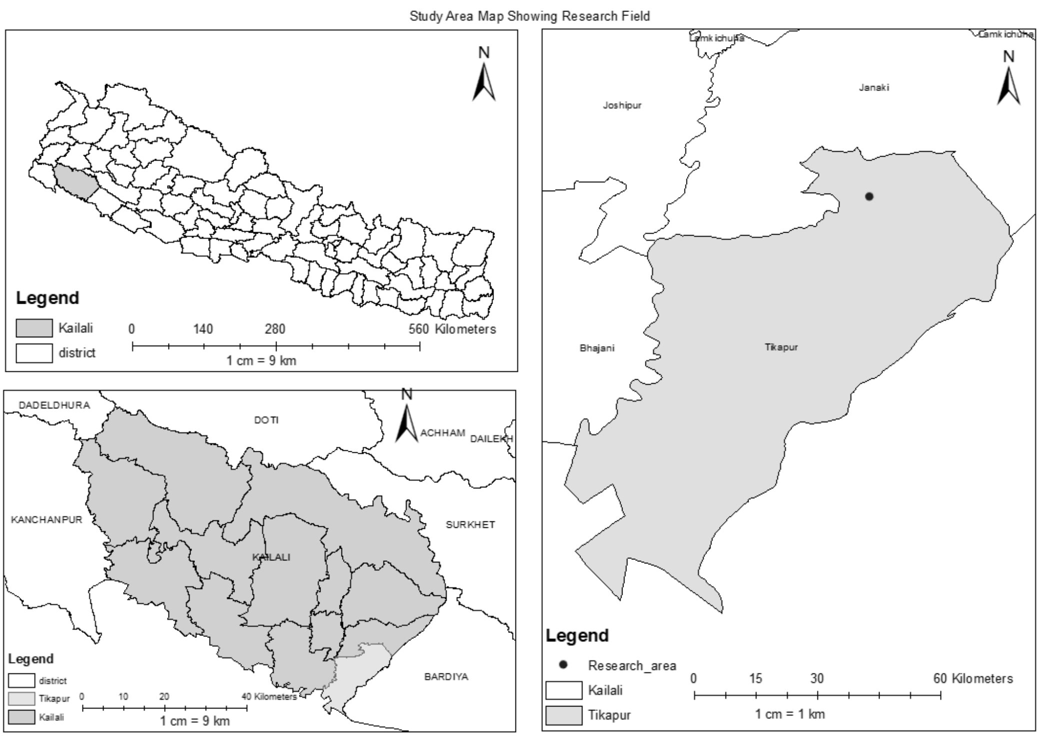
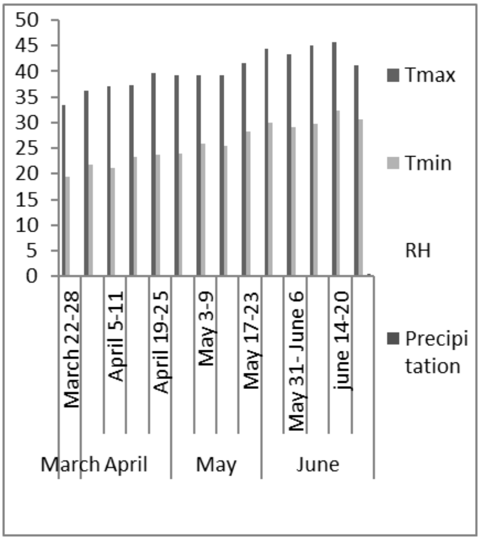


Figure 2

Weather Data of Experimental Site during Field Experiment



Note: Tmax: maximum temperature, Tmin: minimum temperature, RH: Relative humidity

Table 1

Physical and Chemical Properties of Soil at Research Site

Soil Parameters	Findings
Soil Texture	Sandy loam
Soil organic matter	2.01% (low)
Soil pH	7.61
Available nitrogen	0.10% (low)
Available phosphorus	12.81 kg ha^{-1}(low)
Available potassium	49.47 kg ha^{-1}(low)
Bulk density	1.68 g cm^{-3}
Particle density	2.5 g cm^{-3}
Porosity	32.8%
Water holding capacity	53.33%

(Source: Soil and Fertilizer Testing Laboratory, Sundarpur, Kanchanpur, 2024)

Sodium molybdate (Na_2MoO_4) was used as a source of molybdenum which was obtained from PSE Life Sciences Pvt. Ltd., New Baneshwar, Kathmandu. It was applied in the lines made for seed sowing one night before seed sowing. *Rhizobium* was collected from Soil Science Division, Khumaltar, Lalitpur. Seeds were soaked in water for 6 hours for good germination and shade dried for one hour. Then as per the treatment, required quantity of seed was treated with *Rhizobium* @ 10 g kg^{-1} seed. For that, 20 % jaggery solution (30 g jaggery in 150 ml water) + 2.5 g *Rhizobium* was mixed and seeds were soaked in that solution for 10–15 minutes. After that seeds inoculated with *Rhizobium* were shade dried for 2 hours before sowing.

Experiment Layout and Design

The experiment was conducted in two factorial RCBD design (Randomized Complete Block Design) with four replications. Two levels of *Rhizobium* (with and without) and three levels of molybdenum (0, 1 and 2 kg ha^{-1}) were used making the six treatments i.e. Control (only RDF), (RDF + 1 kg ha^{-1} molybdenum), (RDF + 2 kg ha^{-1} molybdenum), (RDF + *Rhizobium* inoculation), (RDF + *Rhizobium* inoculation + 1 kg ha^{-1} molybdenum), (RDF + *Rhizobium* inoculation + 2 kg ha^{-1} molybdenum). There were 24 plots. Area of each plot was 6.3 m^2 having seven lines of plant in one plot. The space between the treatments was 0.5m and between the replication was 1m.

Cultivation Practices

The land was ploughed two times, leveled and then layout of the research field was done. Recommended dose of fertilizer 20:20:20 kg ha^{-1} and FYM 6 t ha^{-1} was applied. Half dose of N and full dose of P and K was applied before seed sowing and remaining half dose of N was applied at 35 DAS. Seed sowing was done in lines maintaining the spacing of row to row 30 cm. The depth of the seed sown was 3–4 cm. After two weeks of sowing, thinning was done to maintain the plant to plant spacing of 10 cm. Irrigation was applied frequently according to the crop requirements till pod filling stage as the weather was very dry during its whole cropping cycle. Harvesting was done three times manually when 80% of the pods in the field turned black color.

Sampling Methods

For the growth and yield attributing parameters, plant sample was taken by tagging 10 plants in destructive rows by using simple random sampling. For the root parameters, five plants were uprooted randomly leaving border plants, tagged plants and plants in middle rows. For estimating the yield of mung bean, two middle rows were selected from all the plots.

Data Observations and Statistical Tools Used

Data was collected four times from the field for growth, root, yield and yield attributing parameters i. e, at 30, 45, 60 DAS and at harvest. The entry of collected data was done by tabulating them according to replications and treatments in MS-Excel 2010. Data analysis was done by using doe-bioresearch package with 4.3.1 version of R studio software. Means were separated by using Duncan's Multiple Range Test (DMRT) and compared at 5 % level of significance. Correlation analysis among the selected parameters was done by using Metan package of R studio. Regression analysis of selected parameters and graphs were prepared with MS-Excel 2010.

Results and Discussion

Growth Parameters

Plant Height (cm)

Significant variation was observed in plant height due to the application of molybdenum and *Rhizobium* at 5 % level of significance. Sole *Rhizobium* inoculation increased plant height significantly over control. It was observed that the increasing level of molybdenum increased plant height significantly, but 2 kg ha^{-1} molybdenum was statistically at par with 1 kg ha^{-1} molybdenum. Among the different combinations, *Rhizobium* + 2 kg ha^{-1} molybdenum showed the highest plant height (50.18), followed by *Rhizobium* + 1 kg ha^{-1} while the lowest (43.23 cm) in case of control.

Number of Shoot Branches

Number of shoot branches of mung bean significantly increased with the application of *Rhizobium* over un-inoculated ones. Similarly, the increasing dose of molybdenum increased branch number significantly and the highest number of branches was found in 2 kg ha^{-1} molybdenum. The combined application of *Rhizobium* and molybdenum didn't show significant variation among number of branches, but mean difference was observed. The maximum number of branches (13) was observed in *Rhizobium* + 2 kg ha^{-1} molybdenum followed by *Rhizobium* + 1 kg ha^{-1} molybdenum and minimum (10) was found in control.

Kumar et al. (2010) observed significant increase in plant height, branches per plant due to seed inoculation with *Rhizobium* and application of molybdenum. Similarly, Aslam et al. (2020) found significant difference in plant height and pod bearing branches per plant in the combination of *Rhizobium* and molybdenum 4 g kg^{-1} seed. Ahmad et al. (2013) also found that *Rhizobium* inoculation along with 2 kg ha^{-1} molybdenum improved vegetative growth of mung bean. There was increased vegetative growth of mung bean due to sole inoculation of *Rhizobium* over un-inoculated control which indicates contribution of bacteria in nitrogen fixation by developing nodules on mung bean roots. Similarly, Mo is a part of nitrogenase enzyme that is essential for the fixation of atmospheric nitrogen.

Fresh Weight of Shoot Per Plant (g)

Individual as well as combined application of *Rhizobium* and molybdenum showed significant difference in fresh weight of shoot per plant in mung bean. Sole *Rhizobium* application increased fresh weight of shoot significantly over control. Molybdenum 2 kg ha^{-1} showed the maximum fresh weight of shoot which was statistically at par with 1 kg ha^{-1} molybdenum but different than control. The maximum fresh weight of shoot (65.18 g) was found in combination of *Rhizobium* + 2 kg ha^{-1} molybdenum, followed by *Rhizobium* + 1 kg ha^{-1} molybdenum and minimum (58.23 g) was found in control. Similar result was found by Elkhatib (2009) in common bean during two growing seasons. EL-Mahmoudy et al. (2019) found that *Rhizobium* + Vitamin B12 was the most effective in increasing plant fresh and dry weight followed by *Rhizobium* + molybdenum.

Table 2

Effect of Rhizobium and Molybdenum on Growth Parameters of Mung Bean

Treatments	Plant height (cm)	Number of shoot branches	Fresh weight of shoot per plant (g)
Rhizobium			
R_0 = Inoculation	44.19^b	11.19^b	59.19^b
R_1 = No inoculation	46.99^a	12.07^a	62.00^a
SEm (±)	0.50	0.24	0.50
$LSD_{0.05}$	1.50	0.71	1.50
F-test	**	*	**
Molybdenum			
M_0= 0 kg ha^{-1}	43.66^b	10.97^b	58.66^b
M_1= 1 kg ha^{-1}	45.66^a	11.52^b	60.66^a

M_2= 2 kg ha^{-1}	47.46^{a}	12.40^{a}	62.46^{a}
SEm (±)	0.61	0.29	0.60
$LSD_{0.05}$	0.84	0.88	1.84
F-test	**	*	**
Interaction			
R_0M_0	43.23^{c}	10.78	58.23^{c}
R_0M_1	44.60^{bc}	11.13	59.60^{bc}
R_0M_2	44.74^{bc}	11.67	59.74^{bc}
R_1M_0	44.09^{bc}	11.16	59.09^{bc}
R_1M_1	46.72^{b}	11.92	61.72^{b}
R_1M_2	50.18^{a}	13.14	65.18^{a}
SEm (±)	0.86	0.41	0.86
$LSD_{0.05}$	2.6	1.24	2.60
F-test	*	ns	*
CV (%)	3.78	7.10	2.84
Grand Mean	45.59	11.63	60.60

Note: SEm (±): Standard error of mean, LSD: Least Significant Difference, CV: Coefficient of Variation, ns: non-significant, *: $p \leq 0.05$, **: $p \leq 0.01$, means followed by the same letters within each column are not significantly different at 5% level of significance by DMRT.

Root Parameters

Root Length

Root length was found statistically significant among different combinations of *Rhizobium* and molybdenum. The highest root length throughout the cropping period i. e. 17.03 cm was found in *Rhizobium* + 2 kg ha^{-1} molybdenum followed by *Rhizobium* + 1 kg ha^{-1} molybdenum and lowest (14.85 cm) was found in control. *Rhizobium* inoculation alone provided significant difference over un-inoculated ones in root length which is similar to the findings of Bhuiyan et al. (2008) and Ahmad et al. (2013). Increasing dose of molybdenum up to 2 kg ha^{-1} had increased root length of mung bean significantly as shown in (Table 3).

Ahmad et al. (2013), found *Rhizobium* inoculation alone gave 17% higher root length and *Rhizobium* inoculation along with 2 kg ha^{-1} molybdenum increased root length significantly over un-inoculated control. According to them, *Rhizobium* affects the plant growth and development by various mechanisms like nitrogen fixation, production of PGRs, improved mineral uptake, and suppression of plant disease. For increasing the effectiveness of *Rhizobium*, role of micronutrient molybdenum is essential as it is required for nitrate reductase enzyme for NO_3^- assimilation as mentioned by Hasanah et. al. (2023). That's why combination of *Rhizobium* and molybdenum performed better.

Number of Nodules

Statistically significant difference was observed in total and effective nodules of mung bean at 5 % level of significance. *Rhizobium* inoculation alone increased the total and effective nodules as compared to control. The increasing level of molybdenum when applied alone significantly increased the total and effective nodules. The maximum number of root nodules and effective nodules were found at 2 kg ha^{-1} molybdenum. Application of 1 kg ha^{-1} molybdenum alone showed statistically similar results as control. Similarly, the combination of different levels of *Rhizobium* and molybdenum showed significant variation in total and effective nodules which may be due to synergistic effect of *Rhizobium* and molybdenum on nodule formation as mentioned by Tahir et al. (2011). The maximum number of root nodules (21) and effective nodules (18) were found at the combination of *Rhizobium* + 2 kg ha^{-1} molybdenum. The minimum number of nodules (14) and effective nodules (10) were found at control.

Similar to these findings, *Rhizobium* inoculation + 2 kg ha^{-1} molybdenum produced the maximum number of nodules which was 163 and 91% higher over un-inoculated control and *Rhizobium* inoculation alone (Ahmad et al., 2013). According to Aslam et al. (2020) number of nodules per plant was significantly influenced by application of different levels of molybdenum and *Rhizobium* during 2 years and the lowest number of nodules was found in control. Paudyal et al. (2007) also reported higher number of root nodules formation with *Rhizobium* inoculation in presence of molybdenum. Molybdenum plays vital role to increase nitrogen fixation by *Rhizobium* and for the formation of nodule (Rahman et al., 2008).

Table 3

Effect of Rhizobium and Molybdenum on Growth Parameters of Mung Bean

Treatments	Root length (cm)	Total nodules	Effective nodules	Fresh weight of root (g)	Dry weight of root (g)	Root volume (ml)
Rhizobium						
R_0 = Inoculation	15.15^{b}	14.42^{b}	11.05^{b}	2.08^{b}	0.79^{b}	2.17^{b}
R_1 = No inoculation	16.03^{a}	17.95^{a}	14.71^{a}	2.20^{a}	0.90^{a}	2.29^{a}
SEm (±)	0.16	0.47	0.44	0.02	0.02	0.02
$LSD_{0.05}$	0.47	1.44	1.34	0.06	0.06	0.71
F-test	**	***	***	**	**	**
Molybdenum						
M_0= 0 $kgha^{-1}$	14.99^{b}	14.56^{b}	11.13^{b}	2.05^{c}	0.77^{b}	2.15^{b}
M_1= 1 $kgha^{-1}$	15.61^{a}	15.77^{b}	12.42^{b}	2.14^{b}	0.85^{a}	2.24^{ab}
M_2= 2 $kgha^{-1}$	16.18^{a}	18.22^{a}	15.10^{a}	2.22^{a}	0.91^{a}	2.31^{a}
SEm (±)	0.19	0.58	0.54	0.03	0.02	0.03
$LSD_{0.05}$	0.57	1.76	1.64	0.08	0.07	0.87
F-test	**	**	***	**	**	**
Interaction						
R_0M_0	14.85^{c}	13.84^{c}	10.41^{c}	2.03^{c}	0.76^{c}	2.14^{c}

R_0M_1	15.28^{bc}	14.20^{c}	10.78^{c}	2.09^{bc}	$0.82b^{c}$	2.19^{bc}
R_0M_2	15.33^{bc}	15.23^{bc}	11.96^{bc}	2.10^{bc}	$0.81b^{c}$	2.19^{bc}
R_1M_0	15.12^{bc}	15.29^{bc}	11.85^{bc}	2.07^{bc}	$0.79b^{c}$	2.16^{bc}
R_1M_1	15.95^{b}	17.34^{b}	14.06^{b}	2.18^{b}	0.89^{b}	2.28^{b}
R_1M_2	17.03^{a}	21.22^{a}	18.24^{a}	2.33^{a}	1.02^{a}	2.43^{a}
SEm (±)	0.27	0.83	0.77	0.04	0.03	0.04
$LSD_{0.05}$	0.81	2.49	2.31	0.11	0.10	0.12
F-test	*	*	*	*	*	*
CV (%)	3.46	10.19	11.92	3.41	7.80	3.66
Grand Mean	15.59	16.19	12.88	2.14	0.85	2.23

Note: SEm (±): Standard error of mean, LSD: Least Significant Difference, CV: Coefficient of Variation, ns: non-significant, *: $p \leq 0.05$, **: $p \leq 0.01$, ***: $p \leq 0.001$, means followed by the same letters within each column are not significantly different at 5% level of significance by DMRT.

Fresh Weight of Root, Dry Weight of Root and Root Volume

There was significant difference in fresh weight of root, dry weight of root and root volume of mung bean due to the application of *Rhizobium* and molybdenum. Sole *Rhizobium* inoculation significantly increased these root parameters as compared to control. The increasing dose of molybdenum significantly increased fresh weight of root, dry weight of root and root volume and maximum was found at molybdenum 2 kg ha^{-1}. Among the different combinations, *Rhizobium* + 2 kg ha^{-1} molybdenum provided maximum fresh weight of root (2.33 g), dry weight of root (1.02 g) and root volume (2.43 ml), followed by *Rhizobium* + 1 kg ha^{-1} molybdenum. The lowest fresh weight of root (2.03 g), dry weight of root (0.76 g) and root volume (2.14 ml) was found in control.

Bhuiyan et al. (2008) also found that the effect of phosphorus, molybdenum and *Rhizobium* inoculant significantly increased dry weight of root of mung bean compared to control. The increase in fresh and dry weight of root at combination of *Rhizobium* + 2 kg ha^{-1} molybdenum may be due to higher root length and higher effective root nodules at that combination. The reason behind increasing root volume in combination of *Rhizobium* + molybdenum 2 kg ha^{-1} may be due to higher root length, higher number of total and effective nodules and higher fresh and dry biomass of root at this combination as mentioned in above findings.

Yield Attributing Parameters

Pod Length (cm)

Significant variation was observed in pod length of mung bean due to the individual and combined application of different levels of *Rhizobium* and molybdenum. Among the different combinations, the maximum pod length (8.97 cm) was observed in combination of *Rhizobium* + 2 kg ha^{-1} molybdenum and the minimum (8.04 cm) was found in control.

Number of Seeds Per Pod

Different levels of *Rhizobium* and molybdenum significantly increased the number of seeds per pod in mung bean. The maximum number of seeds per pod (10) was observed in the combination of *Rhizobium* + 2 kg ha^{-1} molybdenum. Other combinations were statistically similar and the minimum number of seeds per pod (8) was observed in control.

Number of Pods Per Plant

Rhizobium and molybdenum significantly influenced the number of pods per plant in mung bean. The number of pods per plant ranged from 29 to 34. *Rhizobium* + 2 kg ha^{-1} molybdenum produced significantly higher number of pods per plant, followed by *Rhizobium* + 1 kg ha^{-1} molybdenum and lower number of pods was found in control.

Sole *Rhizobium* inoculation significantly increased all these yield attributing parameters over control. Similarly, individual application of molybdenum significantly increased the pod length, number of seeds per pod and number of pods per plant and highest value of these parameters was found in @ 2 kg ha^{-1} molybdenum.

Table 4

Effect of Rhizobium and Molybdenum on Yield Attributing Parameters and Seed Yield

Treatments	Pod length (cm)	Number of seeds per pod	Number of pods per plant	Grain yield (t ha^{-1})	Biomass production (t ha^{-1})	1000 grain weight (g)
Rhizobium						
R_0 = Inoculation	8.17^b	9.10^b	30.33^b	1.45^b	6.28^b	48.03
R_1 = No inoculation	8.51^a	9.61^a	32.21^a	1.59^a	6.54^a	49.26
SEm (±)	0.06	0.09	0.33	0.03	0.08	0.70
$LSD_{0.05}$	0.18	0.28	1.01	0.10	0.24	2.12
F-test	**	**	**	*	*	ns
Molybdenum						
M_0= 0 $kgha^{-1}$	8.11^b	9.00^b	29.97^b	1.39b	6.19^b	47.56
M_1= 1 $kgha^{-1}$	8.30^b	9.32^b	31.31^a	1.54a	6.40^{ab}	48.83
M_2= 2 $kgha^{-1}$	8.61^a	9.76^a	32.52^a	1.62a	6.63^a	49.53
SEm (±)	0.07	0.11	0.41	0.04	0.09	0.86
$LSD_{0.05}$	0.22	0.34	1,23	0.13	0.30	2.59
F-test	**	**	**	**	*	ns
Interaction						
R_0M_0	8.04^b	8.92^b	29.69^c	1.33	6.05	47.75
R_0M_1	8.22^b	9.19^b	30.60^{bc}	1.47	6.22	48.73
R_0M_2	8.24^b	9.20^b	30.70^{bc}	1.53	6.56	47.61
R_1M_0	8.18^b	9.09^b	30.26^{bc}	1.45	6.34	47.37
R_1M_1	8.38^b	9.44^b	32.03^b	1.60	6.57	48.94
R_1M_2	8.97^a	10.32^a	34.35^a	1.70	6.71	51.45
SEm (±)	0.11	0.16	0.58	0.06	0.14	1.22
$LSD_{0.05}$	0.32	0.48	1.74	0.18	0.42	3.66
F-test	*	*	*	ns	ns	ns
CV (%)	2.51	3.41	3.70	7.83	4.37	5.00
Grand Mean	8.34	9.36	31.27	1.52	6.41	48.64

Note: SEm (±): Standard error of mean, LSD: Least Significant Difference, CV: Coefficient of Variation, ns: non-significant, *: $p \leq 0.05$, **: $p \leq 0.01$, ***: $p \leq 0.001$, means followed by the same letters within each column are not significantly different at 5% level of significance by DMRT.

Ahmad et al. (2013) observed, application of molybdenum at the rate of 2 kg ha^{-1} increased the number of pods per plant and it was reduced with further addition of molybdenum. Rahman et al. (2008) found significant variation in pod length, number of seeds per pod and the number of pods per plant due to the application of phosphorus, *Rhizobium* and molybdenum. Aslam et al. (2020) also found significant differences among pod length, number of seeds per pod and the number of pods per plant due to combination of different levels of *Rhizobium* and molybdenum. The increase in the yield attribute characters with application of molybdenum and *Rhizobium* might be due to its role in enhanced nitrogen fixation which increases availability of nitrogen to the plants for efficient growth and development. The increase in yield attributes was probably due to source and sink relationship. The improvement in photosynthesis and carbohydrate metabolism results into greater formation of photosynthates and metabolites in source and later on translocated in the newly formed sink i.e. reproductive structures (flowering and seed setting) which ultimately increased pods per plants, pod length and finally grain yield of the crop (Kumar et al., 2010).

Yield Parameters

Grain Yield (t ha^{-1})

Grain yield of mung bean significantly increased with the application of *Rhizobium* over control similarly as mentioned by Ahmad et al. (2013). Molybdenum 2 kg ha^{-1} showed significant variation in yield with control, but it is statistically at par with 1 kg ha^{-1} molybdenum. The combined effects of *Rhizobium* and molybdenum didn't show statistically significant variation in grain yield at 5 % level of significance but the maximum grain yield (1.70 t ha^{-1}) was found in *Rhizobium* + 2 kg ha^{-1} molybdenum followed by *Rhizobium* + 1 kg ha^{-1} molybdenum. The lowest grain yield (1.33 t ha^{-1}) was found in control.

The increase in grain yield of mung bean at *Rhizobium* + 2 kg ha^{-1} molybdenum may be due to higher pod length, number of seeds per pod and higher number of pods per plant in that treatment as mentioned in above findings which is similar to the findings of Kumar et al. (2010) as they mentioned the yield of a crop is the cumulative effect of yield attributing characters. The growth in yield due to increasing dose of molybdenum may be due to increase in *Rhizobium* activity by molybdenum that increases nitrogen fixation and have a positive role in flowering, pod formation and other performance attributes (Ahmad et al., 2021).

Biomass Production (t ha^{-1})

Individual application of *Rhizobium* and molybdenum showed statistically significant difference in biomass production of mung bean. *Rhizobium* inoculation significantly increased the biomass of shoot over un-inoculated control. The increasing level of molybdenum showed significant variation in biomass of shoot over control. The combined application of *Rhizobium* and molybdenum didn't show significant variation in biomass of mung bean but the maximum biomass (6.71 t ha^{-1}) was found in *Rhizobium* + 2 kg ha^{-1} molybdenum, followed by *Rhizobium* + 1 kg ha^{-1} molybdenum. Minimum dry biomass of shoot (6.05 t ha^{-1}) was found at control. Increase in biomass due to *Rhizobium* + 2 kg ha^{-1} molybdenum may be due to balanced growth pattern in that combination which is also mentioned by Aslam et al. (2020). Tahir et al. (2011) found that molybdenum and seed inoculation had a highly significant effect on the biomass production of mung bean.

1000 Grain Weight (g)

The individual and combined effect of *Rhizobium* and molybdenum didn't show statistically significant variation in 1000 grain weight but the average value was different. *Rhizobium* inoculation alone had increased 1000 grain weight over control. The increasing level of molybdenum increased 1000 grain weight as shown in (table 4). Among the different combinations of *Rhizobium* and molybdenum, the maximum 1000 grain weight (51.45 g) was found in combination of *Rhizobium* and 2 kg ha^{-1} molybdenum, followed by *Rhizobium* + 1 kg ha^{-1} molybdenum and the minimum (47.75 g) was observed in control. Aslam et al. (2020) found that sole *Rhizobium* inoculation and combination of *Rhizobium* and molybdenum had a significant effect on 1000-grain weight and seed yield compared to control. The maximum increase in 100-grain weight was caused by *Rhizobium* inoculation along with the application of molybdenum @ 2 kg ha^{-1} which produced 72 and 36% increase over uninoculated control and *Rhizobium* inoculation alone, respectively (Ahmad et al., 2013).

Correlation

Strong and positive correlation was found among different growth, yield and yield attributing parameters of mung bean with effective root nodules. All the growth and root parameters were positively correlated with grain yield of mung bean. Grain yield was increased parallel to increase in yield attributing parameters (pod length, number of seeds per pod and number of pods per plant) as shown in following table.

Table 5

Correlation between Different Parameters of Mung Bean

	EN	PH	SB	RL	DRW	RV	PL	PPP	SPP	GY
EN	1									
PH	0.78***	1								
SB	0.70***	0.52**	1							
RL	0.73***	0.97***	0.43*	1						
DRW	0.75***	0.96***	0.45*	0.97***	1					
RV	0.67***	0.94***	0.39	0.98***	0.94***	1				
PL	0.66***	0.92***	0.37	0.94***	0.91***	0.92***	1			
PPP	0.73***	0.97***	0.43*	0.99***	0.97***	0.98***	0.94***	1		
SPP	0.72***	0.95***	0.47*	0.96***	0.92***	0.94***	0.97***	0.96***	1	
GY	0.52***	0.62**	0.49*	0.64***	0.60**	0.64***	0.66***	0.64***	0.69***	1

Note: EN: Effective nodules; PH: Plant height (cm); SB: Shoot branches; RL: Root length (cm); DRW: Dry root weight (g); RV: root volume (ml); PL: Pod length (cm); PPP: Pods per plant; SPP: Seeds per pod; GY: Grain Yield (t ha^{-1})

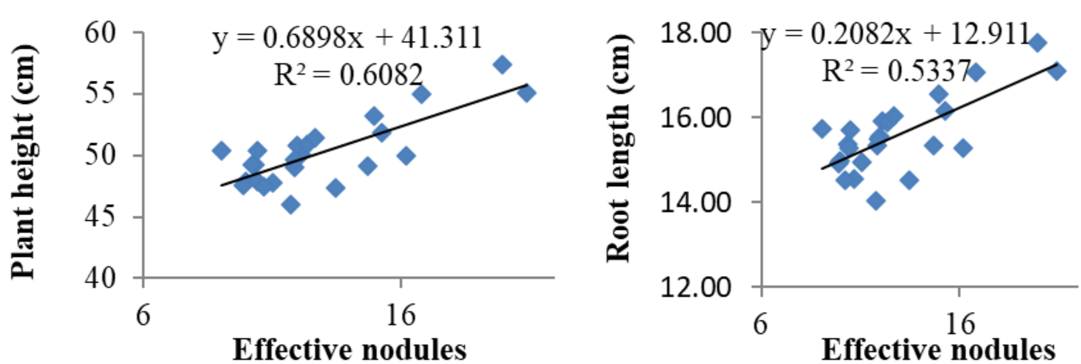
Ahmad et al. (2013) found that the number of nodules per plant showed strong association with plant height, root length, and grain yield. The increase in root length improved nodulation of mung bean which assist in fixation of atmospheric nitrogen through nitrogenase activity of *Rhizobium* that increased plant height along with grain yield. The improvement in nodule formation may be due to molybdenum which is required by *Rhizobium* bacteria for the fixation of atmospheric nitrogen in legumes. Rahman et al. (2008) found dry weight of plant tops, seed yield per plant and yield-contributing characters were positively correlated with the number of nodules per plant.

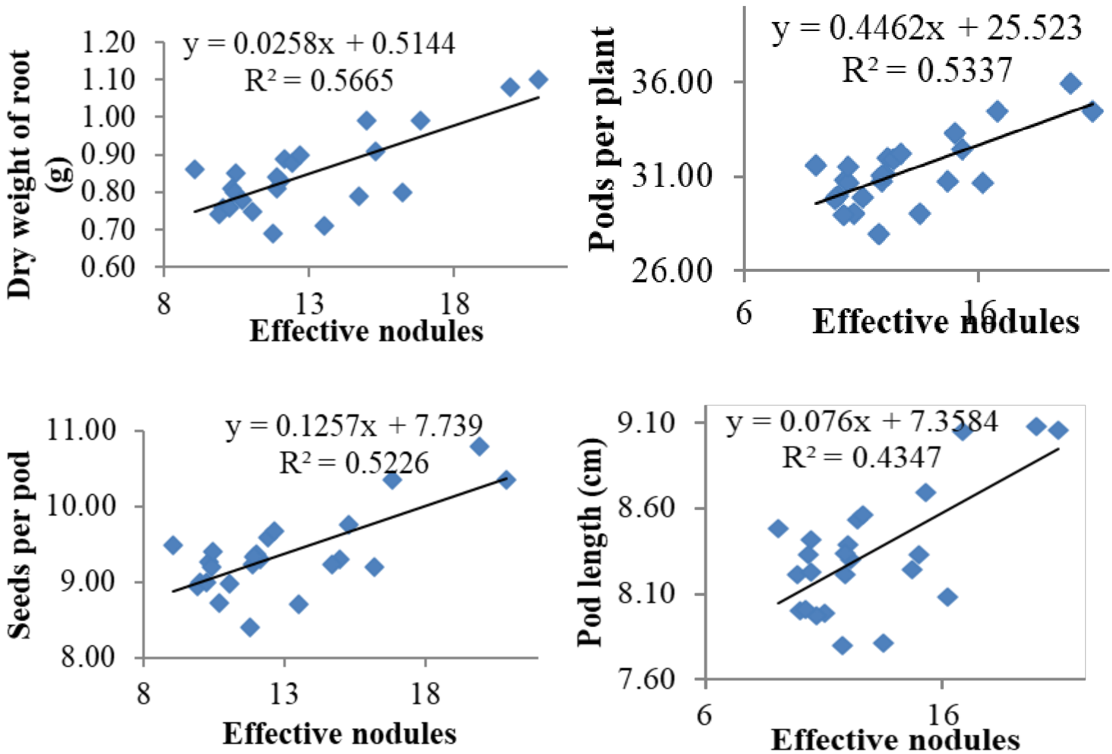
Regression

The number of effective nodules showed positive linear relation with most of the growth and yield parameters. The role of effective nodules in plant height, root length, dry weight of root, pods per plant, pod length and number of seeds per pod was found to be 61% (R^2= 0.61), 53% (R^2= 0.53), 57 % (R^2= 0.57), 53 % (R^2= 0.53), 43% (R^2=0.43) and 52% (R^2= 0.52) respectively as shown in the graphs below.

Figure 3

Relationship between Effective Nodules and Different Parameters of Mung Bean

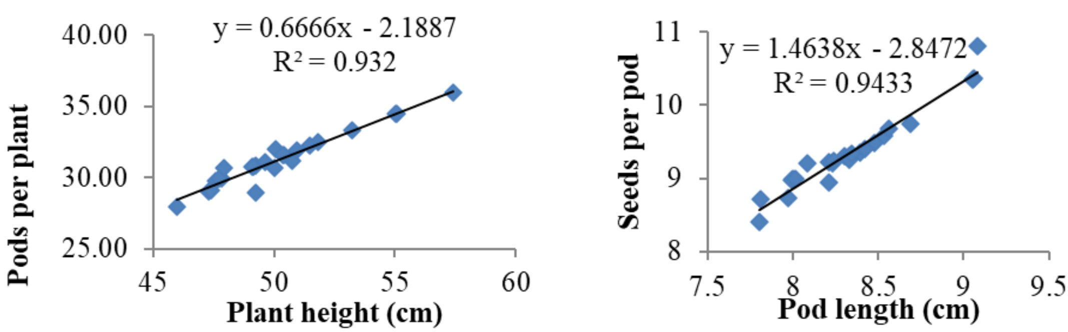


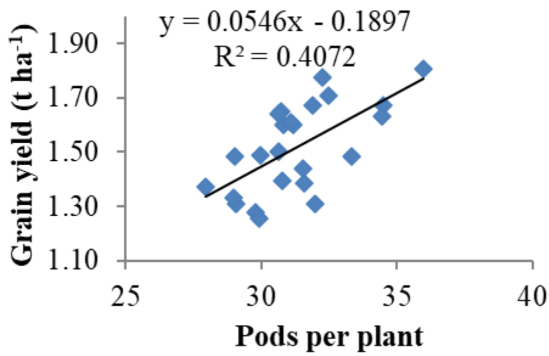


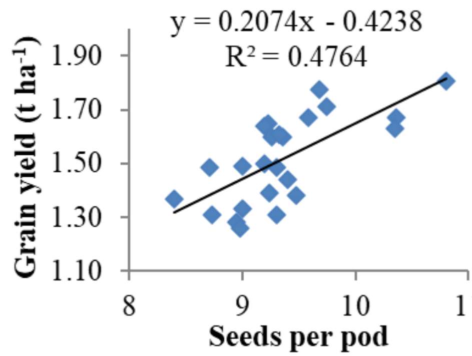
Similarly, plant height contributed 93% (R^2=0.93) on pods per plant and hence pods per plant contributed 41% (R^2= 0.41) on grain yield. The maximum value of coefficient of determination (R^2 = 0.94) was found between pod length and number of seeds per pod i.e. pod length have 94% role to increase the number of seeds per pod and seeds per pod contributed 48 % (R^2= 0.48) in grain yield of mung bean.

Figure 4

Relationship between Yield Attributing Parameters and Grain Yield







Conclusion

According to this study conducted at Tikapur, Kailali, application of molybdenum in combination with *Rhizobium* significantly increased most of the growth, root, yield and yield attributing parameters of mung bean. *Rhizobium* inoculation alone performed better than control in all the parameters as well as individual application of molybdenum also improved all the parameters and increasing level of molybdenum i.e. 2 kg ha^{-1} increased all the parameters significantly over control. Most effective results were obtained at *Rhizobium* inoculation and 2 kg ha^{-1} molybdenum in all the recorded parameters. Based on these findings, it can be concluded that *Rhizobium* along with molybdenum 2 kg ha^{-1} as a best combination for the cultivation of mung bean in Tikapur, Kailali.

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