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Short Communication

ORIGINAL ARTICLE

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Efficacy of Foliar Nutrient Applications on Growth, Yield and Economics of Mung Bean (*Vigna radiata L.*) under Hot Arid Conditions of Rajasthan

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ABSTRACT

The hot, arid conditions of Rajasthan often face multiple challenges such as low soil fertility, high temperatures, erratic rainfall, and poor nutrient-use efficiency. Conventional soil application of fertilizers is less effective because nutrient mobility is restricted due to limited soil moisture. To address these issues, foliar nutrition emerges as a potential solution for direct and rapid absorption of nutrients and to mitigate the impact of dry spells. Against this backdrop, a field experiment was conducted at the Agricultural Research Sub-Station, Nagaur, Agriculture University, Jodhpur, during Kharif 2021 to investigate the effect of foliar application of nutrients on enhancing growth, yield, and productivity, as well as mitigating the effects of dry spells during flower initiation (FI) and pod formation (PF) stages in mung bean (Vigna radiata L.). The eleven treatments included: absolute control (no foliar application); two foliar sprays of nitrogen urea @ 1% at FI and PF stages; two foliar sprays of water- soluble NPK (19: 19: 19) @ 1% at FI and PF stages; two foliar sprays of soluble KNO 3 @ 0.5% at FI and PF stages; two foliar sprays of borate @ 0.5% at FI and PF stages; and two foliar sprays of micronutrient six elements (Fe, Zn, Mn, Cu, Mo, B) @ 0.5% at FI and PF stages. The treatments were laid out in a randomized block design (RBD) with three replications. Results revealed that foliar application of the micronutrient six elements at 0. 5% concentration at FI and PF stages exhibited the highest growth and yield attributes of mung bean, including plant height at maturity (78. 1 cm), number of branches per plant (8. 2), number of active nodules at flowering (24. 6), number of pods per plant (61. 7), number of seeds per pod (13. 2), and 1000- grain weight (43. 8 g), leading to a grain yield of 1420 kg ha- 1. This treatment also resulted in significant improvements in net returns (₹ 71, 555 ha- 1), B:C ratio (2. 25), production efficiency (20. 9 kg ha- 1 day- 1), and monetary efficiency (₹1052 ha- 1 day- 1). The lowest values were observed in the no foliar application treatment. It was concluded that foliar application of six micronutrient elements at 0.5% concentration at FI and PF stages produces superior growth, yields, and returns under the hot, arid conditions of Rajasthan.

1 | INTRODUCTION

Mung bean (*Vigna radiata L.*), also known as green gram, green bean, moong bean, or golden gram, belongs to the Leguminaceae family. It is an important pulse crop in India and is believed to have originated there. India is the world's leading producer and consumer of pulses. With an area of 31.94 lakh hectares, mung bean is the third most important pulse crop in India, cultivated in nearly 10 % of the country's total pulse area. In India, the total production of mung bean is 15.06 lakh tonnes (Anonymous, ICAR-IIPR-2023-24a). Rajasthan has the highest area, production, and yield productivity of mung bean, with about 22.12 lakh hectares, 10.56 lakh tonnes, and 477 kg ha^{-1}, respectively (Anonymous, ICAR-IIPR-2023-24b). The main contributors to mung bean cultivation in terms of area and production are Rajasthan (46 % and 45% respectively), followed by Madhya Pradesh (9% and 14%), Maharashtra (9% and 8%), Karnataka (9% and 6%), Odisha (5% and 4%), Bihar (4% and 5%), Tamil Nadu (4% and 3%), Gujarat (3% and 4%), Andhra Pradesh (3% for both), and Telangana (2% for both) (Anonymous, Annual Report, ICAR-IIPR, 2022-23). In Rajasthan, the districts with the largest mung bean cultivation area are Nagaur (27%), Jodhpur (13.57%), and Pali (12.18%). Together, Nagaur, Jodhpur, and Pali account for more than 50% of Rajasthan's total mung bean cultivation area (Sharma *et al*. 2017).

It plays an important role as a food security crop due to its high nutritional value and ability to survive in severe environmental conditions such as arid and semiarid lands. According to the Food and Agriculture Organization

.(FAO, 2017), by 2050, the world's population is expected to surpass 10 billion, leading to a 50 percent increase in food demand, mainly in developing countries. Globally, micronutrient deficiencies affect about 38% of pregnant women and 43% of preschool-aged children. Reports indicate that over 30% of the world's population is anemic and suffers from hidden hunger (Dogra *et al.*, 2024). The global challenge lies in adopting sustainable crop production approaches to prevent soil and environmental degradation, which results in the loss of both major and micronutrients (Ram *et al*., 2022). Indian soils are deficient in micronutrients such as Zn, Fe, Mn, Cu, B, Mo, and S, with deficiency rates of 48, 12, 5, 4, 33, 13, and 41%, respectively (Boradkar *et al*., 2022). These crops are mainly cultivated for human consumption, flour production, and as sprouts or immature pods used as vegetables. The grains contain roughly 25-28% protein, 3.5-4.5% fiber, 4.5-5.5% ash, and 60-65% carbohydrates on a dry weight basis. They also provide nutrients such as vitamin A (94 µg), vitamin C (8 mg), iron (7.3 mg), calcium (124 mg), magnesium (189 mg), phosphorus (367 mg), and folate (549 mg) (Muchomba *et al*., 2023). In addition to being a rich source of protein, green gram roots are vital for soil nitrogen enrichment. The roots form nodules that facilitate atmospheric nitrogen fixation through rhizobium bacteria, enabling the crop to add approximately 30-40 kg N ha^{-1} in a single season. The vegetative parts, stalks, and husks also serve as valuable leguminous fodder for livestock. Furthermore, the crop functions as an important cover crop and is used in crop rotation systems (Dhakal *et al.*, 2016).

The hot, arid region of western Rajasthan presents a unique challenge for mungbean cultivation due to nutrient deficiencies (Basir *et al*., 2022), which are intensified by limited water availability, high temperatures, and poor soil conditions such as salinity or extreme pH. These conditions impede root-based nutrient uptake, making foliar nutrition an effective approach to overcome fixation and immobilization issues, thereby improving nutrient efficiency, especially for short-duration crops (Pochampally *et al*., 2021). Considering these factors, the present study was conducted to examine growth, yield, productivity, profitability, and to address the dry spell effect through foliar application of nutrients during the flower initiation and pod formation stages of mungbean under the hot, arid conditions of Rajasthan (India).

2 | MATERIALS AND METHOD

2.1 | Experimental Site and Weather Conditions

A field experiment was conducted during the Kharif (Rainy) season of 2021 at the Research farm of Agricultural Research Sub-Station, Nagaur, Agriculture University, Jodhpur, Rajasthan, situated at 27° 12' 7.24" N latitude, 73° 44' 2.18 E longitude, at an altitude of 302 m above the mean sea level. This location falls within agro-climatic zone II A, characterized as an arid and semi-arid transitional plain of the inland drainage zone in Rajasthan. The climate of this region is distinctly arid and semi-arid, marked by significant temperature fluctuations throughout the year. Average annual rainfall of 385 mm, about 80% of which falls during July–September from the southwest monsoon, while the rest is more or less equally distributed during the rest of the year. Weather data during the whole experimental period was recorded and presented as per -

HIGHLIGHTS

- Foliar spray of micronutrients (Fe, Zn, Mn, Cu) @ 0.5% during flowering and pod formation improved mung bean growth and yields.
- The recommended fertilizer dose with foliar application of 0.5% micronutrients (Fe, Zn, Mn, Cu, Mo, B) at flower initiation and pod formation showed the highest growth, yield, returns, and efficiency compared to no spray.

TABLE 1 Weather data during experiment period

Months and Years	Mean monthly maximum temperature (°C)	Mean monthly minimum temperature (°C)	Totally monthly rainfall (mm)	**Mean** Pet (mm)
July 2021	37	29	130	155
August 2021	36	28	126	131
Sept., 2021	33	26	175	109

2.2 | Soil Analysis and Status

The soil samples were drawn from the top 15 cm of soil depth. The experimental soil was sandy loam in texture, and soil pH, electrical conductivity (EC), organic matter, available phosphorus, potassium, and six element micronutrients are presented in Table 2.

TABLE 2 Initial soil nutrient status of the experimental site

Parameters	Parameters
Soil type	Sandy loam Soil
pH	8.2
EC (dSm^{-1})	0.35
OC (%)	0.15
N (kg ha^{-1})	219
P_2O_5 (kg ha^{-1})	15
K_2O (kg ha^{-1})	217
Fe (mg kg^{-1})	2.56
Zn (mg kg^{-1})	0.504
Cu (mg kg^{-1})	0.178
Mn (mg kg^{-1})	2.21
B (mg kg^{-1})	2.34
Mo (mg kg^{-1})	0.64

2.3 | Treatments and Experimental Details

Eleven treatments were applied in a randomized block design (RBD) with three replications. These included: T1, an untreated control; T2, a single foliar spray of 1% nitrogen urea at flower initiation (FI); T3, two sprays of 1% nitrogen urea at FI and pod formation (PF); T4, one spray of 1% soluble NPK (19:19:19) at FI; T5, two NPK sprays at FI and PF; T6, one spray of 0.5% soluble KNO3 at FI; T7, two KNO3 sprays at FI and PF; T8, one spray of 0.5% borate at FI; T9, two borate sprays at FI and PF; T10, one spray of 0.5% micronutrient mix of Fe, Zn, Mn, Cu, Mo, and B at FI;

T11, two micronutrient sprays at FI and PF. Each plot measured 4 x 3 m² (gross) and 3 x 2.6 m² (net). The micronutrient mix was a ready-made combination with Zn 5%, Fe 2%, Mn 2%, Cu 0.5%, B 0.5%, and Mo 0.05%. Borate was di sodium tetra borate penta hydrate (20%), with potassium nitrate (13% nitrate N, 46% K_2O), and soluble urea nitrogen (46%) in water. Applications were made at 500 liters per hectare, using a knapsack sprayer with a flat-fan nozzle, at FI and PF stages, with a 0.5% solution.

2.4 | Crop Management Practices

Certified seeds of Mung bean variety "GM-4" were obtained from the Agricultural Research Sub-station, Nagaur, and manually sown using a 30 x 10 cm planting grid with a seed rate of 15 kg per hectare on July 18, 2021. The crop was grown entirely under rainfed conditions. A recommended fertilizer dose of 40:20 kg N:P_2O_5 per hectare was applied as a basal dose through Urea and Di-ammonium phosphate (DAP), following the local crop management practices. Cultural practices suitable for the agro-climatic zone were maintained throughout the mung bean growth cycle, except for the experimental foliar nutrient management technique. Activities such as gap filling, thinning, irrigation, weeding, mulching, and pest control were carried out as needed to promote optimal plant growth and development.

2.5 | Data Recording

Observations on the number of nodules/plants, plant height (cm), number of branches/plants, number of pods/plants, and number of seeds/pods were conducted by randomly selecting five representative plants from each plot within each replication according to Idnani and Singh (2008). Additionally, test weight (g) and overall yield were documented. The important growth parameters, yield attributes, and yield were recorded following standard procedures. To calculate the net returns for each treatment, the total cost of cultivation was subtracted from the gross returns. The total cost of cultivation was calculated based on input and labor requirements during the experiment. Gross returns were estimated according to the minimum support price of the last three years prevailing at the time of the experiment, and the benefit-cost ratio was calculated from gross returns to the cost of cultivation. Harvesting took place on October 4, 2021. Grain and straw yields were recorded from the net plot area of each treatment. Harvest index (HI) was calculated as:

$$\text{Harvest Index (\%)} = \left[\frac{\text{Grain yield }\left(\frac{\text{kg}}{\text{ha}}\right)}{\text{Biological yield }\left(\frac{\text{kg}}{\text{ha}}\right)}\right] \text{x}100$$

Benefit-cost (B:C) ratio was computed to assess the economic viability of different treatment combinations as:

$$\text{B:C Ratio} = \frac{\text{Net Returns (₹ ha}^{-1}\text{)}}{\text{Cost of cultivation (₹ ha}^{-1}\text{)}}$$

Monetary Efficiency was calculated as:

$$\text{Monetary efficiency (₹ ha}^{-1}\text{ day}^{-1}\text{)} = \frac{\text{Net returns obtained (₹ ha}^{-1}\text{)}}{\text{Number of growing days (Days)}}$$

2.6 | Statistical Analysis

The experimental data were subjected to statistical analysis employing standard techniques of analysis of variance (ANOVA). Mean analysis of the data was conducted, adhering to the methodology outlined by Gomez and Gomez (1984). Furthermore, mean comparison was carried out based on critical differences at the 5% probability level.

3 | RESULTS AND DISCUSSION

3.1 | Effect of Foliar Application of Nutrients on Growth and Yield traits

Foliar application of different nutrients at flower initiation (FI) and pod formation (PF) stages significantly affected the growth, yield attributes, and yield parameters of mungbean. Among various treatments, foliar application of soluble nitrogen urea, NPK, KNO_3, borate, and micronutrient six elements showed a significant increase in plant growth, yield attributes, economic returns, production, and efficiency over the control (Table 3). The highest values of plant height at maturity (78.1 cm), number of branches per plant (8.2), active nodules at flowering (24.6), pods per plant (61.7), seeds per pod (13.2), and 1000-grain weight (43.8 g) were observed when treated with foliar application of micronutrient six elements (Fe, Zn, Mn, Cu, Mo, B) at 0.5% concentration during flower initiation and pod formation stages (Table 3). Conversely, the lowest values for plant height (63.4 cm), branches per plant (6.7), active nodules at flowering (21.8), pods per plant (46.7), seeds per pod (10.9), and 1000-grain weight (40.5 g) were found in mungbean grown without foliar application. This improvement can be attributed to the increased availability of both macro and micronutrients to the plants through foliar nutrient application. This enhanced nutrient availability facilitated early root growth, cell multiplication, and nutrient absorption from deeper soil layers. Consequently, these factors contributed to increased plant height, improved food synthesis, and better resource partitioning (Dhaliwal et al. 2023). These findings align with those of Zafar et al. (2023), who reported significant improvements in the number of branches, plant height, pods per plant, pod length, seeds per pod, 1000-grain weight, and grain yield of mungbean with foliar application of Zn at 0.3%. Zinc plays a complex role in plant physiology by regulating water uptake and its effective utilization by plants (Bahadari *et al.* 2020).

The yield data showed that applying micronutrient elements (Fe, Zn, Mn, Cu, Mo, B) at 0.5% concentration during flower initiation and pod formation stages resulted in the highest seed yield of 1420 kg ha^{-1} (Table 3). These treatments also significantly improved stalk yield (2290 kg ha^{-1}), biological yield (3710 kg ha^{-1}), and harvest index (38.3%). Following this, foliar application of borate at 0.5% during the same stages yielded 1270 kg ha^{-1} of seed, 2310 kg ha^{-1} of straw, a biological yield of 3580 kg ha^{-1}, and a harvest index of 35.5%. The lowest values for seed yield (1061 kg ha^{-1}), straw yield (2040 kg ha^{-1}), biological yield (3410 kg ha^{-1}), and harvest index (32.6%) were observed in mungbean grown without foliar nutrient application (Table 1 & 2).

Foliar application of microelements might have increased plant height, leaf area index, 1000-grain weight, totalchlorophyll content, grain protein percentage, proline accumulation, under both stress and non-stress conditions (Amirani and Kasraei, 2015). Applying micronutrient elements (Fe, Zn, Mn, Cu, Mo, B) at 0.5% during flower initiation and pod formation significantly increased the number of branches per plant, pods per plant, seeds per plant, active nodules per plant, seed yield, and harvest index, showing respective increases of 21.8%, 32.1%, 21.1%, 12.8%, 33.9%, and 11.9% over plants without foliar nutrient application.

TABLE 3 Effect of foliar nutrient application on growth and yield traits of mungbean

Treatments	Plant height at maturity (cm)	Number of branches/ plants	Number of active nodules at flowering	Number of pod/plant	Number of seeds/pod	1000-grain weight (gm)	Seed yield ($kgha^{-1}$)	Stalk yield ($kgha^{-1}$)	Biological yield ($kgha^{-1}$)	Harvest index
Absolute control (Without foliar application)	63.4	6.7	21.8	46.7	10.9	40.5	1061	2040	3100	34.2
Foliar spray of nitrogen Urea @ 1% at FI stage	72.7	7.8	23.6	50.5	11.4	40.7	1185	2150	3335	35.5
Foliar spray of nitrogen Urea @ 1% at FI and PF stage	73.5	7.9	23.9	51.5	11.6	41.9	1205	2150	3355	35.9
Foliar spray soluble NPK (19:19:19) @ 1% at FI stage	73.1	7.9	24.3	50.3	11.7	42.1	1205	2260	3465	34.8
Foliar spray soluble NPK (19:19:19) @ 1% at FI and PF stage	75.7	8.0	24.3	51.9	12.1	41.7	1230	2270	3500	35.1
Foliar spray of soluble KNO_3 @ 0.5% at FI stage	71.1	8.0	24.4	51.2	12.2	41.9	1200	2320	3520	34.1
Foliar spray of soluble KNO_3 @ 0.5% at FI and PF stage	72.1	8.0	24.5	53.0	11.9	42.4	1240	2260	3500	35.4
Foliar spray of borate @0.5 % at FI stage	73.7	8.1	24.6	53.6	12.1	44.4	1230	2300	3530	34.8
Foliar spray of borate @ 0.5 % at FI and PF stage	74.8	8.1	24.6	53.9	12.3	43.3	1270	2310	3580	35.5
Foliar spray of micronutrient 6'S element (Fe, Zn, Mn, Cu, Mo, B) @0.5 % at FI stage	72.9	8.1	24.9	54.2	12.4	43.6	1275	2240	3515	36.3
Foliar spray of micronutrient 6'S element (Fe, Zn, Mn, Cu, Mo, B) @0.5 % at FI and PF stage	78.1	8.2	24.6	61.7	13.2	43.8	1420	2290	3710	38.3
Sem±	2.5	0.33	0.81	2	0.24	0.34	41	62	74	0.84
CD (*P*=0.05)	7.6	1.06	2.51	6.1	0.71	1.03	123	165	221	2.53

TABLE 4 Effect of foliar nutrient application on Economics of mungbean production

Treatments	Cost of Cultivation (₹ ha^{-1})	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	Benefit cost ratio	Production efficiency (kg ha^{-1} day^{-1})	Monetary efficiency (₹ ha^{-1} day^{-1})
Absolute control (Without foliar application)	26000	77115	5115	1.97	15.6	752
Foliar spray of nitrogen Urea @ 1% at FI stage	27530	86209	58679	2.13	17.4	863
Foliar spray of nitrogen Urea @ 1% at FI and PF stage	29060	87664	58604	2.02	17.7	862
Foliar spray soluble NPK (19:19:19) @ 1% at FI stage	27600	87664	60064	2.18	17.7	883
Foliar spray soluble NPK (19:19:19) @ 1% at FI and PF stage	29200	89483	60283	2.06	18.1	887
Foliar spray of soluble KNO_3 @ 0.5% at FI stage	27600	87300	59700	2.16	17.6	878
Foliar spray of soluble KNO_3 @ 0.5% at FI and PF stage	29200	90210	61010	2.09	18.2	897
Foliar spray of borate @0.5 % at FI stage	27950	89483	61533	2.20	18.1	905
Foliar spray of borate @ 0.5 % at FI and PF stage	29950	92393	62443	2.08	18.7	918
Foliar spray of borate @ 0.5 % at FI and PF stage	28875	92756	63881	2.21	18.8	939
Foliar spray of micronutrient 6'S element (Fe, Zn, Mn, Cu, Mo, B) @0.5 % at FI and PF stage	31750	103305	71555	2.25	20.9	1052
Sem±	-	-	-	-	0.41	28.6
CD (*P*=0.05)	-	-	-	-	1.25	85.8

**Gross return calculated based on MSP prevalent in kharif -2021 (₹7,275 per quintal) of mung bean*
Input cost: One foliar spray cost (₹ 1500 ha^{-1}): Micronutrient 6, s element (₹ 550 $liter^{-1}$): Boron (₹ 180 kg^{-1}): Urea (₹ 5.5 kg^{-1}): NPK (₹ 10 kg^{-1}) and KNO_3 (₹ 10 kg^{-1})

The same results were obtained under the combined application of ZnSO4.7H2O (0.5%), FeSO4.7H2O (0.5%), and borax (0.1%), which could be considered the most effective combination for enhancing yield, nutritional quality, and economic returns of mung bean (Dhaliwal *et al*., 2023). A significant increase in yield and yield attributes due to foliar application of ferrous sulfate, zinc sulfate, and borax might be attributed to increased leaf area (Ali *et al*., 2008). The addition of zinc and ferrous to the soil may also have caused higher activation of micronutrients, mainly due to their positive effects in mobilizing native nutrients to improve their availability, as well as providing better nutrition over a longer period. The coactive effect of both nutrients on yield components (Bahadari *et al*., 2020) could also contribute to this improvement. Such effects might also be attributed to the favorable influence of these nutrients on metabolism and biological activity, as well as their stimulatory effects on photosynthetic pigments and enzymatic activity, which in turn increase vegetative growth (Ali *et al*., 2014). Similarly, foliar fertilization of NPK with Fe, Zn, and Mn has been shown to increase vegetative growth, yield components, and nutrient concentrations in cowpea plants (Ali *et al.*, 2014).

3.2 | Effect of foliar spray of nutrients on economics, production and monetary efficiency

The economic analysis of mung bean cultivation as influenced by foliar application of various soluble nutrients such as nitrogen urea, NPK, KNO3, borate, and micronutrient 6's element showed that the highest cost of cultivation was observed for micro nutrient 6's element (₹ 31,750 ha^{-1}), followed by borate application (₹ 29,950 ha^{-1}). Conversely, the lowest cost was seen in plots without foliar application (₹ 26,000 ha^{-1}) during flower initiation and pod formation stages. The highest gross return (₹1,03,305 ha^{-1}) and net return (₹71,555 ha^{-1}) were achieved with foliar application of micro nutrient 6's element (Fe, Zn, Mn, Cu, Mo, B) at 0.5% concentration during flower initiation and pod formation stages, while the lowest gross return (₹77,115 ha^{-1}) and net return (₹51,115 ha^{-1}) occurred in plots without foliar application (Table 4). Similar findings were reported by Diwedi *et al*. (2024). The highest B:C ratio (2.25), production efficiency (20.9 kg ha^{-1} day^{-1}), and monetary efficiency (₹1052 ha^{-1} day^{-1}) were also observed with foliar application of micronutrient 6's element at 0.5% concentration during flowering initiation and pod formation stages. This was followed by foliar application of borate, which resulted in production efficiency of 18.7 kg ha^{-1} day^{-1} and monetary efficiency of ₹918 ha^{-1} day^{-1}. The minimum production efficiency (15.5 kg ha^{-1} day^{-1}) and monetary efficiency (₹752 ha^{-1} day^{-1}) were recorded in plots without foliar application. Similar results were also reported by Dhaliwal et al. (2023), emphasizing the benefits of integrated nutrient management combined with an optimum irrigation level of 0.8 IW/CPE to enhance input efficiency (Bandyopadhyay *et al*., 2021).

4 | CONCLUSIONS

The study clearly emphasizes the importance of foliar nutrient application during flowering and pod formation in mungbean to boost growth, yield, and profitability. The recommended fertilizer doses with foliar application of soluble nutrients at these stages—such as urea @ 1%, NPK (19:19:19) @ 1%, KNO3 @ 0.5%, and micronutrients including Fe, Zn, Mn, Cu, Mo, B at 0.5%—showed superior performance in growth, yield, economic returns, and production efficiency compared to the control. Therefore, applying a 0.5% solution of micronutrient 6's element (Fe, Zn, Mn, Cu, Mo, B) during flowering and pod formation can be an effective strategy for increasing growth, yield, and economic returns of mungbean, especially under the hot, arid conditions of Rajasthan (India).

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CONFLICT OF INTEREST

This research is conducted ethically and in compliance with relevant guidelines and regulations. We, all the authors, have declared that no conflict of interest exists that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

Available with the author on request.

AUTHOR CONTRIBUTION

This work was carried out as an in-house activity under the ZREAC recommendation by RB.

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