Plant Bulletin, Vol 4, (2) 2025: 137-148 ISSN: 2959-3379 (Print), 2959-3387 (Online)

Research Article

Evaluating the Role of Seed Rate in Modulating Growth, RUE and Yield of Mung Bean Cultivars

Muhammad Daod Khan[1], Shahid Nazeer[1,2*], Rabia Nadeem[3], Asif Mehmood[1], Muhammad Saud Khan[4], Raza Mustafa[5], Muhammad Hur[1], Abdul Rehman[6] and Muhammad Usman Arshad[1]

[1]Department of Agronomy, University of Agriculture, Faisalabad, 38000, Pakistan
[2]Barani Agricultural Research Institute, BARI Chakwal
[3]Agronomic Research Institute, Faisalabad
[4]College of Life Science and Technology Tarim University Xinjiang Alaer China
[5]University of Poonch Rawalakot Azad Jammu & Kashmir, Pakistan
[6]Institute of Agricultural Resources and Regional Planning (CAAS), Beijing, China
Correspondence: nazeershahid46@gmail.com

ABSTRACT
Optimizing seed rate plays a vital role in enhancing crop performance and productivity. Study was investigated with factors as two cultivars (PRI-NIAB Mung 2022 and PRI Mung 2018) and 4 seed rates (15, 20, 25 and 30 kg ha^{-1}) were used in a randomized complete block design with factorial arrangement field experiment at the University of Agriculture, Faisalabad. The collected data showed that all growth and yield characteristics were strongly impacted by seed rate. More grain yield (1301.7 kg ha^{-1}), biological yield (8.35 t ha^{-1}), total dry matter (573.2 g m^{-2}) and harvest index (18.14%) obtained under seed rate of 20 kg ha^{-1}. 25 kg ha^{-1} produced the highest LAI (2.90), but 15 kg ha^{-1} produced the most pods per plant (51.26), grains per pod (11.73), and 1000-grain weight (60.33 g). In most metrics, including RUE, PRI-NIAB Mung 2022 fared better than PRI Mung 2018. The study overall conclusion is that, given the agro climatic conditions of Faisalabad, 20 kg ha^{-1} with PRI-NIAB Mung 2022 is optimal for enhancing mung bean yield.

Keywords: Mungbean**,** seed rate, yield, PRI NIAB Mung 2022, PRI Mung 2018.

INTRODUCTION

Agriculture is vital for feeding people, boosting the economy, and helping rural areas grow in Pakistan. It makes up 22.9% of our economy and provides jobs for 37.4% of our workers. But several challenges are putting pressure on how much food we can grow. These include less land available for farming, changing weather patterns, and more people moving from villages to cities. On top of these, our population is rising quickly and our diets are changing. To keep up, we need better ways to manage our crops and we must start growing more high-yield, nutrient-rich varieties. Mung bean (*Vigna radiata* L.) stands out as a fast-growing pulse crop that can help.

It is popular because it is packed with nutrients, enriches the soil and can be grown in many different regions (Ijaz et al., 2023a). It is the third most important pulse crop in the country, after chickpea and pigeon pea (Nair et al., 2019). Mung bean is especially prized for its 28.5% protein, easy-to-digest carbs, healthy fats, fiber, and important minerals like potassium, calcium, iron and zinc (Ali et al., 2021).

Mung bean thrives in hot weather and does well in loamy soils, even in saline and alkaline conditions. The crop goes from seed to harvest in just 75 to 90 days, making it an excellent fit in cereal-based cropping systems, whether rotated with wheat or rice. As a bonus, mung bean improves soil health by fixing nitrogen from the air, which helps reduce the fertilizer needs of the next crop (Sajjad et al., 2024; Khaliq et al., 2023). Still, mung bean farmers in Pakistan are not getting the yields that the crop is capable of or that researchers see in other countries. The main reasons are the use of older, low-yielding seed varieties, planting at the wrong time, not enough or too many

Article History
Received: July 30, 2025, Accepted: October 06, 2025, Published: November 11, 2025.

plants per area and other poor farming practices (Sajjad et al., 2025a; Nazeer et al., 2024). Among these, seed rate is perhaps the most important. The number of seeds planted per acre affects how many plants grow, how much light the canopy captures, how plants compete for nutrients and water, and, in the end, how much grain they produce. The right seed rate gives a uniform plant stand, a well-developed canopy, and efficient use of resources, which together help keep weeds in check (Sajjad et al., 2025b; Rehman et al., 2025). On the other hand, planting too many seeds can crowd the plants, increase competition, raise the chances of disease, and lead to a higher number of empty or unfilled pods (Singh and Kumar, 2014). For these reasons, it is crucial to fine-tune the seed rate for each mung bean variety if farmers want to reach the crop's full yield potential (Nazeer et al., 2020).

One key concept that impacts crop yield is radiation use efficiency, or RUE. RUE measures how well a plant turns the sunlight it catches into fresh plant material. It is usually reported in grams of dry matter produced for every megajoule of sunlight that the crop intercepts. RUE reflects how good the plant is at photosynthesis, and it is shaped by both its genes, like how big its leaves are and how its branches grow and by farming choices, like how many seeds are sown and how far apart the rows are (Ahmed et al., 2023; Murchie et al., 2018). When the seed rate is just right, the plant canopy can catch more sunlight, grow more dry matter, and boost the final yield (Geetika et al., 2022). During the crop's life cycle, the share of sunlight that the canopy catches changes and this share is closely linked to the final amount of plant material and the seed yield (Geetika et al., 2022; Shakeel et al., 2021). Sowing more seeds can usually thicken the canopy and capture more light in the early growth phase, which is a good thing. However, packing in too many seeds can hurt RUE. Crowded plants might block light from getting to the lower leaves, leading to more energy wasted on respiration. On the flip side, sowing too few seeds can leave gaps in the canopy and miss out on sunlight. The key is to find the right seed rate that gives the canopy enough density to catch light but not so many plants that they compete fiercely with one another. Getting this balance right is essential for boosting growth and yield in mung bean varieties. Mung beans are well-known for their nutritional and farming advantages, yet we still lack detailed studies that show how different seed rates shape growth, light capture, and overall yield for local cultivars. Learning how seed rate and these factors interact can guide both farmers and scientists in crafting recommendations that boost mung bean output while being environmentally sound. Prior research has looked at how choosing the right cultivar and basic farming techniques affect yields, but we still don't fully understand how changing seed rates influences growth, light use, and yield for various mung bean types in our specific climate. Seed rates play a key role in how mung bean plants develop, how effectively they capture sunlight, and how much they produce at harvest. This study aims to fill that gap by testing a range of seed rates on several mung bean cultivars, measuring their growth, how well they use light, and their final yield. The goal is to find the best seed rate and cultivar pair that performs well in our agricultural land.

MATERIALS AND METHODS

Area and Field Demonstration Details

A field experiment was carried out at the University of Agriculture, Faisalabad using a randomized complete block design (RCBD) with three replications to evaluate the effects of two mung bean cultivars and four different seed rates on crop growth and yield. Size of net plot measured 3 m × 1.5 m, with a consistent row to row distance of 30 cm used throughout the experiment. Soil quality analysis were collected before planting at two depths by augering. Weather data obtained during the trial are summarized in Table 1. To assess the primary and secondary effects on mung bean performance, two cultivars PRI-NIAB Mung 2022 (V1) and PRI Mung 2018 (V2) were sown at four seed rates such as 15 (S1), 20 (S2), 25 (S3) and 30 kg ha^{-1}.

Table 1. Weather attributes

Months	Average temp. (°C)	Rainfall (mm)	Relative humidity (%)	Sunshine Radiation (Hours)
June	29.9	3.05	44.55	25.14
July	31.9	5.89	68.14	19.19
August	32.14	0.69	52.24	22.19

Table 2. Soil Quality Analysis

Parameters	Units	Optimum Ratio	Results	Remarks
Sand	%	25-40	42	Loam
Silt	%	40-60	41	
Clay	%	0-30	29	

Saturation percentage	%	25-45%	33.9	---
Bulk density	mg m^{-3}	1.45-1.60	1.521	Moderate
EC	dS m^{-1}	1.10-1.80	1.351	High
pH	---	8.29-8.35	8.351	Mildly alkaline
Total organic content	%	0.59-0.80	0.721	Moderate
Total N	%	0.05-0.059	0.049	High

Crop Husbandry

To get the field ready, we used a rotavator, then cultivated twice and finished with planking until the soil was nice and fine for planting. The rows were set 30 centimeters apart. Using seeds provided by the Ayub Agricultural Research Institute in Faisalabad, we planted the mung bean types for the experiment. Three irrigations were planned: the first during plant emergence, the second during blooming, and the third during pod filling. We used 25 kilogram of phosphorus, 100 kg of nitrogen, and 100 kg of potassium of fertilizer per acre. We split the nitrogen into two parts: half was mixed with the complete phosphorus and potassium at the first irrigation, and the other half went in with the second irrigation. To keep weeds in check, we used the recommended pre- and post-emergence herbicides. All other farming steps followed standard practices. We harvested when about 90% of the pods were mature, bundled the plants, and let them dry in the sun for ten days until the grain moisture dropped to 12%. Then we separated the pods and threshed the seeds.

Observations and Data Collection

Growth and productivity measurement followed standard protocols. Each experimental plot was divided into two parts: one was used for regular sampling and the other was left on at end of harvest. First sampling started 25-30 days after planting and was done every 14 days until the plants are fully mature. A one-foot-square area was clipped for each sampling, and fresh weights were recorded immediately in the field. From this bulk sample, leaf area was measured using a leaf area meter from a 5 g leaf sample. A 5 g piece of leaf was obtained from this bulk sample and measured by using a leaf area meter. Five plants were marked in each plot to document the number of days' till harvesting. Fresh and dry weights were connected to determine the TDM. Leaf area divided by ground area was used to calculate LAI, and the average LAI times the duration between sample dates was LAD. The change in dry weight and leaf area over time was used to calculate CGR and NAR. With intercepted radiation approximated using Beer's Law, RUE was determined by connecting the total intercepted photo-synthetically active radiation to dry matter and grain yield. When the crops were mature, each plot was harvested to measure final yield and its parts.

To collect data on plant population, a square frame called a quadrat was used to count how many plants grew in each square meter. I then chose five plants at random and measured each one from the ground to the tallest leaf tip to get the average height. From additional plants, I counted how many branches each had, how many pods grew on each plant, and how many grains were in each pod. I also measured the weight of 1,000 grains to see how heavy the grains were when dry.

For the grain and biological yields, I collected the entire above-ground biomass and the harvested grain and then weighed each. Finally, I calculated the harvest index by dividing the grain yield by the total biomass and multiplying by 100 to get the percentage. This percentage tells us how much of the total plant weight was made up of grain.

Statistical Analysis

The acquired data statistically analyzed using Fishers Analysis of Variance technique. The statistical significance of treatment means was assessed at 5% level using the LSD test (Steel et al., 1997).

RESULTS AND DISCUSSION

Impact of Cultivars and Seed Rates on the Mung Bean's Leaf Area Index (LAI)

In the study, the LAI means for different seed rates showed that the highest value, 2.92, occurred at 25 kg per hectare, while the lowest value, 1.32, came from a seed rate of 15 kg per hectare (Figure 1). Mung bean cultivars also affected LAI. The PRI NIAB Mung 2022 recorded the highest LAI at 2.14, while PRI Mung 2018 recorded the lowest at 2.03. A low seed rate led to fewer leaves and a reduced LAI, which in turn lowered the final yield. Higher seed density increased competition for light among plants, prompting them to produce larger leaves and a denser canopy.

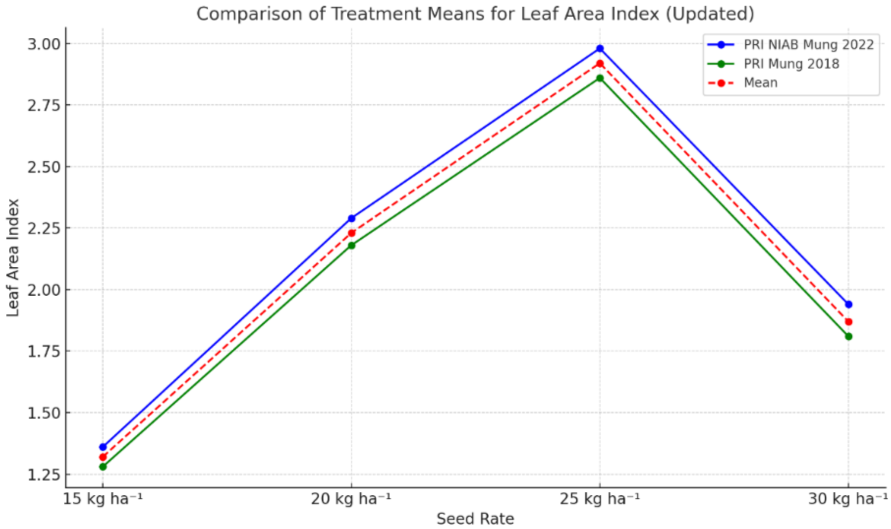

Figure 1. Impact of cultivars and seed rates on the mung bean's leaf area index (LAI)

Impact of Cultivars and Seed Rates on Mung Bean Leaf Area Duration (LAD) (days)

Leaf area duration (LAD) is the time a crop leaves can actively photosynthesize. We calculated the LAD using Hunt's formula. The longest LAD for the PRI NIAB Mung variety was recorded in 2022, while the shortest came from PRI Mung in 2018 (Figure 2). Differences in LAD were noticed when we changed the seed rates. The best LAD of 71.903 days came from a seed rate of 20 kg per hectare, followed by 25 kg per hectare (61.150 days), 15 kg per hectare (50.220 days), and the lowest from a rate of 30 kg per hectare (47.788 days). This means PRI NIAB Mung 2022 gave the best performance at a seed rate of 20 kg per hectare.

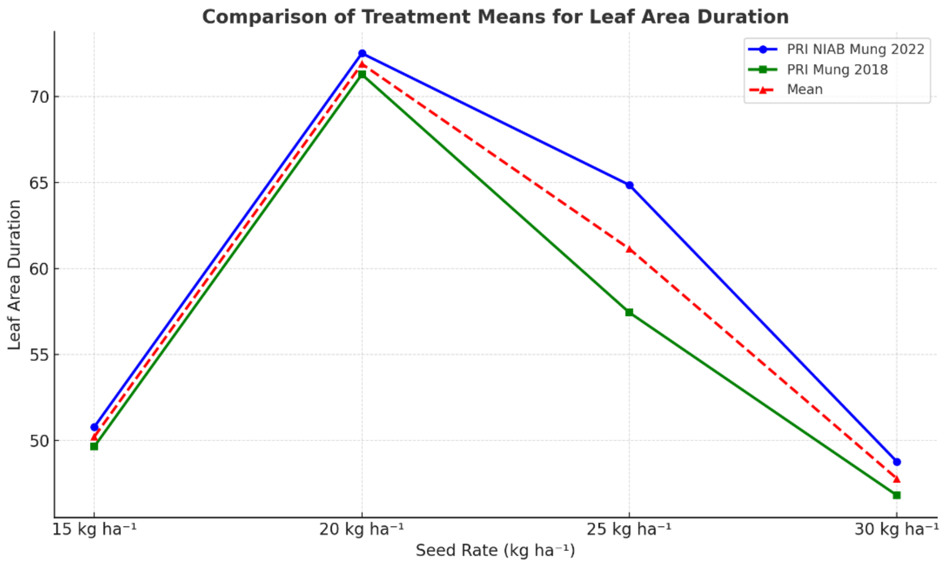

Figure 2. Impact of cultivars and seed rates on mung bean leaf area duration (LAD) (days)

Impact of Cultivars and Seed Rate on Mung Bean Dry Matter (g m^{-2})

The trial showed that the highest average TDM was 572.50 g m^{-2} at the 20 kg ha^{-1} seed rate. It was followed sequentially by 25, 15, and 30 kg ha^{-1}. The less average TDM, 451.50 g m^{-2}, came from the 30 kg ha^{-1} seed rate (Figure 3). The TDM at 15 kg ha^{-1} was 503.77 g m^{-2} and at 25 kg it was 536.13 g m^{-2}. Yield was positively related to leaf area and total dry matter. PRI NIAB Mung 2022 gave the highest yield at a seed rate of 20 kg ha^{-1}. Its TDM decreased when the seed rate rose past this optimum rate.

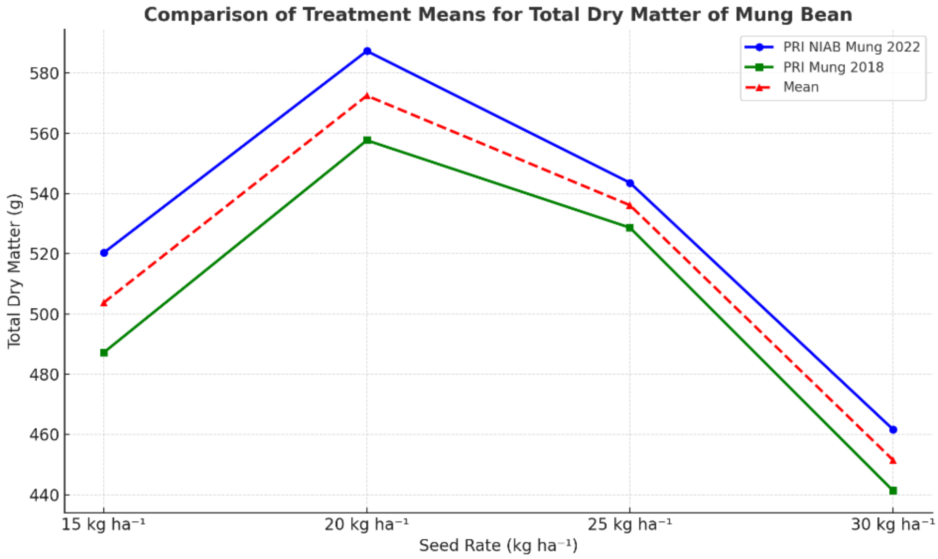

Figure 3. Impact of cultivars and seed rate on mung bean dry matter (g m^{-2})

Impact of Cultivars and Seed Rates on Mung Bean Crop Growth Rate (g m^{-2} day^{-1})

At a seed rate of 20 kg ha^{-1}, the crop recorded the highest average crop growth rate (CGR) of 13.110 g m^{-2} day^{-1}. In contrast, the lowest rate of 8.605 g m^{-2} day^{-1} was measured at 30 kg ha^{-1}. CGR indicates how quickly a crop adds new biomass (Figure 4). We found that seed rate, variety, and their interaction all had a significant impact on CGR. Different cultivars also affected CGR; PRI NIAB Mung 2022 recorded the highest rate at 11.275 g m^{-2} day^{-1}, followed by PRI Mung 2018 at 10.658 g m^{-2} day^{-1}. Both seed rate and varietal differences revealed a downward trend in crop growth. PRI NIAB Mung 2022 surpassed PRI Mung 2018, possibly due to higher LAI.

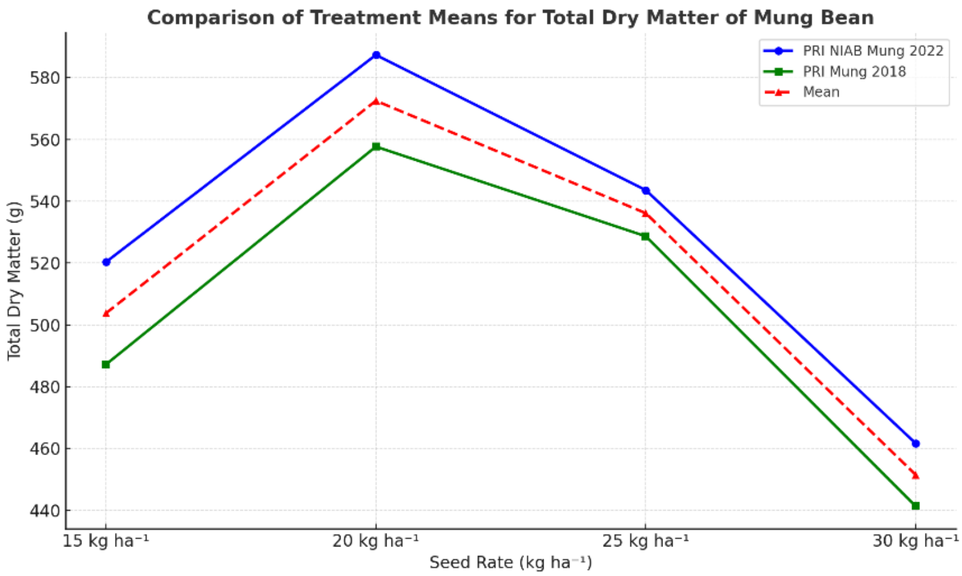

Figure 4. Impact of cultivars and seed rates on mung bean crop growth rate (g m^{--2} day^{-1})

Net Assimilation Rate (g m^{-2} day $^{-1}$) of Mung Bean as Influenced by Cultivar and Seed Rate

In tests with different seed rates, the 20 kg ha^{-1} rate gave the highest NAR at 9.07 g m–2 day^{-1}, while the 30 kg ha^{-1} rate produced the lowest (Figure 5). The 20 kg ha^{-1} plants captured more light and used nutrients more effectively, turning them into organic matter and reaching maturity in a shorter time. Among the varieties, PRI NIAB Mung 2022 achieved the top NAR at 7.95 g m^{-2} day^{-1}, while PRI Mung 2018 recorded a low of 7.49 g m^{-2} day^{-1}. PRI NIAB Mung 2022 outperformed PRI Mung 2018 at every seed rate tested.

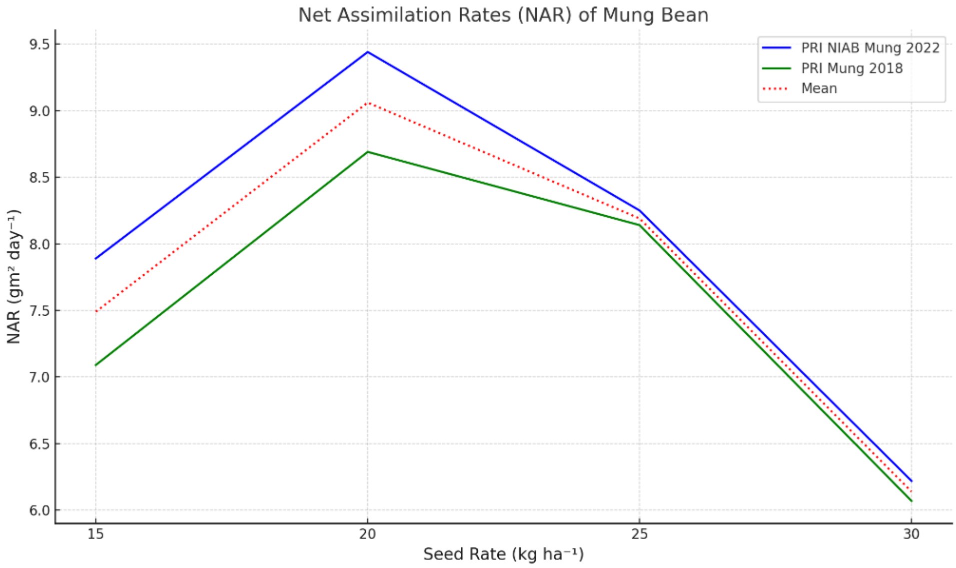

Figure 5. Net Assimilation Rate (g m^{-2} day $^{-1}$) of Mung Bean as Influenced by Cultivar and Seed Rate

Radiation Use Efficiency (g MJ^{-1}) for Total Dry Matter in Mung Bean as Affected by Seed Rate and Cultivar

Radiation use efficiency (RUE) measures how well a crop captures photosynthetically active radiation (PAR) and converts it into biomass, or total dry matter (TDM) and yield. We used least squares fitting to relate final TDM to cumulative intercepted PAR (Sa) for each treatment (Figure 6). The best RUE for TDM, at 2.85 g MJ^{-1}, came from a seed rate of 20 kg ha^{-1}, while the lowest, at 1.79 g MJ^{-1}, came from 30 kg ha^{-1}. The 2022 PRI NIAB Mung variety led in average RUE for TDM, recording 2.42 g MJ^{-1}, slightly ahead of PRI Mung 2018. For grain, the highest RUE was also in PRI NIAB Mung 2022, hitting 0.70 g MJ^{-1}, while PRI Mung 2018 lagged at 0.60 g MJ^{-1}; the difference among the cultivars was statistically significant. All four seed rates produced highly significant changes in grain RUE. The best mean RUE for grain yield came at 20 kg ha^{-1}, reaching 0.85 g MJ^{-1} and the lowest was at 30 kg ha^{-1}, dropping to 0.42 g MJ^{-1}.

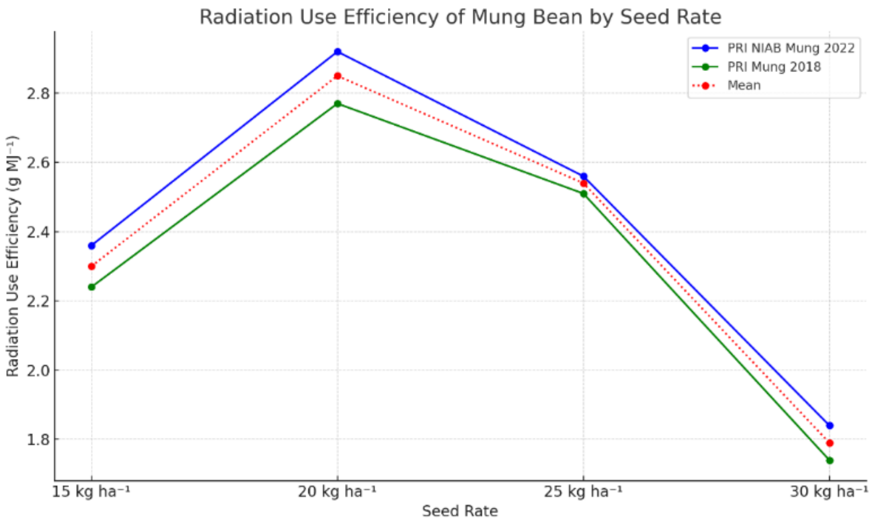

Figure 6. Radiation Use Efficiency (g MJ^{-1}) for Total Dry Matter in Mung Bean as Affected by Seed Rate and Cultivar

Response of Mung Bean Plant Height (cm) to Seed Rate and Cultivar Differences

Seed rate had a strong effect on plant height. The tallest plants reached an average of 65.72 cm at a seed rate of 30 kg ha^{-1}, while the shortest plants measured 48.90 cm at a rate of 15 kg ha^{-1} (Figure 7). Among the different cultivars tested, PRI NIAB Mung 2022 produced the tallest plants at the 30 kg ha^{-1} rate, closely followed by PRI Mung 2018. Height measurements show a clear trend: as the seed rate increased, the plants tended to grow taller, peaking at 30 kg ha^{-1}, with a slightly shorter average at 25 kg ha^{-1}. Conversely, the 15 kg ha^{-1} rate yielded the shortest plants, with height similar to those at 20 kg ha^{-1}.

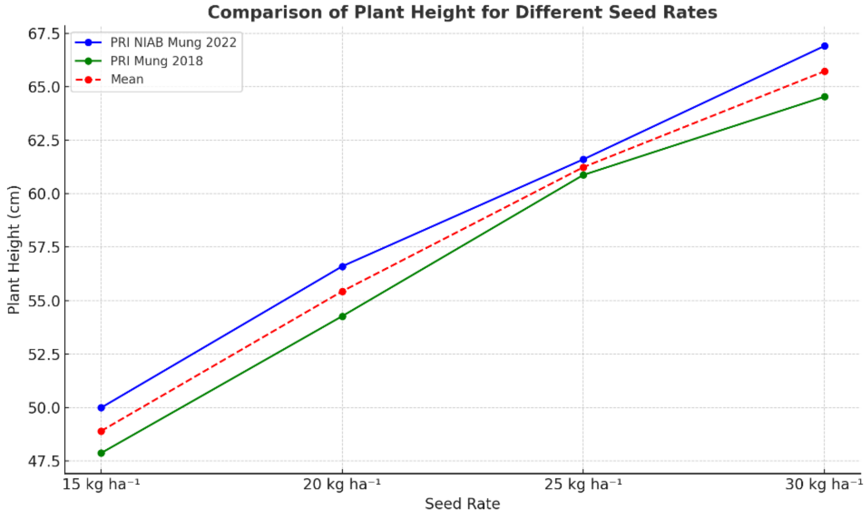

Figure 7. Response of Mung Bean Plant Height (cm) to Seed Rate and Cultivar Differences

Impact of Cultivars and Seed Rates on the Number of Pods Produced by a Mung Bean Plant

Grain yield in legumes mainly depends on how many pods each plant carries. The highest pod count we recorded was 51.27 pods at a 15 kg per hectare seed rate, while the lowest was 21.75 pods at 30 kg (Figure 8). The drop in pods per plant at the higher seed rate likely comes from there being too many plants in the same space, which creates tough competition for nutrients, room, and moisture. In contrast, the cultivar PRI NIAB Mung 2022 at 15 kg per hectare gave the best pod count, averaging 52.87 pods, while PRI Mung 2018 at 30 kg per hectare had the lowest average of 18.17 pods. The superior pod count for PRI NIAB Mung 2022, followed closely by PRI Mung 2018, can be traced to more branches on those plants, which boosts the seed yield per hectare.

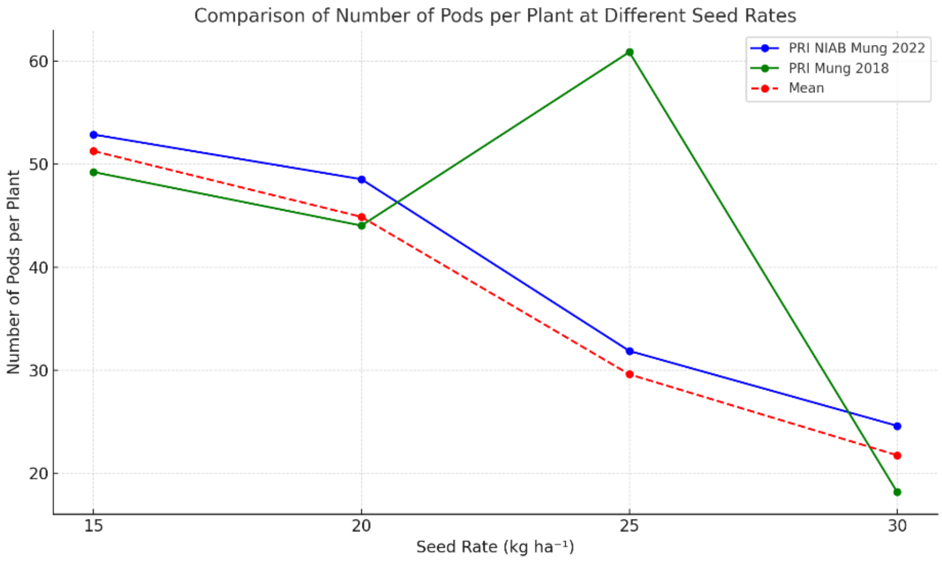

Figure 8. Impact of cultivars and seed rates on the number of pods produced by a mung bean plant

Effect of Seed Rate and Cultivar on Grains per Pod in Mung Bean

Maximum average grains per pod, 11.723, came from a seed rate of 15 kg per hectare, while a seed rate of 30 kg per hectare produced the lowest average of 6.585 grains per pod (Figure 9). Using a lower seed rate reduces the competition between plants for nutrients, water, and sunlight. Among the mung bean cultivars tested, PRI NIAB Mung 2022 produced the most grains per pod, averaging 9.3642, while PRI

Mung 2018 averaged 8.4625. The decline in grains per pod at higher seed rates likely results from lower total assimilates produced; a smaller leaf area is unable to gather enough energy and nutrients to fill all the seeds in the pod. The 15 kg per hectare seed rate consistently resulted in a higher seed number per pod compared to the 30 kg rate (Dainavizadeh and Mehranzadeh, 2013; Ijaz et al., 2023b).

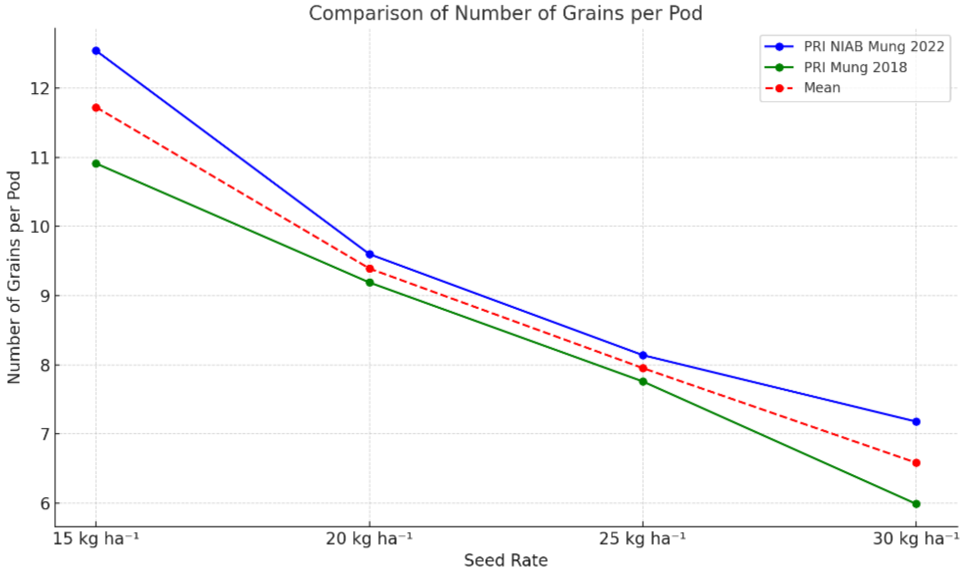

Figure 9. Effect of Seed Rate and Cultivar on Grains per Pod in Mung Bean

Impact of Cultivars and Seed Rates on Mung Bean 1000-Grain Weight (g)

Grain weight is mostly determined by genetics, but factors can cause it to change a bit. Among different seed rates, a rate of 15 kg ha^{-1} produced the heaviest 1000-grain weight, while a rate of 30 kg ha^{-1} gave the lightest (Figure 10). The highest 1000-grain weight 63.57 g came from the PRI NIAB Mung 2022 cultivar at the 15 kg ha^{-1} rate. The lightest weight 33.34 g was from the PRI Mung 2018 cultivar at the 30.1 kg ha^{-1} rate. The PRI NIAB Mung 2022 consistently outperformed the PRI Mung 2018 across all seed rates.

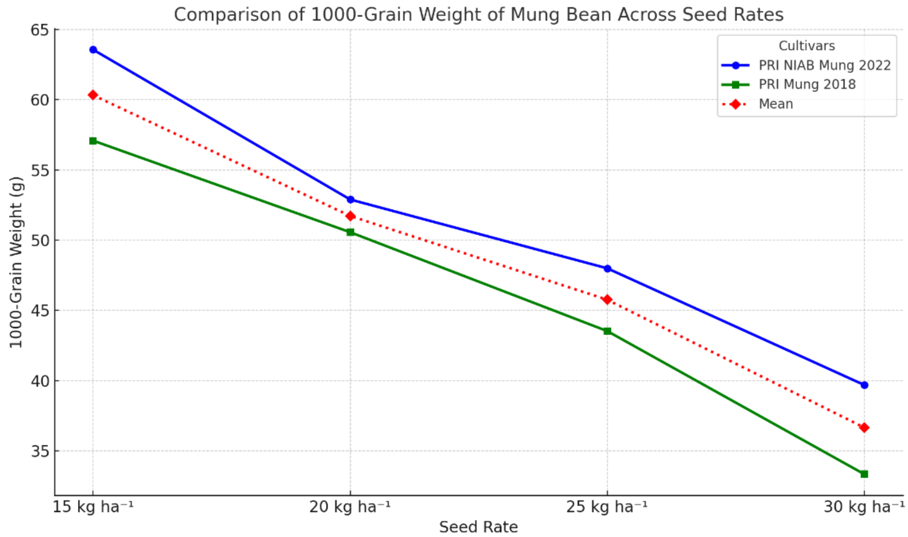

Figure 10. Impact of cultivars and seed rates on mung bean 1000-grain weight (g)

Impact of Cultivars and Seed Rates on Mung Bean Grain Yield (kg ha^{-1})

Grain yield tells us how much grain we can harvest from a piece of land and is key to food security, since it shows how much food is available for people and livestock. In trials, the variety PRI NIAB Mung 2022 produced 1186.9 kg of grain per hectare, while PRI Mung 2018 produced a lower yield of 1071.6 kg ha^{-1}

(Figure 11). When we look at different seeding rates, planting at 20 kg ha^{-1} gave us the best yield at 1300.6 kg ha^{-1}, while seeding at 30 kg ha^{-1} gave the lowest yield of 933.2 kg ha^{-1}. Throughout all the seeding rates, PRI NIAB Mung 2022 outperformed PRI Mung 2018, mainly because it had a greater total dry matter, leading to a larger seed yield. PRI NIAB Mung 2022 has reliably increased seed yield by boosting the no. of pods per plant, seeds per pod and thousand grain weight.

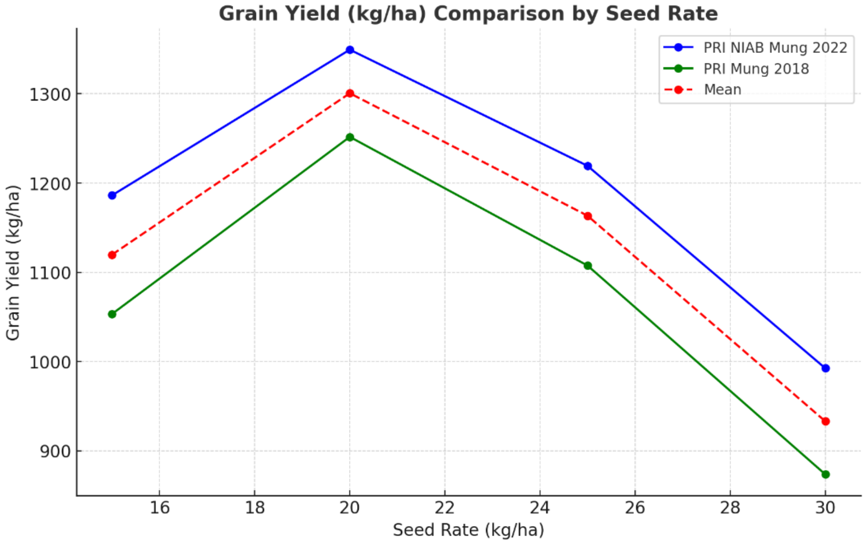

Figure 11. Impact of cultivars and seed rates on mung bean grain yield (kg ha^{-1})

Impact of Cultivars and Seed Rates on Mung Bean Biological Yield (t ha^{-1})

A crop's biological yield is the total biomass it produces throughout the growing season. In the study, plots sown with 20 kg of seed per hectare produced the highest biological yield of 8.38 t ha^{-1}, while the lowest biomass of 6.131 t ha^{-1} came from plots sown with 30 kg ha^{-1} (Figure 12). The combination of both factors did not significantly affect biological yield. NIAB Mung 2022 achieved the highest biological yield of 7.61 t ha^{-1}, while PRI Mung 2018 had the lowest at 7.04 t ha^{-1}. The highest overall yield, 8.63 t ha^{-1}, for PRI NIAB Mung 2022, was recorded at a seed rate 20 kg ha^{-1}. The PRI NIAB Mung 2022 cultivar showed stronger performance than the PRI Mung 2018 variety. This improvement came from a higher rate of crop growth and more dry matter accumulation throughout the growing season.

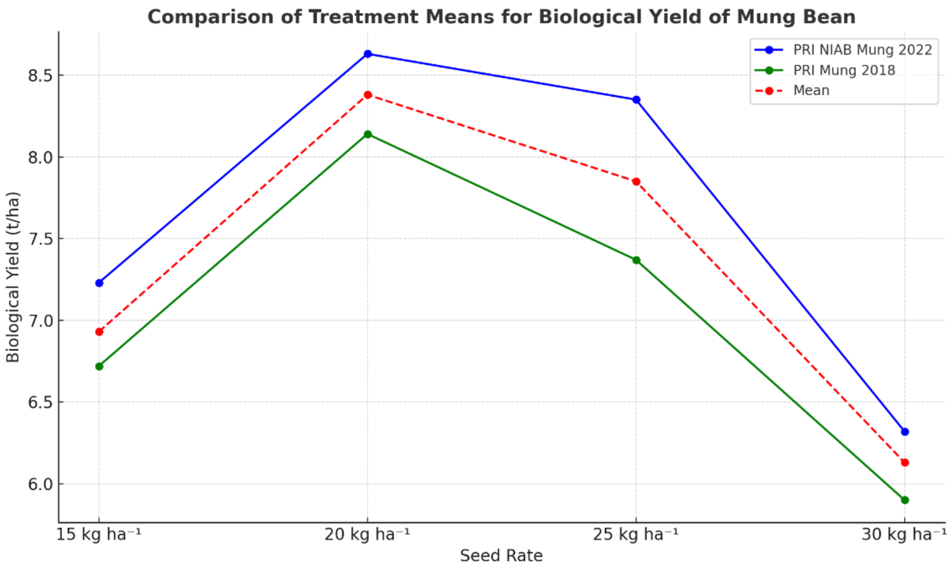

Figure 12. Impact of cultivars and seed rates on mung bean biological yield (t ha^{-1})

Impact of Cultivars and Seed Rates on the Mung Bean Harvesting Index

The harvest index (HI) tells us how much of a plant's total dry weight grows into the parts we can actually sell. Recent studies show that both seed rate and plant variety can change the HI. Among the tested varieties, PRI NIAB Mung 2022 achieved the best HI, outperforming PRI Mung 2018 (Figure 13). When seeding rate was adjusted, a rate of 20 kg of seed per hectare gave the best HI, while a rate of 30 kg per hectare produced the lowest. The highest harvest index of 18.173 kg ha^{-1} came from a seed rate of 20 kg ha^{-1}, but the lowest of 12.738 kg ha^{-1} was gained at 30 kg ha^{-1}. This trend shows that concerning parameter for mung bean crops declines when seed rates exceed the optimum level. As more plants are crowded together, they compete more fiercely for light, water, and nutrients. A seed rate of 20 kg ha^{-1} produced a harvest index that was significantly better than those for 15 kg ha^{-1}, 25 kg ha^{-1}, and 30 kg ha^{-1}.

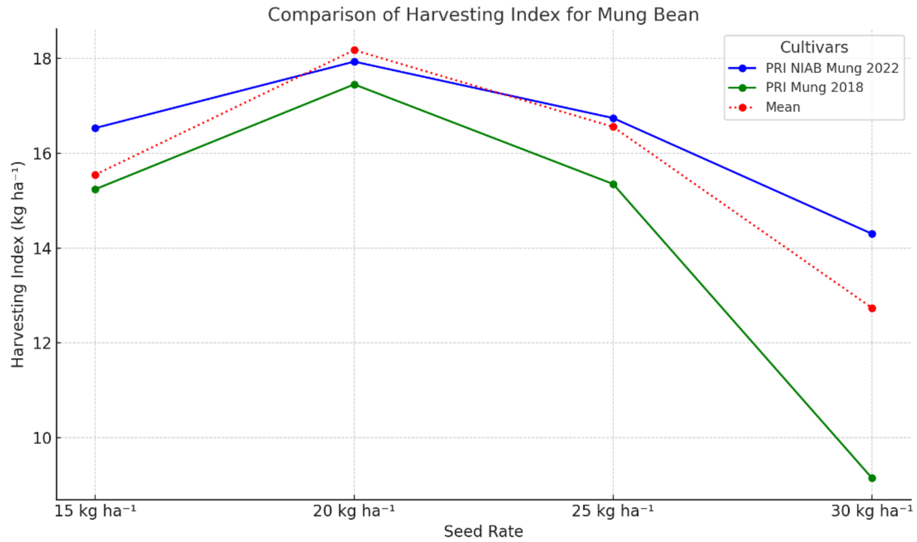

Figure 13. Impact of cultivars and seed rates on the mung bean harvesting index

CONCLUSION

The research project showed that mung bean genotypes growth, radiation usage efficiency, and yield are all strongly impacted by seed rate. The highest levels of grain production, biological yield, and radiation usage efficiency were consistently obtained with a seed rate of 20 kg ha^{-1} across the evaluated treatments. In the majority of growth and yield metrics, the cultivar PRI NIAB Mung 2022 outperformed PRI Mung 2018. These findings emphasize how crucial it is to maximize production by adjusting seed rate. In semi-arid environments, mung bean output can be sustainably increased by using the suggested seed rate.

Conflicts of Interest

The authors declare no competing interests.

Data Availability Statement

The data that support the findings of study are available from the corresponding author upon reasonable request

Author Contribution

Muhammad Daod Khan: Conceptualization and writing original draft; Shahid Nazeer: Analysis, investigation; Rabia Nadeem; Visualization; Asif Mehmood: Revison; Muhammad Saud Khan: Formatting; Raza Mustafa: Editing; Muhammad Hur: Validation; Abdul Rehman: Revision

REFERENCES

Ahmed, F., Waris, F., ibni Zamir, S., Sajjad, M., Nazeer, S., Khan, A., & Mustafa, F. (2023). Response of Different Organic and Inorganic Fertilizers on Alfalfa Yield Under Different Types of Irrigation Water. *Haya Saudi J Life Sci*, 8(1), 1-8.

Ali, A., Arooj, K., Khan, B.A., Nadeem, M.A., Imran, M., Safdar, M.E., Amin, M.M., Aziz, A., & Ali, M.F. (2021). Optimizing the growth and yield of mungbean (Vigna radiata L.) cultivars by altering sowing dates. *Pakistan Journal of Agricultural Research*, *34*(3), 559.

Amin, H., Habib, A., Asif, M., Hameed, M. U., Wassi, M., Manzoor, M., & Sajjad, M. (2023). Effect of Foliar Application of Boron, Zinc and Manganese on Growth, Yield and Oil Contents of Sunflower (*Helianthus annuus* L.). *Asian Journal of Soil Science and Plant Nutrition*, *9*(4), 86-94.

Begum, M.S.T.N., Begum, M., Anwar, M.P., & Juraimi, A.S. (2009). Optimizing seed rate for summer mungbean varieties. *Journal of Agriculture and Social Sci*ences, *5*, 114-118.

Corinzia, S.A., Crapio, E., Testa, G., Cosentino, S.L., Patanè, C., & Scordia, D. (2023). Leaf area duration and crop radiation use efficiency determine biomass yield of lignocellulosic perennial grasses under different soil water content. *Agronomy*, *13*(9), 2270.

Dainavizadeh, P., & Mehranzadeh, M. (2013). Effect of seed rate on growth, yield components and yield of mungbean grown under irrigated conditions in the north of Khuzestan.

Geetika, G., Hammer, G., Smith, M., Singh, V., Collins, M., Mellor, V., Wenham, K., & Rachaputi, R.C. (2022). Quantifying physiological determinants of potential yield in mungbean (*Vigna radiata* (L.) Wilczek). *Field Crops Research*, *287*, 108648.

Ijaz, B., Nazeer, S., Sajjad, M., Nadeem, M., Anwar, H., Idrees, M., & Khan, R. H. U. (2023a). Effect of various foliar applied micronutrients (Zn+ Fe+ Cu+ B) on growth and yield of wheat under Faisalabad condition. *Journal of Global Innovations in Agricultural Sciences*, *11*(2), 184-189.

Ijaz, B., Waraich, E. A., Shah, A., & Nazeer, S. (2023b). Morpho-physiological responses of wheat (*Triticum aestivum* L.) to foliar applied potassium under different planting geometry. *Journal of Global Innovations in Agricultural Sciences*, 11(1), 27-33.

Iqbal, N., Akbar, N., Ali, M., Sattar, M., & Ali, L. (2010). Effect of seed rate and row spacing on yield and yield components of wheat (*Triticum aestivum* L.). *Journal of Agricultural Research (03681157)*, *48*(2).

Iqtidar, H., Khan, M.A., & Khan, H. (2010). Effect of seed rates on the agro-physiological traits of wheat. *Sarhad Journal Agric*ulture, *26*(2), 169-176.

Jahan, M.S., & Hamid, A. (2004). Effect of population density and planting configuration on dry matter allocation and yield of mungbean (*Vigna radiate* (L.) Wilczek). *Pakistan Journal of Biological Sci*ences *7*(9), 1493-1498.

Khalil, S.K., Wahab, A., Amanulla, A., & Khan, A.Z. (2011). Variation in leaf traits, yield and yield components of faba bean in response to planting dates and densities. *Egyptian Academic Journal of Biological Sciences, H. Botany*, *2*(1), 35-43.

Khaliq, A., Zafar, M., Sajjad, M., Hassan, M.U., Mudassar, M.A., Shakoor, M.A., Yasin, M., & Niaz, S. (2023). Nitrogen use efficiency in sunflower (helianthus annuus l.) influenced by various fertigation and bed planting techniques. *Pakistan Journal of Biotechnology*, *20*(02), 385-392.

Khan, E.A., Aslam, M., Ahmad, H.K., Ayaz, M., & Hussain, A. (2010). Effect of row spacing and seeding rates on growth yield and yield components of chickpea. *Sarhad Journal of Agriculture*, *26*(2), 201-211.

Liu, B., Liu, X.B., Wang, C., Jin, J., Herbert, S.J., & Hashemi, M. (2010). Responses of soybean yield and yield components to light enrichment and planting density.

Mansoor, M., Khan, H., Ayaz, M., & Nadim, M.A. (2010). Effect of different planting densities on some physiological parameters of mungbean. *Gomal University Journal of Research*, *26*(2), 1-8.

Mondal, M.M.A., Puteh, A.B., Malek, M.A., & Ismail, M.R. (2012). Determination of optimum seed rate for mungbean based on morpho-physiological criteria. *Legume Research-An International Journal*, *35*(2), 126-131.

Murchie, E.H., Kefauver, S., Araus, J.L., Muller, O., Rascher, U., Flood, P.J., & Lawson, T. (2018). Measuring the dynamic photosynthome. *Annals of botany*, *122*(2), 207-220.

Nair, R.M., Pandey, A.K., War, A.R., Hanumantharao, B., Shwe, T., Alam, A.K.M.M., Pratap, A., Malik, S.R., Karimi, R., Mbeyagala, E.K., & Douglas, C.A. (2019). Biotic and abiotic constraints in mungbean production progress in genetic improvement. *Frontiers in Plant Science*, *10*, 1340.

Nazeer, S., Sajjad, M., Ahmad, T., Idrees, M., Ali, A., Khurshid, M.A., Yasir, M., Amjad, M., Shahid, H., Ijaz, B., & Khaliq, A. (2024). Effect of micronutrients (zinc, iron and boron) application on the yield and quality of late sown wheat. *Plant Health*, *3*(1), 41-47.

Nazeer, S., Tahir, M., Sajjad, M., Idrees, M., Hameed, M. U., Saleem, M. A., & Shehzad, A. (2020). Response of Different Micronutrients (Zn, Cu and Mn) Soil Application on Yield and Quality of Late Sown Wheat (Triticum aestivum L.) in Agro-Climatic Conditions of Faisalabad, Pakistan. *Pakistan Journal of Life & Social Sciences*, *18*(2).

Rehman, A., Imran, M., Sajjad, M., Umair, R., Nawaz, S., & Ijaz, B. (2025). Evaluation of herbicide efficiency and their impact with reduced rates along with adjuvants at varying application time in maize (*Zea mays* L.). *Journal of Agricultural Research (JAR)*, *63*(1), 49-57.

Sajjad, M., Hussain, K., Hakki, E. E., Ilyas, A., Gezgin, S., & Shakil, Q. (2025a). Impact of Irrigation Techniques on Water-Use Efficiency, Economic Returns, and Productivity of Rice. *Sustainability*, *17*(17), 7712.

Sajjad, M., Hussain, K., Wajid, S.A., & Saqib, Z.A. (2024). The Impact of Split Nitrogen Fertilizer Applications on the Productivity and Nitrogen Use Efficiency of Rice. *Nitrogen*, *6*(1), 1.

Sajjad, M., Ijaz, B., Khil, A., Ibtahaj, I., Hur, M., Azizi, N., Chughatta, A. R., Sajid, M., Rashid, A. & Babar, S. (2025b). Influence of different organic mulches on growth, yield and oil content of maize (*Zea mays* L.) hybrids and soil physical properties. *Journal of Ecological Engineering*, 26(11).

Shakeel, A., Anjum, L., Ibni Zamir, S., Rizwan, M., Arshad, M., Mehmood, Q., Sajjad, M., & Waqas, A. (2021). Irrigation water quality effects on CO2 emissions along with crop and soil responses. *Pakistan Journal of Agricultural Sciences*, *58*(2), 637-642.

Singh, M., & Kumar, R. (2014). Effect of date of sowing and seed rate on the growth and yield of Kharif mash (*Vigna mungo* L). *Agricultural Science Digest-A Research Journal*, *34*(3), 211-214.

Sohaib, N., Arif, M., Shah, M. N., Mahmood, S., Ali, H., Amjid, M., & Anwar, H. (2023). Exploring the Role of Anti-Oxidant on Growth and Yield of Cotton to Mitigate the Heat Stress. *Journal of Global Innovations in Agricultural Sciences*, *11(1)*, 41-47.

Steel, R.G.D., Torrie, J.H., & Dickey, D.A. 1997. Principles and procedures of statistics: A biometrical approach. 2nd ed. McGraw Hill, New York, USA.

Tang, L., Song, J., Cui, Y., Fan, H., & Wang, J. (2025). Research Progress on a Wide and Narrow Row Cropping System for Crops. *Agronomy*, *15*(1), 248.

Teema, K.A., Kubde, K.J., Kumar, P., Bhattacharjee, S., Kumar, S., Deshmukh, M.R., Goud, V.V., & Deshmukh, P.W. (2020). Influence of seed rate and fertilizer dose on the growth, development and yield attributes of blackgram (*Vigna mungo*) under dryland Vertisols. *Research on Crops*, *21*(3), 456-465.

Wakweya, K., Dargie, R., & Meleta, T. (2016). Effect of sowing date and seed rate on faba bean (*Vicia faba* L.,) growth, yield and components of yield at Sinana, Highland conditions of Bale, Southeastern Ethiopia. *International Journal of Agricultural Science*, *3*(1), 25-34.