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Optimization of Phosphorus and Potassium Fertilization for Mungbean Under Arid Agroclimatic Conditions of Thal, Punjab, Pakistan

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Abstract: Macronutrients including potassium (K), and phosphorus (P) are vital for the growth and development of plants. Compromised availability of these nutrients not only reduces the quantity and quality of crop yield but also threatens agricultural sustainability and food security. Improved utilization efficiency of plant nutrients offers a potential way to reduce the negative impact of nutrient (K and P) deficiencies. Mungbean is a major pulse crop of the Thal region, Punjab, Pakistan. However, its regional average grain yield is lower than its yield potential. This yield gap can be attributed to due to several crop management issues, mainly inadequate and imbalanced crop nutrition. A two-year (2017 and 2018) field experiment was planned to optimize the combination and level of K and P fertilizers for mungbean crop in the Thal region, Punjab, Pakistan. An experiment was conducted at Adaptive Research Farm, Karor Laal Eissen during kharif seasons (2017 and 2018), arranged in triplicate using randomized complete block design (RCBD). Mungbean plants were exposed to five combinations of phosphorus and potassium fertilizers including P_0K_0 (Control, without P and K); $P_{30}K_0$ (30 kg P_2O_5, 0 kg ha^{-1} K_2O); $P_{45}K_{50}$ (45 kg P_2O_5, 50 kg ha^{-1} K_2O); $P_{57}K_{62}$ (57 kg P_2O_5, 62 kg ha^{-1} K_2O) and $P_{85}K_{75}$ (85 kg P_2O_5, 75 kg ha^{-1} K_2O). Plant height, pods plant^{-1}, grains pod^{-1}, 1000-grain weight and yield kg ha^{-1} were minimum where no fertilizers (Control, T_1) were used. Studied growth and yield parameters of mungbean showed an increasing trend with the increasing level of both P and K fertilizer applications till $P_{57}K_{62}$. However, further increase in P and K nutrient levels negatively affected the mungbean growth and yield. Dry matter accumulation crop growth rate of mungbean plants was maximum when treated with $P_{57}K_{62}$. However, performance of mungbean plants was statistically inferior in terms of plant height (cm), number of pods plant^{-1}, number of seeds pod^{-1}, 1000-grain weight (g) and grain yield during both years, when treated with other fertilizer application treatments i.e., $P_{30}K_0$, $P_{45}K_{50}$, $P_{85}K_{75}$. From the presented results it can be concluded that under Thal region of Pakistan, higher mungbean yield can be increased by the application of $P_{57}K_{62}$ (57 kg ha^{-1} of P_2O_5 and 62 kg ha^{-1} of K_2O).

Keywords: Phenology, Pulses, macronutrients, crop yield, Crop development, time to flowering, Arid climatic conditions, Potassium, Phosphorus

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1. Introduction

The Thal Desert is a triangular region, located between the two main rivers of Punjab i.e., Indus and Jhelum, with an area of 2.5 million hectares (Yasin et al., 2016) with an approximate location between 30°70 and 32°30' N and 71° and 72° E and 120-200 m above sea level (Ahmad et al., 2022; Garzanti, et al., 2020). The agroclimatic conditions of the Thal region are challenging for agriculture (Aulakh et al., 2020). Semi-arid or arid subtropical climatic conditions with annual rainfall ranging between 120-200 mm are the main features of this region (Liang et al., 2019; Nawaz et al., 2019). Calcareous soil with a sandy texture dominates in the Thal region with low fertility and soil erosion due to frequent strong winds (Yasin et al., 2016). Regardless of these challenges, the Thal region has the potential to be a productive agricultural area if supplemented with adequate crop management practices.

Mungbean is a key legume crop in Pakistan and the Thal area during kharif season (Ullah et al., 2020). It is very well adapted to the arid conditions of Thal region due to drought tolerance. However, the area under cultivation of mungbean and other pulses is decreasing due to various abiotic and biotic stresses (Ullah et al., 2020). Mungbean is highly popular owing to its high nutritive value and digestible protein (Iqbal et al., 2021; Schreinemachers et al., 2019).

Mungbean provides a wide range of phytochemicals like protein, dietary fiber, minerals, vitamins, polyphenols, polysaccharides, and peptides, which are associated with significant health advantages. Therefore, mungbean is potentially considered an alternative functional food (Kabre et al., 2022; Hou et al., 2019; Zafar et al., 2023).

Mungbean is a legume plant and can fix atmospheric nitrogen through a synergetic effect of bacteria present in root nodules and supply to plants in ample amount (Dev et al., 2023; Favero et al., 2022; Shahrajabian et al., 2022). It is well adapted in the Thal region due to drought tolerance and can grow well in rainfed conditions. It performs better on marginal lands of the Thal region as compared to other crops (Pasley et al., 2023; Singh et al., 2019). Currently cultivated cultivars of mungbean have a yield potential from 1650 to 3200 kg ha^{-1} depending on genotype, agroclimatic conditions, crop management, and location (Ullah et al., 2020).

Fertilizer application plays a key role in agricultural production, as it is a crucial input supplying essential nutrients required by plants. However, judicious use of fertilizers can help to improve crop yields and quality, ensuring sustainable agriculture without compromising the environment. However, imbalanced and inappropriate application of fertilizers causes extensive collateral damage to agricultural systems and has serious environmental and economic implications, and threatens sustainable crop production (Pretty, 2018). Moreover, nutrient runoff, pollution (air, soil and water), reduced soil productivity, and soil degradation are major results of injudicious application of fertilizers (Noor et al., 2023; Pahalvi et al., 2021). The residual effects of excessive fertilizer applications disturb the nutrient balance in the soil and inhibit healthy plant growth. Appropriate fertilizer by adjusting the amount and combinations of fertilizers applied depending upon cite specific requirements and using suitable fertilizers can help to achieve sustainable agriculture production (Lu et al., 2015; Wu and Ma, 2015).

Being an N-fixing crop, mungbean yield is not significantly dependent on nitrogen fertilization. However, phosphorus and potassium are important commonly needed macro-nutrient to obtain higher mungbean yields per unit area (Wajid et al., 2013; Naz et al., 2021; Awais et al., 2015). Their dynamics in agricultural soils and availability to plants primarily depend on their applied forms. Both macronutrients are important parts of all biochemical reactions from germination to maturity in plants.

Globally P deficiency is a major limiting factor restricting crop productivity (Bi et al., 2013; Khan et al., 2022; Zhu et al., 2018). Phosphorous is an integral constituent of important biomolecules like nucleic acids, phospholipids, proteins, and ADT/ATP. Therefore, adequate availability of P is critical for the growth and development of crop plants. Phosphorus is also involved in the regulation of important reactions of enzymes during metabolism, and also a vital part of all plant parts including flower, fruit, and seed (Amin et al., 2017; Malhotra et al., 2018; Zhu et al., 2018). In addition, to yield, it also improves the quality of forages, grains, fruits, and vegetables (Yin et al., 2018; Wang et al., 2021). In legumes, P participates in root development, nutrient uptake, energy transformation (in nodules), and crop growth (Mitran et al., 2018). Generally, P in agricultural soils is adequate to meet the requirements of efficient biological nitrogen fixation, therefore, significant yield reduction in legumes is caused by P deficiency (Janati et al., 2021).

Potassium is the 3rd most important essential nutrient plant required for their growth, development, and physiological processes (after N and P). Unlike N and

P, K is not part of cell structure, however, it is involved in protein synthesis, and several vital physiological processes including enzyme activation, photosynthesis, and translocation. Moreover, K regulates stomatal opening and closing (Rawat et al., 2022). It is a key element regulating plant resistance against abiotic and biotic stresses. Therefore, its role is critical for crop yield and quality improvement, and plant immunity and resistance against various abiotic stresses including temperature, salinity, and drought stresses (Johnson et al., 2022; Naz et al., 2021; Perelman et al., 2022). Deficiency of K increases plant susceptibility to these stresses, which are common in rainfed areas where legume crops are widely grown (Askari-Khorasgani, et al., 2021; Rehman et al., 2021; Yasir et al., 2021).

Changing climate conditions have significantly influenced crop yields and pressurized the agricultural systems to increase crop production (Rehmani et al., 2021). Significant increase in temperature (Hussain et al., 2018; Ullah et al., 2020 Hussain et al., 2021) and anomalies in rainfall patterns have been reported and further anomalies are predicted in the Thal region (Hussain et al., 2020). These observed and predicted climatic anomalies in the Thal region have enhanced the importance of the balanced use of fertilizers as an adaptation to climate change (Ahmed et al., 2015; Manzoor et al., 2022). Therefore, the current study was designed to investigate the most suitable levels and combinations of P and K for better growth, development, and grain yield of mungbean in the Thal Region of Punjab, Pakistan.

2. Materials and Methods

2.1. Description of Experimental Site and Soil Characteristics

Adaptive Research Farm, Karor is located between 30°-45' to 31°-24 N and 70°-44 to 71°-50 E (Hussain et al., 2022). Soil samples were collected before the experiment at a depth of 0-15 cm, collected samples were sent to Soil and Water Testing Laboratory, Layyah, Pakistan for determination of available P and K. According to laboratory reports, the soil of experimental site was sandy loam with 41% sand, 37% silt, 22% clay, pH (8.0), organic matter (0.4%), CaCo3 (5.5%), EC (1.4 ds m^{-1}), available P (6 ppm) and K (40 ppm). Weather data (Fig. 1) from experimental site during experimentation was collected from a weather observatory situated close to the experimental site.

2.2. Experimental Details

A field experiment was conducted at Adaptive Research Karm, Karor Laal Eissen, during kharif seasons of 2017 and 2018. Nutrient treatments, including P_0K_0: Control, without P and K; $P_{30}K_0$: 30 kg P_2O_5, 0 kg ha^{-1} K_2O; $P_{45}K_{50}$: 45 kg P_2O_5, 50 kg ha^{-1} K_2O; $P_{57}K_{62}$: 57 kg P_2O_5, 62 kg ha^{-1} K_2O and $P_{85}K_{75}$:85 kg P_2O_5, 75 kg ha^{-1} K_2O, were arranges using randomized complete block design (RCBD) and performed in triplicate. The seedbed was prepared by three plowings followed by planking.

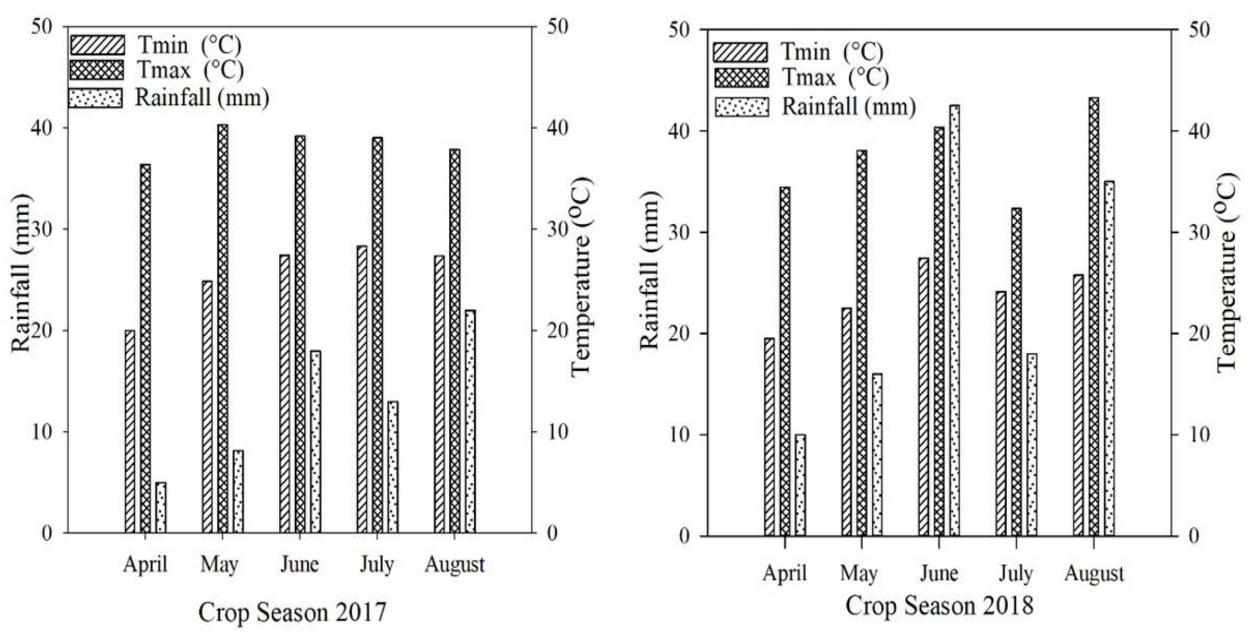

Fig. 1. Monthly means of daily maximum and minimum temperatures (°C), and rainfall (mm) during crop season 2017 and 2018.

Seeds of mungbean cultivar NM-2011 were sown during the last week of May during both experimental years (2017 and 2018). Both P and K were applied according to treatment levels in the form of diammonium phosphate (DAP) and sulfate of potash (SOP). All other crop management practices including variety methods), seed rate (14 kg $acre^{-1}$ or 34.6 kg ha^{-1}), sowing methods, irrigations, plant protection measures, and harvesting method were kept similar for all treatments.

2.3. Data Collection and Analysis

For days to 50% flowering, five plants were selected randomly tagged and noted the time of flowering. These tagged plants were further used to record 90% days to maturity. Time course data of crop growth rate was recorded through harvesting of a middle line of one-foot length from ground level. Samples were not collected from border lines to avoid border effects. After sample collection, samples were sun-dried, and weight was measured after oven-drying till constant weight. Crop growth rate (CGR) was calculated using the method described by Hunt (1978).

$$CGR = (W_2 - W_1) / (t_2 - t_1) \quad [1]$$

Where W_1 and W_2 are the dry weight harvested at the time interval of t_1 and t_2, respectively.

Crop was harvested at the maturity from 3 m^2 avoiding the border areas to find the grain yield of mungbean and converted into grain yield kg ha^{-1} by the unit method. Plant height was measured by randomly selecting 10 plants from each experimental plot. Pods $plant^{-1}$, were counted from 10 randomly selected plants from each experimental plot. These pods were threshed to count the no. of grains pod^{-1}. 1000-grain weight was recorded by randomly selecting 1000 grains and weighing them on a digital weight balance.

Data collected of all parameters were pooled and analyzed using analysis of variance technique of Fisher. Statistix 8.1 was used to compare treatment means for significance by Tuckey's test at 0.05 probability level (Steel et al., 2007).

3. Results

3.1. Germination (m^{-2})

Results given in Table 1 indicate that different levels and combination of P and K have no impact on germination m^{-2} of mungbean during both years 2017 and 2018. Plant population was not affected due to sowing of uniform seed rate and the application of different doses of fertilizers usually does not affect germination.

3.2. Crop Development

In legumes, reproductive development including time to flowering, flowering and podding rates, and duration of these phenological phases are regulated by plant genetic structure, however, modulated by environmental conditions (Geetika et al., 2022; Liu et al., 2022).

In mungbean plants of tested cultivars, fertilizer levels, and their combinations could not produce a significant influence on the number of days to 50% flowering from sowing, during both experimental years (Fig. 2). However, maximum number of days to 50% flowering (42 days) were recorded with the application of $P_{85}K_{75}$ during 2017 and minimum number of days for 50% flowering were recorded in P_0K_0 during 2017 and 2018. An increasing trend in the number of days to 50% flowering was recorded with an increase in amount of fertilizers (P and K).

Different P and K fertilizer rates and combinations could not produce a significant impact on the days to maturity of mungbean cultivars. Mungbean plants recorded the most days to maturity (Fig. 2) when exposed to a fertilizer combination of $P_{85}K_{75}$, however, minimum days to maturity were recorded when grown without application of P and K i.e., treatment P_0K_0 (during both experimental years 2017 and 2018), which were statistically at par with each other.

Table 1. Yield and yield components of mungbean (*Vigna radiata* l.) to different levels of phosphorus and potash under agroclimatic conditions of Thal, Punjab, Pakistan

Treatments	Germination (m^{-2})		Plant Height (cm)		Pods $Plant^{-1}$		Grains $Pods^{-1}$		1000-Grain Weight (g)		Grain Yield (kg ha^{-1})	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
P_0K_0 (Control)	34.0 a	36.0 a	52.6 c	55.6 c	15.1 c	14.3 c	4.5 c	4.7 c	44.6 c	37.1 c	476 d	472 c
$P_{30}K_0$	33.3 a	35.3 a	61.8 b	65.8 b	22.6 b	19.7 b	5.7 b	5.5 bc	46.1 c	42.0 b	566 c	601 b
$P_{45}K_{50}$	35.3 a	36.3 a	65.7 ab	69.7 ab	25.6 a	25.7 a	6.5 a	6.4 a	47.7 b	49.0 a	637 a	745 b
$P_{57}K_{62}$	35.6 a	36.6 a	66.1 a	71.1 a	24.6 a	25.6 a	6.5 a	6.7 a	49.7 a	50.0 a	663 a	785 a
$P_{85}K_{75}$	34.6 a	35.6 a	66.8 a	70.8 a	26.0 a	21.5 b	5.5 b	5.8 ab	48.4 ab	43.1 b	599 b	648 b

P_0K_0 (Control): without P_2O_5, and K_2O application; $P_{30}K_0$: 30 kg P_2O_5, 0 kg ha^{-1} K_2O; $P_{45}K_{50}$: 45 kg P_2O_5, 50 kg ha^{-1} K_2O; $P_{57}K_{62}$: 57 kg P_2O_5, 62 kg ha^{-1} K_2O; $P_{85}K_{75}$: 85 kg P_2O_5, 85 kg ha^{-1} K_2O.

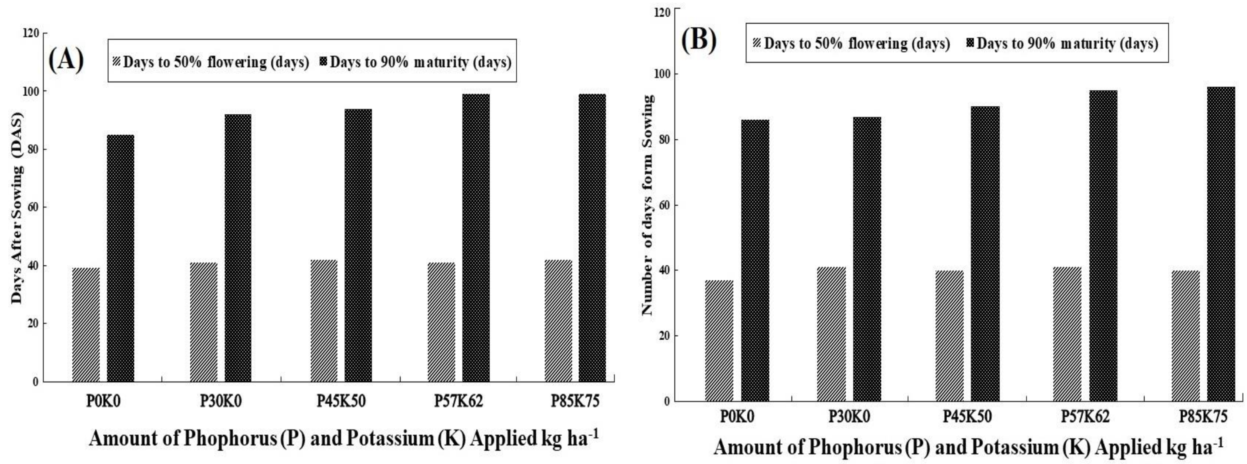

Fig. 2. Impact of different levels and combinations of Phosphorus and Potassium on days to 50% flowering and days to 90% maturity of Mungbean (A) 2017; (B) 2018. P_0K_0 (Control): without P_2O_5 & K_2O application; $P_{30}K_0$: 30 kg P_2O_5 & 0 kg ha^{-1} K_2O; $P_{45}K_{50}$: 45 kg P_2O_5 & 50 kg ha^{-1} K_2O; $P_{57}K_{62}$: 57 kg P_2O_5 & 62 kg ha^{-1} K_2O; $P_{85}K_{75}$: 85 kg P_2O_5 & 85 kg ha^{-1} K_2O.

Plant height is the result of combined effect of genetics, environment, and management (Mariotti et al., 2009). In our study, height of mungbean plants was significantly affected by the different levels of P and K (Table 1) during both experimental years. Maximum plant height (71.1 cm) was recorded when plants were exposed to treatment $P_{57}K_{62}$, followed by plants treated with $P_{85}K_{75}$, but, both nutrient treatments were statistically at par with each other. The smallest plants (52.6 cm) were recorded in control plots (P_0K_0), where P and K fertilizers were not applied.

3.3. Crop Growth

Crop Growth rate (CGR) is an important parameter that indicates the accumulation rate of dry matter (g day^{-1} m^{-2}). In this analysis, growth trend of mungbean was recorded from sowing to maturity. Maximum CGR was observed in $P_{57}K_{62}$ of season 2017 after 60 days of sowing while CGR was minimum during 2018 after 82 days of sowing $P_{30}K_0$. During 2017, CGR was the lowest with P_0K_0 from sowing to maturity. Different between CGR were significantly different during experimental season 2017 while this difference was lesser during season 2018 (Fig. 3).

Dry matter accumulation has been shown in Fig. 4. Dry accumulation rate was higher from sowing to 80 days after sowing in all treatments except P_0K_0 during both years 2017 and 2018. Maximum dry matter was accumulated during 2018 at maturity in $P_{57}K_{62}$ (3500 kg ha^{-1}) while the minimum was recorded during 2017 in P_0K_0. Interestingly, overall dry matter in 2018 was higher as compared to 2017.

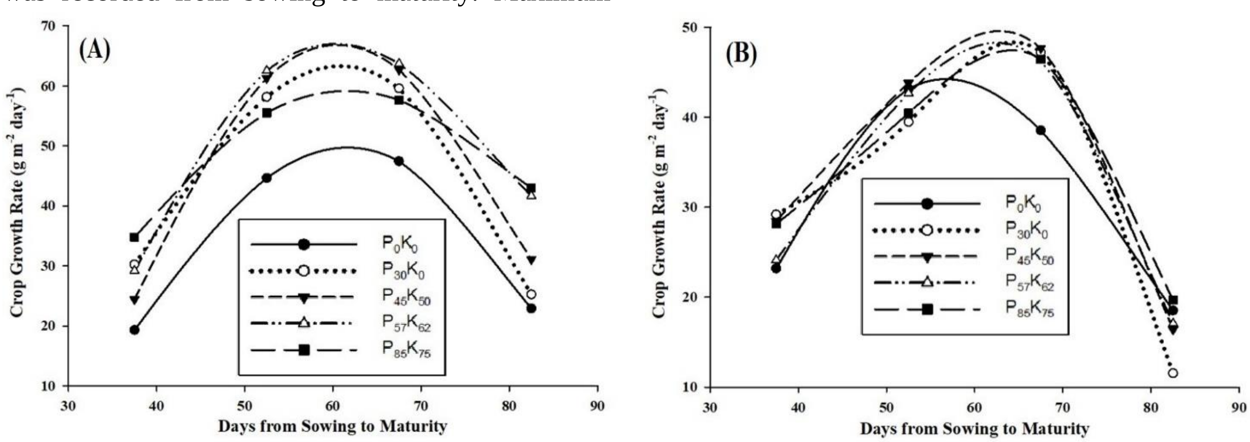

Fig. 3. Crop growth rate (g m^{-2} day^{-1}) of Mungbean under different levels and combinations of phosphorus and potassium fertilizers (A) 2017, (B) 2018. P_0K_0 (Control): without P_2O_5 & K_2O application; $P_{30}K_0$: 30 kg P_2O_5 & 0 kg ha^{-1} K_2O; $P_{45}K_{50}$: 45 kg P_2O_5 & 50 kg ha^{-1} K_2O; $P_{57}K_{62}$: 57 kg P_2O_5 & 62 kg ha^{-1} K_2O; $P_{85}K_{75}$: 85 kg P_2O_5 & 85 kg ha^{-1} K_2O from sowing to maturity during two experimental years.

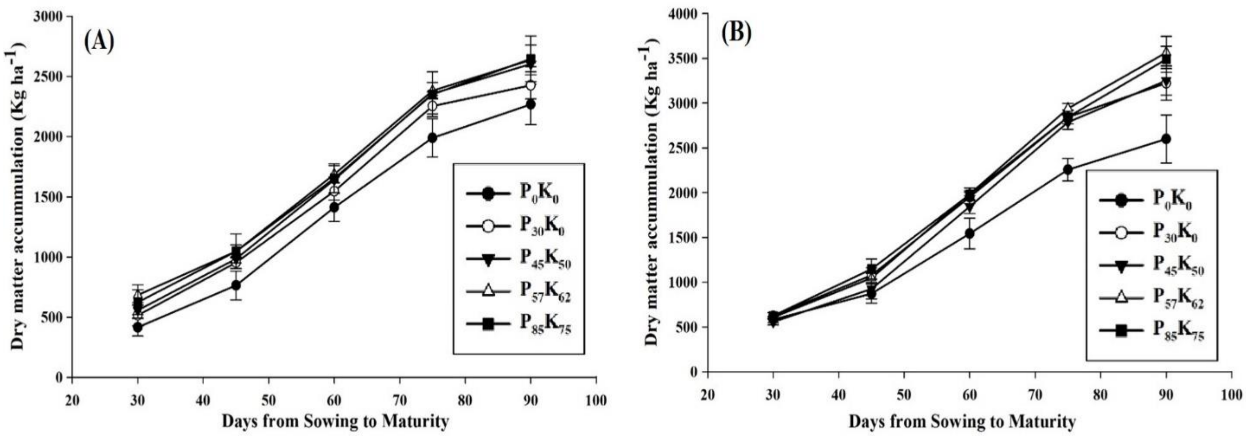

Fig. 4. Temporal variations in dry matter accumulation (kg ha^{-1}) of mungbean under different levels and combinations of phosphorus and potassium fertilizers (A) 2017, (B) 2018. P_0K_0 (Control): without P_2O_5 & K_2O application; $P_{30}K_0$: 30 kg P_2O_5 & 0 kg ha^{-1} K_2O; $P_{45}K_{50}$: 45 kg P_2O_5 & 50 kg ha^{-1} K_2O; $P_{57}K_{62}$: 57 kg P_2O_5 & 62 kg ha^{-1} K_2O; $P_{85}K_{75}$: 85 kg P_2O_5 & 85 kg ha^{-1} K_2O during two experimental years.

3.4. Yield and Yield Components

Phosphorus and potash levels significantly affected pods plant^{-1}, and maximum pods plant^{-1} 26 (during year 2017) and 19.33 (2018), were recorded in plots with $P_{57}K_{62}$ (Table 1). Applications of phosphorus and potash (such as $P_{85}K_{75}$) beyond $P_{57}K_{62}$ cannot increase the number of pods plant^{-1} to a significant level.

Number of grains pod^{-1} is an important factor that is directly involved in final grain yield in leguminous crops. Their number of pods and seed-bearing capacity determines the performance of leguminous plants. Results presented in Table 1 indicated that different levels of phosphorus and potash significantly influenced grains pod^{-1}. It may be the main reason for more grains pod^{-1}. Maximum number of grains pod^{-1} (6.7 and 6.5) were recorded in $P_{57}K_{62}$ during kharif seasons of 2018 and 2017, respectively. In $P_{57}K_{62}$ plots, P and K were available in optimum dose to the plant for the completion of mentioned stages without facing any difficulty whereas the lowest number of grains were recorded in control plots. The number of grains pod^{-1} were increased with increasing level of phosphorus and potash $P_{30}K_0$, $P_{45}K_{50}$ and $P_{57}K_{62}$ against control but beyond $P_{57}K_{62}$ i.e., $P_{85}K_{75}$; p and k could not increase the number of grains pod^{-1} to a significant level.

The data regarding 1000-grain weight (Table 1) highlighted that application of phosphorus and potash ($P_{57}K_{62}$) resulted in a maximum 1000-grain weight of 50.0 g and 47.33 g during seasons 2017 and 2018, respectively. Experimental plots treated with higher rates of P and K i.e., $P_{85}K_{75}$; cannot increase the 1000-grain weight to a significant level, produced grain weight was statistically at par with the grain weight produced in experimental plots treated with treatment $P_{57}K_{62}$. Minimum 1000-grain weight of 46.0 g and 43.33 g was noted in control plots (P_0K_0). Lower rates of P and K fertilizer i.e., $P_{30}K_0$ and $P_{45}K_{50}$ resulted in a statistically similar 1000-grain weight, indicating inadequate nutrient supply.

Grain yield of mungbean was significantly influenced by changing P and k levels which is the combined effect of no. pods plant^{-1}, grains pod^{-1} and 1000-grain weight. Maximum grain yield of 785 kg ha^{-1} and 663 kg ha^{-1} (Table 1) were obtained during the kharif seasons of 2018 and 2017, respectively from plots fertilized with $P_{57}K_{62}$ followed by P and K fertilization $P_{45}K_{50}$ with grain yield of 745 kg ha^{-1} during season 2018. Minimum mungbean yield i.e., 472 kg ha^{-1}, was recorded from control plots (P_0K_0). Soils of Thal region are deficient in macronutrients which resulted in stunted growth where zero or insufficient P and K were applied.

4. Discussion

Soils of Thal region are marginal and extremely deficient in nutrients and organic matter. Mungbean is a well-adapted crop in this region due to its lower nutrients and water requirement as compared to other crops (Hossain et al., 2018). With the increase in cropping intensity of the region, soil fertility is deteriorating with the passage of time, and mungbean in facing nutrient deficiency, especially P and K (Imran et al., 2016). Mungbean being a nitrogen-fixing crop does not face the deficiency of nitrogen except at the initial stage (Hussain et al., 2022). Mungbean is generally grown in marginal or rainfed areas with limitations for crop production. In order to avoid loss of resources or other factors application of fertilizers (for NPK) are rarely practiced, which significantly affects mungbean yield in the region. Plants of mungbean significantly responded to different levels of fertilizers earlier (Yin et al., 2018; Iqbal et al., 2021).

Application of phosphorus and potassium promotes crop growth and development in mungbean (Imran et al., 2016). Application of P, as DAP, at sowing helps to early root development and nitrogen supply, which helps in better nutrient and water uptake and better crop stand (Yin et al., 2018). While K plays a functional role in enzyme activation, photosynthesis, protein synthesis, and resistance against biotic and abiotic stress (Askari-Khorasgani, et al., 2021; Johnson et al., 2022). Deficiency of P and K causes stunted growth of mungbean plant while their adequate supply enhances the plant growth processes, which ultimately cause an increase in grain yield (Yin et 2018). In the study under discussion, P and K substantially enhanced the crop growth, total dry matter, yield and yield components.

Germination process was not affected by the application of P and K (Table 1) because germinating seed utilizes biomolecules stored in the seed for their energy and nutrient requirements and does not depend on soil nutrients (Table 1). Application of different nutrients affected the plant heights (Mota et al., 2021). Application of P and K fertilizers significantly influences mungbean plant height. Study under discussion has significant differences among treatment levels of phosphorus and potash, which have significant effects on final height of mungbean plant. While days to 50% flowering and days to 90% maturity were substantially decreased to stunted growth where no nutrients were applied while the difference among different levels was non-significant due to availability of some quantity of nutrients (Fig. 2).

Crop growth rate was different among treatments, recorded minimum where deficiency on P and K caused the stunted growth (Fig. 2). CGR and dry matter accumulation was higher in 2018 as compared to 2017 mainly due to higher rainfall during 2018 and cultivation of mungbean continuously on the same soil (Fig. 4). Higher P supplementation enhanced the vegetative growth and branch plant^{-1} (Yin et al., 2018). Yield and yield components were significantly affected due to changes in nutrient levels (Table 1). Number of pods, number of grains and 1000-grain weight were significantly higher with increased application of P and K. Mota et al. (2021) found the P fertilizer resulted in a significant increase in the number of pods plant^{-1}, grains pod$^{-1,}$ and 1000-grain weight. The number of pods plant^{-1} is an important parameter to yield which is mainly dependent on crop health and nutrition (Yin et al., 2018). Assimilation of nitrogen is the major factor, which caused production (476 and 472 kg ha^{-1}) in P_0K_0 during both years 2017 and 2018, respectively. However, application of P and K enhanced the mungbean yield by 40 to 90% as compared to no application of P and K. Proper use of nutrients enhanced the crop yield, and improved soil health and profit of farmers.

5. Conclusion

Mungbean production in Thal region of Pakistan needs a significant amount of P and K nutrient supplementation for proper growth and yield. Application of P and K enhanced the final crop yield with improvements in pods plant^{-1}, grains pod^{-1} and 1000-grain weight. It is recommended that application of P and K at 57 (P_2O_5) and 62 (K_2O) kg ha^{-1}) at the time of mungbean sowing can achieve maximum grain yield under arid agroecological conditions Thal region, Punjab, Pakistan.

Conflict of Interest: The authors have declared that they have no competing interests and there is no conflict of interest exists.

Author's Contribution: ZA, MA and GA perceived the idea, performed experiment and collected data. JH and TM analyzed the data and draw figure. SH and MAB wrote and reviewed the manuscript. All authors read and approved the final draft of manuscript.

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References

Ahmad, A., M. Ashfaq, G. Rasul, S. A. Wajid, T. Khaliq, F. Rasul, U. Saeed, M. H. u. Rahman, J. Hussain, I. A. Baig et al., 2015. Impact of Climate Change on the Rice–Wheat Cropping System of Pakistan. In: Handbook of Climate Change and Agroecosystems. p. 219-258.

Ahmad, S., S. Zafar, F. Jabeen, N. Akhter, M. Akram, E. Mohiuddin, S. M. A. Shah, S. Siddiqui, M. A. Chishti and G. Sarwar. 2022. Antipyretic activity of medicinal plants from the Thal Desert. Lett. Appl. NanoBioScience. 12: 62.

Amin, A., W. Nasim, M. Mubeen, M. Nadeem, L. Ali, H. M. Hammad, S. R. Sultana, K. Jabran, M. H. u.

Rehman, S. Ahmad, et al., 2017. Optimizing the phosphorus use in cotton by using CSM-CROPGRO-cotton model for semi-arid climate of Vehari-Punjab, Pakistan. Environ. Sci. Pollut. Res. 24: 5811-5823.

Askari-Khorasgani, O., M. I. A. Rehmani, S. H. Wani and A. Kumar. 2021. Osmotic stress: an outcome of drought and salinity. In: Handbook of Plant and Crop Physiology. CRC Press. p. 445-464.

Aulakh, A. M., G. Qadir, F. U. Hassan, R. Hayat, T. Sultan, M. Billah, M. Hussain and N. Khan. 2020. Desert soil microbes as a mineral nutrient acquisition tool for chickpea (*Cicer arietinum* L.) productivity at different moisture regimes. Plants. 9: 1629.

Awais, M., A. Wajid, A. Ahmad, F. Saleem, U. Bashir, U. Saeed, J. Hussain, and H. Rehman. 2015. Nitrogen fertilization and narrow plant spacing stimulates sunflower productivity. Turk. J. Field Crops. 20(1):99-108.

Bi, J., Z. Liu, Z. Lin, M. A. Alim, M. I. A. Rehmani, G. Li, Q. Wang, S. Wang and Y. Ding. 2013. Phosphorus accumulation in grains of japonica rice as affected by nitrogen fertilizer. Plant Soil. 369: 231-240.

Dev, P., U. Singh, L.N. Singh, Y.S. Shivay, M. Kumar and P.R. Raiger. 2023. Zinc biofortification of mungbean (*Vigna radiata* L.) as influenced by varieties and zinc fertilization. J. Environ. Agric. Sci. 25 (1&2): 1-17.

Favero, V. O., R. H. de Carvalho, A. B. C. Leite, D. M. T. dos Santos, K. M. de Freitas, R. M. Boddey, G. R. Xavier, N. G. Rumjanek and S. Urquiaga. 2022. Bradyrhizobium strains from Brazilian tropical soils promote increases in nodulation, growth and nitrogen fixation in mung bean. Appl. Soil Ecol. 175: 104461.

Garzanti, E., W. Liang, S. Andò, P. D. Clift, A. Resentini, P. Vermeesch and G. Vezzoli. 2020. Provenance of Thal Desert sand: Focused erosion in the western Himalayan syntaxis and foreland-basin deposition driven by latest Quaternary climate change. Earth-Sci. Rev. 207: 103220.

Geetika, G., M. Collins, V. Singh, G. Hammer, V. Mellor, M. Smith and R. C. N. Rachaputi. 2022. Canopy and reproductive development in mungbean (*Vigna radiata*). Crop Pasture Sci. 73: 1142-1155.

Hossain M.E. and M.S. Islam. 2018. Effect of manures with fertilizers on yield and yield traits of mungbean (*Vigna radiata* L.). Bangladesh Agron. J. 20(2): 115-122.

Hou, D., L. Yousaf, Y. Xue, J. Hu, J. Wu, X. Hu, N. Feng and Q. Shen. 2019. Mung bean (*Vigna radiata* L.): Bioactive polyphenols, polysaccharides, peptides, and health benefits. Nutrients. 11: 1238.

Hunt, R. 1978. Plant growth analysis. Edward Arnold, U.K., pp: 26-38.

Hussain, I., G. Abbas, J. Hussain, Z. Abbas, T. Mehmood, M. Amer, Q. Maqsood and I. Rasool. 2022. Application of sulphate of potash enhances mungbean (*Vigna radiata*) yield under agroclimatic conditions of Thal, Pakistan. J. Environ. Agric. Sci. 24(3&4):23-28.

Hussain, J., T. Khaliq, A. Ahmad, J. Akhter and S. Asseng. 2018. Wheat responses to climate change and its adaptations: a focus on arid and semi-arid environment. Int. J. Environ. Res. 12: 117–126.

Hussain, J., T. Khaliq, M. H. u. Rahman, A. Ullah, I. Ahmed, A. K. Srivastava, T. Gaiser and A. Ahmad. 2021. Effect of temperature on sowing dates of wheat under arid and semi-arid climatic regions and impact quantification of climate change through mechanistic modeling with evidence from field. Atmosphere. 12: 927.

Hussain, J., T. Khaliq, S. Asseng, U. Saeed, A. Ahmad, B. Ahmad, I. Ahmad, M. Fahad, M. Awais, A. Ullah and G. Hoogenboom. 2020. Climate change impacts and adaptations for wheat employing multiple climate and crop models in Pakistan. Clim. Change 163: 253-266.

Imran, A.A. Khan, I. Inam and F. Ahmad. 2016. Yield and yield attributes of Mungbean (*Vigna radiata* L.) cultivars as affected by phosphorous levels under different tillage systems. Cogent Food Agric. 2: 1151982.

Iqbal, J., G. Shabbir, K. N. Shah, H. Fayyaz ul and A. Qayyum. 2021. Deciphering of genotype × environment interaction to identify stable heat-tolerant mung bean genotypes by GGE Biplot Analysis. J. Soil Sci. Plant Nutrit. 21: 2551-2561.

Janati, W., B. Benmrid, W. Elhaissoufi, Y. Zeroual, J. Nasielski and A. Bargaz. 2021. Will Phosphate Bio-Solubilization Stimulate Biological Nitrogen Fixation in Grain Legumes? Front. Agron. 3:637196.

Johnson, R., K. Vishwakarma, M. S. Hossen, V. Kumar, A. M. Shackira, J. T. Puthur, G. Abdi, M. Sarraf and M. Hasanuzzaman. 2022. Potassium in plants: Growth regulation, signaling, and environmental stress tolerance. Plant Physiol. Biochem. 172: 56-69.

Kabré, J. d. A. W., D. Dah-Nouvlessounon, F. Hama-Ba, A. Agonkoun, F. Guinin, H. Sina, A. N. Kohonou, P. Tchogou, M. Senou, A. Savadogo and L. Baba-Moussa, 2022: Mung bean (*Vigna radiata* (L.) R. Wilczek) from Burkina Faso used as antidiabetic, antioxidant and antimicrobial agent. Plants. 11: 3556.

Khan, K., M. Ali, M. Naveed, M. Rehmani, M. Shafique, H. Ali, N. Abdelsalam, R. Ghareeb and G.

Feng. 2022. Co-application of organic amendments and inorganic P increase maize growth and soil carbon, phosphorus availability in calcareous soil. Front. Environ. Sci. 10:949371.

Liang, W., E. Garzanti, S. Andò, P. Gentile and A. Resentini. 2019. Multimineral fingerprinting of Transhimalayan and Himalayan sources of Indus-Derived Thal Desert sand (Central Pakistan). Minerals. 9: 457.

Liu, C., Q. Zhang, J. Dong, C. Cai, H. Zhu and S. Li, 2022: Genome-wide identification and characterization of mungbean CIRCADIAN CLOCK ASSOCIATED 1 like genes reveals an important role of VrCCA1L26 in flowering time regulation. BMC Genomics. 23: 374.

Lu, Y., A. Jenkins, R. C. Ferrier, M. Bailey, I. J. Gordon, S. Song, J. Huang, S. Jia, F. Zhang, X. Liu, Z. Feng and Z. Zhang, 2015. Addressing China's grand challenge of achieving food security while ensuring environmental sustainability. Sci. Adv. 1: e1400039.

Malhotra, H., Vandana, S. Sharma and R. Pandey. 2018. Phosphorus Nutrition: Plant Growth in Response to Deficiency and Excess. In: M. Hasanuzzaman, M. Fujita, H. Oku, K. Nahar and B. Hawrylak-Nowak (Editors). Plant Nutrients and Abiotic Stress Tolerance. Springer Singapore, Singapore. p. 171-190.

Manzoor, R., M. S. Akhtar, K. S. Khan, T. Raza, M. I. A. Rehmani, C. Rosen, M. K. U. Rehman, N. Zidan, F. M. Alzuaibr and N. M. Abdulsalam. 2022. Diagnosis and Recommendation Integrated System Assessment of the nutrients limiting and nutritional status of tomato. Phyton-Int. J. Exp. Bot. 91: 2759-2774.

Mariotti, M., A. Masoni, L. Ercoli and I. Arduini. 2009. Above- and below-ground competition between barley, wheat, lupin and vetch in a cereal and legume intercropping system. Grass Forage Sci. 64: 401-412.

Mitran, T., R. S. Meena, R. Lal, J. Layek, S. Kumar and R. Datta, 2018: Role of Soil Phosphorus on Legume Production. In: R. S. Meena, A. Das, G. S. Yadav and R. Lal (Editors). Legumes for Soil Health and Sustainable Management. Springer Singapore, Singapore. p. 487-510.

Mota, F. M., D. S. Balla and M. B. Doda. 2021. Response of mung bean varieties (*Vigna radiata* L.) to application rates and methods of blended NPS Fertilizer at Humbo. Int. J. Agron. 2021: 3786720.

Nawaz, Z., X. Li, Y. Chen, Y. Guo, X. Wang and N. Nawaz. 2019. Temporal and spatial characteristics of precipitation and temperature in Punjab, Pakistan. Water. 11: 1916.

Naz, T., M. Mazhar Iqbal, M. Tahir, M. M. Hassan, M. I. A. Rehmani, M. I. Zafar, U. Ghafoor, M. A. Qazi, A. EL Sabagh and M. I. Sakran. 2021. Foliar application of potassium mitigates salinity stress conditions in spinach (*Spinacia oleracea* L.) through reducing NaCl toxicity and enhancing the activity of antioxidant enzymes. Horticulturae. 7: 566.

Noor, R., A. Maqsood, A. Baig, C. B. Pande, S. M. Zahra, A. Saad, M. Anwar and S. K. Singh. 2023. A comprehensive review on water pollution, South Asia Region: Pakistan. Urban Climate. 48: 101413.

Pahalvi, H. N., L. Rafiya, S. Rashid, B. Nisar and A. N. Kamili. 2021. Chemical Fertilizers and Their Impact on Soil Health. In: G. H. Dar, R. A. Bhat, M. A. Mehmood and K. R. Hakeem (Editors). Microbiota and Biofertilizers, Vol 2: Ecofriendly Tools for Reclamation of Degraded Soil Environs. Springer International Publishing, Cham. p. 1-20.

Pasley, H., K. Wenham, L. Bell, N. Huth, D. Holzworth, A. Chaki, D. Gaydon and M. Collins. 2023. APSIM next generation mungbean model: A tool for advancing mungbean production. Field Crops Res. 298: 108955.

Perelman, A., P. Imas and S. K. Bansal. 2022. Potassium Role in Plants' Response to Abiotic Stresses. In: N. Iqbal and S. Umar (Editors). Role of Potassium in Abiotic Stress. Springer Nature Singapore, Singapore. p. 15-39.

Pretty, J. 2018. Intensification for redesigned and sustainable agricultural systems. Science. 362: eaav0294.

Rawat, J., N. Pandey and J. Saxena. 2022. Role of Potassium in Plant Photosynthesis, Transport, Growth and Yield. In: N. Iqbal and S. Umar (Editors). Role of Potassium in Abiotic Stress. Springer Nature Singapore, Singapore. p. 1-14.

Rehman, M., A. Bakhsh, M. Zubair, M. I. A. Rehmani, A. Shahzad, S. Nayab, M. Khan, W. Anum, R. Akhtar, N. Kanwal, N. Manzoor and I. Ali. 2021. Effects of Water Stress on Cotton (Gossypium spp.) Plants and Productivity. Egyptian J. Agron. 43: 307-315.

Rehmani, M. I. A., C. Ding, G. Li, S. T. Ata-Ul-Karim, A. Hadifa, M. A. Bashir, M. Hashem, S. Alamri, F. Al-Zubair and Y. Ding. 2021. Vulnerability of rice production to temperature extremes during rice reproductive stage in Yangtze River Valley, China. J. King Saud Uni. Sci. 33: 101599.

Schreinemachers, P., T. Sequeros, S. Rani, M. A. Rashid, N. V. Gowdru, M. S. Rahman, M. R. Ahmed and R. M. Nair. 2019. Counting the beans: quantifying the adoption of improved mungbean varieties in South Asia and Myanmar. Food Secur. 11: 623-634.

Shahrajabian, M. H., W. Sun and Q. Cheng. 2022. Chapter 20 - A survey of biological nitrogen fixation in adzuki beans, soybeans, and mung beans, three legumes in traditional Chinese medicine. In: R. B. Singh, S. Watanabe and A. A. Isaza (Editors). Functional Foods and Nutraceuticals in Metabolic and Non-Communicable Diseases. Academic Press. *p.* 301-316.

Singh, G., P. Singh and G. Sodhi. 2019. Analysis of yield gaps in pulse production in south western Punjab. J. Commun. Mobilization Sustain. Develop. 14: 572-578.

Steel, R.G.D., J.H. Torrie and D.A. Dickey. 1997. Principles and Procedures of Statistics: A Biometrical Approach. 3rd ed. McGraw Hill, New York, NY.

Ullah, A., T. M. Shah and M. Farooq. 2020. Pulses production in Pakistan: Status, constraints and opportunities. Int. J. Plant Prod. 14: 549-569.

Wajid, A., M.H. Rahman, A. Ahmad, T. Khaliq, N. Mahmood, F. Rasul, M.U. Bashir, M. Awais, J. Hussain and G. Hoogeboom. 2013. Simulating the interactive impact of nitrogen and promising cultivars on yield of lentil (*Lens culinaris*) using CROPGRO-legume model. Int. J. Agric. Biol. 15: 1331–1336.

Wang, Y., Y.-F. Chen and W.-H. Wu. 2021. Potassium and phosphorus transport and signaling in plants. J. Integr. Plant Biol. 63: 34-52.

Wu, W. and B. Ma, 2015. Integrated nutrient management (INM) for sustaining crop productivity and reducing environmental impact: A review. Sci. Total Environ. 512-513: 415-427.

Yasin, G., M. F. Nawaz, F. Rasool, M. T. B. Yousuf, M. Q. Nazir and A. Javed. 2016. Effect of Canopy Cover of Capparis decidua Forsk. on Soil Conditions in Thal Desert. J. Bioresour. Manag. 3: 3.

Yasir, T. A., A. Khan, M. Skalicky, A. Wasaya, M. I. A. Rehmani, N. Sarwar, K. Mubeen, M. Aziz, M. M. Hassan, F. A. S. Hassan, M. A. Iqbal, M. Brestic, M. S. Islam, S. Danish and A. EL Sabagh. 2021. Exogenous sodium nitroprusside mitigates salt stress in lentil (*Lens culinaris* Medik.) by affecting the growth, yield, and biochemical properties. Molecules. 26: 2576.

Yin, Z., W. Guo, H. Xiao, J. Liang, X. Hao, N. Dong, T. Leng, Y. Wang, Q. Wang and F. Yin. 2018. Nitrogen, phosphorus, and potassium fertilization to achieve expected yield and improve yield components of mung bean. PLOS ONE 13(10): e0206285.

Zafar, S. H., M. Umair and M. Akhtar. 2023. Nutritional evaluation, proximate and chemical composition of mungbean varieties/cultivars pertaining to food quality characterization. Food Chem. Adv. 2: 100160.

Zhu, J., M. Li and M. Whelan. 2018. Phosphorus activators contribute to legacy phosphorus availability in agricultural soils: A review. Sci. Total Environ. 612: 522-537.