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Productivity and profitability of soybean as influenced by phosphorus and molybdenum fertilization in an acid *Alfisol*

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Abstract

A field experiment was conducted during *kharif* 2021 on soybean at Palampur on silt-clay loam soil (acid *Alfisol*). Graded levels of 0, 30, 60 and 90 kg of P_2O_5 ha^{-1} and 0, 1.0 and 2.0 kg of Mo ha^{-1} were integrated to frame twelve treatments which were arranged in randomized complete block design, replicated thrice. Application of phosphorus and molybdenum significantly influenced the grain and biological yield up to 90 kg P_2O_5 (24.8 q ha^{-1} and 64.2 q ha^{-1}) and 2.0 kg Mo ha^{-1} (22.1 q ha^{-1} and 57.7 q ha^{-1} respectively) along with high net returns and B:C ratio. In contrary, significant increase in straw yield was registered only up to 30 kg P_2O_5 ha^{-1}. The interaction between varied phosphorus and molybdenum levels had no impact on yield. Application of 90 kg P_2O_5 alongside 2.0 kg Mo ha^{-1} proved superior in enhancing productivity and profitability of soybean under acid *Alfisol*.

Key words: *Alfisol*, phosphorus, molybdenum, soybean

Soybean (*Glycine max* L.), world's leading oilseed crop of Fabaceae family, is renowned for its versatility, adaptability, multi utility and high protein (40%) and oil content (20%) (Hossain *et al*. 2024). It fixes about 150 kg ha^{-1} of atmospheric nitrogen and provides 40 kg ha^{-1} residual nitrogen to succeeding crop (Jangir et al. 2022). Alongside, it encompasses essential amino acids, crucial for human health (Sultani *et al*. 2022). The aforesaid perks of soybean along with expanding growers awareness for crop diversification are escalating it's demand and prompting both scientists and growers to seek innovative strategies to improve its productivity. Furthermore, emerging multi-nutrient deficiencies and edaphic factors like soil nutrient availability and high acidity are significant constraints in soybean production. Kakar *et al*. (2002) emphasized the significance of P and Mo in enhancing the nutritional quality and performance of oilseed crops. Indeed, regular replenishment of soil with harmonious blend of these (P and Mo) nutrients is required for sustaining the productivity and profitability of the crop (Ahmad *et al*. 2022).

Inspite of climatic conditions, P availability has always remained a key concern in acid soils. Around 80% of total applied P fertilizer tends to be inaccessible to plant due to the formation of complexes with excessive aluminium and iron, restricting the productivity of soybean by about 10-15% (Wyngaard *et al*. 2016). In legumes, deficiency of P results in reduced photosynthetic efficiency, poor root and nodule formation and delayed primordia initiation (Tehria *et al*. 2014). Moreover, in soybean, the demand for phosphorus is on peak during pod and seed development which are the major P sinks and stores around 60% of it (Pradhan *et al*. 2022). Improvements in soybean yields in response to P application have been documented by several researchers. For instance, an investigation on P-deficient soils elucidated improvement in both the productivity and quality of soybean upon administering 36 kg P ha^{-1} in silty loam soils (Rabbani *et al*. 2023).

Similar to P, acid soils are the hotspots of Mo deficiency and crops grown under such soils are bound to respond positively to its application. In legumes, Mo is particularly important for N-fixation, crop photosynthetic performance, stomatal conductance and increase both biomass and grain yield in soybean (Cakmak *et al*. 2023). Furthermore, Karpagam and Girishchander (2014) accrued highest seed yield and B:C in green gram grown under sandy clay loam soils with the application of 1.0 kg Mo ha^{-1}.

However, very few studies have explored the behavior of varied P rates and graded Mo doses under field situations. Additionally, there is a lack of research on the combined application of P and Mo on the productivity and economic feasibility of soybean in acid *Alfisol* soils. Therefore, this study aims to delineate the relationship between Mo and P in soybean cultivation in the NW Himalayas, anticipating a positive correlation between graded P and Mo rates. The experiment was initiated during *kharif*, 2021 with primary objective: To evaluate the effect of P and Mo on yield and profitability of soybean.

Materials and Methods

To evaluate the effects of P and Mo levels on the soybean production and profitability, a field experiment was conducted at the experimental farm of Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur situated at 32°6′N latitude, 76°3′ E longitude at an elevation of 1290 m AMSL in northwestern Himalayas during *kharif* season (June-Oct, 2021). Palampur falls under a subtemperate humid zone of Himachal Pradesh, characterized by mild summers and severe winters, and experiences occasional snowfall during winters. The region receives an average rainfall of 2800 mm per annum, the major portion of which (about 75%) is received from June to September. The mean maximum and minimum temperatures during cropping season were 31.1^{0}C and 10.5^{0}C, respectively. The crop received total rainfall of 1882 mm and the weekly relative humidity varied from 60 to 94.03 %. Soil of the study area was silty clay loam in texture and classified as *Typic Hapludalfs* as per the Taxonomic System of Soil Classification. At the start of the experiment, soil pH was 5.32, soil organic carbon (SOC) 7.31 g kg^{-1}, and the content of available N, P, K were 307, 16.3 and 119 kg ha^{-1} and Mo was 0.160 mg kg^{-1} and were estimated using potentiometry, rapid titration, micro kjeldahl, colorimetry, flame photometry and ammonium oxalate extraction methods, respectively. The field experiment was laid out in a randomized complete block design with four levels of phosphorus (0, 30, 60 and 90 kg P_2O_5 ha^{-1}) and 3 levels of molybdenum (0, 1.0 and 2.0 kg Mo ha^{-1}) comprising 12 treatments replicated thrice: T_1- (P_0Mo_0); T_2 - (P_0Mo_1); T_3- (P_0Mo_2); T_4- (P_1Mo_0); T_5- (P_1Mo_1); T_6- (P_1Mo_2); T_7- (P_2Mo_0); T_8- (P_2Mo_1); T_9 (P_2Mo_2); T_{10} (P_3Mo_0); T_{11}- (P_3Mo_1) and T_{12} - (P_3Mo_2). The recommended fertilizer doses of 20 kg N and 40 kg K_2O ha^{-1} were applied to the crop at the time of sowing through urea and muriate of potash. Phosphorus and Mo as per treatments were applied at the time of sowing through SSP and sodium molybdate, respectively. The crop was sown on 18th June, 2021 in 2.25 m x 5.0 m plot at a spacing of 45 cm× 15 cm. All the cultural practices were followed as per recommended package and practices during the entire growth period of crop. The crop was harvested in October 2021 and the data on grain, straw and biological yields were recorded.

Economic evaluation

a) The cost of cultivation was calculated by adding all the expenditures incurred as per the prevailing market rates.
b) Gross returns were worked out by multiplying the economic yield with market price of grain.
c) Net returns were calculated for each treatment after deducting the corresponding cost of cultivation from gross returns.
d) Benefit-cost ratio was worked out by dividing net returns with cost of cultivation.

Statistical analysis

The data generated were statistically analyzed following the technique of analysis of variance for randomized block design as suggested by Gomez and Gomez (1984).

Results and Discussion

Grain yield

Our study revealed that the individual factors (P and Mo) exerted a significant influence on soybean yield, whereas their combined impact exhibited statistical equivalence (Figure 1). Amidst the varied P levels, the treatment involving 90 kg P ha^{-1} resulted in the highest grain yield (24.8 q ha^{-1}) of soybean, while the plots deprived of P supplementation registered the lowest yield (15.4 q ha^{-1}). These findings are consistent with Runia (2018), who observed lower grain yields in P-devoid treatments compared to P-treated plots, highlighting the importance of P fertilization in enhancing productivity. Numerous studies have

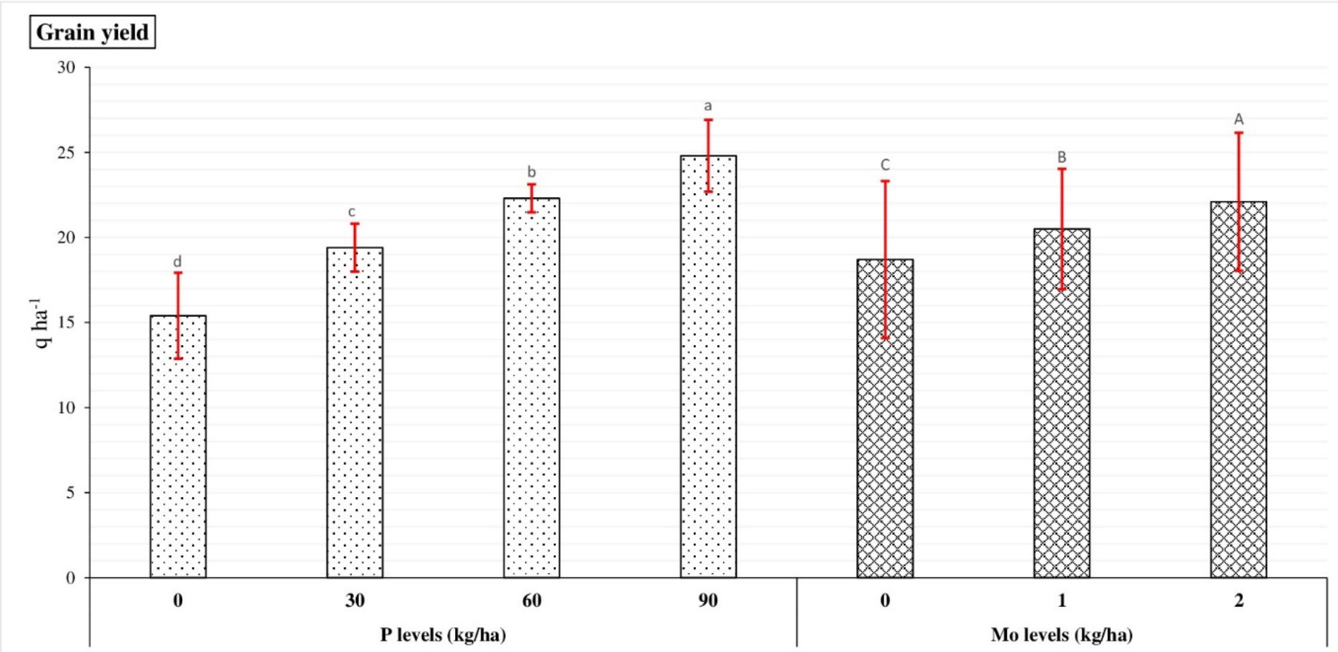

Fig. 1 Influence of P and Mo levels on grain yield of soybean. Bars with identical pattern belong to the single group. Bars labeled with different letters indicate significant differences (p value ≤0.05) within group as per Duncan's New Multiple Range Test. Error bars represents standard error of each treatment

reported the low availability of P in acid soils due to its high fixing capacity, which aligns with our findings that showed a consistent decrease in soybean yield with decreasing P levels (Pradhan *et al*. 2022). The highest yield increase recorded with 90 kg ha^{-1} of P might have provided an adequate supply of P to meet the nutrient requirements of soybean under the studied conditions. The other possible reason could be due to the development of more roots, greater absorption of nutrients and a greater accumulation of dry matter during the growth period and the translocation of more photosynthates to the seed (Ahmad *et al*. 2022). P fertilizer aids in creation of extra seeds and other reproductive measures that eventually subsidized the yield (Rani *et al*. 2016). Furthermore, a reduction in P dosage resulted in significant decline in yield at each reduced P level.

An analogous pattern was observed with the graded Mo dose, where the highest grain yield (22.1 q ha^{-1}) was achieved with the application of 2 kg Mo ha^{-1}. Additionally, yield increments of 18.1 and 9.62 per cent were observed with the application of 2 kg Mo ha^{-1} and 1 kg Mo ha^{-1}, respectively, compared to the treatment devoid of Mo. As, Mo plays a crucial role in enhancing symbiotic biological N fixation making soil environment favorable for absorption of other nutrients, leading to better crop growth and ultimately achieving higher grain yield (Heshmat *et al*. 2021). This probably contributed in higher yield in response to Mo doses in our study, which corroborate with the findings of Ahmad *et al*. (2022) who also demonstrated higher yields of mung bean with Mo application.

While comparing the significance of the assessed nutrients indicated that omitting P application resulted in substantial decrease in soybean yield compared to the exclusion of Mo.

Straw yield

Our study elucidated that the discrete elements, (P and Mo), alongside their synergistic effect exhibited statistical parity in influencing straw yield (Figure 2). Among the varied P levels, the 90 kg P ha^{-1} treatment produced the peak straw yield (39.4 q ha^{-1}) in soybean, while the plots devoid of P fertilization recorded the lowest (25.7 q ha^{-1}). Moreover, successive reductions in phosphorus (P) dosage at each level registered a marked diminution in the straw yield. The supplementation of 90 kg P ha^{-1} showed statistical equivalence to 60 kg P ha^{-1}. As P is responsible for increasing the chlorophyll content, photosynthetic rate and stable acid phosphatase activity, the higher straw yield might be due to the enhanced activity of aforementioned parameters, which accumulated more

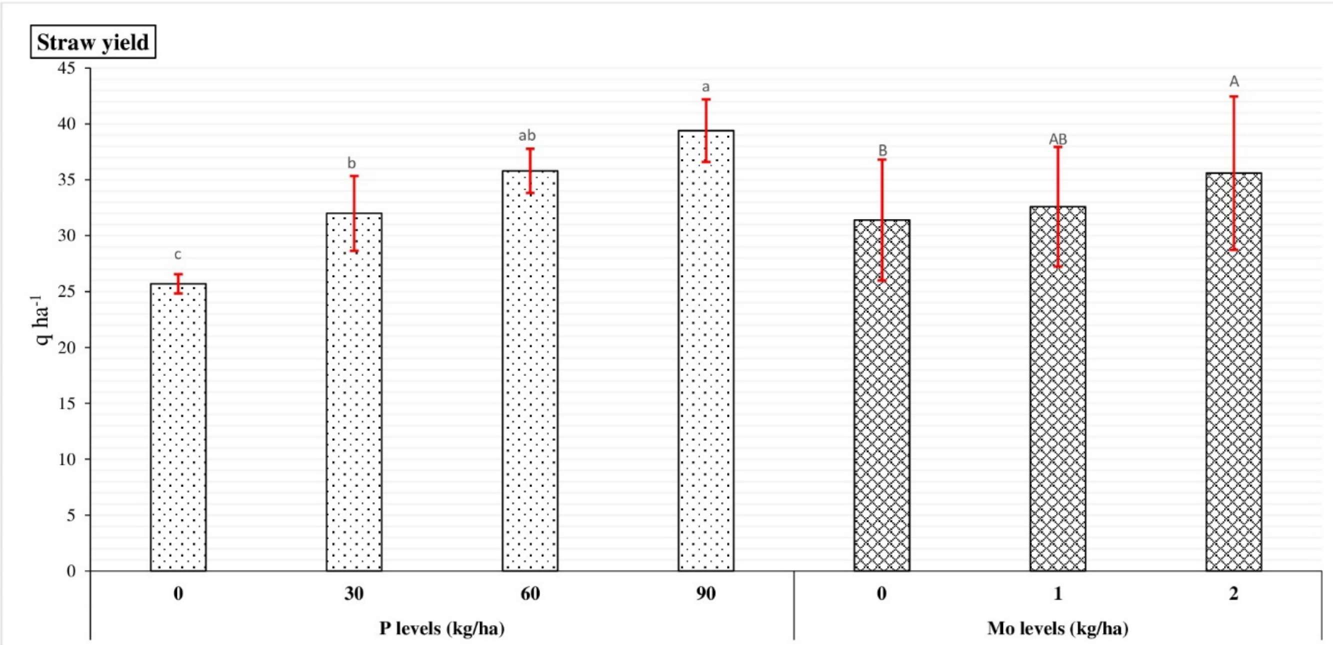

Fig. 2 Influence of P and Mo levels on straw yield of soybean. Bars with identical pattern belong to the single group. Bars labeled with different letters indicate significant differences (p value ≤0.05) within group as per Duncan's New Multiple Range Test. Error bars represents standard error of each treatment

dry matter after anthesis (Begum *et al*. 2015). Considering the significance of P, its role in pod and seed formation, that's why our study found statistical parity in 90 and 60 kg ha^{-1} P application and generally the nutrient uptake by leguminous crop gets reduced towards maturity. Conversely, Pranav *et al*. (2024) registered increased straw yield with increased levels of P.

Increased levels of Mo however did not show any significant impact but a numerical increase in straw yield was registered. The magnitude of increase in yield with 1 and 2 kg Mo ha^{-1} being 3.8 and 13 % respectively over no application. Likewise, Singh *et al*. (2017) also encountered an increment of 19.4% in straw yield of lentil with the application of 2 kg Mo ha^{-1} over no application. The interaction between Mo and P did not result a significant relationship with their application rates, likely due to the minimal influence of Mo on the function of P in plant physiology (Qin *et al*. 2023).

Biological yield

Conjoint P and Mo application at graded levels failed to show any significant impact. However, their sole additions resulted in significant increase in biological yield (Figure 3). Skipping P application in soybean showed negative impact on biological yield. The increased P doses consistently exhibited significant influence and highest yield was registered with the highest P application of 90 kg P ha^{-1} (64.2 q ha^{-1}). The per cent increase was 56.2, 41.3 and 25% with application of 90, 60 and 30 kg P ha^{-1} respectively, over control. Highest biological yield achieved might be owing to the concomitant increase in growth and yield attributes of soybean and improved nutritional environment in rhizosphere favouring higher plant metabolism and photosynthetic activity (Meena *et al*. 2015). The other possible reason could be that P supports the crop to create more seeds and further propagative fragments that eventually contribute to other components of yield and biological performance (Ahmad *et al*. 2022). Also, P application causes in greater root growth and biological performance as reported by Rani *et al*. (2016). Similar results have also been reported by Spandana *et al*. (2021) in soybean who also highlighted that lack of P deteriorated the roots growth thereby negatively impacting the other physiological and metabolic functions of soybean. Likewise, Mo application at increased levels (0 to 2 kg ha^{-1}) resulted in increased yield and significantly higher being with 2 kg Mo ha^{-1} (57.7 q ha^{-1}); the multi functionality of molybdenum as aforementioned and it's predominant role in accelerating the enzymatic

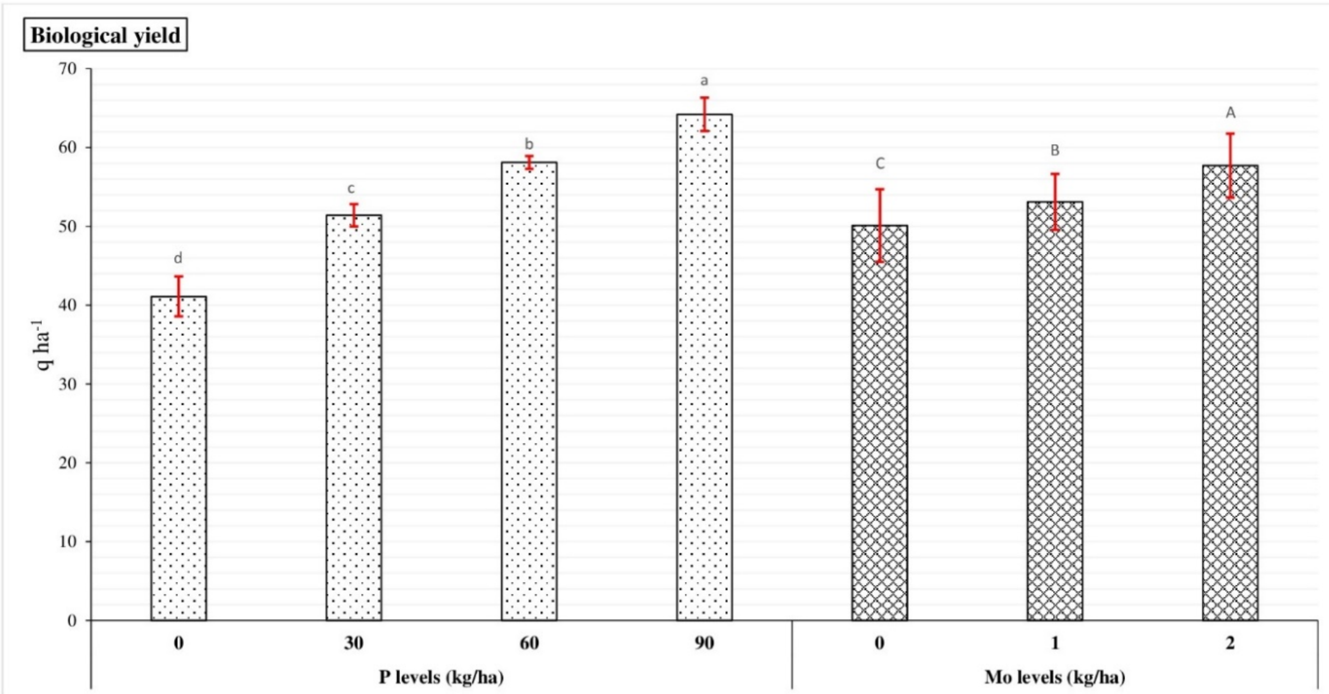

Fig. 3 **Influence of P and Mo levels on biological yield of soybean. Bars with identical pattern belong to the single group. Bars labeled with different letters indicate significant differences (p value ≤0.05) within group as per Duncan's New Multiple Range Test. Error bars represents standard error of each treatment**

activities collectively contributing to the improved biological yield of soybean as has also been highlighted by Rana *et al*. (2020).

Effect of different treatments on economics of soybean

The application of both P and Mo nutrients at their highest levels resulted in higher productivity and profitability; addressing the biggest disquiet among farmers. Highest cost of cultivation, gross, net returns and B:C (₹ 49217 ha^{-1}, ₹ 175422 ha^{-1}, ₹126205 ha^{-1} and 2.56, respectively) were discerned with T_{12} (P_3Mo_2) whereas, the lowest (₹ 42218 ha^{-1}, ₹ 82978 ha^{-1}, ₹ 40760 ha^{-1} and 0.97, respectively) under T_1 (P_0Mo_0) (Table 1). Albeit, the cost of cultivation was highest in T_{12}

Table 1. Effect of graded phosphorus and molybdenum levels on the economics of soybean

Treatment	Cost of cultivation (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	B:C
T_1 - P_0Mo_0	42218	82978	40760	0.97
T_2 - P_0Mo_1	45218	104756	59537	1.32
T_3 -P_0Mo_2	48218	112756	64537	1.34
T_4 - P_1Mo_0	42551	116489	73938	1.74
T_5 -P_1Mo_1	45551	125556	80004	1.76
T_6 -P_1Mo_2	48551	135200	86649	1.78
T_7 -P_2Mo_0	42884	139111	96227	2.24
T8- P_2Mo_1	45884	143911	98027	2.14
T_9 -P_2Mo_2	48884	150044	101160	2.07
T_{10} - P_3Mo_0	43217	148933	105716	2.45
T_{11} - P_3Mo_1	46217	157289	111072	2.40
T_{12} - P_3Mo_2	49217	175422	126205	2.56

(P_3Mo_2), but despite of that the B:C was found to be highest owing to higher yield advantages in comparison to the costs involved in this treatment combination. The percent increment of benefit cost ratio was to the tune of 164 and 82% in the treatments T_{12} (P_3Mo_2) and T_{11} (P_3Mo_1) over T_1 (P_0Mo_0). Karpagam and Girishchander (2014) working on green gram found highest net returns with 1.0 kg Mo ha^{-1} application over Mo devoid treatment. Similarly, Spandana *et al*. (2021) in an acid *Alfisol* registered highest gross and net returns and B:C under soybean with the application of 60 kg P_2O_5 ha^{-1} and 6 g kg^{-1} molybdenum as seed treatment.

Conclusion

The results from the present study demonstrated a significant effect of phosphorus and molybdenum application on productivity of soybean in acid soil. The highest doses of both the nutrients responded significantly in enhancing the soybean yield. To achieve maximum monetary returns, conjoint application of 90 kg P_2O_5 ha^{-1} and 2.0 kg Mo ha^{-1} proved to be the best combination in acid Alfisol of Himachal Pradesh.

Conflict of interest: Authors declare no competing interest.

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