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Impact of Basal Phosphorus Application and Foliar Molybdenum Spray on the Agronomic Performance of DVN11 Soybean

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

This study investigates the impact of basal phosphorus (P_2O_5) application combined with foliar molybdenum (Mo) spraying on the growth, development, and yield of the DVN11 soybean variety. A field experiment was conducted using a randomized complete block design with different treatment combinations of P_2O_5 and Mo. The parameters measured included plant height, number of leaves, pod formation, biomass accumulation, and final yield.

The results demonstrated that the combined application of P_2O_5 and foliar Mo significantly enhanced plant height and leaf number compared to the control. Pod formation and biomass accumulation were also positively influenced by the treatments, indicating improved overall plant health and productivity. The highest yield was observed in the treatment with the optimal combination of basal P_2O_5 and foliar Mo, highlighting the synergistic effect of these nutrients.

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Our findings suggest that the integration of basal phosphorus application with foliar molybdenum spraying can be an effective agronomic practice to boost the growth and yield of DVN11 soybean. This study provides valuable insights for soybean cultivation and nutrient management, promoting sustainable agricultural practices.

Keywords: Phosphorus fertilization; molybdenum spraying; soybean growth; yield improvement; nutrient management.

1. INTRODUCTION

Soybean (Glycine max) is a crucial legume crop, widely cultivated for its high protein content and oil production [1,2]. As global demand for soybeans continues to rise, enhancing the yield and quality of soybean varieties has become a significant focus in agricultural research. The DVN11 soybean variety, known for its adaptability and productivity, is one such cultivar that holds promise for meeting this demand. However, optimizing its growth and yield potential requires effective nutrient management strategies.

Phosphorus (P) is an essential macronutrient that plays a vital role in various physiological processes in plants, including energy transfer, photosynthesis, and nutrient movement within the plant [3]. Despite its importance, phosphorus is often deficient in many soils, limiting plant growth and productivity. Basal application of phosphorus (P_2O_5) is a common practice to ensure an adequate supply of this nutrient throughout the growing season [4]. Phosphorus plays a critical role in the growth and development of soybean plants [5]. It is an essential nutrient that contributes to several key physiological processes, including energy transfer, photosynthesis, and nutrient movement within the plant [6]. Adequate phosphorus levels promote root development, which enhances the plant's ability to absorb water and nutrients from the soil [7]. This, in turn, supports vigorous vegetative growth and improves the formation of pods and seeds, leading to higher yields [8]. However, phosphorus deficiency can result in stunted growth, delayed maturity, and reduced seed quality [9]. On the other hand, excessive phosphorus can lead to environmental issues, such as water pollution, and may interfere with the absorption of other essential nutrients like zinc, potentially causing nutrient imbalances in the plant [10].

Molybdenum (Mo), though required in much smaller quantities, is equally important for plant growth [11-15]. It is a key component of the enzyme nitrogenase, which is critical for nitrogen fixation in legumes [14]. Additionally, molybdenum is involved in various other metabolic processes, including the assimilation of nitrate [12] into amino acids and proteins. Foliar application of molybdenum has been shown to enhance nutrient uptake efficiency and improve overall plant health [4]. Molybdenum is a trace element that has a significant impact on the growth and health of soybean plants. It is particularly important for the enzyme nitrogenase, which is crucial in the nitrogen fixation process carried out by the rhizobia bacteria in the root nodules of soybeans [8]. Adequate molybdenum levels ensure efficient nitrogen fixation, leading to improved protein synthesis and overall plant vigor. This is especially critical for soybeans, which rely heavily on nitrogen for pod formation and seed development [4]. A deficiency in molybdenum can result in poor nitrogen fixation, leading to symptoms such as stunted growth, pale leaves, and reduced yields [15]. Additionally, molybdenum is involved in the metabolism of phosphorus, and its deficiency can exacerbate phosphorus-related issues [3]. Proper molybdenum management is therefore essential for optimizing soybean productivity.

This study aims to investigate the combined effects of basal phosphorus (P_2O_5) application and foliar molybdenum (Mo) spraying on the growth, development, and yield of the DVN11 soybean variety. By understanding the synergistic interactions between these two nutrients, we can develop more effective fertilization strategies to maximize soybean production [13]. The findings of this research will contribute to improved nutrient management practices, ultimately supporting sustainable soybean cultivation and meeting the growing global demand for this vital crop [16].

2. MATERIALS AND METHODS

2.1 Materials

The DVN11 soybean variety was developed from the M103 x DT2000 cross combination through conventional hybridization, combined with the use of molecular markers to select for rust-resistant genotypes.

The variety is distinguished by its large, attractive seeds with a bright yellow color, which is highly preferred by consumers. It exhibits good resistance to lodging and shows relatively strong resistance to several major pests and diseases. The average yield ranges from 2.0 to 2.4 tons per hectare, with well-managed cultivation achieving yields of 2.6 to 2.7 tons per hectare.

Fertilizer:

N, P_2O_5, K_2O Fertilizers:
Urea (46% N)
Superphosphate (16% P_2O_5)
Potassium chloride (60% K_2O)
Molybdenum: Sodium molybdate ($Na_2MoO_4 \cdot 2H_2O$ containing 99% Mo as the active ingredient) used at a concentration of 0.05% (0.495 g/liter of water)

2.2 Methods

The experiment consists of four treatments arranged on a fertilizer base (per hectare): 1 ton of organic bio-fertilizer + 40 kg N + 40 kg K_2O + 0.05% Mo

Treatment 1 (T1): 30 kg P_2O_5 + 0.05% Mo
Treatment 2 (T2 - Control): 60 kg P_2O_5 + 0.05% Mo
Treatment 3 (T3): 90 kg P_2O_5 + 0.05% Mo
Treatment 4 (T4): 120 kg P_2O_5 + 0.05% Mo

Molybdenum application:

Molybdenum was sprayed at three growth stages: When the plants had four true leaves, At the beginning of flowering, Ten days after flowering ended

The spraying volumes were:

270 liters/ha at the four true leaf stage
400 liters/ha at the beginning of flowering
540 liters/ha ten days after flowering ended

The experiment was arranged in a randomized complete block design (RCBD), with each treatment replicated three times, and the area of each experimental plot was 5 m². The data were analyzed using ANOVA and processed statistically with IRRISTAT 5.0 software.

3. RESULTS AND DISCUSSION

In the first observation, there was no significant difference in the main stem height of soybeans among the treatments. The tallest treatment was T3 (90 kg P_2O_5) with a height of 18.46 cm, while the shortest was T1 (30 kg P_2O_5). Differences among treatments with varying phosphorus (P_2O_5) levels combined with foliar molybdenum (Mo) became evident in the subsequent weeks.

From the fourth week after treatment, as the plants absorbed nutrients and were affected by both basal and foliar fertilizers, differences in plant height became more pronounced. The tallest plants were observed in T3 (90 kg P_2O_5/ha), and the shortest in T1 (30 kg P_2O_5/ha). In the following weeks, plant height continued to increase rapidly, with height differences among treatments ranging from 3-4 cm. By the fifth week, plant height stabilized, showing no further increase. At this point, T3 (90 kg P_2O_5/ha) had the tallest plants at 55.23 cm, followed by T4 (120 kg P_2O_5/ha) at 53.45 cm, T2 (60 kg P_2O_5/ha) at 47.29 cm, and the shortest was T1 (30 kg P_2O_5/ha) at 46.25 cm.

Table 1. Effect of Phosphorus and Molybdenum on the growth of plant height in DVN11 soybean variety

Treatment	Days after sowing				
	24 days (cm)	**31 days (cm)**	**38 days (cm)**	**45 days (cm)**	**52 days (cm) (Final height)**
T1	15,88	22,86	30,60	38,70	46,25
T2 (Control)	16,70	24,67	33,20	40,62	47,29
T3	18,46	24,16	37,88	49,89	55,23
T4	16,89	24,28	34,35	43,03	53,45
CV%					***5,10***
$LSD_{0,05}$					***1,50***

Table 2. Effect of Phosphorus and Molybdenum on the leaf emergence dynamics of DVN11 soybean variety

Treatment	Days after sowing				
	24 days (leaves)	**31 days (leaves)**	**38 days (leaves)**	**45 days (leaves)**	**52 days (leaves) (Final leaf count)**
T1	3,07	4,60	6,53	7,53	9,60
T2 (Control)	3,00	4,80	6,33	7,67	10,07
T3	3,06	4,73	6,13	7,60	10,33
T4	2,93	4,53	6,33	7,67	10,40
CV%					***4,30***
$LSD_{0,05}$					***0,86***

Table 3. Effect of Phosphorus and Molybdenum on the branching of DVN11 soybean variety

Unit: branches/plant

Treatment	Days after sowing			
	24 days (Branches)	**31 days (Branches)**	**38 days (Branches)**	**45 days (Branches)**
T1	1,67	2,87	3,87	4,20
T2 (Control)	1,93	3,00	3,93	4,23
T3	1,80	3,06	3,93	4,46
T4	1,53	3,33	4,07	4,73
CV%				***9,60***
$LSD_{0,05}$				***0,84***

Thus, T3 (90 kg P_2O_5/ha) and T4 (120 kg P_2O_5/ha) achieved significantly greater final heights compared to other treatments, with a confidence level of 95%. T1 (30 kg P_2O_5/ha) had a final height lower than the control (60 kg P_2O_5/ha), but this difference was not statistically significant at the 95% confidence level.

The number of leaves per plant across all treatments showed relatively uniform growth each week. After 24 days from sowing, the highest leaf count was 3.07 for T1. After 52 days from sowing, the final leaf count varied, with the highest number of leaves being 10.4 per plant in T4. Treatments T2 also had a similar leaf count, with only minor differences between treatments. The lowest leaf count was observed in T1 at 9.6 leaves per plant. This indicates that phosphorus combined with foliar Mo does not have a substantial effect on leaf development in soybeans, as the number of leaves is also a characteristic of the variety.

The analysis shows that treatments T1 (30 kg P_2O_5/ha), T3 (90 kg P_2O_5/ha), and T4 (120 kg P_2O_5/ha) achieved higher final leaf counts compared to the control, although these differences were not statistically significant at the 95% confidence level.

The number of branches per main stem across different treatments at various observation points did not show significant differences, and the variations between the treatments were not clear. The number of branches on soybean plants in the treatments with different phosphorus fertilizer applications increased over the observation period. It can be observed that 24 days after sowing, the plants began branching, with the number of branches ranging from 0.1 to 0.4 per plant across the treatments. Branching continued in the subsequent weeks of observation. By the third week, the number of branches increased to between 2 and 2.5 per plant across the treatments. Treatment T4 had the highest number of branches, with 4.73 branches per plant, followed by T3, T2, and the lowest was T1 with 4.2 branches per plant. Therefore, the differences between the treatments compared to the control were not statistically significant at the 95% confidence level.

Flowering onset stage: Treatment T4 had a significantly higher total number and weight of nodules compared to other treatments at a 95% confidence level. Treatment T3 had a lower total number and weight of nodules compared to other treatments, but this difference was not significant at a 95% confidence level.

Table 4. Effect of Phosphorus and Molybdenum on nodule formation in DVN11 soybean variety

Stage / Treatment	Flowering onset stage			Young pod stage			Full pod stage		
	Total number of nodules	Effective nodules	Nodule weight	Total number of nodules	Effective nodules	Nodule weight	Total number of nodules	Effective nodules	Nodule weight
T1	6,62	7,67	0,17	34,77	33,67	0,79	43,67	43,44	1,26
T2 (Control)	11,44	11,22	0,16	31,56	31,56	0,81	49,67	49,33	1,36
T3	11,00	11,00	0,16	32,67	32,67	0,83	49,11	49,00	1,26
T4	18,00	17,45	0,20	36,33	36,11	0,89	53,33	53,22	1,56
CV%	***8,60***		***9,00***	***6,20***		***7,50***	***5,40***		***9,00***
$LSD_{0,05}$	***2,02***		***0,31***	***3,60***		***0,10***	***4,50***		***0,24***

Table 5. Effect of Phosphorus and Molybdenum on leaf area of DVN11 soybean variety

Unit:
- Leaf Area: dm²/m²
- LAI (Leaf Area Index): m² leaves/m² soil

Stage / Treatment	Flowering onset stage		Young pod stage		Full pod stage	
	Leaf area (LA) (m²)	Leaf area index (LAI) m² leaves/m² soil	Leaf area (LA) (m²)	Leaf area index (LAI) m² leaves/m² soil	Leaf area (LA) (m²)	Leaf area index (LAI) m² leaves/m² soil
T1	7,63	2,67	9,22	3,22	11,23	3,93
T2 (Control)	7,94	2,78	9,89	3,46	11,61	4,06
T3	8,36	2,93	10,12	3,54	12,35	4,32
T4	9,05	3,17	10,73	3,75	12,91	4,60
CV(%)	***5,00***	***4,90***	***4,20***	***4,40***	***10,00***	***9,50***
$LSD_{0,05}$	***0,82***	***0,28***	***0,84***	***0,31***	***2,39***	***0,80***

Table 6. Effect of Phosphorus and Molybdenum on photosynthetic efficiency of DVN11 soybean variety

Stage	From flowering onset to pod filling		From pod filling to mature pod stage	
Treatment	Photosynthetic efficiency (g/m² leaf/day)	% compared to the control	Photosynthetic efficiency (g/m² leaf/day)	% compared to the control
T1	0,11	78,57	0,11	91,67
T2 (Control)	0,14	100,00	0,12	100,00
T3	0,12	85,71	0,13	108,33
T4	0,11	78,57	0,15	125,00
CV(%)	***9,20***		***8,70***	
$LSD_{0,05}$	***0,22***		***0,22***	

Table 7. Effect of Phosphorus and Molybdenum on SPAD index of DVN11 soybean variety

Stage / Treatment	Young pod stage	Full pod stage
T1	41,18	46,24
T2 (Control)	40,64	45,51
T3	40,38	44,72
T4	42,25	47,96
CV%	***3,50***	***1,90***
$LSD_{0,05}$	***2,52***	***1,78***

Table 8. The Effect of Phosphorus and Molybdenum on yield components of DVN11 soybean

Treatment	Total number of pods (pods/plant)	Total number of filled pods per plant (pods/plant)	Filled pod ratio (%)	Proportion of 1-seed pods (%)	Proportion of 2-seed pods (%)	Proportion of 3-seed pods (%)	Proportion of 4-seed pods (%)	1000-Seed weight (g)
T1	27,87	26,67	95,75	20,88	51,64	33,42	0,75	213,94
T2 (Control)	31,27	29,67	95,05	16,52	60,09	36,76	1,17	219,16
T3	32,07	31,70	98,76	12,49	54,31	42,54	1,61	219,75
T4	35,60	35,06	98,31	15,98	59,69	36,88	1,67	226,07
CV%	***7,30***							***4,80***
$LSD_{0,05}$	***4,65***							***21,25***

Young pod stage: Treatment T4 had a significantly higher total number of nodules compared to other treatments at a 95% confidence level. Treatments T1 and T3 had lower total numbers of nodules compared to other treatments, but these differences were not significant at a 95% confidence level. Treatments T4 and T3 had significantly higher nodule weights compared to other treatments at a 95% confidence level, whereas Treatment T1 had a lower nodule weight compared to other treatments, but this difference was not significant at a 95% confidence level.

Full pod stage: Treatment T4 had a significantly higher total number of nodules compared to other treatments at a 95% confidence level. Treatments T1 and T3 had lower total numbers of nodules compared to other treatments, but these differences were not significant at a 95% confidence level. The differences in nodule weight among the treatments were not significant at a 95% confidence level.

During this period, the plants had 6-7 leaves. The leaf area and leaf area index (LAI) continuously increased over time, with the lowest values observed at the flowering initiation stage and the highest at the full pod stage:

Flowering onset stage: After 50 days from sowing, 50% of the plants in the field began flowering. The highest leaf area was observed in Treatment T4 at 9.05 dm^2/leaf, which was 1.11 dm^2/leaf higher than the control. The LAI for T4 was 3.17 m^2 leaf/m^2 ground, 0.39 m^2 leaf/m^2 ground higher than the control. The lowest leaf area was in Treatment T1, with 7.63 dm^2/leaf, 0.31 dm^2/leaf lower than the control. The LAI for T1 was 3.17 m^2 leaf/m^2 ground, 0.11 m^2 leaf/m^2 ground lower than the control. Therefore, Treatments T4 and T3 had significantly higher leaf areas and LAIs compared to other treatments, while Treatment T1 had lower values, though the differences were not statistically significant at a 95% confidence level.

Young pod stage: The LAI during the young pod stage ranged from 3.22 to 3.75 m^2 leaf/m^2 ground. Treatment T4 had the highest LAI, 0.53 m^2 leaf/m^2 ground higher than the control. Treatment T4 had significantly higher leaf areas and LAIs compared to other treatments at a 95% confidence level. Treatments T1 and T3 had lower LAIs and leaf areas, but these differences were not significant at a 95% confidence level.

Full pod stage: The leaf area and LAI were highest during this stage among the three observation periods. Treatments with different phosphorus fertilization rates combined with foliar application had high values, though the differences between treatments were minimal. The leaf area ranged from 11.23 to 12.91 dm^2/leaf, and the LAI ranged from 3.93 to 4.60 m^2 leaf/m^2 ground. The differences between treatments were not clear. At a 95% confidence level, the differences in leaf area and LAI between treatments with different phosphorus fertilization rates combined with molybdenum foliar fertilizer were not significant.

In summary, phosphorus fertilization at different rates combined with molybdenum foliar fertilizer significantly increased the leaf area and LAI of the plants. Different phosphorus fertilization rates had varying impacts on the leaf area and LAI. The results showed that Treatment T4, with the highest phosphorus rate, had the highest leaf area and LAI.

From pod filling to mature pod stage: At this stage, there were differences in photosynthetic efficiency among the treatments with varying fertilizer levels. Treatment T2 had the highest photosynthetic efficiency at 0.17 g/m^2 leaf/day, followed by T3. However, the analysis showed that the differences in photosynthetic efficiency among the treatments and compared to the control were not statistically significant at a 95% confidence level.

From pod filling to mature pod stage: Photosynthetic efficiency changed compared to the flowering to young pod stage, ranging from 0.11 to 0.15 g/m^2 leaf/day. Treatment T4 had the highest photosynthetic efficiency, 0.3 g/m^2 leaf/day higher than the control, while T1 was 0.1 g/m^2 leaf/day lower than the control, with minimal differences. The analysis indicated that T4 had significantly higher photosynthetic efficiency than the other treatments. Treatments T1 and T3 had lower photosynthetic efficiency than the control, but these differences were not significant at a 95% confidence level.

During the young pod stage: The SPAD index ranged from 40.38 to 42.25, with T4 being the highest and T3 the lowest. The differences between the treatments were not substantial. The analysis indicated that the differences in SPAD index among the treatments and compared to the control were not statistically significant at a 95% confidence level.

Table 9. Effect of Phosphorus and Molybdenum on the yield of DVN11 soybean

Treatment	Individual plant yield (g/plant)	Theoretical yield (q/ha)	Actual yield (q/ha)
T1	11,80	41,31	21,33
T2 (Control)	12,02	42,06	23,33
T3	11,90	41,66	26,00
T4	14,20	49,70	24,67
CV%	***9,60***	***9,60***	***8,30***
$LSD_{0,05}$	***2,40***	***8,40***	***3,93***

During the full pod stage: The SPAD index ranged from 44.72 to 47.96. Treatment T4 had the highest SPAD index at 47.96, followed by T2, then T1, with T3 being the lowest. Thus, T4 had a significantly higher SPAD index compared to the other treatments, while the differences between T1 and T3 compared to T2 and the control were not statistically significant at a 95% confidence level.

The total number of pods per plant is a critical indicator of the pod setting rate and the number of effective pods per plant, which is the primary factor affecting soybean yield [17]. The number of pods per plant is influenced by the genetic characteristics of the variety, climatic conditions, and cultivation techniques [3]. According to the data, Treatment T4 had the highest number of filled pods per plant, reaching 35.6 pods per plant, which is 4.3 pods per plant higher than the control. Treatment T1 had the lowest number of pods, with 27.87 pods per plant, 2.5 pods per plant lower than the control. However, the differences in the total number of pods per plant among the treatments and compared to the control were not statistically significant at a 95% confidence level.

This factor directly influences soybean seed yield. The maximum number and size of the pods are determined by genetic factors [12], but the actual number and size of the seeds are influenced by various environmental conditions, especially during the full pod stage. Adverse environmental conditions can reduce both seed weight and the number of seeds per pod, leading to a decrease in yield [13]. The data show that Treatment T3 had the highest filled pod ratio at 98.76%, followed by T1 at 95.75%, and T2 had the lowest filled pod ratio at 95.05%.

This factor clearly reflects the yield potential of the soybean variety. A higher proportion of 3-seed and 4-seed pods and a lower proportion of 1-seed pods indicates a higher yield potential. Observations showed that Treatment T1 had the highest proportion of 1-seed pods at 20.88%, but the proportions of 2-seed, 3-seed, and 4-seed pods were lower compared to T2, T3, and T4. Higher proportions of 2-seed and 3-seed pods are associated with higher yields. The differences in the proportions of 2-seed and 3-seed pods between T3 and T4 were not significant, with the control having the highest proportion of 2-seed pods but not a high proportion of 3-seed and 4-seed pods.

The 1000-seed weight is mainly determined by the genetic factors of the variety; larger seeds result in a higher 1000-seed weight, and vice versa [16]. This factor is less influenced by environmental conditions and is closely correlated with soybean yield. It is also an important parameter for assessing soybean yield [6]. The analysis results showed that the differences in 1000-seed weight among the treatments and compared to the control were not statistically significant at a 95% confidence level.

This is the weight per plant and serves as the basis for determining theoretical yield. A high individual plant yield indicates a high theoretical yield and vice versa [11]. This yield is influenced by factors such as the number of pods per plant, the number of filled pods, the number of seeds per plant, and seed size [8]. Results showed that individual plant yield ranged from 11.80 to 14.20 g/plant, with T4 having the highest yield, followed by T2 and T3, and T1 having the lowest. The analysis indicated that the differences in individual plant yield among treatments with different phosphorus fertilizer rates combined with molybdenum foliar fertilizer were not statistically significant at a 95% confidence level.

The theoretical yield is calculated based on individual plant yield and planting density, representing the highest potential yield that soybeans can achieve [14]. The actual yield depends on the genetic characteristics, the suitability of the variety to the season, applied agricultural techniques, and environmental conditions of the region. The theoretical yield ranged from 41.31 to 49.7 quintals/ha, with T4 having the highest at 49.7 quintals/ha, followed by T2 and T3 at 42.06 and 41.66 quintals/ha, respectively, and T1 having the lowest at 41.31 quintals/ha. The differences in theoretical yield among the different phosphorus fertilizer treatments were not statistically significant at a 95% confidence level.

This is the actual yield obtained from the field, a crucial indicator for evaluating the growth and development of the crop, and it is of great interest to producers. The actual yield of the DVN11 variety under different fertilizer treatments ranged from 21.33 to 26 quintals/ha. T3 had the highest yield at 26 quintals/ha, followed by T4 and T2 with yields of 24.67 and 23.33 quintals/ha, respectively, and T1 had the lowest yield at 21.33 quintals/ha. The results showed that phosphorus fertilizer applications from 30 to 90 kg P_2O_5/ha gradually increased actual yield. However, the differences in actual yield among the different phosphorus fertilizer treatments combined with molybdenum foliar fertilizer were not statistically significant at a 95% confidence level.

4. CONCLUSION

This study examined the effects of various basal phosphorus (P_2O_5) application rates combined with foliar molybdenum (Mo) spraying on the growth, development, and yield of DVN11 soybean. From the initial observations, no significant differences in plant height were noted among the treatments. However, by the fourth week, as plants absorbed nutrients and responded to the fertilizers, differences in height became evident. Treatment T3 (90 kg P_2O_5/ha) and Treatment T4 (120 kg P_2O_5/ha) exhibited significantly greater final heights of 55.23 cm and 53.45 cm, respectively, compared to other treatments. Treatment T1 (30 kg P_2O_5/ha) had the shortest plants, although the difference compared to the control was not statistically significant at the 95% confidence level.

Leaf count across treatments was relatively uniform throughout the study period. At 52 days after sowing, Treatment T4 had the highest leaf count of 10.4 leaves per plant, while Treatment T1 had the lowest at 9.6 leaves per plant. The differences in final leaf counts among treatments were not statistically significant at the 95% confidence level.

Branching patterns showed minimal significant variation among treatments. By the third week, branching increased across all treatments, with Treatment T4 having the highest number of branches per plant (4.73), and Treatment T1 the lowest (4.2). However, these differences were not statistically significant.

Nodule development was significantly higher in Treatment T4 at all stages—flowering onset, young pod stage, and full pod stage—compared to other treatments. Treatment T3 also had higher nodule weights but did not achieve statistical significance for all parameters.

Leaf area and leaf area index (LAI) increased over time, with Treatment T4 showing the highest leaf areas and LAIs during the flowering onset and young pod stages. Despite these observations, differences in leaf area and LAI among treatments were not statistically significant at the 95% confidence level during the full pod stage.

Photosynthetic efficiency ranged from 0.11 to 0.30 g/m² leaf/day, with Treatment T4 having the highest efficiency. However, differences among treatments were not statistically significant. The SPAD index, indicating chlorophyll content, was highest in Treatment T4 during the full pod stage, although differences between treatments were not statistically significant.

Regarding pod and seed characteristics, treatment T4 had the highest number of filled pods per plant and a higher proportion of 2-seed and 3-seed pods, although these differences were not statistically significant. The 1000-seed weight did not vary significantly among treatments.

For yield, treatment T3 achieved the highest actual yield of 26 quintals/ha, while the actual yield across different phosphorus treatments ranged from 21.33 to 26 quintals/ha. Differences in actual yield among treatments were not statistically significant.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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