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Physiological growth indices of field bean (*Lablab purpureus* (L.) Sweet) as influenced by foliar application of nano DAP

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Abstract
Field bean (*Lablab purpureus* (L.) Sweet) is a multipurpose legume grown widely in Karnataka, yet its productivity is constrained by low phosphorus use efficiency in conventional fertilizers. Nano di-ammonium phosphate (DAP), with nanoscale phosphorus (16% P_2O_5) and nitrogen (8% N), offers enhanced solubility, absorption and translocation when applied as a foliar spray. A field experiment was conducted during late *kharif* 2024 at College of Agriculture, Shivamogga, to study the effect of foliar-applied nano DAP on physiological growth indices and yield of field bean under the Southern Transitional Zone of Karnataka (STZ). The experiment was laid out in randomized complete block design with ten treatments and three replications, comprising 100 per cent and 75 per cent recommended dose of fertilisers (RDF) (25:50:25 N:P_2O_5:K_2O kg ha^{-1}) combined with foliar sprays of nano DAP (2 and 4 ml L^{-1}) once at 30 DAS or twice at 30 and 60 DAS. Results revealed significant improvement in physiological growth indices under nano DAP treatments. The treatment with 100 per cent RDF + nano DAP @ 4 ml L^{-1} at 30 and 60 DAS (T_8) recorded the highest leaf area index (2.30 at 60 DAS), absolute growth rate (0.50 g plant^{-1} day^{-1}) and crop growth rate (7.42 g m^{-2} day^{-1}). In contrast, relative growth rate (0.020 g g^{-1} day^{-1}) and net assimilation rate (2.98 g m^{-2} day^{-1}) were superior under 75 per cent RDF + nano DAP @ 4 ml L^{-1} 30 and 60 DAS (T_{10}), reflecting the crop's ability to maintain strong physiological performance even under reduced fertilizer input. Yield attributes followed a similar trend, with T_8 producing the highest seed yield (1234 kg ha^{-1}), with 25 per cent increase over RDF alone. Also recorded the maximum haulm yield (2035 kg ha^{-1}). The study highlights that foliar application of nano DAP, particularly at 4 ml L^{-1} twice during the crop growth cycle, plays a crucial role in improving key physiological growth indices and enhancing yield of field bean under STZ conditions.

Keywords: Field bean, nano DAP, foliar spray, physiological growth indices, yield

1. Introduction
Field bean (*Lablab purpureus* (L.) Sweet), also called as dolichos bean or hyacinth bean or *avare* in Southern parts of India. It is an important multipurpose legume crop cultivated extensively across tropical and subtropical regions (Amkul *et al.*, 2021) [2]. It is valued for its diverse uses as a pulse, vegetable, fodder and green manure and it plays a crucial role in rainfed farming systems due to its adaptability to varied agro-climatic conditions, drought tolerance and ability to improve soil fertility through biological nitrogen fixation. In Karnataka, particularly in the Southern Transitional Zone (STZ), field bean is deeply integrated into traditional farming and food cultures, often thriving on marginal and semi-arid lands where other crops fail. Despite providing 20-25% protein and essential minerals (Raghu *et al*., 2018) [21], the productivity of field bean remains low and inconsistent compared to its genetic potential. One of the major constraints limiting productivity is the inadequate availability of phosphorus (P). Phosphorus is indispensable for legumes as it influences root development, energy transfer, photosynthesis and pod formation. However, in Indian soils, a large fraction of applied phosphorus becomes fixed due to reactions with calcium carbonate, iron and aluminium oxides, forming insoluble complexes. Consequently, the use efficiency of conventional phosphorus fertilizers such as diammonium phosphate (DAP) remains very low, typically in the range of 10-25%, forcing farmers to apply higher doses that increase costs and cause environmental risks (Van de Wiel *et*

al., 2016; Manjunatha *et al*., 2016) [11]. To overcome these challenges, nanotechnology-based nutrient management has emerged as a promising innovation.

Nano fertilizers, by virtue of their nanoscale size, high surface area and reactivity, enhance nutrient solubility, uptake and use efficiency, while reducing losses through leaching and volatilization. Nano DAP, which contains nanoscale particles of phosphorus (16%) and nitrogen (8%) smaller than 100 nm, is particularly effectively, when applied as a foliar spray, ensuring direct nutrient absorption and rapid translocation within plant tissues (Mahil and Kumar, 2019) [10]. Foliar application of nano DAP provides a sustainable alternative to conventional fertilizers by improving phosphorus use efficiency and reducing nutrient losses.

Several studies have demonstrated that nano DAP improves plant growth, nutrient uptake, yield and quality in crops such as rice, maize, groundnut and wheat. In wheat, the integration of basal fertilizer with foliar nano DAP sprays enhanced grain yield by 34.8 per cent in the 2022-23 season and 14.7 per cent in 2023-24 (Reddy *et al*., 2023) [17]. Similarly, in cluster bean, foliar-applied nano fertilizers significantly improved growth and productivity. In blackgram, combining foliar nano DAP with reduced basal doses of N and P enhanced seed and straw nutrient content as well as nutrient uptake, outperforming conventional fertilization practices (Pandey *et al*., 2025) [28].

Foliar-applied nano fertilizers contribute to improved physiological efficiency, promote chlorophyll synthesis and photosynthesis, which in turn enhance physiological growth indices such as leaf area index (LAI), absolute growth rate (AGR), crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR). Such indices provide valuable insights into crop growth dynamics and their relationship with productivity. Moreover, nanofertilizers are aligned with principles of precision agriculture and environmental sustainability, as they reduce nutrient runoff and greenhouse gas emissions. For resource-poor smallholder farmers, nano DAP presents a cost-effective strategy to achieve higher yields with lower input requirements.

Despite encouraging results in cereals and other legumes, there is a significant gap in research on how soil application of recommended fertilizer dose (RDF) in combination with foliar sprays of nano DAP influences the physiological growth indices and yield of field bean under the STZ of Karnataka. Therefore, the present study was undertaken to evaluate the impact of foliar-applied nano DAP on key physiological growth indices such as LAI, AGR, CGR, RGR and NAR as well as on seed and haulm yield of field bean.

2. Material and Methods

The field experiment was conducted during the late *Kharif* season of 2024 at College of Agriculture, Navile, Shivamogga, Karnataka. The experimental site lies in the Southern Transitional Zone (Zone 7) of Karnataka at 13°56′N latitude, 75°34′E longitude and an altitude of 615 m above mean sea level. The region is characterized by a tropical climate. The total rainfall received during the cropping period was 644.2 mm. The mean maximum and minimum temperature during the cropping period was 29.7°C and 20.5 °C, respectively. The soil of the experimental plot was sandy loam (*Typic Haplustalf*, Alfisol) with low organic carbon (0.45 percent), low in available nitrogen (230.47 kg ha^{-1}), medium in available phosphorus (38.20 kg ha^{-1}) and medium in available potassium (199.85 kg ha^{-1}). The soil reaction of the experimental field was slightly acidic (pH 5.23) with an electrical conductivity of 0.18 dSm^{-1}.

The experiment was laid out in a Randomized Complete Block Design (RCBD) with ten treatments replicated thrice. Each gross plot measured 5.4 m × 2.7 m, while the net plot size was 3.6 m × 2.1 m. The field bean variety *Hebbal avare 5* (HA-5) was sown at 30 kg ha^{-1} with spacing of 45 cm × 15 cm. The treatments comprised varying combinations of 100% and 75% recommended dose of fertilizers (RDF: 25:50:25 kg $N:P_2O_5:K_2O$) with foliar nano DAP sprays at concentrations of 2 and 4 ml l^{-1} applied either once (30 DAS) or twice (30 and 60 DAS). An absolute control without fertilizers was included. Before sowing; FYM @ 7.5 t ha^{-1} was applied uniformly except absolute control. Nano DAP (8% N, 16% P_2O_5) was sprayed at 500 l ha^{-1} spray volume. Conventional fertilizers were applied basally according to treatment.

Treatment details

T_1	: Absolute Control
T_2	: 100% RDF
T_3	: 100% RDF + foliar spray of nano DAP @ 2 ml L^{-1} at 30 DAS
T_4	: 100% RDF + foliar spray of nano DAP @ 4 ml L^{-1} at 30 DAS
T_5	: 75% RDF + foliar spray of nano DAP @ 2 ml L^{-1} at 30 DAS
T_6	: 75% RDF + foliar spray of nano DAP @ 4 ml L^{-1} at 30 DAS
T_7	: 100% RDF + foliar spray of nano DAP @ 2 ml L^{-1} at 30 and 60 DAS
T_8	: 100% RDF + foliar spray of nano DAP @ 4 ml L^{-1} at 30 and 60 DAS
T_9	: 75% RDF + foliar spray of nano DAP @ 2 ml L^{-1} at 30 and 60 DAS
T_{10}	: 75% RDF + foliar spray of nano DAP @ 4 ml L^{-1} at 30 and 60 DAS

Field preparation was carried out by tractor ploughing, followed by harrowing and levelling. Healthy seeds of field bean (*HA*-5) were sown manually in lines and thinned to maintain the required spacing. Standard agronomic practices for weed control, irrigation and plant protection were followed uniformly across treatments to ensure normal crop growth. Physiological growth indices were computed using standard formulas from periodic measurements of plant dry matter and leaf area (30 DAS, 60 DAS and harvest). The parameters studied included:

2.1 Leaf area index

Leaf area index is the ratio of leaf area to ground area occupied by the crop plant. Leaf area index (LAI) was worked out using the following formula given by Watson, (1952) [29].

$$LAI = \frac{\text{Leaf area per plant (cm}^2\text{)}}{\text{Ground area covered by the plant (cm}^2\text{)}}$$

2.2 Absolute growth rate
Absolute growth rate (AGR) indicates the dry weight increase per unit time and expressed in g plant^{-1} day^{-1}. It was calculated by using the following formula given by Radford (1967) [30].

$$AGR = \frac{W_2 - W_1}{t_2 - t_1}$$

Where,
W_1 and W_2 are dry weight of plant at time t_1 and t_2, respectively.

2.3 Crop growth rate
Crop growth rate (CGR) is defined as rate of dry matter production per unit ground area per unit time. It is expressed in g m^{-2} day^{-1} and calculated by the formula.

$$CGR = \frac{W_2 - W_1}{(t_2 - t_1) \times A}$$

Where,
W_1 and W_2 are dry weight of plant at time t_1 and t_2, respectively.
A = Spacing (m^2) or land area

2.4 Relative growth rate
Relative growth rate (RGR) is defined as the rate of increase in plant dry matter per unit of existing dry matter per unit time. It was calculated by using the formula suggested by Radford (1967) [30] and expressed in g g^{-1} day^{-1}.

$$RGR = \frac{\ln W_2 - \ln W_1}{t_2 - t_1}$$

Where,
W_1 and W_2 are dry weight of plant at time t_1 and t_2, respectively.
ln stands for the natural logarithm

2.5 Net assimilation rate
Net assimilation rate (NAR) is the rate of dry matter production per unit leaf area per unit time, which indicates the photosynthetic efficiency of the crop. It was calculated by using the formula suggested by Radford (1967) [30] and expressed in g m^{-2} day^{-1}.

$$NAR = \frac{(W_2 - W_1)(\ln L_2 - \ln L_1)}{(t_2 - t_1)(L_2 - L_1)}$$

Where,
W_1 and W_2 are dry weight of plant at time t_1 and t_2, respectively.
L_1 and L_2 are leaf area of plant at time t_1 and t_2, respectively
ln stands for the natural logarithm

Yield attributes *viz*, number of pods per plant, pod length, number of seeds per pod and 100-seed weight were recorded at harvest. Seed yield, haulm yield and harvest index were computed on a per-plot basis and expressed on a hectare scale. The data on physiological growth indices, yield attributes and yield were subjected to analysis of variance (ANOVA) technique described by Gomez and Gomez (1984) [7]. Treatment means were compared using the critical difference (CD) test at 5% probability level. Whenever the calculated 'F' value exceeded the table value at the corresponding error degrees of freedom, treatment differences were considered significant and the critical difference (CD) was computed to compare means. When the 'F' test was non-significant, the CD was omitted and denoted as 'NS'.

3. Results and Discussion
3.1 Leaf area index (LAI)
Leaf area index (LAI), a key indicator of photosynthetic efficiency, varied significantly across treatments (Table 1). At 30 DAS, the highest LAI (0.70) was recorded in T_7 (100% RDF + foliar spray of nano DAP @ 2 ml L^{-1} at 30 and 60 DAS) and T_8 (100% RDF + foliar spray of nano DAP @ 4 ml L^{-1} at 30 and 60 DAS), while the lowest was in the absolute control (0.48). At 60 DAS, T_8 (2.30) maintained the maximum LAI, on par with T_7 (2.27) and T_{10} (2.07), but significantly higher than 100 per cent RDF (1.95) and the absolute control (1.35). At harvest, T_8 again registered the highest LAI (1.44), followed by T_{10} (1.38) and T_7 (1.35), with the control lowest (0.76). The superior LAI in nano DAP treatments is attributed to improved nutrient assimilation, particularly nitrogen for chlorophyll synthesis and phosphorus for energy metabolism, enhancing cell division, leaf expansion and delayed senescence. Similar improvements in LAI with nano fertilizers were also reported by Saleem *et al.* (2021) [31] and Reddy *et al.* (2017) [23].

Table 1: Leaf area index (LAI) of field bean at different growth stages as influenced by different levels of nano DAP application

Treatments	Leaf area index (LAI)		
	30 DAS	60 DAS	At harvest
T_1	0.48	1.35	0.76
T_2	0.68	1.95	1.09
T_3	0.67	2.23	1.15
T_4	0.69	2.26	1.23
T_5	0.57	2.01	1.14
T_6	0.60	2.03	1.23
T_7	0.70	2.27	1.35
T_8	0.70	2.30	1.44
T_9	0.61	2.05	1.29
T_{10}	0.61	2.07	1.38
S.Em ±	0.02	0.07	0.05
C.D (P = 0.05)	0.07	0.20	0.14

Values are mean of three replications. DAS = Days after sowing. S.Em ± = Standard error of mean;
CD (P = 0.05) = Critical difference at 5% probability level.

3.2 Absolute growth rate (AGR)
Absolute growth rate (AGR) differed significantly among treatments during both growth phases (Table 2). From 30-60 DAS, the highest AGR (0.40 g day^{-1}) was observed in T_7 (100% RDF + foliar spray of nano DAP @ 2 ml L^{-1} at 30 and 60 DAS) and T_8 (100% RDF + foliar spray of nano DAP @ 4 ml L^{-1} at 30 and 60 DAS), followed by T_3 and T_4 (0.39 g/ day), while the absolute control (T_1) recorded the lowest (0.21 g day^{-1}). During 60 DAS-harvest, AGR was maximum in T_8 and T_{10} (0.50 g day^{-1}), which were significantly superior to RDF alone (0.22 g day^{-1}) and the control (0.21 g day^{-1}). Higher AGR under nano DAP treatments indicates sustained vegetative and reproductive growth. Primarily due to improved photosynthetic surface area (higher LAI), better nutrient uptake and efficient assimilate partitioning. Similar enhancement of growth rates with nano fertilizers was also reported by Ghahremani *et al.* (2014) [6] and Yasmeen *et al.* (2022) [32], who attributed the response to slow nutrient release and prolonged availability of nutrients, thereby improving crop growth dynamics.

Table 2: Absolute growth rate (g day^{-1}) and Crop growth rate (g m^{-2} day^{-1}) of field bean at different growth stages as influenced by different levels of nano DAP application

Treatments	Absolute growth rate (g day^{-1})		Crop growth rate (g m^{-2} day^{-1})	
	30- 60 DAS	60- Harvest	30- 60 DAS	60- Harvest
T_1	0.21	0.21	3.10	3.08
T_2	0.31	0.22	4.77	3.32
T_3	0.39	0.32	5.79	4.81
T_4	0.39	0.33	5.84	4.88
T_5	0.35	0.36	5.23	5.34
T_6	0.36	0.39	5.27	5.81
T_7	0.40	0.42	5.88	6.29
T_8	0.40	0.50	5.97	7.42
T_9	0.36	0.39	5.28	5.74
T_{10}	0.36	0.50	5.29	7.42
S.Em ±	0.03	0.03	0.39	0.44
C.D (P = 0.05)	0.08	0.09	1.13	1.28

Values are mean of three replications. DAS = Days after sowing. S.Em ± = Standard error of mean;
CD (P = 0.05) = Critical difference at 5% probability level.

3.3 Crop growth rate (CGR)

The results revealed significant differences in crop growth rate (CGR) across treatments (Table 2). During 30-60 DAS, the maximum CGR (7.42 g m^{-2} day^{-1}) was recorded in T_8 (100% RDF + nano DAP @ 4 ml l^{-1} at 30 and 60 DAS), followed by T_7 (7.21 g m^{-2} day^{-1}), while the lowest was observed in the absolute control (3.79 g m^{-2} day^{-1}). From 60 DAS to harvest, T_8 again registered the highest CGR (7.42 g m^{-2} day^{-1}), which was on par with T_{10} (7.29 g/ m^2/ day), whereas the absolute control (3.79 g m^{-2} day^{-1}) recorded the minimum. The higher CGR under nano DAP treatments can be attributed to improved photosynthetic activity, greater nutrient uptake efficiency and sustained leaf area index that prolonged assimilatory surface during the reproductive phase. These results are in agreement with Ghahremani *et al.* (2014) [6] and Yasmeen *et al.* (2022) [32], who reported that nano fertilizers improve growth dynamics by ensuring slow nutrient release, prolonged nutrient availability and efficient partitioning of assimilates. The decline in CGR towards harvest is primarily due to leaf senescence and a reduction in photosynthetic surface area, as also noted in maize by Edwards *et al.* (2014) [5].

3.4 Relative growth rate (RGR)

The results indicated that relative growth rate (RGR) varied significantly across treatments during 60 DAS to harvest, while differences at 30-60 DAS were non-significant (Table 3). The highest RGR (0.022 g g^{-1} day^{-1}) was observed in T_{10} (75% RDF + foliar spray of nano DAP @ 4 ml l^{-1} at 30 and 60 DAS), which was on par with T_8 (0.020 g g^{-1} day^{-1}). The lowest RGR was recorded in the absolute control (0.011 g g^{-1} day^{-1}), followed by RDF alone (0.014 g g^{-1} day^{-1}). The superior RGR under nano DAP treatments reflects enhanced nutrient availability, particularly phosphorus and nitrogen, which supported efficient metabolic activity, biomass accumulation and assimilate partitioning during the reproductive phase. The combined foliar sprays at critical growth stages sustained nutrient supply and delayed leaf senescence, thus enhancing physiological efficiency. These findings are in close agreement with Saitheja *et al.* (2021) [34] in green gram and Omran *et al.* (2020) [33] in mung bean, who reported that integrated nutrient management with nano fertilizers significantly improved relative growth dynamics and yield attributes.

Table 3: Relative growth rate (g g^{-1} day^{-1}) and Net assimilation rate (g m^{-2} day^{-1}) of field bean at different growth stages as influenced by different levels of nano DAP application

Treatments	Relative growth rate (g g^{-1} day^{-1})		Net assimilation rate (g m^{-2} day^{-1})	
	30- 60 DAS	60- Harvest	30- 60 DAS	60- Harvest
T_1	0.029	0.011	2.53	1.12
T_2	0.035	0.014	3.01	1.52
T_3	0.036	0.015	3.01	2.13
T_4	0.036	0.015	2.97	2.09
T_5	0.035	0.017	3.00	2.59
T_6	0.035	0.018	3.00	2.67
T_7	0.036	0.018	2.97	2.60
T_8	0.036	0.020	2.98	2.98
T_9	0.035	0.018	2.99	2.58
T_{10}	0.035	0.022	2.97	3.23
S.Em ±	0.003	0.002	0.16	0.25
C.D (P = 0.05)	NS	0.005	NS	0.73

Values are mean of three replications. DAS = Days after sowing. S.Em ± = Standard error of mean;
CD (P = 0.05) = Critical difference at 5% probability level.

3.5 Net Assimilation Rate (NAR)

Net assimilation rate (NAR) showed non-significant variation among treatments during 30-60 DAS, but significant differences emerged from 60 DAS to harvest (Table 3). At this stage, the highest NAR (3.23 g m^{-2} day^{-1}) was observed in T_{10} (75% RDF + nano DAP @ 4 ml l^{-1} at 30 and 60 DAS), which was statistically on par with T_8 (2.98 g m^{-2} day^{-1}) and T_7 (2.60 g m^{-2} day^{-1}). The lowest NAR was recorded in the absolute control (1.12 g m^{-2} day^{-1}), followed by RDF alone (1.52 g m^{-2} day^{-1}). The higher NAR values under nano DAP treatments indicate sustained photosynthetic efficiency and effective conversion of assimilates into biomass during the reproductive phase. This can be attributed to improved nutrient availability, particularly nitrogen and phosphorus, which enhanced chlorophyll synthesis, delayed senescence and maintained higher leaf activity at later stages of crop growth. Similar findings were reported by Liu and Lal (2014) [9], who highlighted that nano nutrients improve photosynthetic rate and assimilatory efficiency, thereby supporting prolonged growth and higher productivity.

3.6 Seed yield (kg ha⁻¹)

The results revealed that seed yield of field bean was significantly influenced by nano DAP application as illustrated in Fig. 1. The highest seed yield (1234 kg ha^{-1}) was recorded in T_8 (100% RDF + foliar spray of nano DAP @ 4 ml l^{-1} at 30 and 60 DAS), which was 25.0 per cent higher than RDF alone (987 kg ha^{-1}). Treatments T_{10} (1178 kg ha^{-1}) and T_7 (1150 kg ha^{-1}) were statistically on par with T_8 (100% RDF + nano DAP @ 4 ml l^{-1} at 30 and 60 DAS), while the lowest yield was obtained in the absolute control (459 kg ha^{-1}). Similar results of enhanced yield with nano DAP were also reported by Sarika *et al.* (2025) [35] in chickpea, Pandey *et al.* (2025) [28] in black gram, Veeramallu *et al.* (2024) [36] and Prakash *et al.* (2023) [37] in soybean.

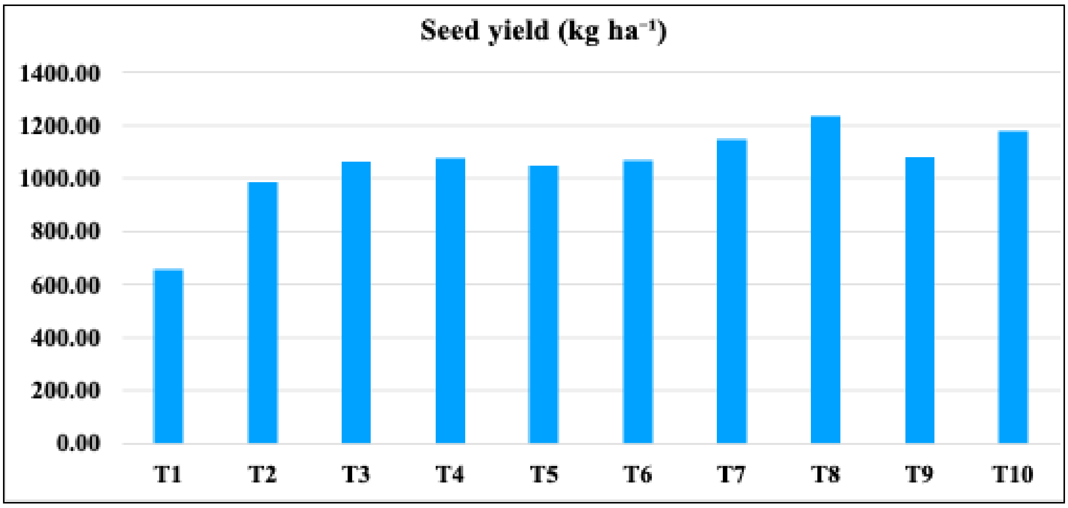

Fig 1: Seed yield (kg ha^{-1}) of field bean as influenced by different levels of nano DAP application

4. Conclusion

The findings of this study indicate that the combined application of soil-applied RDF with foliar application of nano DAP significantly enhanced the growth and yield of field bean. The synergistic effect of basal nutrient supply along with timely foliar supplementation was evident in improved growth indices *viz*, CGR, RGR and NAR. This improvement in production can be attributed to enhanced nutrient availability and better synchronization of nutrient demand during the critical growth stages. The treatment involving 100 per cent RDF + foliar spray of nano DAP @ 4 ml L^{-1} at 30 and 60 DAS recorded superior physiological parameters and yield compared to other combinations, thereby ensuring greater assimilate partitioning to economic sinks. Treatments where RDF was reduced to 75 per cent but supplemented with nano DAP also maintained competitive performance, highlighting the potential of nano fertilizers to reduce dependency on conventional fertilizers without compromising yield. These improvements can be attributed to the integrated nutrient approach, enhanced photosynthetic activity, efficient assimilatory processes and prolonged functional leaf area. The combined application of soil and foliar nutrients, particularly nano DAP, played a pivotal role in optimizing metabolic processes and biomass accumulation throughout the crop growth cycle, ultimately resulting in higher productivity and improved nutrient use efficiency in field bean.

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