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Effects of Nano DAP on Growth and Yield of Tea (*Camellia assamica* sub-sp. *lasiocalyx* (Planch. MS))

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A study was conducted to investigate the growth and yield parameters of tea after application of Nano DAP on tea plants during the time frame of February, 2024 to December, 2024. The experiment was done on TV 23 clone of mature tea plants in experimental garden for plantation crops, AAU-Jorhat. The layout was in RBD with four replications and five treatments. Nano DAP was found effective towards the growth of tea plants. The growth and yield attributes of tea plants increased with application of Nano DAP. The growth and yield parameters were recorded significantly higher in treatments T_2 (Recommended doses of N, P_2O_5, K_2O +3 sprays of Nano DAP @ 3ml/l) and T_3 (Recommended dose of N and K_2O + 75% recommended dose of P_2O_5 + 3 foliar sprays of Nano DAP @ 3 ml/l) over treatment T_1 (Recommended doses of N, P_2O_5 and K_2O). The study revealed that the application of three sprays of Nano DAP @ 3ml/l with recommended dose of fertilizers performed similar with reduction of 25 per cent of basal dose of recommended phosphate

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and recommended dose of nitrogen and potassium along with three sprays of Nano DAP in tea plants. This approach can be a potential and economically feasible method to increase yield of tea plants and to promote the sustainable development of the tea industry.

Keywords: Nano DAP; tea; foliar application; plucking point density; fine leaf count; fresh weight of plucked shoots; dormancy index; green leaf yield.

1. INTRODUCTION

Tea (*Camellia assamica sub-sp. lasiocalyx (Planch. MS))* is a commercially grown perennial crop and widely cultivated across the world. Tea is the world's second most consumed beverage after water. India's tea sector is one of the most organized industries, contributing significantly to the nation's economy (Adhikari et al., 2014).

The tea production in world reached 6422.66 million kg in 2022 (Tea statistics, Tea board of India, https://www.teaboard.gov.in/). India produced 1291.49 million kg during 2023-24 (Tea statistics, Tea board of India, https://www.teaboard.gov.in/). At the international level, China, with a production of 3090.00 million kg (in the year 2020) dominates the world tea market (Tea statistics, Tea board of India, https://www.teaboard.gov.in/). Total export of tea from India has estimated at 226.98 million kg in the year 2022 (Tea statistics, Tea board of India, https://www.teaboard.gov.in/).

The fertilizer requirement for tea crop varies at different growth stages and under different agro-climatic & soil conditions. Nitrogen, phosphorus and potassium are the most important primary macronutrients required by tea. One quintal of made tea removes 5.00 kg of nitrogen, 1.00 kg of phosphate and 2.00 kg of potash from soil (Adnan et al., 2003). Fertilizer application is an important part of the normal intensive production of tea and one of the regular field management practices with significant bearing on both yield and quality of tea. Manuring in mature tea is done on the basis of cyclic yield of the crop and available soil potash content. Soil potash status is termed as low when available potash content in soil is less than 60 ppm, medium when available potash content in soil ranges from 60 to 100 ppm & high when available potash content in soil is more than 100 ppm (Adnan et al., 2003).

Fertilization with nitrogen, phosphorus and potassium is an effective strategy for achieving high tea yield and quality (Anon, 1996). Nitrogen is an essential mineral nutrient for plant growth and reproduction. Apart from being a fundamental building block of proteins and nucleic acids, nitrogen also participates in carbon fixation through photosynthesis as a component of chlorophyll (Anon, 2023). Nitrogenous fertilizer application can significantly improve tea yield and quality (Kumar et al., 2018). It facilitates the formation of amino acids, including theanine, arginine, and glutamic acid, which are positively correlated with tea quality (Sun et al., 2023).

The bulk of the inorganic nitrogen, phosphorus and potassium given to the soil is lost by leaching, erosion, volatilization, or is immobilized in soil organic matter. Only a small part of soil nitrogen is readily available to the plants and the majority remains unavailable (Barua, 1989).

Phosphorus is crucial for plant development and reproduction and is a key component of fertilizers for modern agriculture. Phosphorus helps in photosynthesis, energy storage, And cell division. The availability of phosphorus governs the uptake of nitrogen and potassium as well. Adequate response to nitrogen is possible only when phosphate need of the soil is well satiated (Barua & Dutta, 1972. An analysis of 30 years data of NPK experiments in Assam shows significant and positive interaction between phosphorus and nitrogen (Bernard & Habash, 2009). Positive effects of P-K interactions on yield were noticed in long-term NPK trials in tea plantations of Assam and Doors (Biswas & Biswas, 1984) as well as in Sri Lanka (Biswas & Biswas, 1984).

In acidic and highly weathered soils, 75-80 per cent of the applied phosphate is fixed onto the surfaces of iron and aluminium oxides and hydroxides (Bray & Kurtz, 1945). It has been reported that less than 15 per cent of fertilizer applied phosphorus is taken up by the crop during the year of application (Deo et al., 2022).

In the present investigation, foliar spraying of Nano DAP along with recommended basal doses of N and K_2O was found to be an efficient method for increasing growth and yield attributes in tea plants. Nanotechnologies have the potential to produce a significant boost in crop yield along with improvement of food production

systems. Nanotechnology has a greater nutrient uptake efficiency, and it will soon transform the methods used for foliar application. Nano fertilizers were an effective alternative to costly conventional fertilizers (Dutta, 1956). Moreover, foliar spraying transports nutrients quickly and efficiently to the location of food synthesis, reducing the need for fertilizer. Foliar nutrient application was found to be more beneficial than soil application in terms of reducing losses due to leaching and fixation. When moisture availability is restricted, fertilizer administration via foliar spray provides excellent absorption. While foliar spray does not replace soil treatment, it should definitely be considered as a supplemental technique (Gomez & Gomez, 1984).

2. MATERIALS AND METHOD

The experiment was conducted at Experimental Garden for Plantations Crops (EGPC), Section number 2(A), Department of Tea Husbandry and Technology, Assam Agricultural University, Jorhat from February, 2024 to December, 2024. The experiment was laid out in Randomized Block Design (RBD) with five treatments and four replications. The planting material for the experiment was TV 23 clone planted with spacing 105 cm x 70 cm. Collection of plucked tea leaves were done using nylon bags.

The treatment details of the experiment are presented below:

T_1 : Recommended doses of N, P_2O_5 and K_2O

T_2 : Recommended doses of N, P_2O_5, K_2O +3 sprays of Nano DAP @ 3ml/l

T_3 : Recommended dose of N and K_2O + 75% recommended dose of P_2O_5 + 3 foliar sprays of nano DAP @ 3 ml/l

T_4 : Recommended dose of N and K_2O + 50% recommended dose of P_2O_5 + 3 foliar sprays of nano DAP @ 3 ml/l

T_5 : Recommended dose of N and K_2O + 25% recommended dose of P_2O_5 + 3 foliar sprays of nano DAP @ 3 ml/l

2.1 Fertilizer Application

In this experiment, the recommended doses of fertilizers were N, P_2O_5, K_2O @ 100:25:75 kg/ha. The fertilizers were applied in the form of Urea, Single Super Phosphate (SSP) and Muriate of Potash (MOP) as basal application. For foliar application, Nano Di Ammonium Phosphate (Nano DAP) was used @ 3ml/l. Nano DAP (Liquid) is a novel Nano fertilizer developed and patented by IFFCO (Indian Farmers Fertilizer Cooperative Limited) in 2023. It contains Nitrogen (8.0 % N w/v) and Phosphorus (16.0 % P_2O_5 w/v) (Jagadeesh et al., 2024).

2.2 Time Schedule for Application of Fertilizers

The application of Urea and Muriate of Potash (MOP) was applied in 2 splits viz; first split (60%) during April, 2024 and second split (40%) during August, 2024. The Single Super Phosphate (SSP) was applied as first split (100%) during April, 2024. The first, second and third foliar spray of Nano DAP @ 3ml/l was done in April, July, and October, 2024.

2.3 Methods for Estimating Plant Growth and Yield Parameters

2.3.1 Plucking point density (No./2500 cm2)

It was determined by counting numbers of shoots plucked in each plucking round. At each plucking round the plucking point density was calculated by the method described by Jayaraman, (1962). A bamboo grid of 50×50 cm^2 was placed on the top of the tea bushes and the number of the plucking points was counted from where the shoots were plucked. The records were expressed in no/2500 cm^2.

2.3.2 Fine leaf count (%)

A bulk of green leaves samples were collected from each nylon bags and weighed 100 g of green leaves. Separate the one leaf and a bud, two leaf and a bud, soft banjhis, single soft leaf and weighed all of them against the total weight of the sample and expressed in percentage (%) (Khemshetty et al., 2024).

2.3.3 Fresh weight of plucked shoot (g)

From each treatment and replication, 100 numbers of shoots were collected after each plucking round. Then weighed them in a digital weighing balance and the data was expressed in grams (g).

2.3.4 Dormancy index

The dormancy Index is the ratio between the number of shoots with buds which are less than half the length of the topmost leaf to those which are greater than half the length of the topmost leaf (Liu et al., 2021).

The dormancy index of tea was measured by using the following formula:

$$Dormancy\ index = \frac{The\ no.of\ shoots\ with\ buds\ which\ are\ less\ than\ half\ the\ length\ of\ the\ topmost\ leaf}{The\ no.of\ shoots\ with\ buds\ which\ are\ greater\ than\ half\ the\ length\ of\ the\ topmost\ leaf}$$

2.3.5 Green leaf yield (Kg/plot)

Plucking of green leaves was done at a time interval of 7-8 days. The green leaf yield per plot throughout the whole experiment period (February-December, 2024) was recorded against each treatment and replication using weighing balance and expressed in kg/plot.

2.4 Statistical Analysis

Analysis of variance (ANOVA) was carried out as per the design (RBD) following standard statistical procedure. The treatment mean values was compared by least significance difference based on ANOVA (Ma et al., 2021). All computations were carried out by using MS Excel 2021. The critical difference (C.D) values were calculated at 5 per cent level of significance.

3. RESULTS AND DISCUSSION

The experimental findings of the present research experiment are presented below. Field studies were conducted to study the growth and yield parameters of tea plants after application of Nano DAP. The data were statistically analyzed to come to a conclusion on influence of Nano DAP application on tea plants. The mean values were tabulated and the associated CD values at the 5 per cent probability level were computed and displayed in tables.

3.1 Effect of Nano DAP on Growth and Yield of Tea Plants

The growth and yield parameters studied in this experiment were plucking point density, fine leaf count, fresh weight of plucked shoots, dormancy index and green leaf yield. All these yield attributes were recorded with respect to all the treatments during the time period from March, 2024 to November, 2024. For evaluating the yield parameters, the cropping season was divided into three seasons *viz.,* early season (March - May), rainy season (June- September), back-end season (October - November).

3.1.1 Plucking point density (No./2500 cm^2)

The experimental findings on number of plucking point density/2500 cm^2 of tea plants in various treatments of the investigation are presented in Table 1.

As evident from the data presented in Table 1., Plucking point density of tea plants were significantly influenced by application of Nano DAP in all the three seasons. The treatments T_2, T_3 and T_4 showed significant difference in numbers of plucking point density/ 2500 cm^2 of tea plants over treatment T_1 (Recommended dose of N, P_2O_5 and K_2O) during all three seasons. The highest plucking point density (64.12 no/2500 cm^2, 83.77 no/2500 cm^2 and 83.88 no/2500 cm^2) was observed in treatment T_3 (Recommended dose of N and K_2O + 75% of recommended dose of P_2O_5 + 3 foliar spray of Nano DAP @ 3 ml/l) followed by plucking point density (64.12 no/2500 cm^2, 83.59 no/2500 cm^2, 83.13 no/2500 cm^2) observed in treatment T_2 (Recommended dose of N, P_2O_5, K_2O + 3 foliar spray of Nano DAP @ 3 ml/l) in all three seasons. However, treatment T_2 and treatment T_3 exhibited similar results in plucking point density during all three seasons. It was also reported that the plucking point density in tea was maximum (50 no/m^2) during rain flush when they applied 0.4% Nano-urea in 3 sprays (Tea Board of India, no year). The increase in plucking point density in tea plants might be due to the synergistic effect of foliar application of Nano DAP along with basal application of recommended fertilizer. Also, the increase in number of pluckable shoots led to higher yield in tea (Saikia & Gogoi, 2023).

The plucking point density (59.50 no/2500 cm^2, 78.39 no/2500 cm^2 and 78.26 no/2500 cm^2) in treatment T_4 (Recommended dose of N and K_2O + 50% of recommended dose of P_2O_5 + 3 foliar sprays of Nano DAP @ 3 ml/l) was significantly lower than the plucking point density recorded in treatment T_2 and treatment T_3 in all three seasons. The lowest plucking point density (51.50 no/2500 cm^2, 73.08 no/2500 cm^2 and 52.94 no/2500 cm^2) was observed in treatment T_1 (Recommended dose of N, P_2O_5 and K_2O) followed by treatment T_5 (Recommended dose of N and K_2O + 25% P + 3 foliar sprays of Nano DAP @ 3 ml/l) in all three seasons.

3.1.2 Fine leaf count (%)

The fine leaf count (%) of plucked tea shoots during early season (March - May), rainy season (June- September) and back-end season (October - November) are shown in Table 2.

Table 1. Plucking point density (No./2500 cm^2) as influenced by application of Nano DAP based fertilizers

Treatment	Plucking point density (No./2500 cm^2)		
	Early season (March - May)	Rainy season (June - September)	Back-end season (October - November)
T_1	51.25	66.31	58.63
T_2	64.12	83.59	83.13
T_3	64.75	83.77	83.88
T_4	59.50	78.39	78.26
T_5	52.50	66.59	65.47
CD	2.34	1.66	2.22
SE(d)	1.07	0.76	1.02

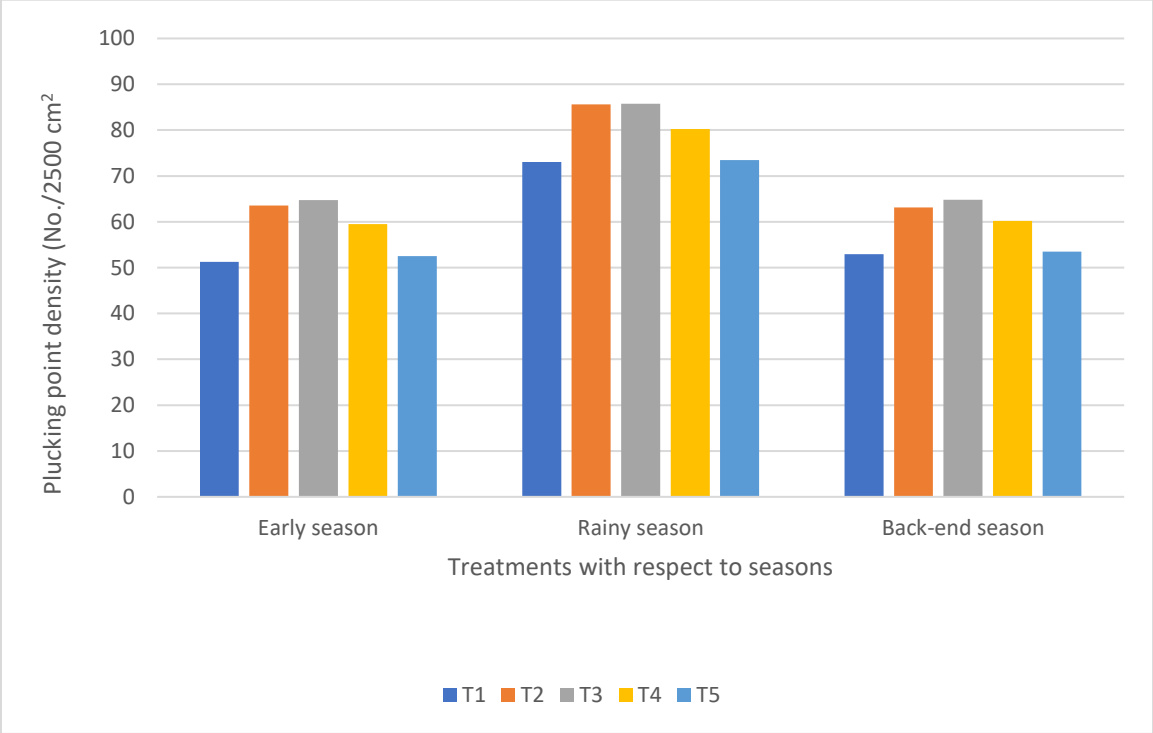

Fig. 1. Plucking point density (no./2500 cm^2) as influenced by application of nano DAP based fertilizers

Table 2. Fine leaf count (%) as influenced by application of Nano DAP based fertilizers

Treatment	Fine leaf count (%)		
	Early season (March - May)	Rainy season (June - September)	Back-end season (October - November)
T_1	54.62	64.62	45.25
T_2	56.08	68.58	58.87
T_3	56.78	66.78	54.37
T_4	55.25	62.75	53.5
T_5	54.20	59.20	49.5
CD	N/A	5.42	4.57
SE(d)	1.79	2.49	2.10

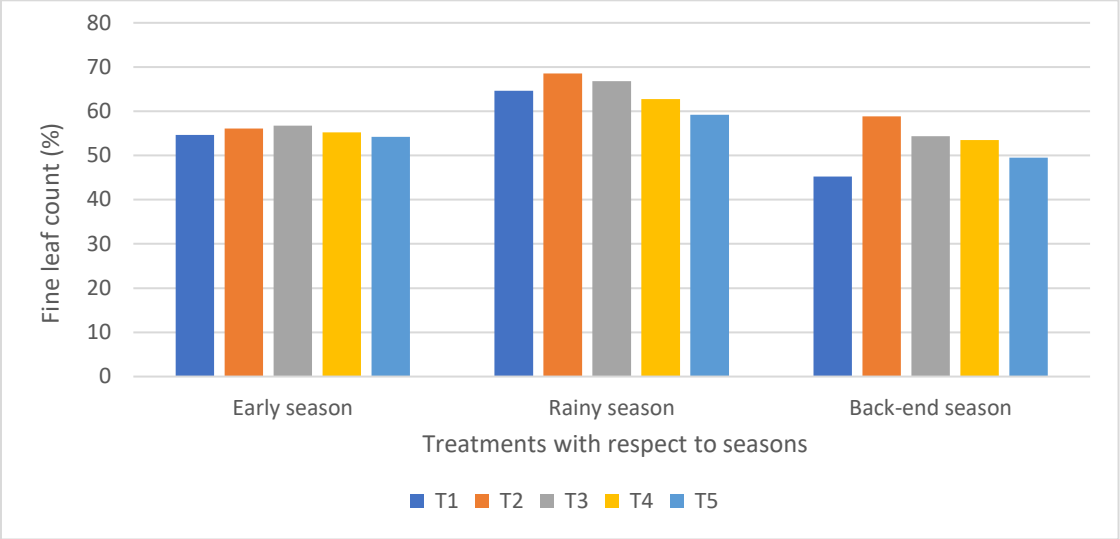

Fig. 2. Fine leaf count (%) as influenced by application of nano DAP based fertilizers

From the data presented in Table 2, no significant difference was observed among the treatments in fine leaf count (%) during early season. Fine leaf count (%) was significantly higher in treatments T_2, T_3, T_4 as compared to treatment T_1 (Recommended dose of N, P_2O_5 and K_2O) at back-end season. The treatment T_2 (Recommended doses of N, P_2O_5, K_2O +3 sprays of Nano DAP @ 3ml/l) showed highest fine leaf count (%) in rainy season (68.58%) and back-end season (58.87%). The fine leaf count (%) in treatment T_3 (Recommended dose of N and K_2O + 75% recommended dose of P_2O_5 + 3 foliar sprays of Nano DAP @ 3 ml/l) during rainy season (66.78%) and back-end season (54.37%) was not significantly different from the fine leaf count (%) observed in treatment T_2. Similar results were obtained by Tea Board of India, (no year). The fine leaf count was maximum during first flush when 0.4 per cent Nano-urea was applied in 3 sprays (Tea Board of India, no year). Increase in fine leaf count during back–end season due to application of nano DAP is expected to contribute to the production of quality made tea.

Lowest fine leaf count (%) was observed in treatment T_5 (Recommended dose of N and K_2O + 25% recommended dose of P_2O_5 + 3 foliar spray of Nano DAP @ 3 ml/l) during rainy season (59.20%) and in treatment T_1 (Recommended dose of N, P_2O_5 and K_2O) during back-end season (45.25%).

3.1.3 Fresh weight of 100 shoots (g)

The observations of the fresh weight of 100 shoots (g) during early season (March - May), rainy season (June- September) and back-end season (October - November) are presented in Table 3.

Table 3. Fresh weight of 100 shoots (g) of tea plants as influenced by application of Nano DAP based fertilizers

Treatment	Fresh weight of 100 shoots (g)		
	Early season (March - May)	Rainy season (June - September)	Back-end season (October - November)
T_1	78.54	94.32	90.40
T_2	85.20	98.48	94.12
T_3	83.87	97.25	93.84
T_4	80.90	95.36	92.01
T_5	78.29	93.24	84.75
CD	2.58	1.33	1.67
SE(d)	1.18	0.61	0.76

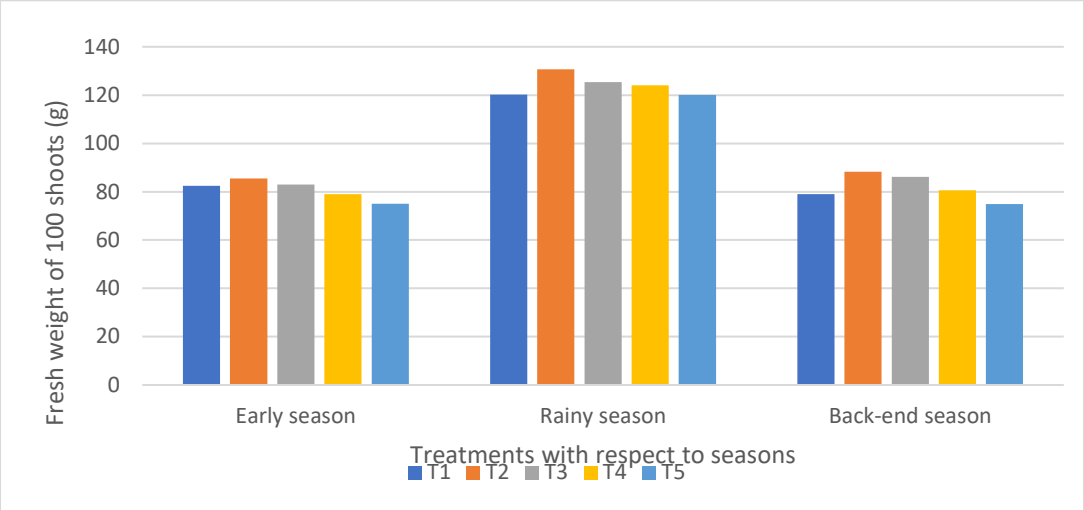

Fig. 3. Fresh weight of 100 shoots (g) of tea plants as influenced by application of nano DAP based fertilizers

The fresh weight of 100 shoots of tea plants recorded in treatments T_2 and T_3 were found significant in early season, rainy season and back-end season. The treatment T_2 (Recommended dose of N, P_2O_5, K_2O + 3 foliar sprays of Nano DAP @ 3 ml/l) was found to produce significantly higher fresh weight of shoots in early season (85.20 g), rainy season (98.48 g) and back-end season (94.12 g) over treatment T_1 (Recommended dose of N, P_2O_5 and K_2O). The treatment T_3 (Recommended dose of N and K_2O + 75% recommended dose of P_2O_5 + 3 foliar sprays of Nano DAP @ 3 ml/l) exhibited similar results in fresh weight of 100 shoots during early season (83.87 g), rainy season (97.25 g) and back-end season (93.84 g) as that of treatment T_2 in all three seasons. These results are in conformity with (Salehi & Hajiboland, 2008). It was reported that an increase in overall growth of young teas (measured in terms of leaf and pruning weights) due to potash manuring in young tea (Ruan et al., 2010). Nano phosphorus fertilization increased maize weight when compared to other treatments and controls (Poudel et al., 2023). Application of Udaipur nano rock phosphate (34% P_2O_5) considerably boosted the yield attributes like 100 grain weight in maize plants as compared to the control (Magda & Hussein, 2015).

Lowest fresh weight of 100 shoots was observed in treatment T_5 (Recommended dose of N and K_2O + 25% recommended dose of P_2O_5 + 3 foliar spray of Nano DAP @ 3 ml/l) during early season (78.29 g), rainy season (93.24 g) and in back-end season (84.75 g).

3.1.4 Dormancy index

The experimental findings on dormancy index during early season (March - May), rainy season (June- September) and back-end season (October - November) are presented below in Table 4.

Table 4. Dormancy index of tea plants as influenced by application of Nano DAP based fertilizers

Treatment	Dormancy index of tea plants		
	Early season (March - May)	Rainy season (June - September)	Back-end season (October - November)
T_1	1.08	0.51	1.07
T_2	0.88	0.49	0.90
T_3	0.93	0.52	0.97
T_4	1.01	0.54	1.05
T_5	1.19	0.56	1.64
CD	0.07	N/A	0.24
SE(d)	0.03	0.02	0.11

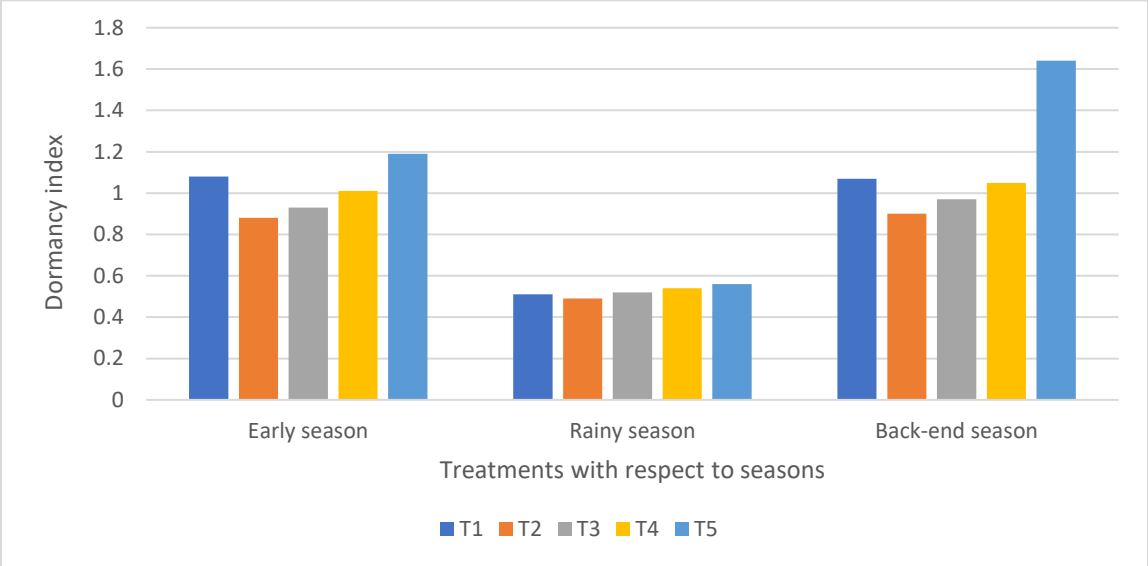

Fig. 4. Dormancy index of tea plants as influenced by application of nano DAP based fertilizers

The lowest dormancy index (0.88, 0.90) was observed in treatment T_2 (Recommended dose of N, P2O5, K_2O + 3 foliar spray of Nano DAP @ 3 ml/l) followed by treatment T_3 (Recommended dose of N and K_2O + 75% recommended dose of P_2O_5 + 3 foliar spray of Nano DAP @ 3 ml/l) in early season (0.88) and back-end (0.90) season respectively. However, treatment T_2 and T_3 were not significantly different in both early and back-end season. These findings are in close agreement with (Sarkar et al., 2021). More than 75 per cent of the stored nitrogen within the whole plant is re-translocated to promote the sprouting of dormant buds in tea plants (Tang et al., 2021).

The dormancy index (1.08, 1.07) in treatment T_4 (Recommended dose of N and K_2O + 50% recommended dose of P_2O_5 + 3 foliar sprays of Nano DAP @ 3 ml/l) and dormancy index (1.01, 1.05) in treatment T_1 (Recommended dose of N, P_2O_5 and K_2O) were at par in both early season and back-end season. No significant difference was observed in dormancy index during rainy season.

The treatment T_5 (Recommended dose of N and K_2O + 25% recommended dose of P_2O_5 + 3 foliar sprays of Nano DAP @ 3 ml/l) showed highest dormancy index (1.19, 1.64) in early season and back-end season respectively. The reduction in basal application of phosphate in treatment T_5 might hinder the growth of buds as compared to growth of buds in treatments T_2, T_3 and T_4 due to reduced photosynthesis rate. The growth of tea plants is directly related to photosynthesis and phosphorus deficiency inhibited photosynthesis in tea plants (Thakur et al., 2024).

3.1.5 Green leaf yield (kg/plot)

The experimental findings on green leaf yield of tea plants (kg/plot) during early season (March - May), rainy season (June- September) and back-end season (October - November) are presented in Table 5.

Table 5. Green leaf yield (kg/plot) of tea plants as influenced by application of Nano DAP based fertilizers

Treatment	Green leaf yield (kg/plot) (plot size = 44.10 m^2)		
	Early season (March - May)	Rainy season (June - September)	Back-end season (October - November)
T_1	3.18	4.89	4.21
T_2	4.45	6.32	6.25
T_3	4.33	6.24	6.10
T_4	3.83	5.75	5.71
T_5	3.27	4.94	4.48
CD	0.24	0.14	0.26
SE(d)	0.11	0.06	0.12

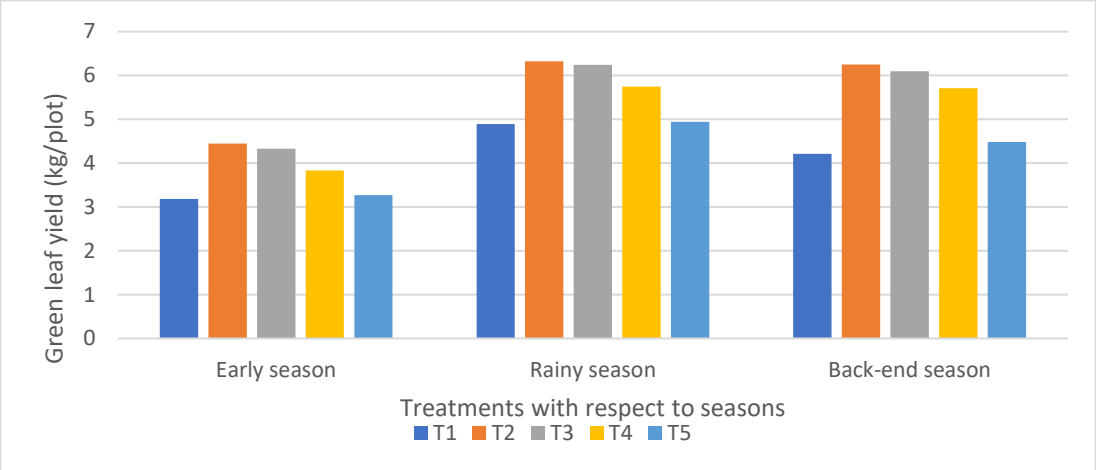

Fig. 5. Green leaf yield (kg/plot) of tea plants as influenced by application of nano DAP based fertilizers

From the data presented in Table 5, it was evident that the green leaf yield recorded in treatments T_2, T_3 and T_4 showed significant difference over treatment T_1 (Recommended doses of N, P_2O_5, K_2O). The highest green leaf yield (4.45 kg/plot, 6.32 kg/plot and 6.25 kg/plot) was observed in treatment T_2 (Recommended doses of N, P_2O_5, K_2O +3 sprays of Nano DAP @ 3ml/l) followed by green leaf yield (4.33 kg/plot, 6.24 kg/plot, 6.10 kg/plot) observed in treatment T_3 (Recommended dose of N and K_2O + 75% recommended dose of P_2O_5 + 3 foliar spray of Nano DAP @ 3 ml/l) in all three seasons. The treatment T_3 exhibited similar results in green leaf yield as that of treatment T_2 during all three seasons. These findings are in close agreement with the findings of (Tea Board of India, no year) in green leaf yield of tea crop for nano urea. Similar findings were reported in Nano DAP for other crops in grain yield of wheat (Zulfiqar et al., 2019), in grain yield of rice (Okano et al., 1994), in grain yield of maize (Magda & Hussein, 2015), and in finger millet (Sharma et al., 1977).

The green leaf yield (3.83 kg/plot, 5.75 kg/plot and 5.71 kg/plot) observed in treatment T_4 (Recommended dose of N and K_2O + 50% recommended dose of P_2O_5 + 3 foliar sprays of Nano DAP @ 3 ml/l) was significantly lower than the green leaf yield observed in treatments T_2 and T_3 in all three seasons. Lowest green leaf yield (3.18 kg/plot, 4.89 kg/plot, 4.21 kg/plot) was observed in treatment T_1 (Recommended doses of N, P_2O_5 and K_2O) which was not significantly different from treatment T_5 (Recommended dose of N and K_2O + 25% recommended dose of P_2O_5 + 3 foliar sprays of Nano DAP @ 3 ml/l) in all three seasons.

4. CONCLUSION

From the present investigation, it is evident that aall the yield attributes viz., plucking point density, fresh weight of 100 shoots, fine leaf count, dormancy index was recorded maximum when three foliar sprays of Nano DAP @ 3m/l was applied along with recommended dose of N, P_2O_5, K_2O or recommended dose of N and K_2O and 75% of recommended dose of P_2O_5 in tea. Higher plucking point density, shoot weight and reduction of dormancy index might have contributed to higher yield in these treatments. Based on the superior results on these growth and yield attributes and considering reduction in cost of cultivation, foliar application of three sprays of Nano DAP @ 3ml/l along with recommended basal dose of N & K_2O and 75 per cent of recommended dose of phosphate can be suggested for application in tea plants to get higher yield.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc have been used during writing or editing of this manuscript

Details of the AI usage are given below:

1. QuillBot
2. ChatGPT

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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