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Effect of nutrient management on physio morphological and yield attributes of field pea (*Pisum sativum* L.)

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Sustainability

ABSTRACT

A field experiment was conducted to investigate the impact of nitrogen management on the growth and yield of field peas. The experiment took place during the rabi season (October–March of 2022–2023) at Lovely Professional University's Agriculture Research Farm in Phagwara, Punjab, India. Fifteen different treatment combinations were utilized, involving the application of chemical fertilizers (NPK) and micronutrients (boron and zinc). The experimental design followed a randomized complete block approach with three replications. Among the treatment combinations, the application of foliar spray with B at a rate of 0.2%, Zn at a rate of 0.5%, along with 100% recommended dose of fertilizer (RDF), resulted in the highest measurements for plant height (70.44 cm), leaf count (70.60), branch count (18.86), leaf area (32.24 cm^2), dry matter accumulation (6.12 g), crop growth rate (0.299 g m^{-2} day^{-1}), and relative growth rate (0.05933 g g^{-1} day^{-1}). Furthermore, treatments involving 100% RDF, 0.2% B, and 0.5% Zn exhibited enhanced yield characteristics, including the number of seeds per pod (10.26), pods per plant (12.33), test weight of seeds (15.06 g), seed yield (3537 kg ha^{-1}), and harvest index (47.49%). Furthermore, 100% RDF and the inclusion of 0.2% B and 0.5% Zn outperformed the control. Applying 100% RDF along with the micronutrients B and Zn is recommended to maximize production and net profit in field pea cultivation.

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1 Introduction

Field pea, a grain legume classified under the Leguminosae family, is a major pulse crop. Its substantial content of carbohydrates, proteins, vitamins A and C, calcium, and phosphorus positions it as a widely consumed staple across the globe (Divéky-Ertsey et al. 2022). Notably, lysine and tryptophan are also abundant in field peas (Sharma et al. 2023). This legume crop ranks second internationally. Symbiotic rhizobium bacteria within its root nodules enable nitrogen fixation, a process critical to soil fertility preservation (Zhong et al. 2023). Thus, this plant species is vital for sustainable agriculture. Given the prevailing trend of declining soil fertility, the inherent ability of this crop to restore soil nutrients has rendered it an invaluable component of the cropping system (Haque et al. 2022; Gao et al. 2023). The synergy between nutrient management strategies and cultivar genetics is pivotal in enhancing field pea productivity. Fertilizers play a crucial role in bolstering the growth of field peas. Nitrogen is indispensable for the synthesis of chlorophyll, enzymes, and proteins. Phosphorus, on the other hand, is vital for root development, nodulation, energy storage, transport, and a multitude of metabolic activities. Potassium greatly enhances enzyme functionality, assimilate translocation, and protein synthesis (Uddin et al. 2023). However, the indiscriminate and excessive use of chemical fertilizers seriously threatens soil health, leading to reduced crop yields and long-term unsustainability of agricultural practices and contributing to environmental contamination. Thus, judicious and informed application of fertilizers is imperative to safeguard agrarian production and enhance soil health. The research conducted by Janusauskaite (2023) suggests that this approach can augment crop yields while strengthening the soil's physical, chemical, and biological properties and optimizing fertilizer utilization. Micronutrients have also been shown to positively impact field pea crop yield, as evidenced by the findings of Roy et al. (2022). In particular, boron is crucial in promoting the field pea plant's growth, yield, and nodulation. Similarly, zinc's physiological and enzymatic functions make it an essential element for crop nutrition. Processes such as protein and auxin synthesis, glucose metabolism, membrane maintenance, and pollen production heavily rely on these functions and activities. The application of micronutrients such as zinc through foliar fertilization, as studied by Sümer and Yaraşir (2022), has gained prominence owing to its precision, cost-effectiveness, and speed compared to traditional soil fertilization methods. However, comprehensive research on the nutritional composition of field peas, especially in the context of inorganic fertilizers and micronutrients, remains limited. In this regard, the integration of various nutrients, including the recommended dose of fertilizer (RDF) combined with foliar applications of boron and zinc, was investigated for its impact on the growth and yield of field peas (*Pisum sativum* L.).

2 Materials and Methods

2.1 Preliminary information

The experimentation took place within the agricultural premises of Lovely Professional University's School of Agriculture, located in Phagwara, India. The study employed a randomized block design, encompassing a series of 15 treatment combinations, and each replicated thrice during the rabi season in 2022. The geographic coordinates of the experimental site are 31.25°N latitude and 75.7°E longitude, positioned at an elevation of 232 m above mean sea level (MSL). A subtropical climate with moderate winters and hot summers characterizes the geographical region. Annual mean precipitation ranges from 400 to 500 mm, with approximately 80% of this rainfall concentrated between July and September 2022. The soil type identified at the experimental site is classified as sandy loam. Initial soil nutritional status was evaluated through a pre-experimental soil study. The combined content of nitrogen, phosphorus, and potassium (NPK) accessible at the experimental farm amounted to 149 kilograms per hectare (kg ha^{-1}), along with specific quantities of 17.62 kg ha^{-1}, 179 kg ha^{-1}, and 0.49% for organic carbon. Analysis indicated deficiencies in organic carbon, nitrogen, and potassium, while phosphorus content was sufficient. Additionally, the soil's pH ranges from mildly acidic to alkaline. The treatment plan is delineated as follows. The experimental treatments encompass the following nutrient ratios applied at a rate of kg ha^{-1}: control (0:0:0 N: P_2O_5:K_2O), 100% of the recommended dose of fertilizer (20:60:40 N: P_2O_5:K_2O), absence of nitrogen with 0:60:40 N: P_2O_5:K_2O, absence of phosphorus with 20:0:40 N: P_2O_5:K_2O, absence of potassium with 20:60:0 N: P_2O_5:K_2O, 60:40 N: P_2O_5:K_2O with foliar spray of boron at 0.2%, 20:0:40 N: P_2O_5:K_2O with foliar spray of boron at 0.2%, 20:60:0 N: P_2O_5:K_2O with foliar spray of boron at 0.2%, 60:40 N: P_2O_5:K_2O with foliar spray of zinc at 0.5%, 20:0:40 N: P_2O_5:K_2O with foliar spray of zinc at 0.5%, 20:60:0 N: P_2O_5:K_2O with foliar spray of zinc at 0.5%, foliar spray of boron at 0.2%, foliar spray of zinc at 0.5%, and foliar spray of boron at 0.2% combined with zinc at 0.5%, along with 100% RDF as illustrated in Figure 1.

The fertilizer formulation adhered to predetermined concentration levels for various fertilizer types. On November 1st, 2022, the field pea variety PU-89 sowing commenced, utilizing individual plots measuring 4m×3m. The spacing between rows and plants within each plot was 45 cm ×20cm. The recommended fertilizer composition for field pea, calculated per hectare basis, included 20 kg of N, 60 kg of P, and 40 kg of K. This composition represented 100% of the RDF. Fertilizer application involving Single Super Phosphate (SSP) and Muriate of Potash (MOP) was carried out during the ploughing phase before crop cultivation. Urea, the primary fertilizer used, was applied in two separate doses, i.e., during the blooming and pod formation phases. Prescribed interventions encompassed the foliar application of boron and zinc

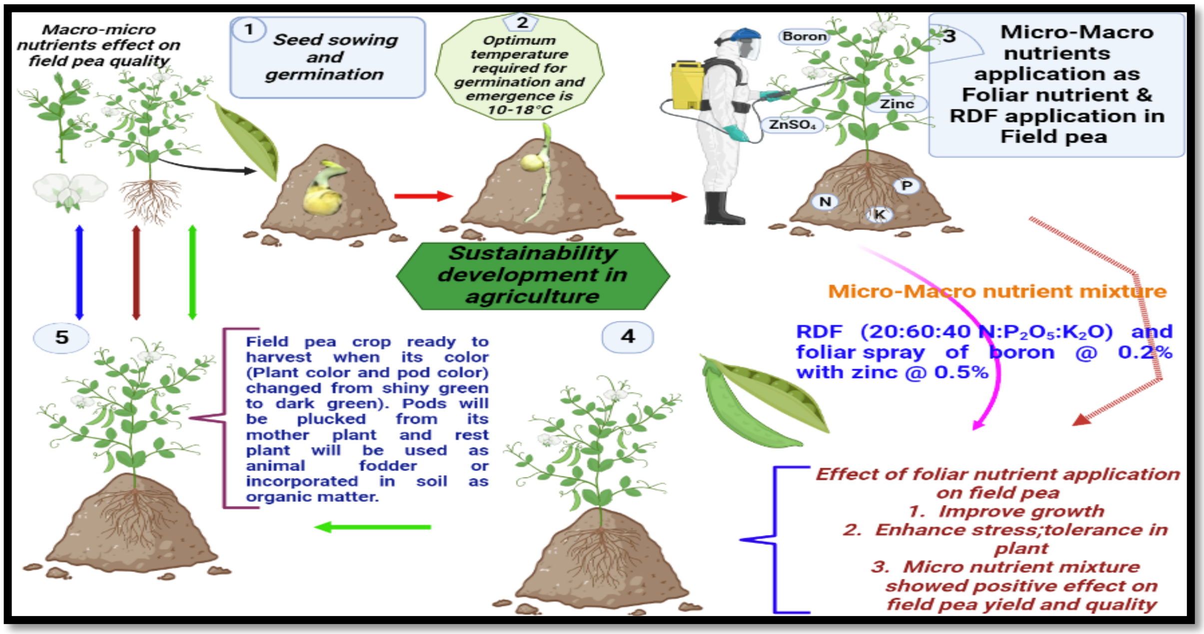

Figure 1 Experimental setup and key results

micronutrients. The cultivation practices adhered to the recommended guidelines. The evaluation of treatment effectiveness encompassed an assessment of its impact on growth, flowering, and yield parameters.

2.2 Morphophysiological and Yield Attributes

Morphophysiological and yield attributes were assessed using standardized methods. Plant height, branch count, plant dry matter, and leaf area were among the morphological and physiological traits measured. Morphological features were evaluated by randomly selecting five plants from each plot, and the mean values were used for analysis. The Chlorophyll index is a quantitative measure employed to assess the chlorophyll concentration inside a specific sample. The chlorophyll index was quantified using the Soil Plant Analysis Development (SPAD) meter, which measures green pigmentation in leaves. Mature leaves were chosen for chlorophyll index assessment, involving three SPAD meter measurements per leaf. Crop growth rate (CGR) signifies the rate of dry weight increase in a defined area over a specific timeframe; CGR is calculated using equations introduced by Watson (1952). Relative growth rate (RGR), expressed as grams per gram per day ($gg^{-1}day^{-1}$), quantifies an organism's mass or size increase within a given time, a concept first coined by Williams in 1946. Plant biomass accumulation represents the overall increase in dehydrated plant mass within a defined period, quantified as the ratio of dry weight to dry weight per unit of time ($g\ g^{-1}\ day^{-1}$). The analyzed parameters encompassed yield-related characteristics, including pods per plant, seeds per pod, test weight, seed yield, and harvest index expressed as a percentage. These attributes were assessed at the maturity stage using well-established techniques.

2.3 Data analysis

The collected data in this study were subjected to statistical analysis using established methodologies. The analytical approach involved utilizing SPSS 22 software, employing the generalized linear model in univariate analysis. This model was specifically chosen to investigate mean variances while considering two parameters. A mean separation technique was applied to identify the most effective treatment, adopting a significance level of $p < 0.05$, alongside the Duncan multiple range test (DMRT). Additionally, Fisher's Least Significant Difference (LSD) test was employed as a posthoc analysis to assess potential statistically significant differences among the means. These calculations were performed utilizing the least significant difference (LSD) at a significance level of 5%.

3 Results and Discussion

3.1 Growth attributes

The findings presented in Tables 1 and 2 underscore the significant impact of the treatments on the plant's growth across various dimensions. Applying a foliar spray with 0.2% B and 0.5% Zn, combined with 100% RDF, led to plants reaching a height of 70.44 cm. In contrast, plants treated only with 100% RDF exhibited a height of 64.5 cm, while the control group displayed the lowest height of 48.30 cm. The observed increase in plant height can be attributed to the prescribed fertilizer quantity administered as a basal

Table 1 Effect of nutrient management on growth parameters of field pea

Treatments	Plant height (cm)	Branch count per plant	Leaf count per plant	Dry matter accumulation (g)
Control	48.30^{h} ± 0.83	12.83^{e} ± 0.41	54.36^{g} ± 0.79	1.33^{f} ± 0.124
100% RDF	64.50^{b} ± 0.521	17.14^{b} ± 0.42	69.08^{ab} ± 0.30	4.16^{c} ± 0.124
0:60:40 N:P_2O_5:K_2Okg ha^{-1}	53.55^{g}± 0.95	15.07^{d} ± 0.23	57.26^{f} ± 0.86	2.23^{e} ± 0.094
20:0:40 N:P_2O_5:K_2Okg ha^{-1}	58.83^{d} ± 1.35	16.59^{bc} ± 0.17	63.05^{cd} ± 0.84	3.50^{d} ± 0.163
20:60:0 N:P_2O_5:K_2Okg ha^{-1}	61.26^{c} ± 0.86	17.04^{b} ± 0.14	65.20^{c} ± 0.90	3.60^{d} ± 0.216
0:60:40 N:P_2O_5:K_2Okg ha^{-1} + Foliar spray of 0.2% B	55.44^{fg} ± 0.69	16.17^{bcd} ± 0.12	57.47^{f} ± 2.35	2.46^{e} ± 0.249
20:0:40 N:P_2O_5:K_2Okg ha^{-1} + Foliar spray of 0.2% B	57.40^{de} ± 0.91	17.24^{b} ± 0.20	59.50^{e} ± 0.65	3.43^{d} ± 0.169
20:60:0 N:P_2O_5:K_2Okg ha^{-1} + Foliar spray of 0.2% B	63.42^{b} ± 0.70	17.33^{b} ± 0.85	64.56^{cd} ± 0.52	4.43b^{c} ± 0.339
0:60:40 N:P_2O_5:K_2Okg ha^{-1} + Foliar spray of 0.5% Zn	57.46^{de} ± 0.72	16.63^{bc} ± 0.42	60.56^{e} ± 0.45	3.40^{d} ± 0.294
20:0:40 N:P_2O_5:K_2Okg ha^{-1} + Foliar spray of 0.5% Zn	60.83^{c} ± 0.53	16.97^{b} ± 0.20	67.81^{b} ± 1.78	4.63^{b} ± 0.205
20:60:0 N:P_2O_5:K_2Okg ha^{-1} + Foliar spray of 0.5% Zn	59.40^{cd} ± 0.75	16.900^{b} ± 0.29	65.30^{c} ± 0.82	4.41^{bc} ± 0.127
Foliar spray of 0.2% B	56.44^{ef} ± 0.95	15.55^{cd} ± 0.15	62.73^{d} ± 0.56	3.16^{d} ± 0.124
Foliar spray of 0.5% Zn	54.44^{g} ± 1.64	16.63^{bc} ± 0.21	63.60^{cd} ± 0.49	3.30^{d} ± 0.216
Foliar spray of 0.2% B and 0.5% Zn	58.34^{de} ± 0.73	16.33^{bc} ± 0.77	64.36^{cd} ± 0.83	3.40^{d} ± 0.326
Foliar spray of 0.2% B and 0.5% Zn+ 100% RDF	70.44^{a} ± 0.69	18.86^{a} ± 0.20	70.60^{a} ± 0.44	6.12^{a} ± 0.131

*The mean values followed by letters were significantly different at $p < 0.05$ based on Duncan's multiple range test (DMRT).

Table 2 Effect of nutrient management on phenological parameters of field pea

Treatments	Chlorophyll index (SPAD)	Leaf area (cm^2)	Crop growth rate (gm^{-2}day^{-1})	Relative growth rate (g g^{-1} day^{-1})
Control	36.43^{h} ± 0.79	12.23^{h} ± 0.82	0.060^{i} ± 0.0014	0.03233^{f} ± 0.00073
100% RDF	42.20^{de} ± 0.82	19.23d^{e} ± 0.33	0.236^{b} ± 0.0041	0.05333^{ab} ± 0.0016
0:60:40 N:P_2O_5:K_2Okg ha^{-1}	37.56^{gh} ± 1.06	15.53^{g} ± 0.40	0.085^{h} ± 0.0063	0.03367^{f} ± 0.00328
20:0:40 N:P_2O_5:K_2Okg ha^{-1}	42.20^{de} ± 0.82	17.60^{f} ± 0.29	0.123^{g} ± 0.014	0.03967^{e} ± 0.0052
20:60:0 N:P_2O_5:K_2Okg ha^{-1}	43.20^{cd} ± 0.82	19.43d^{e} ± 0.74	0.136^{fg} ± 0.0027	0.04000^{e} ± 0.00112
0:60:40 N:P_2O_5:K_2Okg ha^{-1} + Foliar spray of 0.2% B	38.43^{g} ± 0.87	19.43^{de} ± 0.29	0.123^{g} ± 0.0101	0.04467^{de} ± 0.00274
20:0:40 N:P_2O_5:K_2Okg ha^{-1} + Foliar spray of 0.2% B	40.33^{ef} ± 0.66	18.66^{ef} ± 0.49	0.134^{fg} ± 0.0009	0.04033^{e} ± 0.00024
20:60:0 N:P_2O_5:K_2Okg ha^{-1} + Foliar spray of 0.2% B	42.20^{de} ± 0.82	18.90^{ef} ± 0.37	0.173^{de} ± 0.0006	0.04533^{de} ± 0.00124
0:60:40 N:P_2O_5:K_2Okg ha^{-1} + Foliar spray of 0.5% Zn	39.40^{fg} ± 0.70	16.33^{g} ± 0.37	0.194^{cd} ± 0.0006	0.05467^{ab} ± 0.00106
20:0:40 N:P_2O_5:K_2Okg ha^{-1} + Foliar spray of 0.5% Zn	44.46^{bc} ± 0.70	17.66^{f} ± 0.49	0.200^{c} ± 0.0285	0.5567^{ab} ± 0.00273
20:60:0 N:P_2O_5:K_2Okg ha^{-1} + Foliar spray of 0.5% Zn	45.20^{ab} ± 0.82	20.33^{d} ± 0.78	0.191^{cd} ± 0.0063	0.05267^{bc} ± 0.00168
Foliar spray of 0.2% B	40.43^{ef} ± 0.79	25.46^{b} ± 0.59	0.160^{ef} ± 0.0097	0.05533^{ab} ± 0.00131
Foliar spray of 0.5% Zn	38.46^{g} ± 0.97	25.47^{b} ± 0.69	0.152^{ef} ± 0.0101	0.05367^{ab} ± 0.00346
Foliar spray of 0.2% B and 0.5% Zn	38.63^{fg} ± 0.74	23.71^{c} ± 0.61	0.199^{c} ± 0.0124	0.04767^{cd} ± 0.00365
Foliar spray of 0.2% B and 0.5% Zn+ 100% RDF	46.40^{a} ± 0.94	32.24^{a} ± 0.73	0.299^{a} ± 0.0240	0.05933^{a} ± 0.0037

* The mean values followed by letters were significantly different at $p < 0.05$ based on Duncan's multiple range test (DMRT)

dose alongside the foliar application of boron and zinc. These treatments likely facilitated enhanced cell division, metabolic and enzymatic activities, and cell size expansion. These physiological changes collectively contributed to the overall elevation in plant stature. This aligns with the findings reported by Kumar et al. (2022). Further, the foliar application of 0.2% B and 0.5% Zn + 100% RDF treatment yielded the highest branch (18.86) and leaf (70.60) counts per plant. Subsequently, applying 100% RDF alone resulted in 17.14 branches and 69.08 leaves. In comparison, the control group had the fewest branches (12.83). Incorporating boron and zinc through foliar and basal fertilizer applications contributed to elevated photosynthetic activity per plant, as evidenced by the increased leaf count and branch development. Additionally, zinc has been known to stimulate enzymes and photosynthetic pigments, thus promoting vegetative growth. Modifying key enzymes significantly influences protein synthesis, energy transmission, and essential nitrogen metabolism (Rahman and Schoenau 2022). The foliar spray treatment with B at 0.2% and Zn at 0.5% + 100% RDF achieved the highest dry matter accumulation, followed by the 100% RDF treatment with a dry matter accumulation of 4.43g. Conversely, the control treatment showed the lowest dry matter accumulation of 1.33g. The observed increase in dry matter within the treatment can be attributed to the increased application of NPK fertilizer, which enhances vegetative growth by stimulating various plant enzymes that play a crucial role in macromolecule synthesis, including proteins and carbohydrates. Furthermore, the essential roles of zinc and boron encompass crucial physiological activities, including photosynthesis, osmoregulation, cellular proliferation, stomatal regulation, water movement within plants, and hydrocarbon integration. While macronutrients are commonly emphasized, this study underscores the significance of micronutrients such as vitamin B and zinc in bolstering crop growth and biomass accumulation. Employing foliar sprays to deliver micronutrients has proven effective in addressing nutrient deficiencies and maintaining optimal nutrient levels in plants (Sharma et al. 2022; Dhaliwal et al. 2022). Quantifying chlorophyll content in plants is important owing to its pivotal role in photosynthesis. Findings indicate that applying a foliar spray containing 0.2% B and 0.5% Zn, coupled with 100% RDF, resulted in a notably higher chlorophyll index (measured at 46.4 SPAD) compared to those in both the control (measured at 36.43 SPAD) and other treatment groups. The chlorophyll content increased when employing a foliar spray containing 0.5% Zn and 0.2% B alongside a recommended dose of fertilizer. This effect was most pronounced in the treatment group receiving a foliar spray of 0.2% B and 0.5% Zn, along with 100% RDF. This phenomenon can be attributed to the enhanced assimilation of both macronutrients and micronutrients, facilitating chlorophyll biosynthesis. This finding aligns with the study conducted by Meena et al. (2022), which established the positive influence of increased nutrient levels on chlorophyll concentration in plants. Leaf area is the leaves' total surface area ratio to the ground's corresponding area. Leaf area, a measure of a plant's efficiency in utilizing sunlight for photosynthesis, indicates the plant's photosynthetic activity. The findings indicate that foliar spray containing 0.2% B and 0.5% Zn, and 100% RDF yielded the largest leaf area (32.24 cm²). This was followed by applying foliar sprays containing 0.2% B, 0.5% Zn, and 100% RDF. The effect of the foliar application of 0.2% B and 0.5% Zn alongside 100% RDF can be attributed to their contribution to the uptake of critical macronutrients and micronutrients involved in photosynthesis and various plant metabolic processes. This, in turn, led to increased foliage production and future growth, consequently enhancing the overall leaf surface area. CGR is a metric to quantify the crop growth rate, reflecting biomass increase over a specific period. Results of the study revealed that applying a foliar spray containing 0.2% B and 0.5% Zn, along with 100% RDF, yielded the highest CGR (0.299 $g^{-1}m^{-2}day^{-1}$) among all treatments. This was followed by applying 100% RDF alone (CGR of 0.236 $g^{-1}\,m^{-2}\,day^{-1}$). The control group exhibited the lowest CGR (0.06 $g^{-1}\,m^{-2}\,day^{-1}$). The observed effects can be attributed to the foliar application of zinc and boron, which likely impacted the uptake of crucial macro and micronutrients, thus enhancing photosynthesis and various plant metabolic processes. This led to new leaf production and subsequent growth, ultimately increasing the leaf area index (Kumar et al. 2022). The relative growth rate (RGR), measuring the pace of plant growth with size, is an effective growth assessment tool. Findings indicate that applying a foliar spray containing 0.2% B and 0.5% Zn and 100% RDF yielded the highest RGR (0.059 $g\,g^{-1}\,day^{-1}$) among all treatments. Conversely, the control group exhibited the lowest RGR (0.053 $g\,g^{-1}\,day^{-1}$). This increase in RGR after the foliar application of 0.2% B and 0.5% Zn, along with 100% RDF, can be attributed to various factors. Vishvakarma et al. (2022) noted that B contributes to cell wall synthesis, pollen tube elongation, and carbohydrate metabolism. Zn activates enzymes and supports photosynthesis and hormone regulation. Direct foliar application of these micronutrients likely supplied them to the plant's photosynthetic tissues, improving metabolic processes and nutrient utilization (Pandey and Parmar 2022). Considering the potential synergistic effects on plant growth resulting from combining B and Zn elements at the recommended 100% RDF is important. The balanced combination of macronutrients (nitrogen, phosphorus, and potassium) and micronutrients (boron and zinc) is pivotal in enhancing nutrient absorption and utilization, resulting in noticeable growth improvements. This aligns with conclusions made by Pathak and Sharma (2023).

3.2 Yield attributes

The results presented in Table 3 illustrate the impact of various treatments on field pea yield parameters, including the number of

Table 3 Effect of nutrient management on yield and yield attributes of field pea

Treatments	Number of seeds per pod	Number of pods per plant	Harvest index (%)	Seed yield (kg ha^{-1})	Test weight (g)
Control	6.700^{f} ± 0.0	5.66^{h} ± 0.47	39.82^{d} ± 2.48	906.67^{j} ± 66.00	7.66^{h} ± 0.41
100% RDF	9.367^{b} ± 0.0	10.66^{b} ± 0.47	45.15^{abc} ± 0.63	3324.67^{b} ± 43.86	15.03^{a} ± 0.31
0:60:40 N:P_2O_5:K_2Okg ha^{-1}	7.333^{ef} ± 0.5	8.00^{de} ± 0.00	44.94^{abc} ± 1.10	1931.33^{h} ± 41.35	9.40^{fg} ± 0.33
20:0:40 N:P_2O_5:K_2Okg ha^{-1}	8.300^{cd} ± 0.2	6.33^{gh} ± 0.47	45.23^{abc} ± 0.52	2274.00^{f} ± 36.36	10.33^{de} ± 0.47
20:60:0 N:P_2O_5:K_2Okg ha^{-1}	8.667^{bc} ± 0.5	7.33^{efg} ± 0.47	46.33^{a} ± 0.55	2694.33^{d} ± 36.12	11.00^{cd} ± 0.29
0:60:40 N:P_2O_5:K_2Okg ha^{-1} + Foliar spray of 0.2% B	7.633^{de} ± 0.0	7.66^{ef} ± 0.47	43.49^{c} ± 0.70	1892.00^{hi} ± 49.67	9.66e^{fg} ± 0.34
20:0:40 N:P_2O_5:K_2Okg ha^{-1} + Foliar spray of 0.2% B	8.333^{cd} ± 0.5	7.33^{efg} ± 0.47	45.86^{a} ± 0.59	2428.33^{e} ± 42.29	10.13^{def} ± 0.34
20:60:0 N:P_2O_5:K_2Okg ha^{-1} + Foliar spray of 0.2% B	9.000^{bc} ± 0.0	8.66^{cd} ± 0.47	46.57^{a} ± 0.56	3113.67^{c} ± 72.50	11.80^{bc} ± 0.45
0:60:40 N:P_2O_5:K_2Okg ha^{-1} + Foliar spray of 0.5% Zn	7.667^{de} ± 0.5	7.00^{efg} ± 0.00	44.55^{abc} ± 0.62	2051.32^{g} ± 66.68	10.53^{de} ± 0.41
20:0:40 N:P_2O_5:K_2Okg ha^{-1} + Foliar spray of 0.5% Zn	8.367^{cd} ± 0.1	9.33^{c} ± 0.47	45.91^{a} ± 0.36	3110.00^{c} ± 40.10	11.00^{cd} ± 0.33
20:60:0 N:P_2O_5:K_2Okg ha^{-1} + Foliar spray of 0.5% Zn	8.667^{bc} ± 0.5	10.33^{b} ± 0.47	45.69^{ab} ± 0.79	3075.00^{c} ± 37.48	12.33^{b} ± 0.25
Foliar spray of 0.2% B	7.667^{de} ± 0.0	7.33e^{fg} ± 0.47	45.86^{a} ± 0.41	2383.67^{e} ± 27.13	8.83^{g} ± 0.21
Foliar spray of 0.5% Zn	6.667^{f} ± 0.5	6.66^{fg} ± 0.47	43.64^{bc} ± 0.69	1798.00^{i} ± 67.49	9.00^{g} ± 0.65
Foliar spray of 0.2% B and 0.5% Zn	7.333^{ef} ± 0.5	7.33^{efg} ± 0.47	45.23^{abc} ± 0.61	2416.00^{e} ± 50.99	8.83^{g} ± 0.68
Foliar spray of 0.2% B and 0.5% Zn+ 100% RDF	10.267^{a} ± 0.0	12.33^{a} ± 0.47	47.49^{a} ± 0.47	3537.33^{a} ± 80.30	15.06^{a} ± 0.25

*The mean values followed by letters were significantly different at $p < 0.05$ based on Duncan's multiple range test (DMRT).

seeds per pod, pods per plant, test weight of seeds, seed yield, and harvest index. Among the diverse treatment combinations, applying a foliar spray containing 0.2% B and 0.5% Zn alongside 100% RDF yielded a notably higher seed count (10.26). The treatment using 100% RDF alone produced a seed count of 9.367. In contrast, the control group exhibited the lowest seed count (6.700). The treatment involving a foliar spray of 0.2% B and 0.5% Zn, and 100% RDF displayed the highest pod count (12.33). This was closely followed by the 100% RDF treatment with a pod count 10.66. Conversely, the control treatment had the lowest pod count (5.66), while the remaining treatments yielded pod counts ranging from 6.33 to 8.66. The synergistic effects of boron and zinc foliar spray application can be attributed to their crucial roles in promoting reproductive growth and development. Using 100% RDF has enhanced access to essential micronutrients and macronutrients, supporting robust plant growth and pod formation (Noori et al. 2023). In terms of the seed yield, employing a foliar spray containing 0.2% B and 0.5% Zn along with 100% RDF led to significantly higher seed yield (3324.67 kg ha^{-1}) compared to those for the control (906.67 kg ha^{-1}) and other treatments (ranging from 1798.00 to 3113.67 kg ha^{-1}). This result can be attributed to the combined effect of foliar sprays containing B and Zn, in addition to the appropriate dosage of fertilizer. The interventions successfully addressed nutritional inadequacies, thus promoting strong plant growth and maximizing seed production. These findings underscore the importance of integrating micronutrient supplementation and adopting optimal fertilization practices to enhance crop productivity. This conclusion aligns with the results reported by Kohli et al. (2023) and Stanton et al. (2022). Moreover, a foliar spray containing 0.2% B and 0.5% Zn along with 100% RDF resulted in the highest seed index (15.03g). This was followed by applying 100% RDF, yielding a seed index of 15.03g. The control group exhibited the lowest seed index of 7.66g. This comprehensive approach produced significant seed index values, showcasing the positive outcomes of combined nutrient supplementation and proper fertilization practices. The simultaneous application of B and Zn through foliar sprays and adequate essential nutrient availability from RDF The developed combination is anticipated to yield favourable results regarding nutrient absorption, enzymatic responses, physiological functions, enhanced seed quality, and amplified production. Furthermore, the treatment utilizing a foliar spray containing 0.2% B and 0.5% Zn and 100% RDF achieved the highest harvest index of 47.49%. Following closely, the 20:60:0 N: P_2O_5:K_2O kg ha^{-1} treatment exhibited a harvest index of 46.33%. Additionally, the 20:60:0 N: P_2O_5:K_2Okg ha^{-1} treatment, combined with a foliar spray of 0.2%

B, demonstrated a harvest index of 46.57%. In contrast, the control treatment reported the lowest harvest index of 39.82%. A higher harvest index signifies efficient resource utilization. The observed phenomenon can be attributed to enhanced nutrient provision through fertilization and foliar spray applications, increasing plant growth and production (Kumar et al. 2022). The efficacy of foliar spray depends on various parameters, including crop type, nutrient form and concentration, application timing, and prevailing environmental conditions (Sumer and Yaraşir 2022).

3.3 Regression analysis

The effect of various parameters (such as the number of nodules per plant, number of pods per plant, and seeds per pod) on the chlorophyll index was predicted using quadratic response regression analysis. The results demonstrated a significant enhancement in field pea seed yield as these parameters increased. This trend is visually depicted in Figures 2, 3, 4, and 5, along with their corresponding R^2 values and polynomial equations. The observed trend shows that robust plant growth facilitates efficient nutrient utilization, resulting in higher chlorophyll indices and greater nodule formation per plant. The higher chlorophyll index leads to an increased accumulation of photosynthates, translating into a higher count of pods per plant and more seeds per pod. The cumulative effect of these growth factors profoundly influences the overall seed yield, and the developed treatments significantly affect this outcome. Therefore, it is clear that there is a positive correlation between the growth factors and the enhancement of yield.

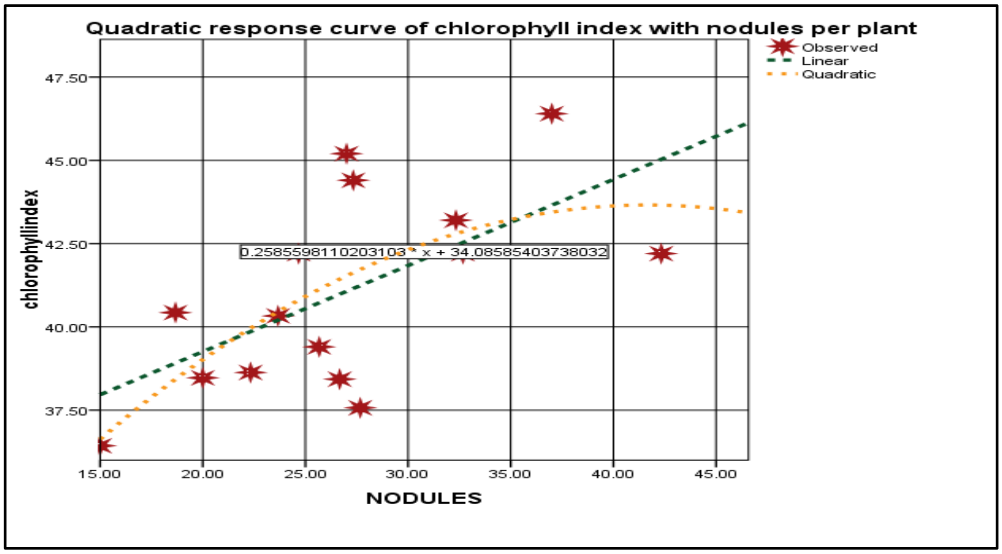

Figure 2 Regression analysis of chlorophyll index vs. number of nodules per plant

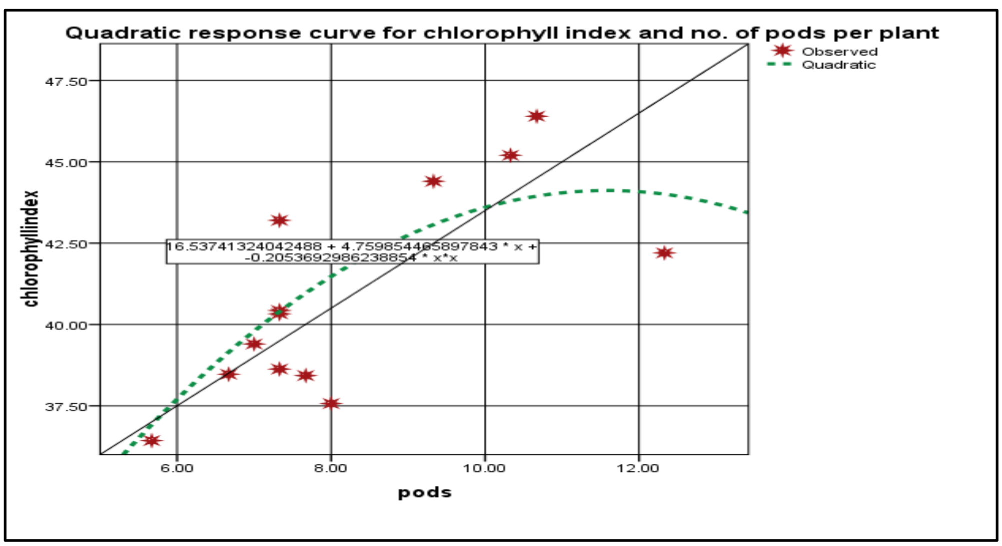

Figure 3 Regression analysis of chlorophyll index vs. number of pods per plant

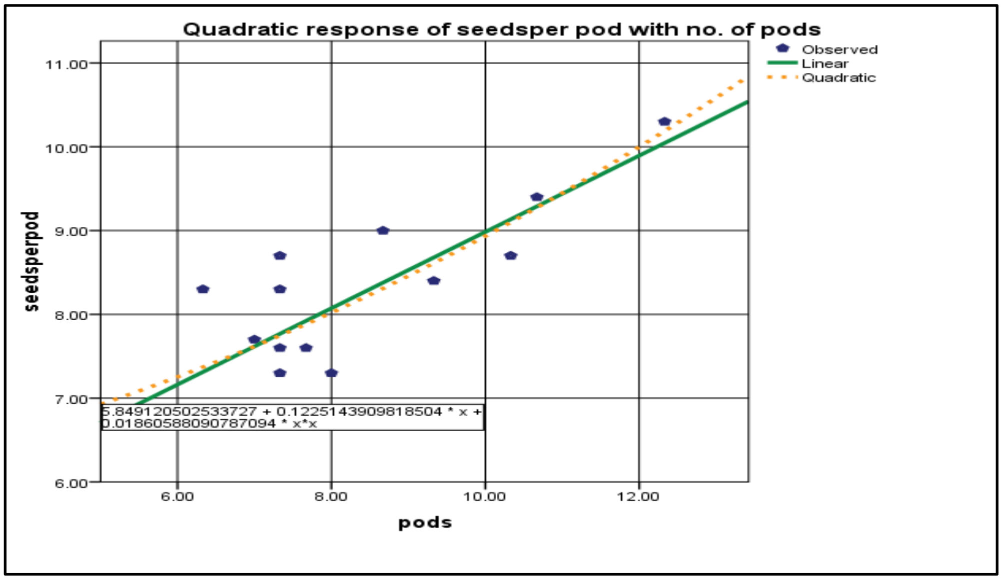

Figure 4 Regression analysis of seeds per pod vs. number of pods per plant

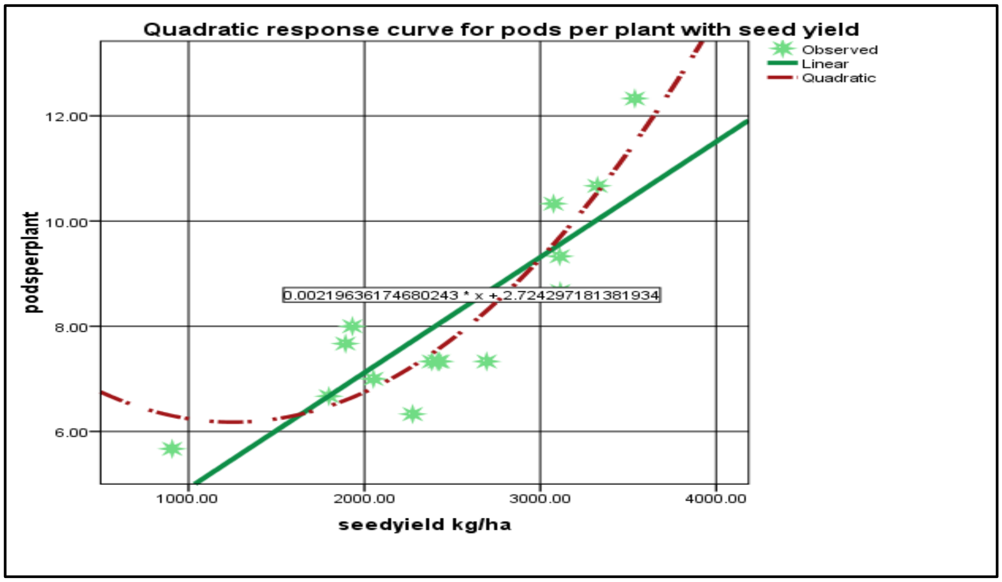

Figure 5 Regression analysis of number of pods per plant vs. seed yield

Conclusion

This study showed that employing 100% RDF, along with 0.2% B and 0.5% Zn, led to notable increases in plant height, branch count, leaf count, dry matter accumulation, chlorophyll index, leaf area, crop growth rate, and relative growth rate. Similarly, using 100% RDF, along with boron and zinc, improved yield-related characteristics. Thus, it can be inferred that applying 100% RDF, 0.2% B, and 0.5% Zn is a promising alternative to the recommended dose of inorganic fertilizers for field pea cultivation within the experimental conditions. This approach enhances crop productivity and contributes to the sustainability of production practices.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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