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Growth, yield and economics of Pusa Gautami variety influenced by nutrient doses and sources

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Abstract
A Field experiment was conducted during the *Rabi* season of 2022-23 at the Agriculture Research Farm of Maharishi Markandeshwar (Deemed to be university), Mullana, Ambala (Haryana). Treatments *viz*. T_1-Control, T_2-100 NPK, T_3-100% NPK + Nano-N spray at 28 and 45 DAS, T_4-100% NPK + Bio-nano-P spray at 28 and 45 DAS, T_5-100% NPK + Bio-nano-K spray at 28 and 45 DAS, T_6-100% NPK + Bio-nano-Zn spray at 28 and 45 DAS, T_7-100% NPK + Nano-N + Bio-nano-P + Bio-nano-K + Bio-nano-Zn spray at 28 and 45 DAS, T_8-75% NPK, T_9-75% NPK + Nano-N spray at 28 and 45 DAS, T_{10}-75% NPK + Bio-nano-P spray at 28 and 45 DAS, T_{11}-75% NPK + Bio-nano-K spray at 28 and 45 DAS, T_{12}-75% NPK + Bio-nano-Zn spray at 28 and 45 DAS, T_{13}-75% NPK + Nano-N + Bio-nano-P + Bio-nano-K + Bio-nano-Zn spray at 28 and 45 DAS were arranged in a randomized block design (RBD) comprising 3 replications. HD-3086, popularly known as "Pusa Gautami" seeds were sown on November 18th, 2022, and the crops were harvested on April 8th, 2023. Urea (46% N), diammonium phosphate (46% P_2O_5 and 18% nitrogen) and muriate of potash (60% K_2O) and 4 kg of zinc sulfate as nutrient doses and sources. HD 3086 responded well to nutrient doses and sources, especially treatment T_7, which exhibited significantly superior results in both yield and economic aspects. This resulted in outstanding grain (5300 kg/ha) and straw (6750 kg/ha) yield, generating net returns of 100,299 Indian Rupees, additionally, it achieved a peak B: C ratio of 2.0. Therefore, farmers can utilize bio-nano-fertilizers as an efficient nutrient delivery system in their fields, as NPK alone is not sufficient.

Keywords: Nutrient doses and sources, wheat, Pusa Gautami, nano-fertilizers, bio-nano-fertilizers, yield

Introduction

Wheat (*Triticum aestivum* L.) ranks as the second utmost crucial essential (staple) food globally, following rice and is among the most widely grown cereal crops worldwide. It is cultivated on approximately 220 million hectares worldwide, yielding over 765 million metric tonnes of grain with 3.47 metric tonnes of productivity per hectare (Sendhil *et al.*, 2023) [23]. India grows wheat on 30.46 million hectares, yielding 104.00 million metric tonnes of wheat per year and 3.41 metric tonnes of productivity per hectare (Singh and Beillard, 2022) [26]. India has around 13.8% of the world's wheat crop, of which, only 14.06% is produced, and its productivity is ranked eighth.

Wheat cultivation in India is primarily concentrated in the *Trans-Gangetic Plains* Region, UP, Punjab and Haryana are the primary states where wheat is grown extensively on a large scale. These states collectively produce 72% of the total wheat produced in India. Unfortunately, in recent periods, there has been a reduction in wheat production due to the result of soil deterioration, uneven and insufficient fertilizer application, postponed wheat planting, increased irrigation demand and reduced terminal heat stress. The nation's food security is under threat due to the decreasing wheat output (Benjamin *et al.*, 2022, Kumar, 2023) [3, 10]. Nevertheless, the state of Uttar Pradesh leads in both areas (9.67 million hectares) and production (27.52 million tonnes), however, its average productivity of UP (2846 kg/ha) is substantially lesser than the produce of Punjab (4307 kg/ha) and Haryana with 4213 kg/ha (Udhayan *et al.*, 2023) [27]. Most of the time, wheat is a widely used cereal grain, which is commonly used by humans in the form of flour for making various food products such as chapatis, semolina, pasta, bread, biscuits, cookies, noodles, vermicelli and more.

Food security in India was made possible by the green revolution of the 1970s, which introduced dwarf wheat and rice genotypes that responded well to fertilizer and produced large yields. Fertilizer inputs have been estimated to contribute between 30 and 40 percent of crop yield. However, deficiencies in macro- and micronutrients, particularly phosphorus, potassium, and zinc, have resulted from the use of conventional blanket fertilizer recommendations and a skewed dependence on high-analysis fertilizer (Noulas *et al*., 2023) [20]. Nitrogen, phosphorus and potassium application ratio under the predominant cropping systems rice-wheat (15:06:01), sugarcane-ratoon-wheat (10:04:01), rice-wheat-gram (13:06:01) and maize-wheat (34:17:01) happened to be drastically abnormal (Gangwar and Singh, 2011) [7]. Ironically, aside from a reduction in the crop response ratio and roughly 8-10 Mt of NPK mining across the country, this has had a negative impact on soil health and human prosperity (Kumar *et al*., 2022) [11]. Due to various losses, it has been discovered that the application of urea, P_2O_5, and K_2O results in a reduction in fertilizer use efficiency, which is between 20 and 50% for N, 10 to 25% for P and 70 to 80 percent for potash and 2 percent for micro-nutrients. These losses also raise the cost of cultivation and lead to the release of GHG and cause some health hazards diseases like blue baby syndrome.

The right use of fertilizers and dosages is essential for healthy food grain crop production. Therefore, it is critical to assess how various nutrient sources and dosages affect wheat development, production and uptake of nutrients by the crop plants. One key element that affects how quickly the plants grow is the fertility of the soil. The sources and doses of nutrients that are necessary for plant growth determine the fertility of the soil. Both primary nutrients and secondary nutrients play a part in improving the enzymatic system of plants as well as crop development, growth and grain yield including plant productivity. The reduction of organic matter in the soil, increased cropping intensity with high-yielding crop varieties, and other factors are all contributing to the increasing nutritional strains on soils. Thus, although the amount of fertilizer needed in the soil is growing the proportion is not entirely balanced. Kumar *et al*. (2020) [12] reported that potassium (K), the primary plant nutrient, is more important since plants need it in comparatively bigger amounts, and it also greatly enhances the quality of grain and increases resistance against different types of stress. Unlike N_2 and P_2O_5, the recommended dose of K_2O in India serves as a dose for maintenance purposes. Nandal and Solanki (2021) [18] found that zinc is a nutrient, which is essential to all higher plants for nitrogen fixation, photosynthesis, respiration, protein synthesis, and other biochemical routes. In wheat, zinc fertilizer application is crucial to achieve maximum yield.

Materials and Methods

Experimental research was undertaken at the Department of Agriculture research farm (Faculty of Agriculture), MM (DU), Mullana-Ambala 133207, which lies in the *Indo-Gangetic plains* of Haryana state. The farm is situated at a height of 264 meters above mean sea level and latitudes 30° 170' 0" N and longitudes 77° 3' 0" E. Soil is clay loam with a pH of 7.7. It exhibited a high content of available potassium (270 kg/ha) and medium of available nitrogen (205 kg/ha) and phosphorus (16.5 kg/ha), while organic carbon (0.41) and zinc content (3.32 µg/g) were relatively low. HD 3086, popularly as Pusa Gautami is the most widely used wheat variety with high-yielding potential and can be sown early or late (up to the 2nd week of December). HD-3086 may grow up to 112 cm and is resistant to leaf rust disease. Each plant has three to four tillers and broad, deep green leaves. Seed-to-seed, the time interval is 127-160 days and heading takes 60-63 days. Amber in hue, grains have a bright amber. It weighs 33-54 g in its test weight and its production potential is more than 5.45 t ha^{-1}. The seeds were procured from the Research farm of Department of Agriculture (Faculty of Agriculture) MM (DU) Mullana-Ambala. The unit plot measured 3.0 by 4.0 meters (12 m^{2}).

Fig 1: Experimental field layout

Nitrogenous, phosphatic, potassic, zinc and bio-nano-fertilizers were applied to the wheat crop.

The seeds were sown by hand plough in furrows having 2 to 3 cm depth from the soil surface and the space between rows was 22.5 cm. As per the recommendation for timely sown wheat, 100 kg of seeds per hectare were sown. After sowing the seed, the furrows were planked manually to cover the seeds for their proper germination.

Observation to be recorded

For crop sampling from every net plot, seven wheat plants were randomly chosen and labeled for taking observations at various stages of growth, like 30, 60, 90, 120 DAS and at harvesting time. The main items of observation include growth parameters, yield and yield-attributing parameters. Data on soil properties and weather conditions were documented during the research period.

Experimental Results

The observations on wheat crops' development and growth, yield and yield attributes, nutrients' uptake and soil properties were taken into consideration to study the "Effect of nutrient doses and sources on growth, yield and nutrient uptake in wheat (*Triticum aestivum* L)" during 2022-23. The data underwent compilation, tabulation, and subsequent statistical analysis. The treatments utilized are detailed in the tables, illustrated in figures and subjected to analysis of variance (ANOVA) as outlined in appendices. The significance of the treatments was tested through the utilization of critical differences and the data for various parameters have been interpreted in form of results by using respective tables and figures under the following headings:

Plant Population

Number of plants per square meter at initial stage (20 DAS) showed no significant differences observed among treatments, however at harvest stage the significant differences were noted highest plant density was recorded in treatment T_7 with 116 plants per square meter and lowest plant density was documented in control with 110 plants per square meter.

Plant Height

Growth pattern (plant height) increased with plant age, showing the most rapid growth up to 90 days after sowing (DAS), then slowing down. Treatment T_7 Achieved the maximum plant height of 96.83 cm at harvest and control recorded a height of 71.10 cm at harvest. The research noted that higher nitrogen content corresponded with a significant increase in plant height as it was seen in all treatments with N. Summarized from Fig.1 The study highlights that the treatment involving a full dose of NPK combined with Nano-N and various Bio-nano nutrient sprays (T_7) resulted in the highest plant density and height, indicating the potential benefits of these nutrient management practices on wheat crop growth.

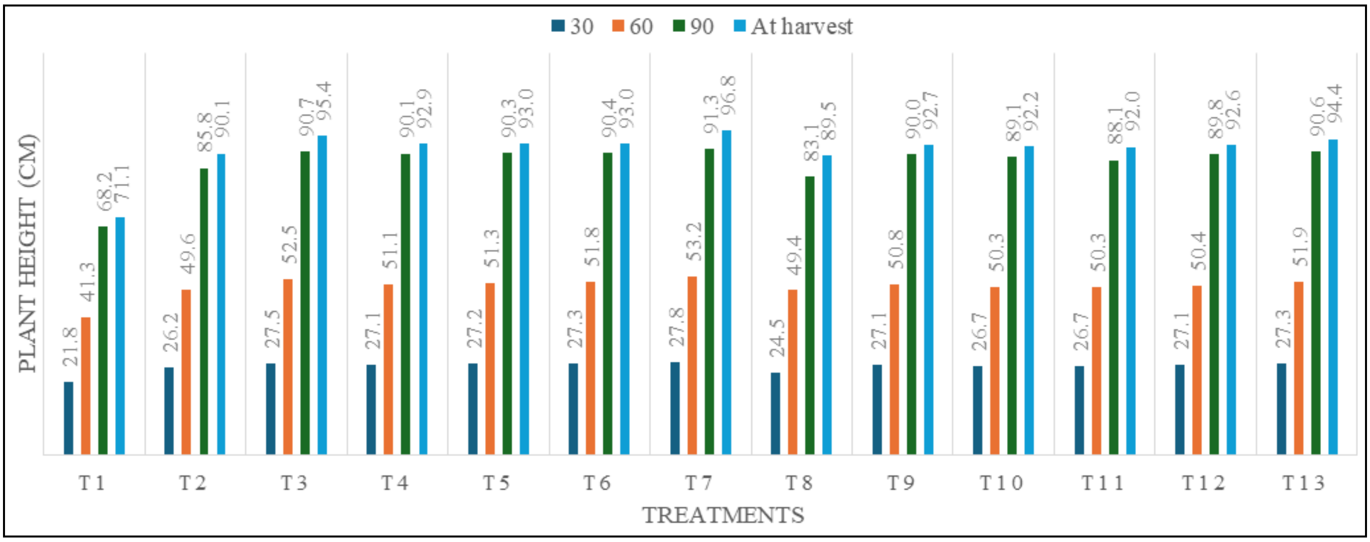

Fig 2: Effect of nutrient sources and doses on wheat crop plant population and plant height

Number of Tillers

Nutrient doses and sources significantly increased the number of tillers compared to the control (no fertilized plot). The tiller count increased rapidly between 30 and 60 days after sowing (DAS) and peaked at harvest. The maximum tillers per unit area was noted at harvesting. Owing to tiller mortality, the number of tillers started to decrease gradually at 90 DAS and harvest time. Supplying a combination of 100% NPK + Nano-N + Bio-nano-P + Bio-nano-K + Bio-nano-Zn spray at 28 and 45 DAS (T_7) led to a higher tiller count (166.67) compared to other treatments, similar to treatment T_3 and T_{13} throughout all growth stages. At 60 days after sowing, treatment T_7 similarly yielded a considerably higher tiller per square meter (387.67) than the other treatments. This trend was consistent even at 90 days after sowing. Moreover, at maturity, the same treatment led to the highest tiller number per unit area (396.67 m^{-2}) among treatments. In contrast, control exhibited the lowest tiller number per unit area. However, results for treatment T_4 and treatment T_5 were comparable. Other treatments with combinations of NPK and nano-fertilizers also performed better than the control.

Dry Matter Weight

The dry matter weight of wheat increased with the application of fertilizers, especially from 60 DAS onwards. The treatment with 100% NPK + Nano-N + Bio-nano-P + Bio-nano-K + Bio-nano-Zn spray (T7) had the highest dry matter accumulation at 1147.53 g/m² at harvest. The control treatment had the lowest dry matter weight at all growth stages. the application of a full dose of NPK along with a combination of nano-fertilizers significantly enhances both the number of tillers and the accumulation of dry matter in wheat crops compared to lower doses or no fertilizer application. The 100% NPK + various nano-fertilizer sprays showed the highest values.

Yield and yield attributing parameters

Study evaluated the impact of various nutrient management strategies on wheat yield and its attributing parameters. Significant variations were observed in parameters like effective tillers, spikelets per spike, and grains per spike due to different nutrient treatments, while wheat test weight showed a non-significant effect.

Effective Tillers

Nutrient treatments significantly increased the number of effective tillers per unit area compared to the control. The application of nano-nutrients, *i.e.*, Nano-nitrogen + phosphorus + potash + zinc as well as nitrogen + phosphorus + potash + zinc with 100% nitrogen, phosphorus and potash significantly rose the effective tiller numbers by 6.7, 5.0, 5.06, 5.6 and 9.6% with, respectively over 100% NPK. On the other hand, the increase with 75% of NPK was 4.7, 4.1, 2.1, 4.2 and 8.4% over 100% NPK. The application of 100% NPK and nano-N + bio-nano-P + bio-nano-K + bio-nano-Zn increased 9.6% effective tiller than 75% NPK, which significantly differed from 75% NPK + Nano-NPK and Zn. Substantively efficient tiller numbers per square meter increased when nano-nutrients were applied and in a descending pattern of Nano -N> Zn > K > P over 100% NPK, hence, the highest increase was observed with the combination of 100% NPK and nano-nutrients

Spike Length

The longest spikes were produced under treatments involving 100% NPK with various nano-nutrient sprays, significantly longer than the control. The greatest spike length (9.77 cm) was attained under treatment T_7 which was at par with T_3 and T_{13} treatments. Compared with all other treatments, crop under control produced the smallest spike length (6.17 cm), which was statistically significant.

Spikelets per Spike

All nutrient treatments resulted in a significantly higher number of spikelets per spike compared to the control. The highest increase was seen with the combination of 100% NPK and multiple nano-nutrients. When nano-nutrients, *i.e.*, Nano-N, P, K, Zn and N + P + K + Zn were applied in addition to 100% NPK, the results showed an increase of 16.2, 10.8, 14.0, 15.1 and 25.5%, respectively. On the other hand, nano-nutrients with 75% of NPK showed an increase in spikelets per spike by 20.90, 11.1, 10.5, 5.5 and 11.6%. Hence, the quantity of spikelets within a spike was lowered by 25% more NPK dosage reduction in conjunction with Nano-nutrient spray. However, such differences were not found significant. Using nano-nutrients as a supplement to 100% NPK increased the number of spikelets for each spike in the increasing sequence of Nano P < Nano K < Nano Zn < Nano N.

All nutrient treatments resulted in a significantly higher number of spikelets per spike compared to the control. The highest increase was seen with the combination of 100% NPK and multiple nano-nutrients.

Grains per Spike

A statistically significant relationship was found between the grain per spike due to the dosages and sources of nutrients. Maximum grains per spike were recorded under the treatment with 100% NPK and a combination of nano-nutrients, while the control had the fewest grains. It was discovered that treatment T_7 produced the maximum grain per spike (62.67), differing considerably from all the rest of the treatments. Once more, control plot yielded the minimum grains per spike (40.00), which differed considerably from all other treatments.

Test Weight

The wheat crop's test weight varied significantly depending on the different nutrient doses and sources applied. The highest test weight (1000 grains) was observed in treatments involving 100% NPK and nano-nutrient combinations, indicating healthier seeds. Treatment T_7 showed maximum test weight of 42.97 g, whereas the minimum (33.20 g) was with control treatment.

Grain Yield

Economic (grain) yield is the main crop yield produced in wheat cultivation. The review of data in Table 1 reveals impact of nutrient amounts and their sources on the grain (economic) yield in wheat cultivation *cv.* HD-3086.The highest grain yield (5.3 t/ha) was achieved with 100% NPK + Nano-N + Bio-nano-P + Bio-nano-K + Bio-nano-Zn spray at 28 and 45 DAS. Treatment T_3 came next, yielding 5.08 t ha^{-1}, which was equivalent to treatment T_{13} while the lowest yield (3.2 t/ha) was observed in the control.

Straw Yield

Based on the experimental results, the maximum straw yield (6.75 t/ha) was also noted in the treatment T_7. In comparison with other treatments, this difference was statistically significant. When compared with the control, the order of the degree of increase with the application of NPK and Zn nano-nutrient was Zn > N > K > P.

Biological Yield

Table 1 presents the biological yield of wheat *cv.* HD-3086 in connection with the effects of supplying nutrient doses and sources. Results for biological yield (t ha^{-1}) indicated that fertilizer doses and sources had a substantial effect. The treatment T_7, T_3 and T_{13} had the maximum biological yield of 12.05, 11.66 and 11.58 t ha^{-1}, respectively. The crop with no fertilizer yielded a minimum biological yield, which was 7.50 t ha^{-1}.

Harvest Index

Harvest index (%) for the wheat *cv.* HD-3086 in relation to nutrient doses and source applications was tabulated in Table 1. Significant results were found for fertilizer effects on the harvest index (%). The maximum HI was 45.28% under treatment T_6, which was at par with the treatments T_{13}, T_9, T_7, T_5 and T_4. Under the treatment T_2, the harvest index was obtained minimum (41.74%).

Economic feasibility of various treatments

Based on the input-output analysis, the economic feasibility of various treatments was determined and computed. Economics-related data are displayed in Table 2. Below is a detailed description of several economic components. Statistical and recorded data showed that the cost of cultivation varied with the crop cultivated without nutrient treatment costing ₹40520 ha^{-1} and the crop grown with T_7 costing ₹50051 ha^{-1}. A crop raised with treatment T_7 achieved the maximum gross return. It exhibited a higher gross return of ₹150350.0 ha^{-1} than the other treatments. The treatment T_1 (untreated control) exhibited least gross income of ₹91900.0 ha^{-1}.

The study indicated that varying nutrient doses and sources resulted in higher net returns from wheat crop *cv.* Pusa Gautami variety in comparison to untreated control plot. The higher net income was obtained in treatment T_7 amounting to 100,299 ₹ per hectare followed closely by treatment T_3, which recorded a net profit of ₹96,104 per hectare. The least net income was noted in control plot with ₹51380 per hectare.

According to the current research findings, treatment T_7 demonstrated a significantly higher benefit-cost ratio (2.0) than the other treatments; nonetheless, it was comparable to treatment T_3 and T_{13}, and the untreated control plot displayed the lowest benefit-cost ratio (1.27).

Table 1: Effect of nutrient doses and sources on grain, straw and biological yield of wheat

Treatment	Yield (t ha^{-1})			
	Grain Yield	Straw Yield	Biological yield	Harvest index (%)
Control (no fertilizer)	3.20	4.30	7.50	42.67
100 NPK (150: 60: 60)	3.83	5.35	9.18	41.74
100% NPK + Nano-N spray at 28 and 45 DAS	5.08	6.58	11.6	43.57
100% NPK + Bio-nano-P spray at 28 and 45 DAS	4.61	5.80	10.41	44.32
100% NPK + Bio-nano-K spray at 28 and 45 DAS	4.95	6.16	11.11	44.53
100% NPK + Bio-nano-Zn spray at 28 and 45 DAS	5.19	6.27	11.46	45.28
100% NPK + Nano-N + Bio-nano-P + Bio-nano-K + Bio-nano-Zn spray at 28 and 45 DAS	5.30	6.75	12.05	43.98
75% NPK	3.75	5.00	8.75	42.86
75% NPK + Nano-N spray at 28 and 45 DAS	4.59	5.65	10.25	44.80
75% NPK + Bio-nano-P spray at 28 and 45 DAS	4.16	5.75	9.91	42.02
75% NPK + Bio-nano-K spray at 28 and 45 DAS	3.97	5.44	9.41	42.21
75% NPK + Bio-nano-Zn spray at 28 and 45 DAS	4.35	5.65	10.00	43.55
75% NPK + Nano-N + Bio-nano-P + Bio-nano-K + Bio-nano-Zn spray at 28 and 45 DAS	5.08	6.50	11.58	43.88
SEm ±	0.03	0.03	0.06	0.48
CD at p=0.05	0.10	0.11	0.17	1.43

Table 2: Effect of nutrient doses and sources on economic parameters of various treatments in wheat crop (₹ ha^{-1})

Treatment	Total Cost	Gross Income	Net Returns	BCR
Control (no fertilizer)	40520.0	91900.0	51380.0	1.27
100 NPK (150: 60: 60)	48186.0	111083.3	62897.3	1.31
100% NPK + Nano-N spray at 28 and 45 DAS	48646.0	144750.0	96104.0	1.98
100% NPK + Bio-nano-P spray at 28 and 45 DAS	48926.0	130566.7	81640.7	1.67
100% NPK + Bio-nano-K spray at 28 and 45 DAS	48426.0	139733.3	91307.3	1.89
100% NPK + Bio-nano-Zn spray at 28 and 45 DAS	49320.0	145591.7	96271.7	1.95
100% NPK + Nano-N + Bio-nano-P + Bio-nano-K + Bio-nano-Zn spray at 28 and 45 DAS	50051.0	150350.0	100299.0	2.00
75% NPK	46134.5	107500.0	61365.5	1.33
75% NPK + Nano-N spray at 28 and 45 DAS	46394.5	129308.3	82913.8	1.79
75% NPK + Bio-nano-P spray at 28 and 45 DAS	46874.5	120416.7	73542.2	1.57
75% NPK + Bio-nano-K spray at 28 and 45 DAS	46374.5	114658.3	68283.8	1.47
75% NPK + Bio-nano-Zn spray at 28 and 45 DAS	46759.5	124133.3	77373.8	1.65
75% NPK + Nano-N + Bio-nano-P + Bio-nano-K + Bio-nano-Zn spray at 28 and 45 DAS	48560.0	144333.3	95773.3	1.97
SEm ±	------	------	------	------
CD at p=0.05	------	------	------	------

Discussion
A crop's yield depends on the health of each plant and the crop stand. Each plant's yield is further influenced by the effective tiller numbers per unit area, spikelets in one spike, grains in one spike and test weight. The size, length and dry matter partitioning efficiency of a crop's photosynthetic system are not the only factors that affect yield production. Thus, diversity, soil fertility and environmental interactions all affect grain yield.

Plant population
Plant population, a crucial growth metric, showed that no discernible difference was observed among the various treatments for plant stands per meter square, most likely because there were sufficient seed reserves for robust emergence and establishment. The results of current research support existing findings of Kumar *et al.*, (2021) [14] indicated that findings of the initial plant population being counted at 15 DAS, uniform germination percentages from low initial N requirements, and identical seed rates and spacing, increasing the rate of N did not pointedly affect initial plant density (population) at seedling stage. As a result, the plant populations in all plots were comparable.

Plant height
Treatment T_7 resulted in maximum plant height under nutrient doses and sources since NPK are essential elements for the growth of the plants. Similar results were also reported by Sharma *et al.* (2022) [24]. Due to a lack of competition among plants for nutrients during the early growth period, plant height was not significantly affected by different treatments. With varying nitrogen levels, wheat plants grew taller. The current study's findings align with those of Singh and Beillard (2022) [26] and Noonari *et al.* (2016) [19].

Number of tillers per meter square
Findings from the present experiment indicated that in 30 DAS there was existed an insignificant variance among the treatments. The number of tillers counted increased significantly to 60 DAS. The maximum tiller numbers per square meter were obtained in a plot treated with complete doses (100%) of NPK plus Nano-N plus Bio-nano-P plus Bio-nano-K plus Bio-nano-Zn spray at 28 and 45 DAS (T_7). As a result of aging, the tillers dried, which occurred after 90 DAS and at maturity. Another explanation was that wheat plants had a certain time for tillering, after which they went into the stage of shoot elongation and ripening, which prevented the new tiller formation. The rise in tiller production was most likely caused by an increased supply of nitrogen, which was needed for cell expansion and multiplication and the generation of nucleic acid and other essential components in the cell sap. Likewise, comparable outcomes were reported by Ramanandan *et al.* (2020) [21].

Dry matter weight

Maximum dry matter weight was noted under the plot treated with T_7, the application of NPK-Zn and their nano-fertilizers significantly influenced dry matter weight at thirty, sixty, and ninety days after sowing (DAS), as well as at maturity. Various growth parameters, such as plant height, tiller density, shoot count, and leaf number, collectively contributed to the dry matter weight. Larger plant tissue, higher chlorophyll generation and accelerated photosynthetic activity were all made possible by the sufficient nutrition supply. Findings of present research were closely proven by the results of Nagora *et al*. (2023) [17] and Waghmare *et al.* (2018) [29]. Additionally, rise in dry matter weight might be due to consistent strong growth that increased nutrient uptake, photosynthetic area, chlorophyll generation and biomass.

Yield and yield attribute parameters

A closer look at Table 2, yield and its yield attributes results presented that the crop fertilized with 100% NPK combined with Nano-N, Bio-nano-P, Bio-nano-K, and Bio-nano-Zn spray at 28 and 45 DAS demonstrated a substantial augument in the sum of productive tillers per square meter (393), spike length (9.77 cm), spikelets per spike (21.68), grains per spike (62.67), weight of 1000 grains (42.97 g) and a harvest index of 2.00. This treatment (T_7) also achieved a straw yield of 6.75 tonnes per hectare and a grain yield of 5.3 tonnes per hectare. Such an increase might have been brought about by good soil conditions fertilized with both a combination of fertilizers and their nano bio-fertilizers and the resulting strong growth (height of crop, tiller numbers per unit area and dry matter weight). It might be caused by appropriate plant nutrient sources and doses supplied in fields of wheat. Findings of present study authenticate with findings of Singh and Singh (2018) [25], Kendra, (2022) [9], Chanchala and Paikra (2020) [4], Kumari (2021) [14] and Waghmare *et al*. (2018) [29] who revealed that all phosphorus treatments, regardless of dosage and application technique, greatly enhanced wheat economics, grain and straw yields, and yield attributes over the control treatment. Additionally, applying nano-urea on the leaves with the proper ratio of NPK and Zn in soil greatly increased various yield parameters. Saad *et al*. (2022) [30] have recommended the foliar utilization of nano-fertilizers to boost yield of wheat crops significantly.

Furthermore, although the wheat grain yield did not rise appreciably when 100% NPK was applied utilizing 100% NPK in conjunction with nano-nutrients enhanced yield of grain, straw and biological matter. This could potentially be attributed by greater root surface area and due to the smaller particle size of nano-fertilizers as compared to ordinary fertilizers, which boosted uptake of nutrients, resulting in improved wheat production. The findings of current research confirm findings of Mahil and Kumar (2019) [15], Akram *et al.* (2020) [2], Vishwakarma *et al.* (2020) [28], Waghmare *et al*. (2018) [29] and Firdous *et al.* (2018) [6] who reported that nano-fertilizers are more reactive and easily pass through the cuticle The high solubility of fertilizer, presence of inorganic nutrients in soil solution, better nutrition absorption, enhanced growth and yield and zinc @ 5 kg/ha showed a substantial rise of grain production.

Outcomes demonstrated a substantial rise in the total tiller numbers and effective tillers per square meter and grain and straw yield compared to the control, but an increase in any of these parameters was not found significant. Applying a complete dose (100%) of NPK combined with Nano-N, Bio-nano-P, Bio-nano-K and Bio-nano-Zn spray at 28 and 45 DAS (T_7) significantly boosted both straw and grain yields. Comparable results were also mentioned by Gite *et al*. (2021) [8], Dawar *et al.* (2022) [5], Mohanta *et al.* (2020) [16] and Kendra (2022) [9].

Economics feasibility of various treatments

The economic analysis results of various nutrient doses and sources under cultivation of wheat crops showed significant variations in expenses incurred in cultivation, total income generated, net profits and the ratio of benefits to costs. There was a significant difference in relative return caused due to variations in both input and output. The cultivation cost of crops grown without nutrient application was recorded as the minimum (₹ 40520 ha^{-1}), while the maximum cultivation cost of ₹ 50051 ha^{-1} was recorded for crops supplied with 100% NPK fertilizers along with nano-N, Bio-nano P, Bio-nano K and Bio-nano Zn at 28 and 45 days after sowing. This cost varied depending on the treatments and variations in fertilizer input and application costs. A considerably higher cultivation cost per hectare was observed for the crop treated with T_7 compared to those treated with other treatment methods. The plot treated with full doses (100%) of NPK, supplemented with Nano-N, Bio-nano P, Bio-nano K and Bio-nano Zn sprays at 28 and 45 DAS (T_7), achieved the highest gross income of ₹150,350 per hectare, net income of ₹100,299 per hectare and a B: C ratio of 2.0. Both Saikia *et al.* (2022) [22] and Kumar *et al.* (2018) [13] additionally documented a great variation in the cost of cultivating wheat under various nutrient doses and sources.

Conclusion and Recommendation

Overall, the study concluded that the application of nano-nutrients along with conventional fertilizers significantly improves yield and yield-attributing parameters in wheat. Specifically, treatment T7, which involves 100% NPK combined with Nano-N, Bio-nano-P, Bio-nano-K, and Bio-nano-Zn sprays at 28 and 45 DAS, produced the best results for growth, yield, and economic returns under favorable conditions. Therefore, farmers should consider using bio-nano-fertilizers as an efficient nutrient delivery system in their fields, as relying solely on NPK is not sufficient for optimal wheat production.

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Conflicts of Interest

The authors declare that they have no conflict of interest.

Data availability

The authors confirm that all data generated or analyzed during this study are included in this research paper. Raw data is available on request from authors.

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