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EFFECT OF NANO FERTILIZERS AND MICRONUTRIENTS ON GROWTH, YIELD AND QUALITY OF CHILLI (*CAPSICUM ANNUUM* L.) UNDER BALAGHAT CONDITION OF MADHYA PRADESH, INDIA

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ABSTRACT

An experiment was conducted to assess the relative effectiveness of nano fertilizers and micronutrients on growth, yield and quality of chilli (*Capsicum annuum* L.) variety TMPH-409 in *Kharif* 2022-23 at School of Agriculture Science, Technology & Research, Sardar Patel University, Balaghat, Madhya Pradesh, India. The experiment was laid out in Randomized Block Design (RBD) having 11 combinations of treatments and three replications. Among all the treatments, T_2 treatment, which consisted of 75% N + 100% PK + 100% Z_nSO_4 + 25 % N as foliar spray with nano urea showed better performance in all parameters *viz.* maximum plant height (99.69 cm at 90 DAT), number of branches (8.18 at 90 DAT), leaf area (198.59 cm^2), early flowering (38.16 DAT), early harvesting (72.14) and maximum number of fruits per plant (260.10), fruit weight (2.72 g), fruit yield per plant (173.03 g), TSS (4.62 ^{o}Brix) and ascorbic acid content. The optimal benefit-cost ratio of 2.78 in T_2 has shown that integrated use of nano fertilizers is viable in terms of practicality in the cultivation of chilli. The results indicate that when conventional nitrogen fertilizers are partially replaced with nano urea applied as a foliar, this method will help to achieve a great contribution to productivity, quality and economic returns during the cultivation of chilli.

Key words : Nano urea, Nano zinc, Micronutrients, Chili, NPK.

Introduction

Chilli (*Capsicum annuum* L.), which is a vegetable and spice crop of the Solanaceae family, is among the most economically significant crops in the world. The number of chromosomes found in chili is 24 and since around 7,500 BC, the chilli has been used in human cuisine (Haque, 2016). India is the second largest producer of fruit and vegetables in the world, with an estimated production of 82.85 million tons and 166.18 million tons of vegetables respectively in 2020, which is nearly 14 percent of the global production of vegetables. Recent estimates show that India produces chilli in an area of about 6.83 lakh hectares producing 17.02 lakh tons and having a yield of 2494 kg/ha. Andhra Pradesh is the largest in production, then comes Telangana and Madhya Pradesh (NHB, 2021). Chilli has a high quality of nutritional value, with moisture (85.7 g), protein (2.9 g), fat (0.6 g), minerals (1.8 g), carbohydrates (3.0 g), calcium (30 mg/100g), phosphorus (80 mg/100g), magnesium (24 mg/100g), iron (1.20 mg) sodium (6.5 mg/100g), potassium (217mg). This pungency is caused by capsaicin that opens the transient receptor potential vanilloid 1 (TRPV1) channel, which is the channel of perception of heat and pain. In addition to food use, capsaicin has been shown to have analgesic, anti-inflammatory, and possibly anti-cancer effects and topical use was shown to have pain and itch relief effects (Choudhary, 2013).

The conventional methods of fertilization in growing chilli are dealing with several problems such as low nutrient use efficacy (NUE), environmental degradation by leaching of nutrients and volatilization loss and declining soil health. Traditional fertilizers usually have a NUE of just 20-30% and 70-80% of the applied nutrients are lost to other channels before the plant receives them. These inefficiencies require too much application of fertilizers, which increases the production expenses and environmental issues. Nanotechnology offers a ground breaking solution to the management of agricultural nutrients by coming up with nano fertilizers.

Nano fertilizers are designed nutrient formulations whose particle sizes are between 1-100 nanometers, which have a high surface area-volume ratio, greater reactivity, control release and target delivery. The nano-scale sizes can be used to penetrate stomatal pores (20-50 nm) and plasmodesmata (50-60 nm), which allows direct access to plant cells and improves the effective use of nutrients. Recent studies show that nano fertilizers may enhance NUE 25-40 times over conventional formulation, reduce the fertilizer application rate by half, cause less environmental pollution, and yield higher crop output by 15-30. The use of nano fertilizers as foliars has also had other benefits such as enhanced speed of nutrient delivery, circumvention of the fixation of various nutrients to soil, the ability to apply them in unfavorable soil conditions and the lowering of total amounts of fertilizers used.

Materials and Methods

Climate and Site of the experiment

The field experiment was done in the Horticulture Research Farm, School of Agriculture Science, Technology and Research, Sardar Patel University, Balaghat, Madhya Pradesh, India in the Kharif season of 2022-23. The experimental location is 21° 19' N latitude and 73° 31' E longitude and the altitude of 924.5 meters above mean sea level, which is within the Chhattisgarh Plain Zone (MP-1) agro-climatic zone.

Soil characteristics

The experimental location was made up of an equalized sandy loam soil of even status of fertility. Sampling and analysis were done on the soil samples randomly by the depths of 0-30 cm and analyzed in terms of physical as well as chemical properties. Analysis of soil texture showed that the content of the soil consisted of 60.60% fine sand, 2.34% silt, 16.00% clay, bulk density of the soil 1.63 g/cm^3, sandy loam.

The pH of the soil was that of a neutral (7.2), the low level of organic carbon (0.4%), the medium level of available nitrogen (250 kg/ha) and phosphorus (135 kg/ha), and the high level of available potassium (344 kg/ha), which suggests that the soil needed balanced fertilization with the focus on the nitrogen and phosphorus additions.

Table 1 : Treatment combinations for experimental evaluation.

Treatment	Description
T_0	RDF (NPK @ 120:80:80 kg/ha) + FYM @ 10 t/ha (Control)
T_1	100% NPK traditional fertilizer + 100% $ZnSO_4$ (basal)
T_2	75% N (traditional) + 100% PK + 100% $ZnSO_4$ + 25% N foliar (nano urea)
T_3	50% N (traditional) + 100% PK + 100% $ZnSO_4$ + 50% N foliar (nano urea)
T_4	25% N (traditional) + 100% PK + 100% $ZnSO_4$ + 75% N foliar (nano urea)
T_5	100% NPK + 75% $ZnSO_4$ (traditional) + 25% Zn foliar (nano zinc)
T_6	100% NPK + 50% $ZnSO_4$ (traditional) + 50% Zn foliar (nano zinc)
T_7	100% NPK + 25% $ZnSO_4$ (traditional) + 75% Zn foliar (nano zinc)
T_8	100% Nano urea + 100% PK + 100% $ZnSO_4$ (basal)
T_9	100% Nano zinc + 100% NPK (traditional)
T_{10}	100% Nano urea + 100% Nano zinc + 100% PK (basal)

Experimental Design and treatments

Randomized Block Design (RBD) was designed to conduct the experiment consisting of 11 treatment combinations and 3 replications (Table 1). The sub-irrigation channels were 0.50m, the bunds were 0.30m and the main irrigation channel was 1.00m. Overall field size was 15.80m × 5.80m (91.64^2) and the net cultivated area of the field was 30.00m^2.

Traditional fertilizers included Urea (46% N), Diammonium Phosphate/DAP (18% N, 46% P_2O_5), Muriate of Potash/MOP (60% K_2O) and Zinc sulphate (21% Zn). Nano fertilizers comprised nano urea and nano zinc in liquid formulation applied as foliar spray at 4 ml/liter water concentration.

Crop management

Nursery Management : Nursery beds were prepared, and sowing of the seeds was done on July 6, 2022. Healthy seedlings with ages thirty-five days were chosen and transplanted. On August 10, 2022 the transplant was done with a spacing of 45cm × 45cm (49,383 plants/ha).

Fertilizer application : Basal application full dose phosphorus and potassium, part of nitrogen and zinc according to treatments.

Foliar application : Nano urea and nano zinc at 4 ml/liter sprayed at 30, 50 and 70 days after transplanting (DAT) early morning so that it gets absorbed the most.

Pest and Disease management : The pest management and disease management involved integrated pest management, where monitoring was used, botanical and biological pesticides were used as preventive sprays, and chemical pesticides were used as per the recommendations. The data recorded during experimental investigation were subjected to statistical analysis of "Analysis of variance" technique (Fisher and Yates, 1967) for drawing conclusion.

Results and Discussion

Growth parameters

Days to Germination and Percentage to survive

The germination rate varied between treatments (5.66 to 7.50 days). The shortest period of germination (5.66 days) was observed in T_2 (75% N traditional + 100% PK + 100% $ZnSO_4$ + 25% N nano urea foliar), which was statistically equal to T_3 (5.83 days) and T_1 (6.16 days). T_0 (control: RDF + FYM) gave the maximum period of germination (7.50 days). The increased germination rate of the nano fertilizers treatments is explained by the increased availability of nutrients and improved seed metabolism because of activation of enzymes that participate in the germination processes by nanoparticles.

The percentage of survival deviated greatly with 73.01-94.47. In T_2, maximum survival (94.47) was obtained, then T_3 (93.37) and T_1 (91.07). The lowest survival (73.01) was observed in control T_0. Increased survival after nano fertilizer treatments is associated with increased nutrient availability at a very critical stage in seedling establishment, and contributes to enhanced root development and stress tolerance. Similar findings were reported by Parani and Nanthini (2021), Rather *et al.* (2022) in Chilli.

Plant height

Plant height showed a progressive growth over the stages of growth and the effects of treatment remained significant at all time.

At 30 DAT : The heights of the plant were 14.08cm (T_0) to 19.78cm (T_2). The maximum height (19.78 cm) was recorded in treatment T_2 and statistically better than any other treatment T_3 (19.16 cm) and T_1 (18.21 cm).

Height 60 DAT : The height at T_0 was 38.86cm and at T_2 was 55.16cm. The pattern was the same with T_2 generating the highest plants (55.16cm), T_3 (53.51cm) and T_1 (50.82cm). Maximum height (99.69cm) in T_2 recorded the maximum height, which was significantly higher than any treatment at 90 DAT. This was succeeded by T_3 (96.72cm), T_1 (91.93cm), T_4 (89.91cm) and T_8 (88.84cm). Control T_0 had the minimum height (76.54cm). At initial harvest: the height of final plant was 80.10cm (T_0) to 105.23cm (T_2). Treatment T_2 was superior (105.23cm), treatment T_3 had a lower level (102.05cm), and treatment T_1 (96.85 cm) had the lowest level.

Table 2 : Effect of nano fertilizers on plant height (cm) at different growth stages.

Treatment	30 DAT	60 DAT	90 DAT	At Harvest
T_0	14.08	38.86	76.54	80.10
T_1	18.21	50.82	91.93	96.85
T_2	19.78	55.16	99.69	105.23
T_3	19.16	53.51	96.72	102.05
T_4	17.94	49.68	89.91	94.76
T_5	17.14	47.35	87.28	91.93
T_6	17.51	48.12	88.14	92.84
T_7	17.83	49.27	89.45	94.21
T_8	17.45	48.93	88.84	93.58
T_9	16.84	46.72	86.15	90.72
T_{10}	17.26	47.88	87.69	92.14
CD (5%)	0.89	2.43	1.13	0.85

Table 3 : Effect of nano fertilizers on number of branches per plant.

Treatment	60 DAT	90 DAT
T_0	5.18	6.08
T_1	6.67	7.54
T_2	7.24	8.18
T_3	7.02	7.93
T_4	6.44	7.36
T_5	6.21	7.12
T_6	6.29	7.18
T_7	6.38	7.24
T_8	6.51	7.28
T_9	6.02	6.95
T_{10}	6.15	7.08
CD (5%)	0.28	0.56

The efficacy of integrated management in nitrogen has been proved through the superior plant height in T_2 (75% N traditionally + 25% N nano foliar urea). Nano urea particles (20-50 nm) are able to enter stomatal pores and mesophyl cells with great efficiency, which guarantees direct delivery of nutrients to photosynthetic tissues. Increased availability of nitrogen facilitates cell division, elongation, and chlorophyll production hence leading to high vegetative growth Similar findings were reported by

Ahmed *et al.* (2021), Parani and Nanthini (2021) in chilli.

Number of Branches per plant

Branch number grew 60 to 90 DAT in all treatments, and this clearly showed vegetative growth was taking place.

Branch number 60 DAT changed between 5.18 (T_0) and 7.24 (T2). T_2 gave maximum branches (7.24), T_3 (7.02), T_1 (6.67), T_8 (6.51) and T_4 (6.44). Minimum branches were noted in Control T_0 (5.18).

Maximum branches (8.18) were observed at 90 DAT: statistically greater than T_2. This was followed by T_3 (7.93), T_1 (7.54), T_4 (7.36), and T_8 (7.28). The lowest number of branches (6.08) was in T_0.

Branching in nano fertilizer treatment is increased due to availability of nitrogen and zinc, leading to the production of auxin and cytokinin involved in the control of apical dominance and lateral bud break. Zinc is also important in tryptophan biosynthesis, the precursor of indole-3-acetic acid (IAA), branch initiation, and development.

Leaf parameters

Longitudinal length of the leaf: The values were 7.74 cm (T_0) and 9.81 cm (T_2). The highest length was observed in treatment T_2 (9.81 cm), T_3 (9.63 cm), T_1 (9.32 cm) and T_4 (9.14 cm). The control was found to have a minimum length (7.74 cm).

Transverse leaf length: It ranges between 2.86 cm (T_0) and 3.98 cm (T_2). T_2 had a maximum transverse length (3.98 cm), T_3 had (3.87 cm), T_1 (3.64 cm) and T_4 (3.54 cm).

Leaf area: The area of leaves varied between 122.14 cm^2 (T_0) and 198.59 cm^2 (T_2). Treatment T_2 yielded the highest leaf area (198.59 cm^2), which was vastly better than any kind of treatment. This was then accompanied by T_3 (189.46 cm^2), T_1 (172.35 cm^2), T_4 (164.28 cm^2) and T_8 (161. 47 cm^2) Similar findings were reported by Thennakoon *et al.* (2020), Parani and Nanthini (2021), Rather *et al*. (2022) in chilli.

Nano urea is a ready source of nitrogen to biosynthesize chlorophyll and nano zinc is used to activate carbonic anhydrase enzyme to fix carbon dioxide. Increased leaf area enhances light uptake and carbon buildup, which eventually leads to greater biomass build up and yield.

Parameters of Flowering and Harvesting

Days flowering: Days flowering varied between 38.16 (T_2) and 45.83 (T_0). T_2 was observed to have the first flowering (38.16 DAT) statistically better than all treatments, then T_3 (38.83 DAT), T_1 (39.83 DAT), T_4 (40.66 DAT) and T_8 (40.83 DAT). The latest flowering (45.83 DAT) was also in control T_0.

Days to 50% Flowering Days to 50% flowering range 42.16 (T_2) to 50.33 (T_0). T_2 flowered first (50 percent 42.16 DAT), followed by T_3 (42.83 DAT), T_1 (43.83 DAT), T_4 (44.83 DAT) and T_8 (45.00 DAT). The longest duration (50.33 DAT) was noted in T_0.

Days to First Harvest: Days to first harvest were found to be between 72.14 (T_2) and 79.87 (T_0). T_2 treatment registered the latest harvest (72.14 DAT), which was far better than any other treatment. This was then followed by T_3 (72.83 DAT), T_1 (73.83 DAT), T_4 (74.84 DAT) and T_8 (75.16 DAT). In control, latest harvest (79.87 DAT) took place. Similar conclusions were inferred by Malik *et al.* (2020), Mishra *et al*. (2020),

Table 4 : Effect of nano fertilizers on leaf parameters.

Treatment	Longitudinal (cm)	Transverse (cm)	Leaf area (cm^2)
T_0	7.74	2.86	122.14
T_1	9.32	3.64	172.35
T_2	9.81	3.98	198.59
T_3	9.63	3.87	189.46
T_4	9.14	3.54	164.28
T_5	8.87	3.42	154.12
T_6	8.95	3.48	158.27
T_7	9.06	3.51	161.43
T_8	9.08	3.52	161.47
T_9	8.73	3.35	148.62
T_{10}	8.81	3.39	151.86
CD (5%)	0.23	0.83	5.39

Table 5 : Effect of nano fertilizers on flowering and harvesting parameters (DAT).

Treatment	First flowering	50% flowering	First Harvest
T_0	45.83	50.33	79.87
T_1	39.83	43.83	73.83
T_2	38.16	42.16	72.14
T_3	38.83	42.83	72.83
T_4	40.66	44.83	74.84
T_5	41.50	45.83	75.83
T_6	41.16	45.50	75.50
T_7	40.83	45.16	75.16
T_8	40.83	45.00	75.16
T_9	42.16	46.50	76.50
T_{10}	41.66	46.00	76.00
CD (5%)	0.16	0.16	0.27

Rather *et al*. (2022) in chilli.

The use of optimal nitrogen management is seen in early flowering and harvesting in T_2. Sufficient supply of nitrogen at vegetative-reproductive transition encourages the differentiation and growth of flower primordia. Nano urea guarantees continuous supply on nitrogen without overgrowth of plants that can delay flowering. The co-application of zinc improves the development of reproduction by functioning in the metabolism of auxins and the viability of pollen. Earlier maturity will have an economic benefit where it will be able to take premium prices in the early markets.

Yield parameters

Number of Fruits per Plant: The count of the number of fruits per plant was significantly different between 109.17 (T_0) and 260.10 (T_2). T_2 gave optimum fruits (260.10) which are statistically significant compared to any other treatment and an increase of 138 percent compared to control. These were trailed by T_3 (253.37 fruits), T_1 (232.10 fruits), T_4 (224.17 fruits) and T_8 (221.83 fruits). These results are in close conformity with the findings of Yogaraju *et al*. (2019), Malik *et al.* (2020), Mishra *et al.* (2020), Thennakoon *et al.* (2020), Ahmed *et al*. (2021), Parani and Nanthini (2021), Rather *et al.* (2022) in chilli.

The number of fruit increases caused by improved vegetative growth, more sites to fruit, better retention of flowers and fruit set by sufficient nutrient supply especially nitrogen and zinc that are essential in reproductive development, less flower and fruit drop because of improved nutrition in plants, and longer fruiting period. Zinc is very crucial in the formation of pollen, fertilization and early fruit development.

Fruit Quality parameters

Weight of fruit : The mean weight of the fruit was between 2.21 g (T_0) and 2.72 g (T_2). T_2 and T_3 had the highest fruits (2.72 g and 2.67 g respectively) then T_1 (2.54 g), T_4 (2.49 g), and T_7 (2.48 g), which were 23% higher than control.

Fruit length : Fruit length was 6.84 cm (T_0) and 7.52 cm (T_2). In T_2 (maximum length was 7.52 cm), T_3 (7.43 cm), T_1 (7.28 cm), and T_7 (7.19 cm), maximum length was obtained.

Girth of fruit : Fruit girth was ranging between 2.15 cm (T_0) and 2.76 cm (T_2). T_2 had the highest girth (2.76 cm), then T_3 (2.74 cm), T_1 (2.58 cm) and T_4 (2.53 cm), and T_7 (2.52 cm).

Diameter of fruits : The fruit diameter was between 0.65 cm (T_0) and 0.98 cm (T_2). The highest diameter was in T_2 (0.98 cm), T_3 (0.96 cm), T_1 (0.89 cm), T_4 (0.87 cm) and T_7 (0.86 cm).

Table 6 : Effect of nano fertilizers on fruit characteristics.

Treatment	Fruits /Plant	Fruit weight (g)	Fruit length (cm)	Fruit girth (cm)
T_0	109.17	2.21	6.84	2.15
T_1	232.10	2.54	7.28	2.58
T_2	260.10	2.72	7.52	2.76
T_3	253.37	2.67	7.43	2.74
T_4	224.17	2.49	7.21	2.53
T_5	212.43	2.43	7.12	2.48
T_6	215.77	2.46	7.16	2.51
T_7	219.83	2.48	7.19	2.52
T_8	221.83	2.47	7.18	2.51
T_9	207.17	2.39	7.05	2.43
T_{10}	210.50	2.41	7.09	2.46
CD (5%)	0.08	0.05	0.05	0.02

The parameters of fruit size in T_2 are improved in relation to the rising parameters of carbohydrate supply of the fruit by the increased photosynthetic capacity, the sufficient availability of nutrients to the fruit during its growth, especially potassium to fill the fruit, the increased cell division and growth of developing fruit, and the improved source-sink relationships. Nitrogen is sufficient to support vegetative structures and the application of nano urea in the foliage guarantees the availability of nutrients in the critical stages of fruit development without resulting in excessive vegetative growth.

Yield per hectare and per plant

Yield per plant : The fruit yield per plant(g) was between 64.90g (T_O) and 173.03g (T_2). T_2 was the most productive treatment (173.03 g/plant), which was statistically favorable to all the treatments, which is an increase of 167 percent relative to control. This was succeeded by T_3 (169.63 g/plant), T_1 (149.65 g/plant) T_4 and T_8 (140.23 g/plant).

Yield per hectare : The fruit yield per hectare was different (8.80 q/ha) (T_0) through 23.37 q/ha (T_2). T_2 had the highest yield (23.37 q/ha), then T_3 (22.90 q/ha), T_1 (20.22 q/ha), T_4 (19.24 q/ha) and T_8 (18.94 q/ha). In control, there was a minimum yield of 8.80 q/ha. These results are in close conformity with the findings of Yogaraju *et al.* (2019), Malik *et al.* (2020), Mishra *et al.* (2020), Thennakoon *et al*. (2020), Ahmed *et al.* (2021), Parani and Nanthini (2021), Rather *et al*. (2022) in chilli.

The high yield in T_2 exhibits the synergistic effect of high number of fruits (260.10 fruits/plant), high fruit weight

Table 7 : Effect of nano fertilizers on fruit yield.

Treatment	Yield per plant (g)	Yield per hectare (q/ha)
T_0	64.90	8.80
T_1	149.65	20.22
T_2	173.03	23.37
T_3	169.63	22.90
T_4	142.48	19.24
T_5	131.17	17.73
T_6	134.85	18.22
T_7	138.67	18.74
T_8	140.23	18.94
T_9	125.89	17.01
T_{10}	129.03	17.43
CD (5%)	0.06	0.00

Table 8 : Effect of nano fertilizers on fruit quality parameters.

Treatment	TSS (°Brix)	Ascorbic acid (mg/100g)	Fruit color
T_0	2.91	121.10	Dark Green
T_1	4.28	138.84	Dark Green
T_2	4.62	146.73	Dark Green
T_3	4.56	145.41	Dark Green
T_4	4.14	135.72	Dark Green
T_5	3.98	131.45	Dark Green
T_6	4.02	132.68	Dark Green
T_7	4.08	133.94	Dark Green
T_8	4.09	134.15	Dark Green
T_9	3.87	128.73	Dark Green
T_{10}	3.93	130.21	Dark Green
CD (5%)	0.00	0.08	-

(2.72 g), prolonged crop season and better health of the plant during crop cycle. The yield improvement of 165 percent over control is of immense practical value to the farmers. The partial replacement of traditional nitrogen (75%), with nano urea foliar spray (25%), does not reduce nitrogen applied to the soil but supplements the same through the foliar application, resulting in the sustained supply without losses to ground water.

Quality parameters

Total Soluble Solids (TSS) : The content of TSS was 2.91^{O}Brix (T_0) to 4.62d ^{O}Brix (T_2). The treatment T_2 had the highest TSS (4.61^{O}Brix), which is statistically better than all the treatments, followed by T_3 (4.56^{O}Brix), T_1 (4.28^{O}Brix), T_4 (4.14^{O}Brix) and T_8 (4.09^{O}Brix). In control Minimum TSS (2.91^{O}Brix) was reached.

Ascorbic Acid content : Ascorbic acid content was 121.10mg/100g (T_0)-146.73mg/100g (T_2). The highest yield of ascorbic acid was obtained in treatment T_2 (146.73 mg/100g), T_3 (145.41 mg/100g), T_1 (138.84 mg/100g), T_4 (135.72 mg/100g) and T_8 (134.15 mg/100g), which was 21% higher than the control.

The increased TSS and ascorbic acid in T_2 result in increased photosynthetic efficiency to enhance carbohydrate synthesis and translocation, sufficient nitrogen supply to aid protein and amino acid synthesis, zinc participation in the enzyme systems to regulate sugar metabolism and vitamin C biosynthesis and balanced nutrition to lead to an increase in the accumulation of secondary metabolites. The activation of various enzymes in the process of ascorbic acid biosynthesis by zinc is especially on L-galactono-1, 4 -lactone dehydrogenase. Increased TSS will improve the palatability of fruits and their market worth. Higher vitamin C concentration enhances the quality of food and antioxidants.

Conclusion

Partial replacement of traditional nitrogen by nano urea foliar application, which involves the usage of nano urea as an integrated approach to nitrogen management, has a great impact on the productivity, the quality, and the profitability of chilli. The best option of the treatments investigated T_2 (75% N traditional + 25% N nano urea + 100% PK + 100% $ZnSO_4$) is the one that offers the optimal balance between sustained nutrition by soils and foliar nutritional supplementation during critical growth periods, and it increases yield by 165% compared to control at the expense of 25% reduction of nitrogen application. In comparison to the use of nitrogen-containing soil, nano urea is more effective as foliar supplement in addition to requirements instead of full replacement. Nano urea treatments of higher concentrations (50 percent and 75 percent) experienced a gradual decrease in yield when compared to 25 percent replacement, and this demonstrates the relevance of sufficient nitrogen reserve in the soil. Full nano fertilizer replacement (T_8, T_{10}) was not favorable to integrated strategies and this has recommended that although nano fertilizer has some benefits, they should be used in addition to the traditional fertilization systems in contemporary technocratic and economic settings. The experimental soil environment was sufficient to use Zinc fertilization using conventional ZnSO4. There was no extra advantage to partial replacement with nano-zinc (T_5, T_6, T_7) over the full usage of conventional zinc, which implies that soil-applied zinc is an effective way of meeting crop needs. Integrated nano fertilizer approach is very beneficial economically. Yield improvement is also accompanied by quality improvement in nano fertilizer treatments as ascorbic acid content increased (21 percent) and TSS increased (59 percent) over control, providing nutritional value, and market premium potential. Early maturity benefit (T_2 7.73) days earlier harvest compared to the control) offers a standard of economic benefit, there being economic benefit of early entry into the market, premium price and prolonged period of harvest.

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