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SB Singh
Acharya Narendra Deva University of
Agriculture & Technology, Kumarganj,
Ayodhya, Uttar Pradesh, India

Crony Singh
Acharya Narendra Deva University of
Agriculture & Technology, Kumarganj,
Ayodhya, Uttar Pradesh, India

Mahendra Singh
Acharya Narendra Deva University of
Agriculture & Technology, Kumarganj,
Ayodhya, Uttar Pradesh, India

Shipra Yadav
Acharya Narendra Deva University of
Agriculture & Technology, Kumarganj,
Ayodhya, Uttar Pradesh, India

Anand Singh
Acharya Narendra Deva University of
Agriculture & Technology, Kumarganj,
Ayodhya, Uttar Pradesh, India

Asheesh Yadav
Acharya Narendra Deva University of
Agriculture & Technology, Kumarganj,
Ayodhya, Uttar Pradesh, India

Dheeraj Kumar
Acharya Narendra Deva University of
Agriculture & Technology, Kumarganj,
Ayodhya, Uttar Pradesh, India

Anant Sharma
Acharya Narendra Deva University of
Agriculture & Technology, Kumarganj,
Ayodhya, Uttar Pradesh, India

Mahima Devi
Acharya Narendra Deva University of
Agriculture & Technology, Kumarganj,
Ayodhya, Uttar Pradesh, India

Ajay kumawat
Acharya Narendra Deva University of
Agriculture & Technology, Kumarganj,
Ayodhya, Uttar Pradesh, India

Shivanshu
Acharya Narendra Deva University of
Agriculture & Technology, Kumarganj,
Ayodhya, Uttar Pradesh, India

Subash Singh
Acharya Narendra Deva University of
Agriculture & Technology, Kumarganj,
Ayodhya, Uttar Pradesh, India

Corresponding Author:
Crony Singh
Acharya Narendra Deva University of
Agriculture & Technology, Kumarganj,
Ayodhya, Uttar Pradesh, India

Impact of nano-fertilizers on growth, nutrient use efficiency and productivity of Rice (*Oryza sativa* L.)

SB Singh, Crony Singh, Mahendra Singh, Shipra Yadav, Anand Singh, Asheesh Yadav, Dheeraj Kumar, Anant Sharma, Mahima Devi, Ajay kumawat, Shivanshu and Subash Singh

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Abstract

A field experiment was conducted during the *kharif* season of 2025 at Agronomy Research Farm, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (U.P.), to evaluate the effect of nano fertilizers on growth, nutrient use efficiency and productivity of rice (*Oryza sativa* L.). The experiment was laid out in a Randomized Block Design with ten treatments and three replications comprising different combinations of recommended NPK Zn, reduced fertilizer doses and nano fertilizers (Nano Urea Plus and Nano DAP) applied through root treatment and foliar sprays. The results revealed that application of 100% NPK Zn (T_2) recorded significantly the highest plant height (138.00 cm), number of tillers (468.6 m^{-2}), dry matter accumulation (1480 $g\ m^{-2}$) and leaf area index (5.9) at 90 DAT, and was statistically *at par* with T_5 (50% N + 2 foliar sprays of Nano Urea Plus @ 4 ml L^{-1}) for most growth parameters. T_2 also recorded the maximum filled grains panicle $^{-1}$ (141), number of panicles m^{-2} (348.67), panicle length (26.83 cm), grain yield (56.17 q ha^{-1}), straw yield (76.20 q ha^{-1}) and biological yield (132.37 q ha^{-1}). Economically, T_2 recorded the highest gross returns (₹1,48,306 ha^{-1}), net returns (₹95,185 ha^{-1}) and B:C ratio (1.79). The superior performance of T_2 was attributed to the balanced and adequate supply of all essential nutrients – nitrogen promoting vigorous vegetative growth and chlorophyll synthesis, phosphorus enhancing root development and energy transfer, potassium regulating enzyme activation and assimilate translocation, and zinc improving auxin synthesis and metabolic activity – collectively sustaining optimum crop growth across all critical stages. Since 100% NPK Zn did not require additional nano-fertilizer inputs, its higher productivity directly translated into the best economic returns without increased input costs. The study concludes that application of 100% recommended NPK with zinc is the most productive and economically profitable nutrient management strategy for transplanted rice under the agro-climatic conditions of eastern Uttar Pradesh.

Keywords: Rice, NPK, nano urea plus, nano DAP, nano zinc, nutrient use efficiency, grain yield, economics.

Introduction

Rice (*Oryza sativa* L.) is a major staple crop of over half of the world's population and an essential element of food and nutritional security, especially in Asia, including India. It covers approximately 43.86 million hectares in India and plays a vital role in agricultural GDP and rural livelihoods (Ministry of Agriculture and Farmers Welfare, 2023) ^[10]. The production of rice in the world is approximately 800 million tonnes (paddy) and the productivity of rice in the world is approximately 4.7 tonnes/ha. The green revolution of 1970's triggered high growth in agriculture which paved the way for food security in India that relied on high yielding varieties which were responsive to inorganic fertilizers and thereby ensuring food security to the 1.39 billion population up to early 21st century. Rice productivity in India is mainly dependent on judicious input use of fertilizers and accounts for about 35 to 40% of the crop productivity. Indiscriminate and imbalanced use of inorganic fertilizers adversely affects the soil health and thereby reduces the soil productivity.

Rice contains 75-80% carbohydrate, 6-8% protein, 2-3% fat, fatty acids. Vitamins minerals and dietary fibre which contribute significantly to human nutrition (Bhattacharya, 2011) ^[1]. Rice proteins mainly consist of glutelin, albumin, globulin, and prolamin fractions (Bhattacharya, 2011) ^[1].

The fat present in rice mainly consists of unsaturated fatty acids which are beneficial for human health. Brown rice contains higher fat content than polished rice because polishing removes the bran layer where most lipids are present (Fageria, 2007) ^[4]. Rice is also an important source of micronutrients such as iron (Fe), zinc (Zn), manganese (Mn), magnesium (Mg), and phosphorus (P), which play vital roles in human metabolism and health (Fageria, 2007) ^[4]. Deficiency of micronutrients in rice grains can lead to nutritional disorders in populations depending heavily on rice-based diets (Bhattacharya, 2011) ^[1]. In India, the Indian Farmers Fertiliser Cooperative Limited (IFFCO) has pioneered the development and commercialization of nano-fertilizers, including Nano Urea Plus, Nano DAP and Nano Zinc. IFFCO Nano Urea Plus is a nanotechnology-based liquid fertilizer containing 4 per cent nitrogen dispersed in nano-sized particles (20-50 nm). According to IFFCO, the nano-sized particles possess nearly 10,000 times greater surface area than conventional urea granules, resulting in higher nutrient availability and nutrient use efficiency exceeding 80 per cent. The product is designed to supplement or partially replace conventional urea application while maintaining crop productivity and reducing environmental losses. Rice is one of the most important cereal crops cultivated worldwide and serves as the staple food for more than half of the global population (FAO, 2025) ^[6]. Global rice cultivation occupies a significant share of the world’s cropped area, particularly in Asian countries where rice is the principal food crop (FAOSTAT, 2024) ^[7]. According to recent global agricultural statistics, the total world rice area during 2024-25 was about 168.79 million hectares with a production of nearly 800 million tonnes of paddy rice (USDA, 2024; FAO, 2025) ^[15, 6]. The average productivity of rice at the global level was approximately 4.72 tonnes ha⁻¹ during the same period (USDA, 2024) ^[15]. Asia contributes around 90% of the total world rice production due to favorable climatic conditions and large rice-growing areas (FAO,

2025) ^[6]. China and India are the leading rice-producing countries and together contribute more than half of the world’s total rice production (FAOSTAT, 2024) ^[7].

Materials and Methods
Location and Climate of the Experimental Site

The experiment was carried out at Agronomy Farm of Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya (U.P.) India. Geographically the experimental site falls under sub-tropical climatic zone of Indo-Gangetic plains and located at 26.53 latitude, 82.82 longitude with an elevation of 113 meters above mean sea level and subjected subjected to rigorous weather extremes. The average annual precipitation is roughly 1189 mm, over 80% of which occurs during the South-West monsoon. The initial soil properties revealed organic carbon content ranging from 0.31-0.34%, electrical conductivity from 0.20-0.23 dSm⁻¹ and soil pH from 8.13-8.18. Bulk density of soil ranged between 1.34 and 1.37 g cm⁻³.

Treatment and Experimental Details

A field experiment entitled “Impact of Nano-fertilizers on Growth, Nutrient Use efficiency and Productivity of Rice (*Oryza sativa* L.)” was conducted during the *kharif* season of 2025. The experiment was conducted using Rice variety NDR-2065. The crop was sown on 20 july 2025, maintaining a spacing of 20 cm × 15 cm and harvested on 10 november 2026. Each experimental plot measured 16.38 m² (4.2 m × 3.9 m). The recommended dose of fertilizer (RDF) for mustard was 120:60:40 kg N: P₂O₅: K₂O ha⁻¹. Nitrogen, phosphorus and potassium were supplied through urea, diammonium phosphate (DAP) and muriate of potash (MOP), respectively, as per treatment requirements. The experiment was laid out in a Randomized Block Design (RBD) with three replications.

Table 1: Treatment details

Treatment No.	Treatment Details
T ₁	Control (N0P0K100 Zn0)
T ₂	100%NPK Zn
T ₃	50% N, 100% PK Zn
T ₄	50% P, 100% NK Zn
T ₅	T ₃ +2 FS of NUP @ 4 ml liter ⁻¹ at AT/MT and PI
T ₆	T ₄ + nDAP RT @ 5 ml litre ⁻¹ +1 st FS nDAP @ 4 ml liter ⁻¹ at AT/MT
T ₇	50%NP, 100%K, no Zn
T ₈	T ₇ + nDAP RT @ 5 ml liter ⁻¹ + 1 st FS nDAP @ 4 ml liter ⁻¹ , Nano Zn @ 1ml liter ⁻¹ , NUP @ 4 ml liter ⁻¹ at AT/MT +2 nd FS NUP @ 4 ml liter ⁻¹ at PI
T ₉	T ₇ + nDAP RT @ 5 ml liter ⁻¹ + 1 st FS of Nano Zn @ 1ml liter ⁻¹ , NUP @ 4 ml liter ⁻¹ at AT/MT + 2 nd FS NUP @ 4 ml liter ⁻¹ at PI + 3 rd FS of NUP and nDAP @ 4 ml liter ⁻¹ at PM stage
T ₁₀	T ₇ + nDAP RT @ 5 ml liter ⁻¹ + 1 st FS of nDAP @ 4 ml liter ⁻¹ , Nano Zn @ 1ml liter ⁻¹ , NUP @ 4 ml liter ⁻¹ at AT/MT,2 nd FS of NUP @4ml litre ⁻¹ at PI+ 3 rd FS of NUP & nDAP @ 4 ml litre ⁻¹ at PM stage

Note:
*FS = Foliar spray
*RT = Root treatment
*DAT = Days after transplanting
*MT = Maximum tillering
*AT = Active tillering
*PI = Panicle initiation
*PM = Physiological maturity

Recommended agronomic practices were followed uniformly for all treatments throughout the crop growth period. Observations on growth parameters, yield attributes, Grain yield, straw yield, biological yield and economics were recorded following standard procedures.

Growth Parameters

For recording plant height, five hills were randomly selected and

tagged in each plot. The height of each plant was measured from the ground level to the tip of the tallest leaf or panicle using a meter scale and the average value was expressed in centimetres. The number of tillers hill⁻¹ was counted from five randomly selected hills at different growth stages and the mean value was recorded.

For determination of dry matter accumulation, five representative hills were randomly selected from each plot and uprooted

carefully. The plant samples were washed thoroughly to remove adhering soil particles and separated into above-ground portions. The samples were first air-dried and subsequently oven-dried at $65 \pm 5^\circ\text{C}$ until a constant weight was obtained. The dry weight was recorded and expressed as g m^{-2} .

Leaf area index (LAI) was calculated by measuring the leaf area of sampled plants and dividing it by the ground area occupied by the crop. Chlorophyll content was estimated using a chlorophyll meter (SPAD meter) from fully expanded upper leaves and expressed as SPAD values. Normalized Difference Vegetation Index (NDVI) observations were recorded using a handheld Green Seeker sensor at specified crop growth stages and the average values were reported.

Yield Parameters

The number of panicles m^{-2} was recorded by counting all productive panicles present within a one square meter area selected from each plot at harvest and the average value was expressed as panicles m^{-2} . Five representative panicles were randomly collected from each plot and used for recording panicle length, which was measured from the panicle base to the tip using a scale and expressed in centimetres.

The number of filled grains panicle $^{-1}$ was determined by counting the filled grains from five randomly selected panicles and the average value was recorded. Grain weight panicle $^{-1}$ was recorded by weighing grains obtained from each sampled panicle on an electronic balance and expressed in grams. Test weight was determined by counting and weighing 1000 fully developed grains from each treatment and expressed in grams.

Yield Estimation

The crop from the net plot area was harvested separately for each treatment at maturity. After threshing, cleaning and drying, grain yield from each plot was recorded and converted into q ha^{-1} . Straw yield was obtained by subtracting grain yield from the total biological yield and expressed in q ha^{-1} . Biological yield was calculated as the sum of grain yield and straw yield and expressed in q ha^{-1} .

Harvest index was calculated using the following formula

Harvest Index (%) = (Grain Yield / Biological Yield) $\times$ 100
and expressed as percentage.

Economic Analysis

Cost of cultivation was calculated by considering both input and operational expenses incurred in the cultivation. Gross income was computed by multiplying grain yield with the minimum support price and price of straw. The net income computed by subtracting the total cost of cultivation from their respective gross returns

The analysis of variance (ANOVA) was built using the R software. The experimental data were statistically analyzed using analysis of variance (ANOVA) appropriate for Randomized Block Design, and treatment means were compared using critical difference (CD) at 5% level of significance.

Results and Discussion

Growth Parameter

The application of nano fertilizers in combination with conventional fertilizers significantly influenced the growth parameters of transplanted rice (Table 1). Among the various nutrient management treatments, treatment T₂ [100% NPK + Zn] recorded superior growth performance over the other treatments. The maximum plant height (138.00 cm) was recorded under T₂

[100% NPK + Zn], which remained statistically at par with T₅ [50% N, 100% PK Zn + 2 foliar sprays of Nano Urea Plus @ 4 ml L $^{-1}$ at active tillering/maximum tillering and panicle initiation] but was significantly superior to the remaining treatments. Enhanced plant height under balanced fertilization may be attributed to improved nutrient availability, higher nutrient uptake efficiency and better physiological activities resulting in vigorous crop growth. Similar findings were reported by Yoshida (1981) [16], Fageria *et al.* (2003) [5] and Dobermann and Fairhurst (2000) [3].

The highest number of tillers (468.6 m $^{-2}$) was recorded under T₂ [100% NPK + Zn], which remained statistically at par with T₅ [50% N, 100% PK Zn + 2 foliar sprays of Nano Urea Plus @ 4 ml L $^{-1}$ at active tillering/maximum tillering and panicle initiation] and significantly superior to the remaining treatments. The increase in tillering may be due to enhanced nitrogen metabolism, improved photosynthetic efficiency and greater assimilate production under balanced nutrient supply. Similar observations were reported by Fageria *et al.* (2003) [5] and Marschner (2012) [9].

The maximum dry matter accumulation (1480 g m $^{-2}$) was recorded under T₂ [100% NPK + Zn], which remained statistically at par with T₅ [50% N, 100% PK Zn + 2 foliar sprays of Nano Urea Plus @ 4 ml L $^{-1}$ at active tillering/maximum tillering and panicle initiation] and significantly superior to the other treatments. Higher dry matter production may be attributed to enhanced photosynthetic activity, efficient nutrient utilization and greater accumulation of assimilates. Similar findings were reported by Yoshida (1981) [16] and Dobermann and Fairhurst (2000) [3].

The highest leaf area index (5.90) was recorded under T₂ [100% NPK + Zn], which remained statistically at par with T₅ [50% N, 100% PK Zn + 2 foliar sprays of Nano Urea Plus @ 4 ml L $^{-1}$ at active tillering/maximum tillering and panicle initiation] and significantly superior to the remaining treatments. Increased leaf area index may be attributed to improved nutrient uptake, greater leaf expansion and enhanced canopy development. Similar findings were reported by Fageria *et al.* (2003) [5] and Marschner (2012) [9].

The maximum NDVI value (0.930) after the second Nano Urea spray was recorded under T₂ [100% NPK + Zn], which remained statistically at par with T₅ [50% N, 100% PK Zn + 2 foliar sprays of Nano Urea Plus @ 4 ml L $^{-1}$ at active tillering/maximum tillering and panicle initiation] and significantly superior to the remaining treatments. Higher NDVI values under T₂ may be attributed to better crop vigour, enhanced chlorophyll concentration and improved canopy development resulting from balanced nutrient availability. Similar observations were reported by Tarafdar *et al.* (2014) [14], Pooniya *et al.* (2022) [11].

Similarly, the highest chlorophyll content after the second Nano Urea spray (23.76 $\mu\text{mol m}^{-1}$) was recorded under T₂ [100% NPK + Zn], which remained statistically at par with T₅ [50% N, 100% PK Zn + 2 foliar sprays of Nano Urea Plus @ 4 ml L $^{-1}$ at active tillering/maximum tillering and panicle initiation] but was significantly superior to all other treatments. Enhanced chlorophyll content under T₂ may be attributed to improved nitrogen availability, greater chlorophyll biosynthesis and increased photosynthetic efficiency. Similar findings were reported by Dimkpa and Bindraban (2018) [2], Tarafdar *et al.* (2014) [14], Pooniya *et al.* (2022) [11].

Yield and Yield Attributes

Yield attributes of transplanted rice were significantly influenced by different nutrient management treatments (Table 4.7). Among the various treatments, treatment T₂ [100% NPK + Zn] recorded

superior performance with respect to yield attributing characters. The maximum number of filled grains panicle⁻¹ (141), grain weight panicle⁻¹ (4.98 g), number of panicles m⁻² (348.67) and panicle length (26.83 cm) were recorded under treatment T₂ [100% NPK + Zn], which remained statistically at par with T₅ [50% N, 100% PK Zn + 2 foliar sprays of Nano Urea Plus @ 4 ml L⁻¹ at active tillering/maximum tillering and panicle initiation]. The improvement in yield attributes under balanced fertilization and nano-fertilizer application might be attributed to enhanced nutrient availability, improved nutrient uptake efficiency and increased photosynthetic activity, resulting in better assimilate partitioning towards reproductive organs. In contrast, the minimum number of filled grains panicle⁻¹ (121), grain weight panicle⁻¹ (3.47 g), number of panicles m⁻² (248.33) and panicle length (22.14 cm) were observed under the control treatment (T₁). Similar findings were reported by Prasad *et al.* (2014)^[12] and Pooniya *et al.* (2022)^[11]. The effect of nutrient management treatments on 1000-grain weight was found non-significant, indicating that this trait is largely governed by the genetic makeup of the crop.

Grain yield and total biological yield of rice were significantly influenced by different nutrient management treatments (Table 4.8). Treatment T₂ [100% NPK + Zn] recorded the highest grain yield (56.17 q ha⁻¹) and total biological yield (132.37 q ha⁻¹), which remained statistically at par with T₅ [50% N, 100% PK Zn + 2 foliar sprays of Nano Urea Plus @ 4 ml L⁻¹ at active tillering/maximum tillering and panicle initiation] but significantly superior to the remaining treatments. The enhanced grain yield under T₂ may be attributed to improved growth parameters, higher dry matter accumulation and superior yield attributes resulting from balanced nutrient availability and efficient nutrient utilization. The lowest grain yield (35.80 q ha⁻¹) and total biological yield (90.60 q ha⁻¹) were recorded under the control treatment (T₁). Application of nano fertilizers also significantly improved straw yield of rice. The maximum straw yield (76.20 q ha⁻¹) was recorded under treatment T₂ [100% NPK + Zn], which remained statistically at par with T₅ [50% N, 100% PK Zn + 2 foliar sprays of Nano Urea Plus @ 4 ml L⁻¹ at active tillering/maximum tillering and panicle initiation] but significantly superior to the other treatments. Improved vegetative growth and higher biomass production under balanced fertilization may have contributed to increased straw yield. The

lowest straw yield (54.80 q ha⁻¹) was observed under the control treatment (T₁). Similar findings were reported by Fageria *et al.* (2003)^[5], Prasad *et al.* (2014)^[12] and Roy *et al.* (2014)^[13]. Harvest index did not vary significantly among different nutrient management treatments, indicating that assimilate partitioning between grain and straw remained relatively unaffected by nutrient management practices. However, numerically higher harvest index (42.43%) was recorded under T₂ [100% NPK + Zn], whereas the lowest harvest index (39.51%) was observed under the control treatment (T₁).

Economics

The cost of cultivation varied among different nutrient management treatments due to variations in fertilizer and nano-fertilizer application (Table 3). The minimum cost of cultivation was recorded under the control treatment (T₁), whereas the maximum cost of cultivation was observed under treatments receiving additional nano-fertilizer applications. The increased cost under nano-fertilizer treatments was mainly attributed to the additional expenditure incurred on nano fertilizer application.

Gross returns, net returns and benefit-cost ratio were significantly influenced by different nutrient management treatments (Table 4.10). The highest gross returns, net returns and benefit-cost ratio were recorded under treatment T₂ [100% NPK + Zn], which remained economically superior to the remaining treatments. The higher gross and net returns under T₂ may be attributed to enhanced grain and biological yields resulting from balanced nutrient availability, improved nutrient uptake and better crop growth. Increased productivity under T₂ ultimately contributed to higher economic returns per unit area. Similar economic advantages under balanced nutrient management and nano-fertilizer application were also reported by Pooniya *et al.* (2022)^[11], Roy *et al.* (2014)^[13], Dobermann and Fairhurst (2000)^[3].

The benefit-cost ratio was also markedly influenced by different nutrient management practices. The highest B:C ratio was recorded under treatment T₂ [100% NPK + Zn], indicating greater economic viability of the treatment. The lowest B:C ratio was observed under the control treatment (T₁). The higher B:C ratio under T₂ may be attributed to increased crop productivity and better returns per unit investment. These findings are in close agreement with the results reported by Pooniya *et al.* (2022)^[11], Roy *et al.* (2014)^[13], Dobermann and Fairhurst (2000)^[3].

Table 1: Effect of nano fertilizers on growth parameters of transplanted rice

S. No.	Treatments	Plant height (cm)	No. of Tillers	Dry matter accumulation (g plant ⁻¹)	Leaf area index	NDVI value	Chlorophyll content
T ₁	Control (N0P0K100 Zn0)	110.4	351.5	980	4.6	0.630	11.340
T ₂	100%NPK Zn	138.0	468.6	1480	5.9	0.930	23.760
T ₃	50% N, 100% PK Zn	128.4	429.3	1390	5.5	0.840	20.790
T ₄	50% P, 100% NK Zn	123.2	402.6	1210	5.1	0.800	18.500
T ₅	T ₃ + 2 FS of NUP @ 4 ml liter ⁻¹ at AT/MT and PI	132.2	452.1	1450	5.7	0.870	23.090
T ₆	T ₄ + nDAP RT @ 5 ml litre ⁻¹ + 1 st FS nDAP @ 4 ml liter ⁻¹ at AT/MT	130.2	435.6	1410	5.6	0.850	21.730
T ₇	50%NP, 100%K, no Zn	116.0	379.5	1120	4.7	0.670	17.680
T ₈	T ₇ + nDAP RT @ 5 ml liter ⁻¹ + 1 st FS nDAP @ 4 ml liter ⁻¹ , Nano Zn @ 1ml liter ⁻¹ , NUP @ 4 ml liter ⁻¹ at AT/MT + 2 nd FS NUP @ 4 ml liter ⁻¹ at PI	119.4	396.5	1190	4.9	0.770	18.360
T ₉	T ₇ + nDAP RT @ 5 ml liter ⁻¹ + 1 st FS of Nano Zn @ 1ml liter ⁻¹ , NUP @ 4 ml liter ⁻¹ at AT/MT + 2 nd FS NUP @ 4 ml liter ⁻¹ at PI + 3 rd FS of NUP and nDAP @ 4 ml liter ⁻¹ at PM stage	122.8	405.9	1320	5.3	0.810	19.170
T ₁₀	T ₇ + nDAP RT @ 5 ml liter ⁻¹ + 1 st FS of nDAP @ 4 ml liter ⁻¹ , Nano Zn @ 1ml liter ⁻¹ , NUP @ 4 ml liter ⁻¹ at AT/MT, 2 nd FS of NUP @ 4ml litre ⁻¹ at PI + 3 rd FS of NUP & nDAP @ 4 ml litre ⁻¹ at PM stage	125.2	412.5	1360	5.4	0.820	20.120
SEm±		2.12	12.88	21.92	0.23	0.02	0.62
CD (P=0.05)		6.29	38.27	65.12	0.68	0.07	1.84

Table 2: Effect of nano fertilizers on yield attributes of transplanted rice

S. No.	Treatments	filled Grain panicle ⁻¹	Unfilled grain panicle ⁻¹	Grain Weight Panicle ⁻¹	1000 Grain Weight (g)	No. of Panicles m ⁻²	Panicle Length(cm)
T ₁	Control (N0P0K100 Zn0)	121	11	3.470	23.12	248.33	22.14
T ₂	100%NPK Zn	141	22	4.980	23.70	348.67	26.83
T ₃	50% N, 100% PK Zn	133	17	4.710	23.57	318.33	25.47
T ₄	50% P, 100% NK Zn	128	15	4.200	23.35	296.67	24.62
T ₅	T ₃ +2 FS of NUP @ 4 ml liter ⁻¹ at AT/MT and PI	139	21	4.850	23.65	330	25.96
T ₆	T ₄ + nDAP RT @ 5 ml litre ⁻¹ +1 st FS nDAP @ 4 ml liter ⁻¹ at AT/MT	135	19	4.670	23.60	314.67	25.18
T ₇	50%NP, 100%K, no Zn	125	13	3.840	23.26	268	23.26
T ₈	T ₇ + nDAP RT @ 5 ml liter ⁻¹ + 1 st FS nDAP @ 4 ml liter ⁻¹ , Nano Zn @ 1ml liter ⁻¹ , NUP @ 4 ml liter ⁻¹ at AT/MT +2 nd FS NUP @ 4 ml liter ⁻¹ at PI	128	14	3.990	23.23	280.33	23.74
T ₉	T ₇ + nDAP RT @ 5 ml liter ⁻¹ + 1 st FS of Nano Zn @ 1ml liter ⁻¹ , NUP @ 4 ml liter ⁻¹ at AT/MT + 2 nd FS NUP @ 4 ml liter ⁻¹ at PI + 3 rd FS of NUP and nDAP @ 4 ml liter ⁻¹ at PM stage	131	16	4.340	23.45	295	24.38
T ₁₀	T ₇ + nDAP RT @ 5 ml liter ⁻¹ + 1 st FS of nDAP @ 4 ml liter ⁻¹ , Nano Zn @ 1ml liter ⁻¹ , NUP @ 4 ml liter ⁻¹ at AT/MT+ 2 nd FS of NUP @4ml litre ⁻¹ at PI+ 3 rd FS of NUP & nDAP @ 4 ml litre ⁻¹ at PM stage	132	16	4.520	23.53	288.67	24.09
SEm±		3.95	0.6	0.17	0.96	4.46	0.32
CD (P=0.05)		11.73	1.79	NS	2.85	14.73	0.96

Table 3: Effect of nano fertilizers on yield parameters of transplanted rice

S. No.	Treatments	Grain yield (q/ha)	Straw Yield (q/ha)	Total Biological Yield (q/Ha)	Harvest Index (%)
T ₁	Control (N0P0K100 Zn0)	35.80	54.80	90.6	39.51
T ₂	100%NPK Zn	56.17	76.20	132.37	42.43
T ₃	50% N, 100% PK Zn	49.55	69.50	119.05	41.62
T ₄	50% P, 100% NK Zn	48.49	68.90	117.39	41.31
T ₅	T ₃ +2 FS of NUP @ 4 ml liter ⁻¹ at AT/MT and PI	50.7	71.60	122.30	41.94
T ₆	T ₄ + nDAP RT @ 5 ml litre ⁻¹ +1 st FS nDAP @ 4 ml liter ⁻¹ at AT/MT	50.12	70.20	120.32	41.18
T ₇	50%NP, 100%K, no Zn	44.53	64.80	109.33	40.18
T ₈	T ₇ + nDAP RT @ 5 ml liter ⁻¹ + 1 st FS nDAP @ 4 ml liter ⁻¹ , Nano Zn @ 1ml liter ⁻¹ , NUP @ 4 ml liter ⁻¹ at AT/MT +2 nd FS NUP @ 4 ml liter ⁻¹ at PI	47.94	66.80	114.74	40.73
T ₉	T ₇ + nDAP RT @ 5 ml liter ⁻¹ + 1 st FS of Nano Zn @ 1ml liter ⁻¹ , NUP @ 4 ml liter ⁻¹ at AT/MT + 2 nd FS NUP @ 4 ml liter ⁻¹ at PI + 3 rd FS of NUP and nDAP @ 4 ml liter ⁻¹ at PM stage	49.28	67.90	117.18	41.78
T ₁₀	T ₇ + nDAP RT @ 5 ml liter ⁻¹ + 1 st FS of nDAP @ 4 ml liter ⁻¹ , Nano Zn @ 1ml liter ⁻¹ , NUP @ 4 ml liter ⁻¹ at AT/MT, 2 nd FS of NUP @4ml litre ⁻¹ at PI+ 3 rd FS of NUP & nDAP @ 4 ml litre ⁻¹ at PM stage	49.48	68.40	117.88	42.05
S.Em±		1.92	1.95	4.02	1.46
CD (P=0.05)		5.70	5.79	11.93	NS

Table 4: Effect of nano fertilizers on economics of transplanted rice

S. No.	Treatment	Grain yield (q/ha)	Cost of cultivation (₹ ha ⁻¹)	Gross Returns (₹ ha ⁻¹)	Net Returns (₹ ha ⁻¹)	B:C Ratio
T ₁	Control (N0P0K100 Zn0)	35.80	43462	95770	52308	1.20
T ₂	100%NPK Zn	56.17	53121	148306	95185	1.79
T ₃	50% N, 100% PK Zn	49.55	52025	131284	79258	1.52
T ₄	50% P, 100% NK Zn	48.49	50648	128652	78004	1.54
T ₅	T ₃ +2 FS of NUP @ 4 ml liter ⁻¹ at AT/MT and PI	50.7	54578	134428	79850	1.46
T ₆	T ₄ + nDAP RT @ 5 ml litre ⁻¹ +1 st FS nDAP @ 4 ml liter ⁻¹ at AT/MT	50.12	57596	132774	75178	1.30
T ₇	T ₇ -50%NP, 100%K, no Zn	44.53	46557	118451	71894	1.54
T ₈	T ₇ + nDAP RT @ 5 ml liter ⁻¹ + 1 st FS nDAP @ 4 ml liter ⁻¹ , Nano Zn @ 1ml liter ⁻¹ , NUP @ 4 ml liter ⁻¹ at AT/MT +2 nd FS NUP @ 4 ml liter ⁻¹ at PI	47.94	56742	126929	70187	1.23
T ₉	T ₇ + nDAP RT @ 5 ml liter ⁻¹ + 1 st FS of Nano Zn @ 1ml liter ⁻¹ , NUP @ 4 ml liter ⁻¹ at AT/MT + 2 nd FS NUP @ 4 ml liter ⁻¹ at PI + 3 rd FS of NUP and nDAP @ 4 ml liter ⁻¹	49.28	57690	130324	72634	1.25
T ₁₀	T ₇ + nDAP RT @ 5 ml liter ⁻¹ + 1 st FS of nDAP @ 4 ml liter ⁻¹ , Nano Zn @ 1ml liter ⁻¹ , NUP @ 4 ml liter ⁻¹ at AT/MT	49.48	57690	130898	73208	1.26

Conclusion

The present investigation revealed that different nutrient management treatments significantly influenced the growth, yield attributes, productivity, nutrient uptake, nutrient use efficiency and economics of transplanted rice. Among the various

treatments, application of T₂ [100% NPK + Zn] recorded superior performance in terms of growth parameters, yield attributes, grain yield, straw yield, biological yield and economic returns. Treatment T₂ produced the highest plant height, tiller density, dry matter accumulation, leaf area index, NDVI and chlorophyll

content, which resulted in improved crop vigour and productivity. The treatment also recorded maximum values of yield attributes including number of filled grains panicle⁻¹, grain weight panicle⁻¹, number of panicles m⁻² and panicle length, leading to higher grain and biological yields. Furthermore, T₂ registered the highest nutrient use efficiency and economic returns, indicating its superiority under the prevailing agro-climatic conditions. The improved crop performance under T₂ may be attributed to balanced nutrient availability, higher nutrient uptake efficiency and enhanced physiological activities of the crop. Therefore, application of T₂ (100% NPK + Zn) can be recommended for achieving higher productivity, profitability and sustainable rice production under similar agro-climatic conditions.

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