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The Impact of Nano-fertilizers on Growth-attributing Characteristics in Transplanted Hybrid Rice (*Oryza sativa* L.)

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Authors' contributions

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

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ABSTRACT

The experiment was conducted during the *kharif* season of 2022 and 2023 at Students' Instructional Farm, Department of Agronomy, Chandra Shekhar Azad University of Agriculture & Technology, Kanpur- 208002 (U.P.) India. The experiment was laid out in Randomized Block Design with three replications. 13 treatments *viz,* T_1- Control, T_2-50 % RDN, T_3-50% RDN+ Nano Urea, T4-75% RDN, T_5-75% RDN + Nano Urea, T_6-100% RDN, T_7-100% RDN + Nano Urea, T_8-50% RDN + Nano Zinc, T_9-50% RDN + Nano Urea + Nano Zinc, T_{10}-75% RDN + Nano Zinc, T_{11}-75% RDN + Nano Urea + Nano Zinc, T_{12}-100% RDN + Nano Zinc and T_{13}-100% RDN + Nano Urea + Nano Zinc. Higher growth attributing characters such as higher plant height, tillers, dry matter accumulation and leaf area index at different crop stages along with maximum grain yield were recorded with application of 100% RDN + Nano Urea + Nano Zinc and over Control, 50 % RDN, 50% RDN+ Nano Urea, 75% RDN, 75% RDN + Nano Urea, 100% RDN, 50% RDN + Nano Zinc and 75% RDN + Nano Zinc in transplanted *Kharif* rice.

Keywords: Nano fertilizer; nano urea; nano zinc; growth; transplanted rice and RDN.

1. INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food for more than half of the world's population, primarily in Asia, where it plays a critical role in daily diets. Originating in Southeast Asia, rice cultivation dates back thousands of years and has become an essential component of global food security. Globally, around 165.68 million hectares area is under rice along with 514.57 million tones production and 4.64 MT ha^{-1} productivity during 2022-23 [1]. In India around 47.83 million hectares area is under rice along with 135.76 million tones production and 4.26 MT ha^{-1} productivity in 2022-23. It is evident that four states *viz*., West Bengal, Uttar Pradesh, Punjab and Andhra Pradesh contribute to almost half of the rice production in India. Rice provides 21% of energy and 15% of protein requirements of human population in the world [2]. It is a calorie-dense diet with 78% carbohydrate, 6-7% protein in white rice and 7.9% in brown rice, 2–2.5% fat, 0.8% cellulose, and 5-9% ash. In addition to grains, its straw and rice hulls are utilized as insulation, mulch, feed, and packaging materials.

The Nano Biotechnology Research Centre, in collaboration with Indian Farmers Fertilizers Cooperative Limited, produces environmentally friendly liquid formulations of Nano urea and Nano Zinc to prevent the uneven and excessive use of these nutrients. Nano-fertilizers represent a revolutionary advancement in agricultural practices, offering a promising solution for enhancing crop growth and productivity. Studies have shown that nano urea and nano zinc can positively affect soil health by maintaining soil nutrient balance and enhancing microbial activity [3]. In the context of transplanted hybrid rice (*Oryza sativa* L.), the application of nano-fertilizers has garnered considerable attention due to their potential to improve growth-attributing characteristics, such as plant height, tiller number, leaf area index (LAI), and chlorophyll content. These fertilizers, which consist of nanoparticles carrying essential nutrients, exhibit superior efficiency in nutrient delivery compared to conventional fertilizers. Due to their nano-scale size, they enable targeted nutrient release and enhanced absorption by plant roots, leading to optimized growth and resource utilization. The impact of nano-fertilizers on hybrid rice is profound. Improved nutrient uptake directly influences the plant's physiological and morphological traits, resulting in better root and shoot development, increased tiller production, and more robust photosynthetic activity. These improvements contribute not only to higher biomass accumulation but also to enhanced grain yield and quality. Additionally, nano-fertilizers reduce the need for excessive chemical inputs, thus minimizing environmental harm while promoting sustainable agricultural practices. Given the global need to increase rice production to meet growing food demands, the integration of nano-fertilizers into rice cultivation presents a valuable tool for achieving higher efficiency in crop production systems. By enhancing soil aggregation, water-holding capacity, and soil organic carbon levels, nano fertilisers also contribute significantly to soil health [4]. Nutrient absorption is increased when nano fertilisers are enclosed in nanoparticles [5]. The long-term benefits, such as improved soil health and reduced environmental pollution, make nano-fertilizers a key component in future strategies for sustainable rice farming. Application ZnO nanoparticles helped in enhancing grain yield and improved Zn concentration in rice grain as reported by [6]. Continuous research and field trials are crucial to fully understand and harness their potential in maximizing growth-attributing traits in hybrid rice.

2. MATERIALS AND METHODS

The experiment was conducted at Students' Instructional Farm, Department of Agronomy, Chandra Shekhar Azad University of Agriculture & Technology, Kanpur- 208002 (U.P.) during *kharif* season of 2022 and 2023. Which is situated in the alluvial tract of Indo-Gangatic plain in central part of Uttar Pradesh between 25^{0}26' to 26^{0}58' North latitude,79^{0}31' to 31^{0}34' East longitude and on the altitude of 125.9 meters. The irrigation facilities are adequately available on this farm. The mean weekly maximum and minimum temperature during the crop growth period ranged from 27.00 °C to 43.90°C and 9.90°C to 29.50 °C, during 2022 and 26.42 °C to 42.20°C and 11.40°C to 29.80 °C during 2023, respectively. The crop availed maximum relative humidity 94%, 93% against minimum 42% and 37% during 2022 and 2023, respectively. Total rainfall of 836.20 mm and 747.80 mm was received during crop period 2022 and 2023, respectively. During the crop growing period, the mean weekly highest and lowest total rainfall recorded ranging from 0.0 mm to 159 mm and 0.0 mm to 128 mm and evaporation ranged from 2.60 to 8.80 mm day^{-1} and 2.01 to 7.09 mm day^{-1} during 2022 and 2023, respectively. The weekly mean wind velocity during the experimental season fluctuated between 1.60 to 10.20 km h^{-1} and 1.20 to 9.60 km h^{-1}during 2022 and 2023 respectively. Bright sun shine also recorded in range from 0.90 to 8.90 day hr^{-1} and from 0.20 to 9.10-day hr^{-1} during 2022 and 2023 respectively. Meteorological observation recorded during vegetative, reproductive and maturity stages of Rice crop.

The experiment was laid out in Randomized Block Deign with three replications and 13 Nano-Fertilizers *viz.* T_1- Control, T_2-50 % RDN, T_3-50% RDN+ Nano Urea, T4-75% RDN, T_5-75% RDN + Nano Urea, T_6-100% RDN, T_7-100% RDN + Nano Urea, T_8-50% RDN + Nano Zinc, T_9-50% RDN + Nano Urea + Nano Zinc, T_{10}-75% RDN + Nano Zinc, T_{11}-75% RDN + Nano Urea + Nano Zinc, T_{12}-100% RDN + Nano Zinc and T_{13}-100% RDN + Nano Urea + Nano Zinc. Recommended dose of fertilizer was 150:60:60; N : P_2O_5 : K_2O, respectively. The Urea, DAP and MOP was used as a source of N, P and K. full P and K were applied as basal; Urea was applied into equal-split at basal, active-tillering and panicle initiation stage. 4 ml L^{-1} of water is the recommended dose of nano nitrogen and 4 ml L^{-1} of water nano Zinc applied in rice field. Certified seeds of rice-variety "*Basanti*" (*Hybrid Rice)* was spread in the rice nursery of 50 m^2 area. Ploughing was done in nursery area twice with the help of tractor drawn disc harrow. For levelling cultivator and planker were used and raised beds of size of 10 m x 1.25 m were made. For facilitating drainage, 50 cm channel was left between two beds. Then, sprouted seeds were sown by broadcasting on raised bed. The 25–days old seedling was used for transplanting. Hill to hill spacing was maintained at 10 cm and row to row spacing of 20 cm was used. To reduce yellow stem borer damage, Cartap hydrochloride 20 kg ha^{-1} was administered at 30 DAT and 65 DAT. Plant height was measured with a meter scale from the base of the plant at ground level up to tallest leaf tip/panicle. No. of tillers per m^2 area was manually calculated from tagged plants at 30, 60, 90 and at harvest time and average values were documented. For recording fresh weight of plant samples were taken at 30, 60, 90 & harvest stage five sample each plot were selected and removed from ground level. Weight of sample from each plot was done on pan balance and figures obtained were divided by five to record fresh weight per plant. These samples were dried in shade for 5–7 days and it was dried in oven (~60±5^{o}C) for 24 hours.

3. RESULTS AND DISCUSSION

3.1 Effect of Treatments on Growth Attributing Characters in Hybrid Rice

Plant height (cm): Pooled data showed significant effect in plant height due to application of various nano fertilizers at 30, 60, 90 DAT and at harvest stages (Table 1). Among nano fertilizers combinations, T_{13}-100% RDN + Nano Urea + Nano Zinc at 30 DAT was recorded significantly taller plant height (52.22cm) as compared to T_1- Control, T_2-50 % RDN, T_3-50% RDN+ Nano Urea and T_8-50% RDN + Nano Zinc and minimum plant height (41.95) recorded under control treatment. However, at 60, 90 DAT and at harvest significantly maximum plant height (77.10, 106.14 and 109.45cm, respectively) were observed with T_{13}-100% RDN + Nano Urea + Nano Zinc over T_1- Control, T_2-50 % RDN, T_3-50% RDN+ Nano Urea, T_4-75% RDN, T_6-100% RDN and T_8-50% RDN + Nano Zinc which was found at par with T_5-75% RDN + Nano Urea, T_7-

100% RDN + Nano Urea, T_9-50% RDN + Nano Urea + Nano Zinc, T_{10}-75% RDN + Nano Zinc, T_{11}-75% RDN + Nano Urea + Nano Zinc and T_{12}-100% RDN + Nano Zinc. Lowest plant height 61.04, 81.10 and 85.34cm at 60, 90 DAT and at harvest were recorded under control treatment. Increasing plant height in transplanted hybrid rice through nano-fertilizers can be achieved by enhancing nutrient uptake efficiency, particularly nitrogen, phosphorus, and potassium. Nano-fertilizers deliver these essential nutrients directly to the plant's root system in a more controlled and precise manner, promoting better root and shoot growth. This targeted nutrient release boosts cell division and elongation, leading to taller, more vigorous plants and improved overall crop performance these improvement also reported by Srivastava et al. [7], Burhan and AL-Hassan [8] and Salama and Badry [9].

Number of tillers (m^{-2}): Result showed significant effect in number of tillers due to various nano fertilizers at 30, 60, 90 DAT and at harvest during both years and on pooled basis also (Table 2). Significantly maximum number of tillers (304) at 30 DAT was recorded with T_{13}-100% RDN + Nano Urea + Nano Zinc over T_1-Control, T_2-50 % RDN, T_3-50% RDN+ Nano Urea, T_4-75% RDN, T_6-100% RDN and T_{10}-75% RDN + Nano Zinc and it's found at par with T_5-75% RDN + Nano Urea, T_7-100% RDN + Nano Urea, T_8-50% RDN + Nano Zinc, T_9-50% RDN + Nano Urea + Nano Zinc, T_{11}-75% RDN + Nano Urea + Nano Zinc and T_{12}-100% RDN + Nano Zinc treatments. However, minimum number of tillers (268) at 30 DAT was recorded under control. Among fertilizers treatments, At 60 DAT and at harvest significantly higher number of tillers 489 and 442, respectively, were recorded with T_{13}-100% RDN + Nano Urea + Nano Zinc treatment which was at par with T_7-100% RDN + Nano Urea, T_9-50% RDN + Nano Urea + Nano Zinc, T_{11}-75% RDN + Nano Urea + Nano Zinc and T_{12}-100% RDN + Nano Zinc and the minimum number of tillers 359 and 307, respectively, observed under control plot in transplanted hybrid rice. While at 90 DAT, T_{13}-100% RDN + Nano Urea + Nano Zinc was produced significantly maximum number of tiller (478) compare other treatments expect T_7-100% RDN + Nano Urea, and T_{11}-75% RDN + Nano Urea + Nano Zinc. The lowest number of tillers (340) was recorded with control treatment. It might be due to nano-fertilizers can be effectively used due to their enhanced nutrient delivery capabilities. Nano-nutrients like nano-nitrogen and nano-zinc improve root development and nutrient uptake efficiency, promoting early and vigorous tillering. These fertilizers ensure a controlled and sustained release of nutrients, stimulating growth hormones and improving overall plant vigor, which leads to a higher number of productive tillers. Similar finding also supported by Pal et al. [10], Ravi et al. [11] and Midde et al. [12].

Dry weight (g m^{-2}): Among nano fertilizers treatments, T_{13}-100% RDN + Nano Urea + Nano Zinc was produced significantly maximum dry weight (158.39, 384.40, 705.50 and 820.44 g m^{-2} at 30, 60, 90 DAT and at harvest, respectively) followed by T_{11}-75% RDN + Nano Urea + Nano Zinc, T_7-100% RDN + Nano Urea, T_{12}-100% RDN + Nano Zinc and T_9-50% RDN + Nano Urea + Nano Zinc which was found at par with each others. The lowest dry weight (120.64, 247.72, 507.98 and 539.92 g m^{-2} at 30, 60, 90 DAT and at harvest, respectively) were recorded under control treatment in transplanted hybrid rice (Table 3). Increasing dry matter accumulation in transplanted hybrid rice (*Oryza sativa* L.) can be achieved through the application of nano-fertilizers, which enhance nutrient uptake efficiency and improve key physiological processes [13]. By delivering nutrients in a controlled and targeted manner, nano-fertilizers boost photosynthetic activity, promote stronger root and shoot development, and optimize biomass production, resulting in greater overall dry matter accumulation**;** which was earlier reported by Attri et al. [14], Yomso and Menon [15] and Bhavani et al. [16].

Leaf area index: The pooled analysis of Leaf Area across different treatments at 30, 60, and 90 days after transplanting (DAT) reveals significant variations among treatments (Table 4). At 30 DAT, the T_1- Control had the lowest LAI (0.88), while T_{13}- 100% RDN + Nano Urea + Nano Zinc recorded a significantly higher LAI (1.17), at par with T_{11}- 75% RDN + Nano Urea + Nano Zinc (1.15) and T_7- 100% RDN + Nano Urea (1.13). At 60 DAT, T_{13}- 100% RDN + Nano Urea + Nano Zinc again demonstrated the highest LAI (4.08), significantly superior to other treatments, though T_{11}- 75% RDN + Nano Urea + Nano Zinc (3.76), T_7- 100% RDN + Nano Urea (3.69), and T_9- 50% RDN + Nano Urea + Nano Zinc (3.51) were statistically at par. At 90 DAT, T_{13}- 100% RDN + Nano Urea + Nano Zinc maintained the highest LAI (2.85), at par with T_{11}-75% RDN + Nano Urea + Nano Zinc (2.81), T_7-100% RDN + Nano Urea (2.78), and T_9- 50% RDN + Nano Urea + Nano Zinc (2.72), while the

Table 1. Effect of treatments on plant height (cm)

Treatments	Plant height (cm)											
	30 DAT			60 DAT			90 DAT			At harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1- Control	41.42	42.48	41.95	60.00	62.08	61.04	80.22	81.98	81.10	84.62	86.07	85.34
T_2-50 % RDN	45.84	46.91	46.38	66.46	68.96	67.71	87.77	91.04	89.41	92.98	96.58	94.78
T_3-50 %RDN+Nano Urea	47.07	48.27	47.67	69.15	71.81	70.48	90.54	94.08	92.31	93.97	97.75	95.86
T_4-75% RDN	47.33	48.54	47.94	69.85	72.54	71.20	98.47	102.33	100.40	100.66	104.70	102.68
T_5-75%RDN+Nano Urea	49.49	50.76	50.13	71.05	73.73	72.39	102.79	106.83	104.81	104.14	108.33	106.23
T_6-100% RDN	48.12	49.35	48.74	70.14	72.84	71.49	99.83	103.75	101.79	102.78	106.92	104.85
T_7-100%RDN+Nano Urea	50.99	52.14	51.56	74.55	77.43	75.99	102.62	106.64	104.63	105.19	109.42	107.31
T_8-50%RDN+NanoZinc	46.76	47.96	47.36	68.35	70.89	69.62	89.71	93.06	91.39	93.83	97.46	95.65
T_9-50%RDN+NanoUrea+ NanoZinc	50.04	51.32	50.68	72.55	75.35	73.95	103.31	107.36	105.33	104.82	108.79	106.81
T_{10}-75%RDN+NanoZinc	49.01	50.26	49.64	71.78	74.55	73.17	101.49	105.45	103.47	103.59	107.75	105.67
T_{11}-75%RDN+NanoUrea+ NanoZinc	51.40	52.35	51.88	74.53	77.31	75.92	103.63	107.57	105.60	106.43	110.71	108.57
T_{12}-100%RDN+NanoZinc	50.74	51.84	51.29	73.57	76.41	74.99	101.61	105.60	103.60	104.99	109.08	107.04
T_{13}-100%RDN+NanoUrea +NanoZinc	51.56	52.88	52.22	75.67	78.52	77.10	104.12	108.15	106.14	107.21	111.69	109.45
SE(d)±	**2.09**	**2.16**	**2.12**	**2.38**	**2.50**	**2.44**	**1.44**	**1.48**	**1.46**	**1.62**	**1.65**	**1.63**
C.D at 5%	**4.34**	**4.48**	**4.41**	**4.94**	**5.19**	**5.04**	**2.99**	**3.08**	**3.03**	**3.36**	**3.42**	**3.39**

Table 2. Effect of treatments on Number of tillers (m^{-2})

Treatments	Number of tillers (m^{-2})											
	30 DAT			60 DAT			90 DAT			At harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1- Control	267	270	268	352	366	359	338	342	340	301	313	307
T_2-50 % RDN	274	282	278	388	401	395	372	387	380	343	357	350
T_3-50 %RDN+Nano Urea	280	289	284	434	448	441	415	433	424	384	400	392
T_4-75% RDN	281	289	285	442	457	450	418	436	427	386	403	395
T_5-75%RDN+Nano Urea	285	294	290	453	468	460	433	451	442	414	432	423
T_6-100% RDN	282	291	286	455	470	463	420	438	429	396	413	404
T_7-100%RDN+Nano Urea	288	297	292	470	486	478	460	476	468	427	445	436
T_8-50%RDN+NanoZinc	279	287	283	425	439	432	398	415	406	379	386	382
T_9-50%RDN+NanoUrea+ NanoZinc	286	295	290	465	480	473	455	473	464	422	440	431
T_{10}-75%RDN+NanoZinc	284	292	288	460	475	468	424	442	433	398	415	406
T_{11}-75%RDN+NanoUrea+ NanoZinc	290	299	295	475	491	483	462	482	472	430	448	439
T_{12}-100%RDN+NanoZinc	287	296	291	468	484	476	457	475	466	424	443	433
T_{13}-100%RDN+NanoUrea +NanoZinc	299	308	304	481	497	489	468	488	478	432	451	442
SE(d)±	**6.57**	**7.11**	**6.87**	**9.52**	**9.69**	**9.53**	**4.80**	**4.96**	**4.99**	**5.22**	**5.68**	**5.39**
C.D at 5%	**13.65**	**14.75**	**14.27**	**19.77**	**20.13**	**19.79**	**9.96**	**10.31**	**10.35**	**10.84**	**11.80**	**11.19**

Table 3. Effect of treatments on Dry weight (g m^{-2})

Treatments	**Dry weight (g m^{-2})**											
	30 DAT			**60 DAT**			**90 DAT**			**At harvest**		
	2022	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T_1- Control	119.34	121.94	120.64	246.30	249.14	247.72	499.81	516.15	507.98	530.99	548.86	539.92
T_2-50 % RDN	126.42	129.22	127.82	262.16	268.50	265.33	530.99	543.63	537.31	574.08	601.07	587.58
T_3-50 %RDN+Nano Urea	137.53	140.57	139.05	285.15	292.21	288.68	563.63	577.49	570.56	613.39	642.05	627.72
T_4-75% RDN	141.01	144.16	142.58	299.29	306.68	302.98	587.42	602.10	594.76	642.64	672.55	657.59
T_5-75%RDN+Nano Urea	151.05	154.42	152.73	337.35	345.73	341.54	665.93	683.34	674.63	735.78	769.50	752.64
T_6-100% RDN	144.51	147.74	146.13	315.03	322.88	318.96	621.07	636.93	629.00	683.14	714.71	698.92
T_7-100%RDN+Nano Urea	155.33	158.54	156.94	370.63	379.80	375.21	682.58	706.35	694.46	794.87	808.36	801.62
T_8-50%RDN+NanoZinc	134.05	136.96	135.50	273.75	280.46	277.10	546.42	559.67	553.05	593.86	621.87	607.86
T_9-50%RDN+NanoUrea+ NanoZinc	153.37	156.79	155.08	351.88	360.62	356.25	673.85	695.65	684.75	771.64	785.27	778.45
T_{10}-75%RDN+NanoZinc	146.92	150.08	148.50	327.20	335.17	331.19	643.03	659.65	651.33	708.91	741.53	725.22
T_{11}-75%RDN+NanoUrea+ NanoZinc	156.06	159.34	157.70	375.51	384.79	380.15	687.55	712.73	700.14	804.23	817.31	810.77
T_{12}-100%RDN+NanoZinc	154.58	158.03	156.30	357.49	366.37	361.93	678.16	701.67	689.91	785.47	797.07	791.27
T_{13}-100%RDN+NanoUrea +NanoZinc	156.60	160.19	158.39	379.70	389.09	384.40	693.38	717.62	705.50	813.75	827.12	820.44
SE(d)±	**2.20**	**2.46**	**2.42**	**10.14**	**10.53**	**10.32**	**11.71**	**12.06**	**11.73**	**23.85**	**24.95**	**24.36**
C.D at 5%	**4.57**	**5.11**	**4.76**	**21.06**	**21.87**	**21.43**	**24.31**	**25.04**	**24.35**	**49.51**	**51.80**	**50.57**

Table 4. Effect of treatments on Leaf Area Index

Treatments	**Leaf Area Index**								
	30 DAT			**60 DAT**			**90 DAT**		
	2022	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T_1- Control	0.870	0.890	0.88	2.333	2.650	2.50	1.607	1.643	1.62
T_2-50 % RDN	0.910	0.930	0.92	3.067	3.160	3.12	1.910	1.987	1.95
T_3-50 %RDN+Nano Urea	0.930	0.950	0.94	3.193	3.293	3.25	2.070	2.153	2.11
T_4-75% RDN	0.990	1.013	1.00	3.243	3.343	3.29	2.320	2.417	2.37
T_5-75%RDN+Nano Urea	1.090	1.113	1.10	3.380	3.490	3.44	2.660	2.757	2.71
T_6-100% RDN	1.040	1.053	1.05	3.267	3.373	3.32	2.570	2.667	2.62
T_7-100%RDN+Nano Urea	1.120	1.140	1.13	3.630	3.750	3.69	2.720	2.830	2.78
T_8-50%RDN+NanoZinc	0.960	0.940	0.95	3.160	3.230	3.20	1.950	2.030	1.99
T_9-50%RDN+NanoUrea+ NanoZinc	1.100	1.123	1.11	3.397	3.617	3.51	2.670	2.780	2.72
T_{10}-75%RDN+NanoZinc	1.050	1.060	1.06	3.323	3.420	3.38	2.583	2.680	2.63
T_{11}-75%RDN+NanoUrea+ NanoZinc	1.140	1.163	1.15	3.660	3.847	3.76	2.750	2.870	2.81
T_{12}-100%RDN+NanoZinc	1.110	1.133	1.12	3.507	3.657	3.59	2.700	2.793	2.75
T_{13}-100%RDN+NanoUrea +NanoZinc	1.153	1.197	1.17	3.930	4.223	4.08	2.790	2.920	2.85
SE(d)±	**0.050**	**0.052**	**0.052**	**0.323**	**0.351**	**0.322**	**0.113**	**0.112**	**0.111**
C.D at 5%	**0.109**	**0.107**	**0.108**	**0.671**	**0.730**	**0.669**	**0.234**	**0.233**	**0.231**

control T_1- Control remained significantly lower (1.62). The results highlight that nano-based nutrient treatments, especially those combined with 100% RDN, significantly enhanced LAI across all growth stages, outperforming conventional fertilizer applications [17]. To increase Leaf Area Index in transplanted hybrid rice, nano-fertilizers enhance nutrient uptake and improve plant metabolism. Their precise delivery of essential nutrients like nitrogen promotes vigorous leaf growth, leading to a higher LAI, better photosynthesis, and ultimately increased crop productivity; Effect of LAI has been also supported by earlier Kumar et al. [18] and Salama and Badry [9].

4. CONCLUSION

It can be concluded from the present investigation that the application of 100% Recommended Dose of Nitrogen (RDN) combined with Nano Urea and Nano Zinc significantly enhanced key growth parameters in transplanted hybrid rice. This treatment resulted in higher plant height, increased tiller, greater dry matter accumulation, and leaf area index compared to traditional fertilization methods**.**

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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