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RESEARCH ARTICLE

Optimization of fertilizer recommendation through integration of nano sources on performance puddled transplanted rice

Vinitha N, M Joseph, M Hemalatha*& R Santhosh Babu

Department of Agronomy, Valluvai Oscar Chidambaram Pillai Agricultural College and Research Institute, Tamil Nadu Agricultural University, Thoothukudi 628 252, Tamil Nadu, India

*Correspondence email - hemalatha.m@tnau.ac.in

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Abstract

The primary objective of this study was to evaluate the combined impact of inorganic fertilizer applied through the soil and nano NPK applied by foliar application at different time intervals on the growth and yield of transplanted rice. The field experiment was conducted from December 2023 to April 2024 during the late Rabi season, at the Department of Agronomy, V.O.C Agricultural College and Research Institute, Killikulam, Tamil Nadu, India. A split-plot design, consisting of 16 treatments combinations and three replications, was used in this trial. The results showed that the application of 100 % Recommended Dose of Fertilizers (RDF) along with a foliar spray of nano source of NPK at four different growth stages, resulted in the highest rice dry matter production (DMP), relative water content (RWC), root length, grain and straw yield. However, this treatment showed statistically comparable results to the application of 100 % RDF with a foliar spray of nano source at three growth stages, as well as the application of 75 % RDF with a foliar spray of nano source at four growth stages. The study concluded that the application of 75 % RDF combined with a foliar spray of nano NPK at four stages was equally effective in improving the growth and yield of puddled transplanted rice.

Keywords: growth; nano NPK; RDF; transplanted rice; yield

Introduction

Rice (*Oryza sativa* L.) ranks as one of the essential crops around the globe and thrives in various climatic areas, spanning tropical nations to temperate subtropical regions, reaching latitudes of 40° S and 50° N from the Equator, with its cultivation noted in 114 out of 193 countries worldwide (1). It is the primary food source for over 3 billion individuals in Asia and contributes to about 30-75 % of their overall calorie intake (2). Rice production needs to rise by at least 30 % worldwide by 2050 to satisfy the future demand; yet achieving higher yields with lower inputs remains a major challenge (3). To provide food, rice is the main crop that is grown in more acreage. The crop is primarily cultivated during the rainy season in highly varied environments, from mountains to shorelines with erratic rainfall patterns. Thus, the slogan “Rice is Life” emphasizes rice’s importance in eliminating hunger, combating poverty and enhancing diets for people throughout Asia and globally (4). Worldwide, rice is cultivated on approximately 165.04 million hectares, yielding around 787 million metric tonnes. In India, the cultivation of rice occurs over approximately 47.6 million hectares, resulting in a production of 138 million metric tonnes with the productivity of 2.8 t ha^{-1} (5). In Tamil Nadu, rice cultivation occurs across approximately 22.05 L ha, yielding 7.85 million metric tonnes and achieving a productivity of 3.5 t ha^{-1}(6). Rice uptake large quantities of traditional mineral fertilizers in general, during its growth phases. The method of irrigating with immersion can lead to the exposure of fertilizers to leaching, volatilization and fixation on the clay textures. So, the unbalanced use of nutrients, with a great focus on supplementing the soil with micronutrients, may lead to a significant deficiency in other nutrients (7). Moreover, balanced fertilization does not imply the use of all types of fertilizers. It rather means applying fertilizers in the soil to achieve availability of all nutrients for an optimal growth environment for the plant growth. The optimum balance of N, P and K fertilizers can affect the growth and yield components of the rice crop (8).

Conversely, conventional fertilizers effectively nourish high-yield crop varieties as they supply essential nutrients in a form accessible to plants. Nevertheless, improper use of fertilizers may lead to soil quality decline caused by various factors, including changes in physical and chemical properties of the soil and decreased microbial activity. Excess use of fertilizers may lead to water pollution through leaching and eutrophication. The common method for rice cultivation is the application of fertilizers to the soil, both as basal and top dressing (9). Although the application significantly boosts grain yield, the low N and P use efficiencies of 35 %–40 % and 15 %–20 %, respectively, remain a significant limitation in rice farming. A large proportion of these nutrients are lost (10-12) due to quick chemical changes, leaching, volatilization losses and fixation. Currently, a major challenge is to attain sustainable development to satisfy the growing food demand and ensure food security for the rising population. Therefore, it is essential to employ a unique and innovative method that can enhance production while avoiding any harmful effects on our ecosystem. Over the past few decades, nanotechnology has been regarded as a promising tool with numerous applications in agriculture (13).

A nanoparticle (or nano-powder, nanocluster, or nanocrystal) is a tiny particle that has at least one dimension under 100 nm. Nano-fertilizers are an altered version of conventional fertilizers, created by utilizing nanoparticles that have a size of less than 100 nm. These offer several benefits, including an increased surface-to-volume ratio, enhanced reactivity with other substances, strong penetrative capability and improved crop growth, yield and nutrient utilization efficiency, while also lowering fertilizer expenses and emission risks (14-17). The use of nanotechnology in agriculture seems to be a hopeful strategy, encouraging the shift of traditional production systems towards improved agricultural methods that prioritize the creation of more efficient and eco-friendly practices (18). Nanotechnology is essential for crop production, ensuring environmental safety, ecological sustainability and economic stability (19).

Thus, considering the perspective of the potential benefits, an experiment titled "Nanotechnology and Crop Yield: Unlocking the Potential of Nano Fertilizers for Future Food Security" was conducted in the Thamirabarani command area of Southern Tamil Nadu during the Rabi season. The study focused on examining the impact of nano-fertilizers on growth parameters, yield and yield components in rice cultivation.

Materials and Methods

Site specifications and features

The current research was conducted in the late Rabi season from December 2023 to April 2024 at the Department of Agronomy, V.O.C Agricultural College and Research Institute, Tamil Nadu Agricultural University, located in Killikulam, Thoothukudi, Tamil Nadu, India. The experimental site is situated in the Southern agro-climatic zone of Tamil Nadu, positioned at a latitude of 8 °42'11.6" N and longitude of 77 ° 51'27.1" E, at an altitude of 40 m above mean sea level (MSL). The soil of experimental plot was sandy clay loam with a pH of 7.27, exhibiting a slight salinity. The soil has organic carbon levels of 5.90 g/kg, available nitrogen at 210 kg/ha, available phosphorus at 14 kg/ha and available potassium at 187 kg/ha. The region experiences a tropical climate, typically hot and humid and receives increased rainfall during the northeast monsoon (NEM) season. The average monthly temperature between December and April fluctuates between 29 °C and 35 ° C. The typical rainfall during the NEM in this area is 680 mm. For the experiment, seeds of the rice variety ASD 16 were obtained from the Agricultural Research Station (ARS) located in Ambasamudram.

Experimental design

The experiment was laid out in a Split Plot design with 3 replications and 16 treatments. The main plot consisted of soil application of different levels of inorganic fertilizer *viz.,* 100 % NPK (M_1), 75 % NPK (M_2), 50 % NPK (M_3) and Absolute control (M_4). Foliar application of nano fertilizer was adopted in the sub -plots, such as Foliar spray of Nano source of NPK applied 2 times (S_1), 3 times (S_2), @ 4 times (S_3) and control (S_4).

Crop cultivation

Transplantation was carried out with rice seedlings that were 21 days old. The recommended fertilizer dosage was 120:40:40 kg NPK/ha. The application of nanofertilizers on leaves was conducted at different intervals according to the treatment. The treatments consisted of 2 applications during the tillering (T) and active tillering (AT) phases; 3 applications at the tillering, AT and PI stages; as well as 4 applications at the tillering, AT, PI and flowering phases. Nano NPK was applied at a concentration of 10 mL/L as per the treatment setup. Fig. 1. presents an aerial view of the research area.

Assessment of growth and yield

Five plants were chosen at random from each treatment to examine the growth and yield characters such as dry matter production (kg/ha), root length (cm), Relative water content (%) (20), grain and straw output (kg ha^{-1}) were calculated for every treatment.

Statistical Analysis

All computed data were statistically analysed using R, a programming language designed for statistical computation and graphics, supported by the R Core Team and the R Foundation for Statistical Computing. Prior to analysis, the weed population data and weed dry matter were subjected to square root transformation ($\sqrt{(X+0.5)}$). The treatments that were not significant were indicated by NS, while the significant treatments were assessed at a 5 per cent probability level.

Results and Discussion

Effect of combined application of inorganic and nano fertilizers on DMP of rice

The quantity of dry matter produced by a crop indicates how efficiently it utilizes resources such as sunlight, water, nutrients and other environmental factors (21).

Fig. 1. Aerial view of experimental field.

Among the various levels of inorganic fertilizer applied through soil, the mean highest dry matter accumulation (3548, 8036 and 11808 kg ha^{-1}) was observed with 100 % NPK (M_1) at the active tillering, panicle initiation and harvest stage, respectively. These values can be compared with 75 % NPK (M_2) that obtained 3400, 7691 and 11317 kg ha^{-1} respectively in their respective growth stages. The results agree with earlier studies (22). The lowest dry matter accumulation of 1776, 4560 and 6268 kg ha^{-1} was observed in the absolute control (M_4) respectively.

In the context of foliar application of nano fertilizer, the average highest dry matter accumulation of 3294 kg ha^{-1} was observed with three sprays (S_2), which was statistically like four sprays (S_3) and two sprays (S_1) during the active tillering stage. However, at the panicle initiation and harvest stages, the maximum dry matter accumulation was recorded with four sprays (S_3), yielding 7544 kg ha^{-1} and 11224 kg ha^{-1}, respectively, which was comparable to three sprays (S_2). These outcomes are consistent with the conclusions of earlier studies (23). The lowest dry matter accumulation (5440 kg ha^{-1} and 7630 kg ha^{-1}, respectively) was observed in the untreated control (S_4).

Among the treatment combinations, the higher dry matter accumulation (3614 kg ha^{-1}) during the active tillering stage was observed with 100 % NPK combined with four times foliar sprays of nano fertilizer (M_1S_3), which was comparable to 100 % NPK with two sprays (M_1S_1;3598 kg ha^{-1}) and three sprays (M_1S_2;3592 kg ha^{-1}). During the panicle initiation and harvest stages, the maximum dry matter accumulation was also recorded with 100 % NPK combined with four foliar sprays of nano fertilizer (M_1S_3;8552 and 12543 kg ha^{-1}, respectively), This can be compared with 75 % NPK along with four sprays (M_2S_3;8351 and 12245 kg ha^{-1}) and 100 % NPK with three sprays (M_1S_2; 8277 and 12128 kg ha^{-1}) respectively. This was followed by 75 % NPK combined with three sprays (M_2S_2) which recorded8117 and 10995 kg ha^{-1} at the panicle initiation and harvest stages respectively. The lowest dry matter accumulation (2584, 4993 and 7626 kg ha^{-1}, respectively) was recorded in the absolute control (M_4S_4). The increased DMP in RDF is attributed to the improved nitrogen availability, which encourages the buildup of dry matter by aiding the production of photo-assimilates in leaves. These photo-assimilates are subsequently distributed to reproductive organs (24). Furthermore, the application of nanofertilizers enhances nitrogen uptake in plants, leading to increased dry matter yield because of better nitrogen availability and decreased ammonia loss (25). These outcomes are consistent with findings from earlier studies (26). Table 1. describes the influence of combined application of inorganic and nanofertilizers on Dry matter production (kg/ha) of rice.

Effect of combined application of inorganic and nano fertilizers on root length of rice

Root acts as the absorbing organ and its development are essential to measure the plant growth (27).

Among the different rates of inorganic fertilizer applied through soil, the greatest root length (19, 24.9 and 27.8 cm) was recorded with 100 % NPK (M_1) at the active tillering, panicle initiation and harvest stages, respectively. These values were comparable to the data recorded with 75 % NPK (M_2) with a root length of 18, 23.7 and 26.6 cm respectively. NPK fertilizer can enhance, increase and prolong crop roots, allowing them to efficiently absorb nutrients from the soil. (28)

In this scenario of foliar nanofertilizer application, the maximum root length of 16.4 cm was noted with four sprays (S_2), which showed no significant difference from two sprays (S_1) and three sprays (S_3) at the active tillering stage. Nevertheless, during the panicle initiation and harvest stages, the maximum root length was measured with four sprays (S_3) at 23.4 cm and 26.4 cm respectively, which was like the results from three sprays (S_2). The shortest root length (19.6 and 21.9 cm respectively) was recorded in the untreated control (S_4). Nanofertilizer containing a phosphorous source has been applied in four / three splits directly on the plant surface increasing the absorption and availability of P in addition to N and K. Nano phosphorus encourages deeper root penetration and more robust root development by enhancing nutrient availability. The regular and ongoing provision of nutrients through various applications promotes continuous root development, resulting in greater root length and volume. The findings are closely related with previous reports (29).

Among the different treatment combinations, the lengthier root during the active tillering phase was recorded with 100 % NPK alongside four applications of nano fertilizer (M_1S_3;19.4 cm), which was like the results from 100 % NPK with three sprays (M_1S_2;19.4 cm) and two sprays (M_1S_1; 19.2 cm). At the panicle initiation and harvest phases, the longest root length was noted with 100 % NPK combined with four times applications of nano fertilizer (M_1S_3; 25.9 and 29.5 cm, respectively). This was comparable to 75 % NPK with four sprays (M_2S_3;25.6 and 28.7 cm) and 100 % NPK using three sprays (M_1S_2;25.4 and 28.5 cm). Comparable findings have been recorded in earlier studies (30). The minimum root length (7.8, 13.3 and 15.4 cm, respectively) was observed in the absolute control (M_4S_4). Fig. 2 illustrates the influence of combined application of inorganic and nanofertilizers on root length (cm) of rice.

Table 1. Influence of combined application of inorganic and nanofertilizers on Dry Matter Production (DMP) (kg/ha) of rice

Treat-ments	DMP at Active Tillering					DMP at Panicle Initiation					DMP at harvest				
	S_1	S_2	S_3	S_4	Mean	S_1	S_2	S_3	S_4	Mean	S_1	S_2	S_3	S_4	Mean
M_1	3598	3592	3614	3388	**3548**	7902	8277	8552	7413	**8036**	11652	12128	12543	10910	**10808**
M_2	3450	3447	3459	3243	**3400**	7224	8107	8351	7081	**7691**	10601	11945	12245	10475	**11317**
M_3	3198	3261	3255	3034	**3187**	6703	7154	7327	6272	**6864**	9632	10740	11421	9307	**10275**
M_4	2814	2876	2831	2584	**2776**	5495	5805	5947	4993	**5560**	8125	8435	8687	7626	**8218**
Mean	**3265**	**3294**	**3290**	**3077**		**6831**	**7338**	**7544**	**6440**		10003	10812	11224	9580	
		M	**S**	**M X S**			**M**	**S**	**M X S**			**M**	**S**	**M X S**	
S.E$_d$		74	69	110			193	139	215			246	226	291	
C.D		150	139	211			386	278	429			492	452	582	

Effect of combined application of inorganic and nano fertilizers on relative water content of rice

Relative water content (RWC) reflects the degree of hydration in cells and tissues. It can evaluate the connection between plant water conditions and yield (31).

Among the various levels of inorganic fertilizer applied on soil, the higher leaf relative water content (84.2 and 86.9 %) was observed with 100% NPK (M_1) during the active tillering and panicle initiation stages, these were comparable to the values observed with 75% NPK (M_2) which recorded a relative water content of 80.7 % and 85 %, respectively. The absolute control (M_4) exhibited the least relative water content of 69.1 % and 74.1 %. The provision of nutrients elevated shoot water content in contrast to the treatment without nutrient supply. These findings are consistent with previous reports (32).

In the case of foliar spray of nanofertilizer, the highest relative water content of 78.2 % was observed with four applications (S_3), which did not significantly differ from two applications (S_1) and three applications (S_2) during the active tillering phase. Nonetheless, at the time of panicle initiation, the highest relative water content recorded with four sprays of Nano NPK (S_3) was 84.2 % and 83.2 % and which were comparable to the three spray(S_2) treatment. These findings are in line with previous documented reports (33). The lowest relative water content (76 % and 78.9 %) was observed in the untreated control (S_4).

Among the various treatment combinations, the highest relative water content during the active tillering stage was observed with 100 % NPK with four sprays (M_1S_3;84.6 %), which were comparable to the results from 100 % NPK with three sprays (M_1S_2;84.5 %) and two sprays (M_1S_1) (84.5 %). During the panicle initiation stages, the highest relative water content was observed with 100 % NPK along with four applications (M_1S_3;88.6 %), which was like 75 % NPK with four sprays (M_2S_3;88 %) and 100 % NPK with three sprays (M_1S_2;87.6 %). The simultaneous use of inorganic and nanofertilizer enhanced the RWC content. Comparable outcomes were also observed, in line with earlier studies (34). The lowest relative water content (66.8 % and 69.6 %) was noted in the absolute control (M_4S_4). Fig. 3. shows the influence of combined application of inorganic and nanofertilizers on relative water content (%) of rice.

Effect of combined application of inorganic and nano fertilizers on grain and straw yield of rice

Yield is the result of crop growth as impacted by various management techniques. The desired economic goods are produced under specific environmental conditions through timely and appropriate input management (21).

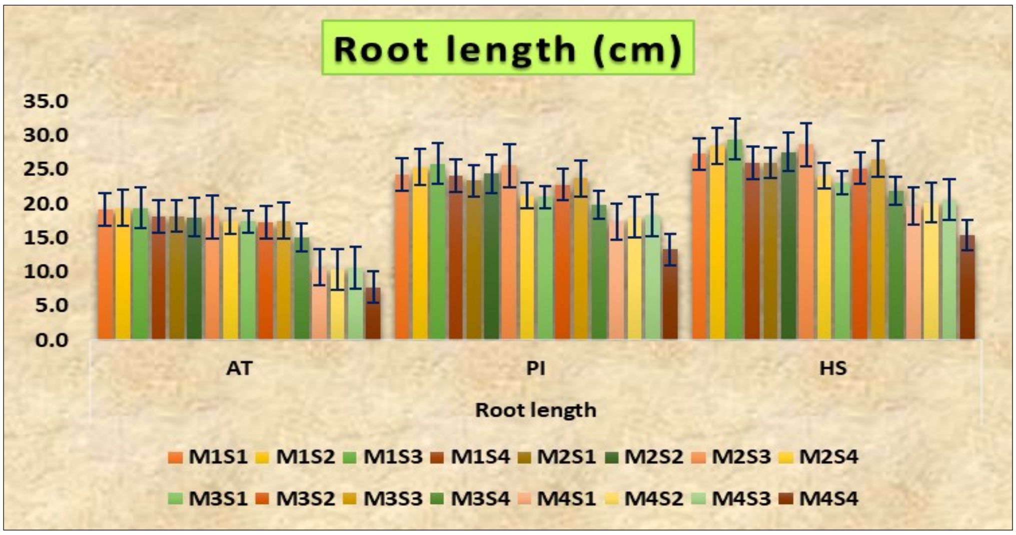

Fig. 2. Influence of combined application of inorganic and nanofertilizers on root length of rice (cm).

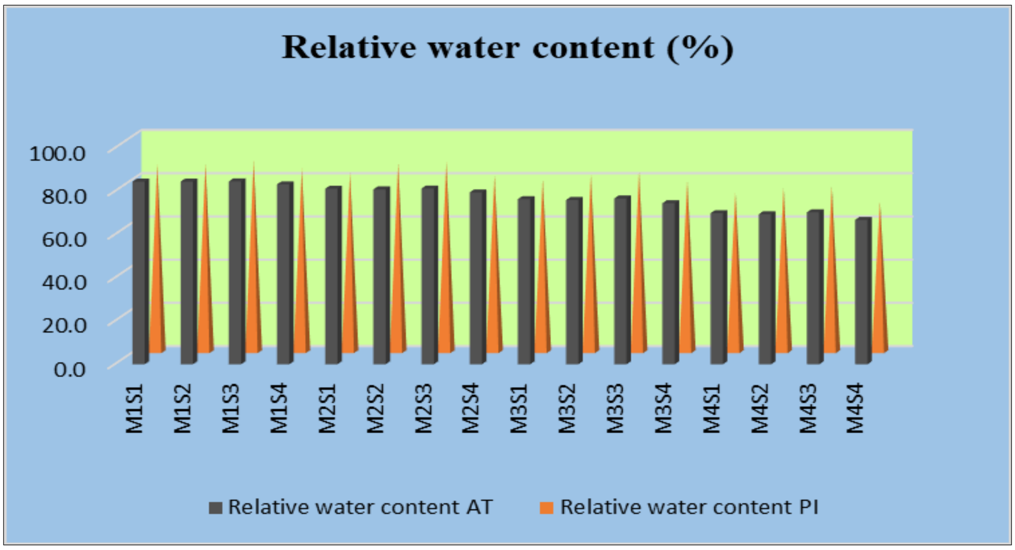

Fig. 3. Influence of combined application of inorganic and nanofertilizers on relative water content of rice (%).

Among the various levels of inorganic fertilizer applied through soil, 100 % NPK (M_1) achieved the highest grain and straw yields of 6000 and 6860 kg ha^{-1}, respectively, which were comparable to the yields from 75 % NPK (M_2) (5555 and 6362 kg ha^{-1}). The lowest grain and straw yields (2658 and 3110 kg ha^{-1}) were recorded in the absolute control (M_4). According to the findings of the research, application of NPK fertilizer can enhance the yield of dry grain weight per hectare. The findings are in alignment with previous studies (28).

In the case of foliar application of nano fertilizer, the highest grain and straw yields of 5413 and 6219 kg ha^{-1}, respectively, were achieved with four sprays (S_3), which were comparable to the yields of 5038 and 5786 kg ha^{-1} obtained from three sprays (S_2). The lowest grain yield (4008 and 4642 kg ha^{-1}) was recorded in the untreated control (S_4). The application of nano fertilizers on leaves may have boosted nutrient absorption, consequently raising the biomass and yield qualities, leading to an enhancement in the yield (35). This could stem from the combined influence of nanofertilizers on the effectiveness of traditional fertilizers, leading to enhanced nutrient uptake by plant cells. This, consequently, enhanced the accumulation and movement of photosynthates to the plant's economic parts, resulting in an increased yield.

Among the several treatment combinations, the highest grain and straw yields (6520 and 7455 kg ha^{-1}) were recorded with 100 % NPK combined with four-time foliar sprays of nano fertilizer (M_1S_3), These yields were comparable to those recorded with 75 % NPK with four-time foliar sprays of nano fertilizer (M_2S_3; (6377 and 7289 kg ha^{-1} and 100 % NPK with three foliar sprays of nano fertilizer (M_1S_2;6340 and 7243 kg ha^{-1}). The lowest grain and straw yields (2079 and 2512 kg ha^{-1}) were observed under the absolute control treatment (M_4S_4). Comparable results are documented in previous studies (36). Table 2. represents the influence of combined application of inorganic and nanofertilizers on yield (kg/ha) of rice.

Effect of combined application of inorganic and nano fertilizers on harvest index (HI)

The Harvest Index (HI) is used as a measure to assess biological efficiency in generating harvestable products. Different combinations of inorganic fertilizers and foliar applications of nano NPK significantly impacted the HI of transplanted rice, which varied between 0.463 and 0.467. The lowest HI of 0.453 was observed in absolute control (M_4S_4). Fig. 4. exemplifies the influence of combined application of inorganic and nanofertilizers on harvest index of rice.

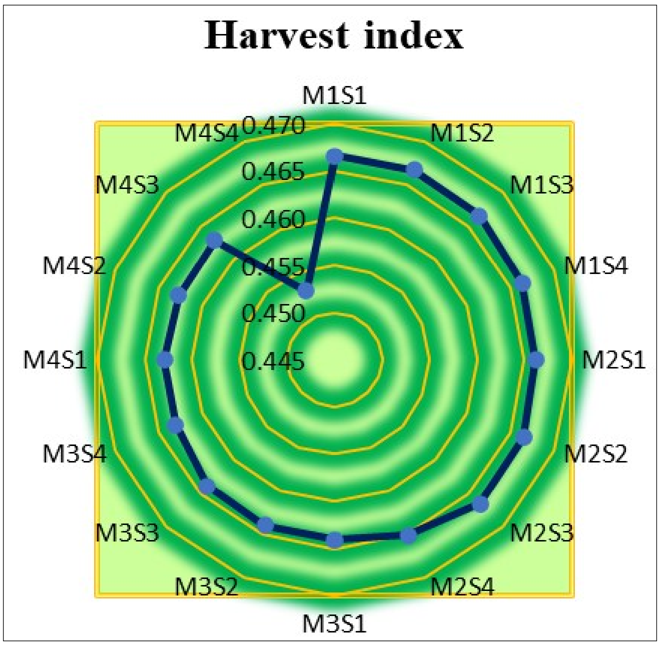

Fig. 4. Influence of combined application of inorganic and nanofertilizers on harvest index of rice.

Conclusion

According to the findings of the study, it can be concluded that the simultaneous use of 100 % NPK and foliar applications of nano source of NPK at four stages (tillering, active tillering, panicle initiation and flowering) resulted in significant improvement in the growth and yield of rice, achieving 11593 kg ha^{-1} of DMP and 29.5 cm of root length at harvest. Likewise, the data showed 6520 kg ha^{-1} of grain yield, 7455 kg ha^{-1} of straw yield, and a harvest index (HI) of 0.467. However, it was comparable to the combined treatment of 75 % NPK and four foliar applications of nano NPK, which achieved a dry matter production (DMP) of 11295 kg ha^{-1}, a root length of 28.7 cm. The treatment also achieved 6377 kg ha^{-1} of grain yield and 7289 kg ha^{-1} of straw yield, with an HI of 0.467 from transplanted rice. From the results mentioned above, we conclude that using a combined approach of 75 % NPK with four foliar applications of nano NPK maximizes yield and nutrient uptake, while minimizing nutrient waste and, reducing environmental impact of traditional fertilizers by decreasing nutrient leaching. Additional studies are recommended to investigate the long-term ecological and financial advantages of using both inorganic and nanofertilizers together under different agricultural scenarios, with the aim of lowering farming expenses and

Table 2. Influence of combined application of inorganic and nanofertilizers on grain and straw yield (kg/ha) of rice

Treatments	Grain yield					Straw yield				
	S_1	S_2	S_3	S_4	Mean	S_1	S_2	S_3	S_4	Mean
M_1	6020	6340	6520	5118	**6000**	6883	7243	7455	5857	**6860**
M_2	4942	6035	6377	4867	**5555**	5660	6902	7289	5597	**6362**
M_3	4234	4919	5563	3969	**4671**	4889	5681	6427	4601	**5400**
M_4	2504	2859	3191	2079	**2658**	2905	3319	3703	2512	**3110**
Mean	**4425**	**5038**	**5413**	**4008**		**5084**	**5786**	**6219**	**4642**	
		M	**S**	**M X S**			**M**	**S**	**M X S**	
$S.E_d$		231	189	235.5			257	228	275	
C.D		462	377	471			513	455	549	

enhancing farmers' net profits.

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Authors' contributions

VN participated in the research activities, field establishment, statistical data analysis and the writing of the research article. MJ and MH edited and reviewed the research article. RSB participated in data analysis. Every author reviewed and endorsed the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors have no conflicts of interest to disclose.

Ethical issues: None

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