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OPTIMIZING NUTRIENT STRATEGIES FOR SUSTAINABLE HYBRID RICE PRODUCTION UNDER EASTERN INDIA CONDITIONS

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ABSTRACT

Rice (*Oryza sativa* L.) is the most important staple food crop, providing about 20% of daily calories to the global population. With increasing demand for both yield and quality, sustainable nutrient management strategies are essential for hybrid rice production. A field experiment was conducted during the *kharif* season of 2022 at the Research Farm of Indira Gandhi Agricultural University, Raipur, to evaluate the effect of integrated nutrient management practices on growth and yield attributes of hybrid rice variety Arize-6444. The experiment was laid out in a randomized block design with ten treatments, including different combinations of recommended dose of fertilizers (RDF), farmyard manure (FYM) and foliar applications of NPK (19:19:19) and zinc (0.5%), replicated three times. Results indicated that nutrient management significantly influenced growth, yield attributes, and yield of hybrid rice. Application of 125% RDF (T10) recorded the highest plant height (130.75 cm), effective tillers (453.16 m^{-2}), panicles per plant (10.26), filled grains per panicle (191.73), grain yield (80.29 q ha^{-1}), and straw yield (93.33 q ha^{-1}). Integrated treatments such as 75% RDF + FYM + foliar spray + Zn (T_5) and 100% RDF + foliar spray + Zn (T_9) also performed well, demonstrating that balanced fertilization integrated with organic and foliar nutrient supplementation can sustain high productivity. The control ($N_0P_0K_0$) consistently recorded the lowest values across all parameters. The findings highlight that enhancing RDF levels and integrating organic and foliar nutrient sources can effectively improve hybrid rice productivity while supporting soil health.

Key words : Optimizing Nutrient Strategies, Sustainable Hybrid Rice.

Introduction

The most significant staple food consumed by the world's population is rice (*Oryza sativa* L.), which is a source of approximately 20% calories in daily food (Cordero-Lara, 2020). It provides food for more than half of the world's population, making it one of the most significant food crops in the universe (Baroudy *et al.*, 2020). Nearly 2 billion people in Asia alone get their energy from rice, which has 80% carbohydrates, 7–8% protein, 3% fat and 3% fibre. Several investigations from different countries have shown how effective different cultivars of rice are in preventing diabetes, hyperlipidaemia, cancer, inflammation and other disorders. Rice has lower antioxidant efficiency or fewer antioxidant molecules than other grains. It may therefore be feasible to develop meals made with rice, pharmaceuticals, food preservatives and cosmetic goods. In terms of natural antioxidant sources and other health benefits, rice is a great contender (Chaudhari *et al.*, 2018). Moreover, the demand for rice with superior quality is experiencing a significant upsurge due to economic development and improved living standards (Cheng *et al.*, 2019; Yuanet *et al.*, 2021). Therefore, it is crucial to achieve the dual goal of high yield and high quality in rice production to meet the growing demand for both quantity and quality.

Over the past few decades, significant efforts have been made to enhance rice yield as the primary focus of breeding programs (Khush, 2023). This approach has yielded remarkable results, with notable increases in rice yields attributed to the development of semi-dwarf rice varieties in the 1950s, hybrid rice in the 1970s, and super hybrid rice in 1996 (Peng *et al.*, 2008). However, it is crucial to note that while yields have shown significant improvement, grain quality has not progressed at the same rate (Zhou *et al.*, 2021 and Huang, 2022).

Hybrid rice is the result of crossbreeding genetically distinct parental lines, with the aim of harnessing the benefits of heterosis or hybrid vigour, which leads to higher yield potential (Peng *et al*., 2008).

Rice hybrids with short duration and higher yield potentials are being developed to replace the inbred cultivars (Gupta *et al*., 2011). It, therefore, necessitates the adoption of advanced agro techniques for narrowing the yield gap. Secondly, slow growth in rice production and the ceiling on yield can be broken by adopting hybrid rice technology which can boost the present rice yield by 15-20% with the present level of input use. Out of the few options left with us, large scale adoption of hybrid rice technology can be effective to keep a steady supply of rice to the entire state (Banerjee *et al*., 2019; Pal *et al*., 2020). The important strategies towards increasing rice productivity include exploitation of local hybrids and improved nutrient management practices (Talathi *et al*., 2009).

The rising cost of chemical fertilizers and the growing need to conserve plant nutrients through recycling have shifted focus towards sustainable nutrient management strategies. The continuous unbalanced use of fertilizers in cropping systems often leads to misappropriate nutrient availability and adverse effect on physicochemical properties of soil which finally results in declined crop yields (Vijayakumar *et al.*, 2021).

Among these, the balanced application of fertilizers—combining inorganic and organic sources—plays a critical role in maintaining soil fertility and ensuring long-term agricultural productivity (Banerjee and Pal, 2012). In many intensively cultivated systems, especially rice-based cropping systems, imbalanced fertilizer use has led to nutrient imbalances, deterioration of soil health, and declining yields. Desirable quantity of nutrients drawn from a sustainable source and applied at an appropriate time favourably influences the nutrient uptake, growth and yield of hybrid rice (Kumar *et al*., 2014). The nutrients, their sources, method and time of application form an important component of fertilizer management strategies (Mondal *et al*., 2019).

To address these challenges, integrated approaches that include timely soil-applied fertilizers along with foliar nutrient applications are gaining importance. Foliar spray serves as an effective method to supplement nutrient supply during critical growth stages, enhance nutrient use efficiency and support crop growth under stress conditions. When integrated with balanced fertilization, foliar nutrition not only boosts nutrient uptake and utilization but also contributes to higher yield and better crop performance and cost reduction. (Parkinson, 2013). Therefore, adopting a holistic nutrient management strategy that combines balanced soil fertilization with foliar application is essential for achieving sustainable rice production and improving soil health. INM approach is flexible and minimizes the use of chemicals but maximize use efficiency of fertilizer and improve the soil health (Jana *et al*., 2020). Continuous use of fertilizer containing major nutrient only may necessitate the application of micronutrients for sustained crop production (Arif *et al*., 2012). Zinc, being the third most important plant nutrient assumes significance in modern agriculture after N and P, limiting the growth and yield of rice. In addition to N, P and K, it also supplies considerable amount of secondary and micronutrients and improves growth and productivity of various crops (Sarkar *et al*., 2021).

Materials and Methods

A field study was carried out during wet season of at the research farm of Indira Gandhi Agricultural University, Raipur. The experiment was laid in a RBD in year 2021-2022 with ten treatments replicated three times. The soil was clay loam, low in available nitrogen (224 kg/ha), medium in available phosphorus (18 kg/ha) and exchangeable potassium (299 kg/ha) with pH 7.4. The treatments comprised *viz.*, T_1: Control; T_2: 75% of GRD + 5 tons/ha FYM; T_3: 75% GRD + 5 tons/ha FYM+ NPK 19: 19: 19 (1%) Foliar spray at 50, 60, 80 DAP; T_4: 75 % GRD + 5 tons/ha FYM + Zinc (0.5%) at 50, 60, 80 DAP; T_5: 75% GRD + 5 tons/ha FYM + NPK 19: 19: 19 (1%) Foliar spray + Zinc (0.5%) at 50, 60, 80DAP; T_6: 100% of GRD T_7: 100% GRD+ NPK 19: 19: 19 (1%) Foliar spray at 50, 60, 80 DAP; T_8: 100% GRD+ Zinc (0.5%) at 50, 60, 80 DAP; T_9 : 100% GRD + NPK 19: 19: 19 (1%) Foliar spray and Zinc (0.5%) at 50, 60, 80DAP; T_{10}: 125% of GRD (187: 100: 75) Foliar spray of NPK (19:19:19) @ 1% and Zinc spray @ 0.5% at 50, 60 and 80 DAP. Rice crop *i.e.* Hybrid rice Arize- 6444 was test crop. The whole amount of P, K was applied as basal dressing, whereas N was applied 33 per cent at active tillering, 33 per cent at panicle initiation and 33 per cent at heading.

The soil available N was in low, P and K was rated

Table 1 : Initial status of NPK in soil.

Nutrient status	**Alkaline $KMnO_4$ -N (kg/ha)**	**Olsen's P (kg/ha)**	**N Amm. acetate Extractable K (kg/ha)**
2022	224	19	299

as medium categories given in Table 1. It is generally observed that available N falls under low rating because of its dynamic nature and previous applied N fertilizers transforms in to various forms through different mechanism like leaching, volatilization and de-nitrification and subjected to loss. Contrary to this, applied P fertilizer it tends to transforms in to insoluble compound upon reaction with soil constituents (Fe, Al, Ca). This transformation renders it less accessible to plants potentially explaining the observed low to medium range of soil phosphorous. Consistent soil available K, could be attributed to the dynamic equilibrium maintained among various forms of K in the soil. This equilibrium ensures a constant replenishment of soil solution K as soon as it is absorbed by the crops because of its dynamic equilibrium nature.

Results and Discussion

The data of plant height of rice crop at 30, 60 and 90 DAT showed that at all the stages, the tallest plant height was recorded with the application of 125% RDF whereas the shortest height was recorded with the treatment of control where no application of fertilizers (N_0:P_0:K_0). Plant height is the one of the important yield determining characters in rice crop. During the *kharif* season of 2022 the mean values of Plant height were recorded at 30, 60, and 90 days after sowing (DAS) under ten different nutrient management treatments (T_1–T_{10}). Across most treatments, the mean values increased from 30 DAS to 60 DAS, followed by either a slight increase or stabilization at 90 DAS. Treatment T_1 control plot consistently exhibited lower values throughout the growth stages. The mean plant height (cm) at 30, 60 and 90 days after sowing (DAS) exhibited significant variation among the nutrient management treatments. At 30 DAS, the tallest plants were observed in T_{10} (125% GRD) with 63.0 cm, which was significantly higher than all other treatments, followed by T_8 (58.5 cm), T_7 (58.4 cm) and T_5 (58.3 cm). The shortest plants were recorded in the control (T_1) with 52.2 cm. At 60 DAS, T_{10} again recorded the highest plant height (99.18 cm), significantly surpassing most treatments except T_5 (97.25 cm) and T_2 (95.08 cm), which were statistically at par. The control treatment (T_1) maintained the lowest plant height (76.73 cm) at this stage. At 90 DAS, T_{10} continued to outperform all treatments with 130.75cm plant height, followed by T_8 (118.71 cm) and T_4 (115.89 cm). The lowest value was recorded in T_9 (104.49 cm) and T_2 (105.9 cm), with the control treatment (111.46 cm) performing better than some nutrient-supplemented treatments at this stage. The standard error of mean (SEm ±) values ranged from 1.82 to 2.53 and the critical difference (CD at P=0.05) values

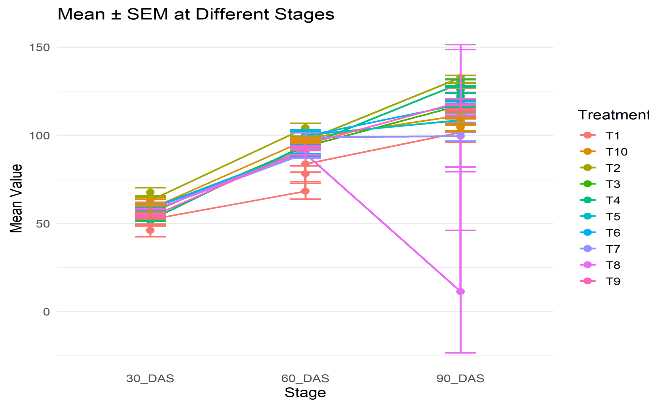

Fig. 1 : Mean ± Standard Error of the Mean (SEM) of plant height at different growth stages at 30 DAS, 60DAS, 90DAS under various treatments.

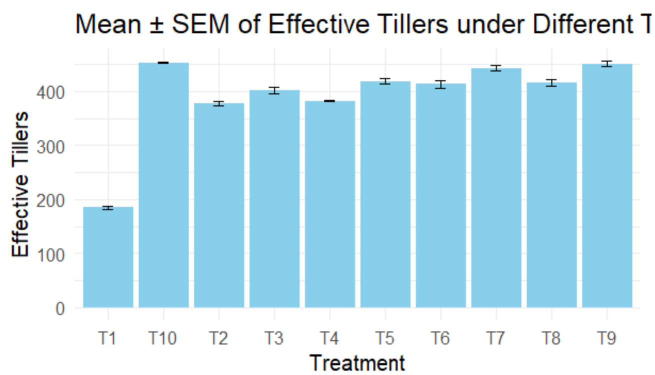

Fig. 2 : Mean SEM of effective tillers under different nutrient management practices.

ranged from 5.40 to 7.51, confirming that the observed differences among treatments were statistically significant. Overall, the application of 125% GRD (T_{10}) consistently produced the tallest plants across all growth stages, indicating its superiority in promoting vegetative growth. The foliar application of NPK or N at different growth stages might have increased the plant height due to the fact that the nutrients supply to rice plants at different growth stages might help cell elongation and increase photosynthetic rate. The work done by Manik *et al*. (2016).

Effective tiller of hybrid rice

The number of effective tillers per m^2 under various nutrient management practices during the *kharif* seasons of 2022. Effective tiller affected significantly with different fertilizer treatment. The highest tiller count 453.16 was observed in 125% GRD (T_{10}), which was at par with T_9 (451.16) 100% GRD + Foliar Spray + Zinc at 50, 60 and 80 days after planting. Control (T_1) recorded the lowest number of effective tillers 185.33, demonstrating the necessity of nutrient inputs for hybrid rice productivity. Nutrient management treatments significantly enhanced tiller production compared to the control. T_3 receiving 75% GRD + FYM + 19:19: 19 (1%) Foliar Spray at 50,

Table 2 : Plant height at different period of crop growth influenced by different nutrient management practices in hybrid rice during *kharif* 2022.

S. no.	Treatment details	30 DAS	60 DAS	90 DAS
		2022	2022	2022
T_1	Control	52.2c	76.73d	111.46d
T_2	75% of GRD + 5 tons/ha FYM	51.9c	95.08bc	105.9ef
T_3	75% GRD + 5 tons/ha FYM (19: 19:19 foliar spray)	56.9b	92.23c	114.03cd
T_4	75 % GRD + 5 tons/ha FYM + Zinc (0.5%)	53.6c	93.99c	115.89c
T_5	75% GRD + 5 tons/ha FYM + 19:19:19 Foliar spray + Zinc (0.5%)	58.3b	97.25ab	107.89e
T_6	100% of GRD	56b	93.07c	115.19c
T_7	100% GRD + 19 :19: 19 (1% Foliar spray)	58.4b	94.11c	111.6d
T_8	100% GRD + Zinc (0.5%)	58.5b	94.11c	118.71b
T_9	100% GRD + 19: 19: 19 Foliar spray and Zinc (0.5%)	57b	94.27c	104.49f
T_{10}	125% GRD	63a	99.18a	130.75a
	SEm(±)	**1.82**	**2.25**	**2.53**
	CD (P= 0.05)	**5.40**	**6.68**	**7.51**

60 and 80 days after planting and T_7 (100% GRD + 19:19: 19 (1%) Foliar Spray produced 402.05 and 442.86 tillers, demonstrating the beneficial impact of foliar spray compared to T_2 (376.74) 75% GRD + FYM and T_6 (413.39) 100% GRD. Jahan *et al*. (2022) reported that increased nitrogen availability enhanced tiller production per m² through accelerated cell division. Among these, productive tillers contributed more effectively to overall rice yield than the total tiller count. Furthermore, the application of nitrogen in evenly split doses improved the number of grains per panicle. This effect was attributed to greater nitrogen uptake from split applications, which promoted the formation of additional panicle branches and thereby increased grain count.

Number of panicles per plant of hybrid rice

The data regarding panicle/plant significantly influenced by fertilizer treatment in hybrid rice 2022. The highest panicle per plant 10.26 was witnessed under the T_{10} received 125% GRD which was at par with T_6 (10) received 100% GRD. Treatments with 100% GRD (T_6, T_7, T_8, T_9) and 125% GRD (T_{10}) consistently showed higher panicle numbers, indicating that recommended and enhanced doses of nutrients are crucial for optimal tiller development. Among fertilizer group 75% GRD+ FYM, T_5 (75% GRD + FYM + NPK 19:19:19 (1%) Foliar spray + Zinc (0.5%) at 50, 60 and 80 days after planting was the most effective, indicating that the integration of foliar sprays and zinc compensates for the reduced nutrient application. Whereas, the lowest panicle per plant was recorded in control (N_0:P_0:K_0). Peng *et al*. (2016) reported the effect of different yield component over yield was rank as follows: number of grains per panicle > setting rate > 1000 grain weight > number of panicles.

The test weight was assessed under different nutrient management practices in hybrid rice during the year 2022. Test weight affected non significantly with different nutrient management practices.

Number of filled and unfilled grain of hybrid rice

The data provides insights into the impact of different nutrient management practices on the number of filled grains per panicle in hybrid rice during the *kharif* season 2022. The application of 125% GRD (T_{10}) yielded the maximum filled grains (191.73) indicating that exceeding the recommended dose positively impact grain filling which was at par with T_9 (188.17) received 100% GRD +19:19:19 (1%) Foliar spray and Zinc (0.5%) and T_7 received (184.69) 100% GRD + 19:19: 19 (1%) Foliar spray both at 50 60 and 80 days after planting**.** Increasing the balanced fertilization from 75% (T_2) to 100% (T_6) significantly improved the number of filled grains (134.4 to 157.56). The addition of FYM and Zinc to 75% GRD (T_4) enhanced grain filling compared to FYM alone (T_2), with values rising from 134.4 to 140.65. The inclusion of both foliar sprays of 19:19:19 (1%) and Zinc spray(0.5%) with 75% GRD + FYM (T_5) resulted in a significant increase in filled grains (170.19) compared to the sole application of either 19:19:19 foliar spray(1%) *i.e.*; 153.5 or Zinc spray (0.5%) 140.65 with 75% GRD + FYM. This indicates that the combined use of foliar sprays and Zinc is an efficient approach for enhancing nutrient availability and improving grain filling.

The number of unfilled grains was assessed under different nutrient management practices in hybrid rice during the year 2022. Unfilled grain affected significantly with fertilizer treatment. During *kharif* season 2022 the highest number of unfilled grains was observed in the

Table 3 : Effect of different nutrient management practices on no. of effective tillers, no. of panicle per plant, test weight, no. of filled and unfilled grain, grain yield and straw yield.

	Treatment details	No of effective tillers	No of panicle per plant	Test weight	No of filled grain	No of unfilled grain	Grain yield	Straw yield	Harvest Index(%)
T_1	Control	185.33e	5.25c	23.56	124.36e	25.8a	36.05c	44.97d	44.72
T_2	75% of GRD + 5 tons/ha FYM	376.74d	8.2b	25.03	134.4de	24.8bc	68.84b	77.9c	46.91
T_3	75% GRD + 5 tons/ha FYM (19: 19:19 foliar spray)	402.05c	9.27ab	24.05	153.5c	23c	72.35ab	83.27bc	46.49
T_4	75 % GRD + 5 tons/ha FYM + Zinc (0.5%)	382d	8.93ab	23.48	140.65d	24c	69.74b	78.74c	46.97
T_5	75% GRD + 5 tons/ha FYM + 19:19:19 Foliar spray + Zinc (0.5%)	418.77b	9.41ab	23.65	170.19b	25.3bc	73.26ab	84.71bc	46.38
T_6	100% of GRD	413.39bc	10a	24.75	157.56c	25.7ab	72.56ab	83.71bc	46.43
T_7	100% GRD + 19 :19: 19 (1% Foliar spray)	442.86a	9.8ab	24.37	184.69a	24.7bc	77.73ab	90.4ab	46.23
T_8	100% GRD + Zinc (0.5%)	415.33bc	9.34ab	23.53	160.8bc	24.3c	72.38ab	84.75bc	46.52
T_9	100% GRD + 19: 19:19 (1% Foliar spray) and Zinc (0.5%)	451.16a	9.87ab	21.9	188.17a	23.3c	78.31ab	91.17ab	45.85
T_{10}	125% GRD	453.16a	10.26a	23.54	191.73a	23c	80.29a	93.33a	46.24
	SEm(±)	**4.80**	**0.35**	**0.62**	**3.60**	**0.64**	**3.34**	**2.66**	
	CD (P = 0.05)	**14.28**	**1.05**	**NS**	**10.68**	**1.91**	**9.94**	**7.90**	

control treatment 25.8 indicating poor grain filling without any nutrient application. Both 75% and 100% GRD with additional inputs like FYM, foliar sprays, and Zinc help reduce the number of unfilled grains, enhancing grain filling. Lowest number of unfilled grain 23 was recorded in 125% GRD (T_{10}). Adding Zinc and foliar sprays, particularly in 100% GRD treatments effectively minimizes unfilled grains. While 125% GRD (T_{10}) improved grain filling 23 compared to 100% GRD (25.7) the reduction in unfilled grains was not significant, indicating that 100% GRD with foliar and Zinc supplements also improve filled grains. Additionally, the accumulation and translocation of photosynthates to sinks trigger physiological activities and promote plant growth and development. Similar findings were reported by Ramachandrian and Balasubramanian (2012), Raj *et al.* (2016).

Grain yield of hybrid rice

During the *kharif* season of 2022 the highest grain yield (80.29 q ha^{-1}) was recorded in T_{10} (125% GRD) and the lowest grain yield (36.05 q ha^{-1}) was recorded in the control plot where no fertilizers or amendments were applied. Among treatments group with 75% GRD T_5 (73.26 q ha^{-1}), which included foliar spray of NPK 19:19:19 and Zinc, achieved the highest grain yield. This was statistically at par with T_3 (72.35 q ha^{-1}). Among treatments with 100% GRD, T_9 (78.31 q ha^{-1}), which combined foliar spray and zinc, recorded the highest grain yield whereas, the lowest grain yield was recorded in T_1 (36.05 q ha^{-1}). On the other hand, the application of balanced fertilization combined with a 0.5% zinc *i.e.* 100% GRD + 0.5% Zn (T_8) showed no significant difference with sole application of balanced fertilization *i.e.* 100% GRD (T_2). Grain yield of hybrid rice was maximized under inorganic fertilizer treatments, which can be attributed to the rapid release of nutrients during critical growth stages. Moreover, the integration of higher levels of inorganic fertilizers with organic manures resulted in further yield improvement, owing to enhanced availability and uptake of macro and micronutrients, along with improved

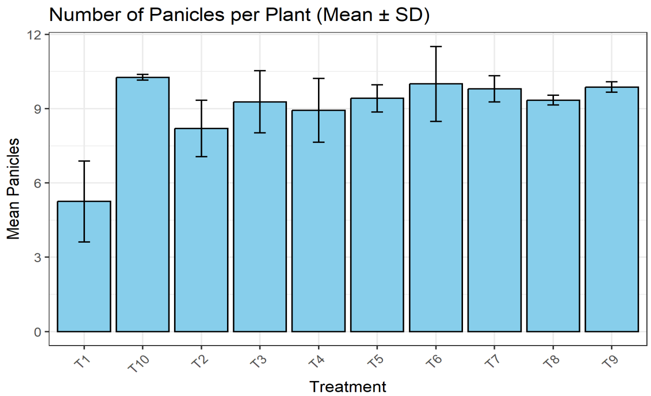

Fig. 3 : Error bar graph of number of panicles per plant under different nutrient management practices.

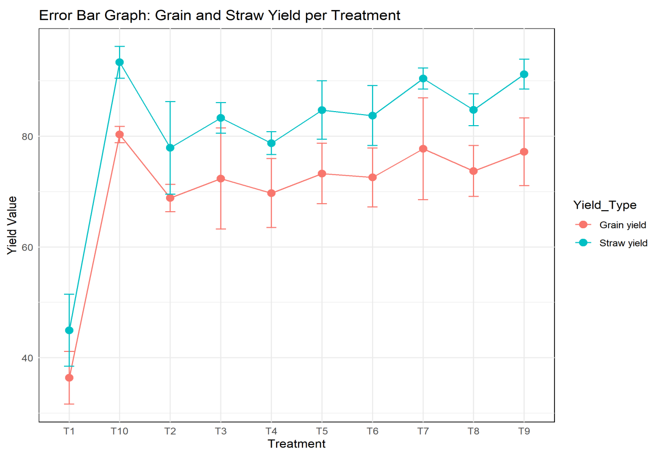

Fig. 4 : Error bar graph of grain and straw yield with different treatment.

carbon assimilation and photosynthetic activity.

Straw yields of hybrid rice

The straw yield of hybrid rice Arise-6444 significantly increase from 44.81 to 92.96 q ha^{-1} on pooled data basis due to various nutrient management practices. During the *kharif* season of 2022 the highest straw yield (93.33 q ha^{-1}) was recorded in T_{10}, which received 125% GRD followed by T_9 (91.17q ha^{-1}). Among the treatments with 75% GRD, T_5 (84.71 q ha^{-1}), which included foliar spray of 19:19:19 and Zinc at 50, 60 and 80 days after planting produced the highest straw yield which was statistically at par with T_3 (83.27 q ha^{-1}) received 75% GRD + FYM +19:19:19 foliar spray. Among the treatments with 100% GRD, T_9 (91.17 q ha^{-1}), which combined foliar spray and Zinc, showed the highest straw yield. Overall the lowest straw yield 44.97 q ha^{-1} was recorded in control plot (N_0:P_0:K_0). Increasing fertilizer application from 75% to 100% and 125%, GRD significantly improved straw yield, highlighting the positive impact of higher nutrient levels.

Statistical analysis

All the data including growth parameter were statistically analysed using WASP 2.0. For Duncan test and the graphing was done using R studio software. All test were performed at the 0.05 significance level.

Conclusion

The experiment revealed that nutrient management practices significantly influenced growth and yield attributes of hybrid rice. Application of 125% GRD (T10) consistently produced the tallest plants, highest number of effective tillers, panicles per plant, filled grains per panicle and ultimately the maximum grain (80.29 q ha^{-1}) and straw yields (93.33 q ha^{-1}). Integrated treatments such as 75% GRD + FYM + foliar spray + Zn (T_5) and 100% GRD + foliar spray + Zn (T_9) also performed well, indicating that balanced fertilization coupled with organic and foliar inputs can partially compensate for reduced basal application. The control ($N_0P_0K_0$) recorded the lowest values across all parameters, confirming the critical role of nutrient inputs in hybrid rice productivity.

Future perspectives

Future research should emphasize long-term soil fertility, nutrient-use efficiency, and economic viability of higher fertilizer doses. Integrated nutrient management approaches combining inorganic fertilizers with FYM, foliar sprays, and micronutrients should be optimized for sustainability. Multi-location and multi-season trials are necessary to validate these findings and develop site-specific recommendations for enhancing hybrid rice productivity under diverse agro-climatic conditions.

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