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Effect of green manuring and zinc fertilization on growth, yield attributes and nutrient uptake of transplanted rice (*Oryza sativa* L.)

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Abstract

A field experiment was carried out in the Experimental Farm, Department of Agronomy, Faculty of Agriculture, Annamalai University, Annamalai Nagar, Cuddalore district, Tamil Nadu, India during June to September, 2023 (*Kuruva*) to investigate the the impact of green manure and zinc fertilization strategies on the growth, yield attributes and nutrient uptake of rice (*Oryza sativa* L.). The experimental design was a Randomized Block Design (RBD) with eight treatments and three replications. The treatments are T₁- Control; T₂- RDF (120:40:40 kg N P₂O₅ K₂O ha⁻¹); T₃ - RDF + GM @ 6.25 t ha⁻¹ + Soil application of ZnSO₄ @ 25 kg ha⁻¹; T₄ - RDF + GM @ 6.25 t ha⁻¹ + Foliar application of 0.2% Nano Zn at 50% flowering, milky and dough stage; T₅ - RDF + GM @ 6.25 t ha⁻¹ + Soil application of 1.0 L ha⁻¹ Zn solubilizers; T₆ - RDF + GM @ 6.25 t ha⁻¹ + Soil application of ZnSO₄ @ 25 kg ha⁻¹ + Foliar application of 0.2% Nano Zn at 50% flowering, milky and dough stage; T₇ - RDF + GM @ 6.25 t ha⁻¹ + Soil application of ZnSO₄ @ 25 kg ha⁻¹ + Soil application of 1.0 L ha⁻¹ Zn solubilizers and T₈ - RDF + GM @ 6.25 t ha⁻¹ + Soil application of ZnSO₄ @ 25 kg ha⁻¹ + Foliar application of 0.2% Nano Zn at 50% flowering, milky and dough stage + Soil application of 1.0 L ha⁻¹ Zn solubilizers. From the results, it was revealed that (T₈ - RDF + GM @ 6.25 t ha⁻¹ + Soil application of ZnSO₄ @ 25 kg ha⁻¹ + Foliar application of 0.2% Nano Zn at 50% flowering, milky and dough stage + Soil application of 1.0 L ha⁻¹ Zn solubilizers) had significant effect on growth, yield attributes and nutrient uptake of transplanted rice.

Keywords: Green manures, zinc, nano zinc, zinc solubilizers

Introduction

Over half of the world population relies on rice (*Oryza sativa* L.) as one of their staple foods. 90 per cent of the world rice production and growing area is in Asia. It is extensively grown worldwide and is referred to as the “global grain”. Globally, rice is cultivated on approximately 166 million hectares of land with a production of 520 million metric tonnes and the productivity of 4.69 tonnes per hectare (FAO, 2022) ^[5]. India, a major producer, cultivates rice across 47.60 million hectares, with a production of 137 million metric tonnes annually (FAO, 2023) ^[6]. About 90 per cent of the world’s rice production and growing area is in Asia. The average productivity in India stands at 4.32 tonnes per hectare (USDA, 2024) ^[28]. With an average production of 6.88 million tonnes and productivity rate of 3.38 tonnes per hectare, rice is grown on 2.03 million hectares in Tamil Nadu (DES, 2021) ^[4].

Modern agriculture, heavily reliant on chemical inputs, has often prioritized maximizing output over input efficiency. This unsustainable approach is exemplified by the excessive use of chemical fertilizers, particularly in rice production, to meet the nation food demands. The over use of these synthetic fertilizers can lead to environmental degradation, soil pollution and diminishing returns over time. Mohankumar *et al.* (2023) ^[14] highlighted the excessive use of synthetic fertilizers by rice farmers in Tamil Nadu has led to a significant reduction in soil organic carbon content, highlighting the negative environmental and human health consequences associated with this practice. Synthetic fertilizers, while providing essential nutrients for crop growth, can also contribute to soil degradation, water pollution and public health risks. The overuse of these chemicals can disrupt soil microbial communities, reduce soil fertility and increase the susceptibility of crops to pests and diseases.

Mykhailova *et al.* (2021) ^[15] emphasized that to prevent environmental damage and protect human health, it is crucial to adopt a careful and balanced approach to fertilizer management. This necessitates considering both organic and inorganic sources, as well as the specific requirements of different crops and soils. By optimizing fertilizer use, farmers can minimize the negative impacts of excessive chemical inputs while ensuring adequate nutrient supply for healthy crop growth.

Green manure emerges as a promising strategy to address these challenges by enhancing crop productivity while safeguarding the environment and human health. By incorporating organic matter into the soil, green manure significantly boosts soil fertility, organic carbon content, nutrient availability, fostering healthier crop growth and ultimately increasing yields (Singh *et al.*, 2023) ^[23].

The most significant factor limiting rice grain yield and a major global nutrition concern is zinc (Zn), which comes in second place to nitrogen (Farooq *et al.*, 2018) ^[7]. Zinc, a vital macro-micronutrient, plays a multifaceted role in various metabolic processes associated with rice growth. As a crucial component of plant defense, zinc enhances plant resilience against pathogens and stresses. It also functions as a cofactor for antioxidant enzymes like peroxidase and catalase, protecting plants from oxidative damage. Additionally, zinc is involved in protein synthesis, enzyme activation, gene expression and carbohydrate metabolism, all of which are essential for optimal plant growth and development. By strategically enhancing the application of zinc through different agronomic techniques, it is possible to optimize its availability to rice plants, leading to improved growth, yield and overall plant health (Hassan *et al.*, 2020) ^[9].

While green manuring offers significant advantages for sustainable rice production, its impact can be further amplified by supplementing it with zinc fertilization. Zinc is a vital micronutrient that plays a crucial role in plant growth, development, and nutrient uptake. By ensuring efficient zinc uptake, zinc fertilizers can enhance plant health, increase yields and improve the nutritional quality of rice grains. The synergistic combination of green manuring and zinc fertilization presents a promising path towards achieving sustainable rice production. This approach not only boosts yields and nutritional quality but also minimizes the environmental impact of agriculture by reducing the reliance on synthetic fertilizers and mitigating soil degradation. By harnessing the complementary benefits of these two practices, farmers can cultivate healthier crops, protect the environment and contribute to a more sustainable food system (Baral *et al.*, 2024) ^[2].

Materials and Methods

A field study was carried out during June 2023 - September 2023 at the Experimental Farm, Department of Agronomy, Faculty of Agriculture, Annamalai University, Annamalai Nagar, Cuddalore District, Tamil Nadu. The experimental farm is situated at 11° 24' N latitude and 79° 44' E longitude and an elevation of + 5.79 m above Mean Sea Level (MSL). The experimental was laid out in RBD with eight treatment and replicated thrice. The treatments are T₁- Control; T₂- RDF (120:40:40 kg N P₂O₅ K₂O ha⁻¹); T₃ - RDF + GM @ 6.25 t ha⁻¹ + Soil application of ZnSO₄ @ 25 kg ha⁻¹; T₄ - RDF + GM @ 6.25 t ha⁻¹ + Foliar application of 0.2% Nano Zn at 50% flowering, milky and dough stage; T₅ - RDF + GM @ 6.25 t ha⁻¹ + Soil application of 1.0 L ha⁻¹ Zn solubilizers; T₆ - RDF + GM @ 6.25 t ha⁻¹ + Soil application of ZnSO₄ @ 25 kg ha⁻¹+ Foliar application of 0.2% Nano Zn at 50% flowering, milky and

dough stage; T₇ - RDF + GM @ 6.25 t ha⁻¹ + Soil application of ZnSO₄ @ 25 kg ha⁻¹+ Soil application of 1.0 L ha⁻¹ Zn solubilizers and T₈ - RDF + GM @ 6.25 t ha⁻¹ + Soil application of ZnSO₄ @ 25 kg ha⁻¹+ Foliar application of 0.2% Nano Zn at 50% flowering, milky and dough stage + Soil application of 1.0 L ha⁻¹ Zn solubilizers. Rice variety ADT 43 was selected for the study with a seed rate of 60 kg ha⁻¹. The green manure applied was *Sesbania aculeata* @ 6.25 t ha⁻¹. The data for Growth attributes viz., plant height, number of tillers m⁻², root length, root volume, LAI and DMP, the Yield attributes viz., number of productive tillers m⁻², number of filled grains panicle⁻¹ and test weight were collected. And also the nutrient uptake by plants were also analyzed. Standard agronomic practices were adopted. Plant height was measured from the soil surface to the tip of the top leaf at harvesting. The average height for five sample plants was calculated and recorded in centimeters. To assess tiller numbers, four 0.25 m² quadrats were randomly placed within each plot at flowering. The total number of tillers within each quadrat was counted and used to estimate the number of tillers per square meter. Leaf area index of the rice crop at flowering was worked out without removing the leaves by using the following suggested by Palanisamy and Gomez (1974).

$$LAI = \frac{K (L \times W)(\text{Number of leaves hill}^{-1})}{\text{Area occupied by the plant}}$$

Where,

K = Adjustment factor (0.75)

L = Leaf length (cm)

W = Leaf width (cm)

To assess root length and volume, entire rice plants were carefully uprooted at flowering stages. The roots were gently washed to remove soil particles, and individual root lengths were measured from the root base to the tip and recorded in centimeters. To determine root volume, the root system of each plant was submerged in a graduated cylinder filled with a known volume of water. The increase in water level, representing the root volume, was recorded in cubic centimeters (cm³) at flowering stages. Plant samples were collected from the study region at harvesting. To ensure accurate measurements, the samples were air-dried and then oven-dried for 48 hours at a temperature of 65 °C ± 5 °C. The dried samples were weighed and the results were expressed in kilograms per hectare (kg ha⁻¹). When the crop reached its maximum tillering stage, the tillers were counted to determine the number of productive tillers m⁻². For the purpose of counting the filled grains panicle⁻¹, the panicles were selected at random. By applying pressure with the fingertips, it was possible to distinguish between well-filled and chaffy grains, which were then counted and noted separately. Thousands of filled grains were gathered at random from the bulk of grain in each plot and their weight was measured at a moisture level of 14 per cent and expressed in g. For the purpose of analyzing total N, P and K, the oven-dried plant samples collected for the generation of dry matter were chopped and ground in a willey mill. The DMP obtained corresponded to the nutritional levels acquired in percentage from the analysis, which were then multiplied and expressed in kg ha⁻¹.

The various growth and yield parameters observed during the study were analyzed statistically using the methods outlined by Gomez and Gomez (1984) ^[8]. Significant differences between treatments were determined using the 'F' test at a 5% probability level (P=0.05), and the critical difference (CD) was calculated accordingly. Non-significant treatment differences were

indicated by 'NS'.

Results and Discussion

Growth and yield attributes

The study demonstrated a significant disparity in all quantitative and qualitative characteristics examined across various nutrient management practices (Table 1). Among all treatments, the application of RDF, GM @ 6.25 t ha⁻¹, Soil application of ZnSO₄ @ 25 kg ha⁻¹, Soil application of 1.0 L ha⁻¹ Zn solubilizer, Foliar application of 0.2% Nano Zn at 50% flowering, milky and dough stage (T₈) emerged as the optimal practice. This treatment resulted in the highest plant height (101.6 cm), number of tillers m⁻² (558), root length (30.1 cm), root volume (26.5 cc), leaf area index (6.1), and dry matter production (13217 kg ha⁻¹). The increase in growth attributes might be due to the integrated nutrient management which significantly enhanced crop growth and yield through various mechanisms. By increasing nutrient availability, it stimulated meristematic activity, leading to increased plant height, tiller production, and leaf area index. Green manure incorporation improved soil health, further enhancing nutrient uptake and plant growth. Zinc, essential for

auxin synthesis, played a crucial role in promoting root and shoot development. Balanced NPK fertilization supported overall plant vigor and seed quality. Additionally, green manure and zinc applications positively influenced photosynthesis and dry matter production. These findings align with previous research by Jalal *et al.* (2024)^[11], Sutardi *et al.* (2022)^[26], Ugile *et al.* (2024)^[27], Ramesh (2024)^[19], Ahirwal (2022)^[1] and Singh *et al.* (2024)^[24].

The data revealed that the application of RDF, GM @ 6.25 t ha⁻¹, Soil application of ZnSO₄ @ 25 kg ha⁻¹, Soil application of 1.0 L ha⁻¹ Zn solubilizer, Foliar application of 0.2% Nano Zn at 50% flowering, milky and dough stage (T₈) was the most effective treatment. This treatment resulted in the highest no of productive tillers m⁻² (348.0), no of filled grains panicle⁻¹ (109.5) and thousand grain weight (15.4 g) at harvest (Table 2). Organic manure treatments outperformed the control in enhancing productive tillers, grains per panicle, spikelet fertility and panicle weight. This improvement is attributed to the consistent and balanced nutrient supply from organic manures, promoting optimal plant growth and development.

Table 1: Effect of green manuring and zinc fertilization on growth attributes of transplanted rice

Treatments	Plant height (cm)	No of tillers m ⁻²	Root length (cm)	Root volume (cc)	Leaf area index	DMP (kg ha ⁻¹)
T ₁ - Control	81.7	432	19.2	17.9	2.8	6105
T ₂ - RDF only	87.4	457	22.0	19.1	3.3	8600
T ₃ - T ₂ + GM @ 6.25 t ha ⁻¹ + Soil application of ZnSO ₄ @ 25 kg ha ⁻¹	92.3	496	25.5	21.7	4.2	10711
T ₄ - T ₂ + GM @ 6.25 t ha ⁻¹ + Foliar application of 0.2% Nano Zn at 50% flowering, milky and dough stage	94.6	513	26.9	23.0	4.7	11210
T ₅ - T ₂ + GM @ 6.25 t ha ⁻¹ + Soil application of 1.0 L ha ⁻¹ Zn solubilizer	89.8	477	23.9	20.4	3.7	9414
T ₆ - T ₂ + GM @ 6.25 t ha ⁻¹ + Soil application of ZnSO ₄ @ 25 kg ha ⁻¹ + Foliar application of 0.2% Nano Zn at 50% flowering, milky and dough stage	99.3	546	29.0	25.4	5.6	12523
T ₇ - T ₂ + GM @ 6.25 t ha ⁻¹ + Soil application of ZnSO ₄ @ 25 kg ha ⁻¹ + Soil application of 1.0 L ha ⁻¹ Zn solubilizer	97.0	531	27.9	24.2	5.1	11764
T ₈ - T ₂ + GM @ 6.25 t ha ⁻¹ + Soil application of ZnSO ₄ @ 25 kg ha ⁻¹ + Soil application of 1.0 L ha ⁻¹ Zn solubilizer + Foliar application of 0.2% Nano Zn at 50% flowering, milky and dough stage	101.6	558	30.1	26.5	6.1	13217
SE(m)	0.33	1.81	0.15	0.17	0.07	81.21
S.ED	0.92	5.1	0.41	0.47	0.18	229
CD (P=0.05)	2.26	11	0.89	1.07	0.39	495

Table 2: Effect of green manuring and zinc fertilization on yield attributes of transplanted rice

Treatments	No of productive tillers m ⁻²	No of filled grains panicle ⁻¹	Thousand grain weight (g)
T ₁ - Control	293.6	89.9	15.3
T ₂ - RDF only	301.4	93.5	15.2
T ₃ - T ₂ + GM @ 6.25 t ha ⁻¹ + Soil application of ZnSO ₄ @ 25 kg ha ⁻¹	317.3	98.6	15.4
T ₄ - T ₂ + GM @ 6.25 t ha ⁻¹ + Foliar application of 0.2% Nano Zn at 50% flowering, milky and dough stage	325.4	101.1	15.4
T ₅ - T ₂ + GM @ 6.25 t ha ⁻¹ + Soil application of 1.0 L ha ⁻¹ Zn solubilizer	309.0	96.1	15.2
T ₆ - T ₂ + GM @ 6.25 t ha ⁻¹ + Soil application of ZnSO ₄ @ 25 kg ha ⁻¹ + Foliar application of 0.2% Nano Zn at 50% flowering, milky and dough stage	340.5	106.8	15.4
T ₇ - T ₂ + GM @ 6.25 t ha ⁻¹ + Soil application of ZnSO ₄ @ 25 kg ha ⁻¹ + Soil application of 1.0 L ha ⁻¹ Zn solubilizer	333.0	104.1	15.3
T ₈ - T ₂ + GM @ 6.25 t ha ⁻¹ + Soil application of ZnSO ₄ @ 25 kg ha ⁻¹ + Soil application of 1.0 L ha ⁻¹ Zn solubilizer + Foliar application of 0.2% Nano Zn at 50% flowering, milky and dough stage	348.0	109.5	15.4
SE(m)	1.23	0.40	0.003
S.ED	3.46	1.12	0.009
CD (P=0.05)	7.42	2.36	NS

Similar to the findings of Sathiyabama *et al.* (2021)^[21], zinc plays a crucial role in post-anthesis cell differentiation, particularly during fertilization. Zinc high concentration in pollen grains and its strategic allocation to seeds likely contributed to the equal or superior performance of yield-related traits in zinc-treated plants. The observed increase in yield

attributes and grain yield following zinc application can be attributed to enhanced zinc uptake, leading to increased biomass production and efficient photosynthate translocation to reproductive structures. Dhaincha incorporation significantly enhanced soil health by providing readily decomposable organic matter, boosting soil organic matter content and nutrient

availability. This improvement in soil properties, combined with increased zinc uptake from applied fertilizers, contributed to the positive outcomes observed in rice growth, yield attributes and grain yield. Beyond nitrogen, dhaincha biomass recycled substantial quantities of phosphorus, potassium, and other essential nutrients, further augmenting soil fertility and overall ecosystem health. These findings align with those of Singh and Shivay (2015)^[22], and Peramaiyan *et al.* (2022)^[18].

Nutrient uptake

Integrated nutrient management significantly influenced rice plants nutrient uptake (nitrogen, phosphorus, potassium, and zinc). The treatment combining RDF,GM @ 6.25 t ha⁻¹, Soil application of ZnSO₄ @ 25 kg ha⁻¹, Soil application of 1.0 L ha⁻¹ Zn solubilizer, Foliar application of 0.2% Nano Zn at 50% flowering, milky and dough stage (T₈) demonstrated the highest nutrient uptake (Table 3). This treatment resulted in the highest uptake of N (158.9 kg ha⁻¹), P (47.9 kg ha⁻¹), K (143.7 kg ha⁻¹) and Zn (149.5 and 349.8 g ha⁻¹). Enhanced plant growth,

characterized by increased plant height, leaf area, photosynthetic activity, root development, and dry matter production, facilitated greater nutrient uptake. This improved nutrient acquisition contributed to higher panicle number, grain number per panicle, and overall productivity. Green manure rapid decomposition and mineralization facilitated efficient nitrogen release, enhancing nutrient availability. NPK fertilizers significantly influenced root development, facilitating efficient nutrient uptake from the soil. Green manure incorporation and NPK fertilization improved soil fertility and nutrient availability, stimulating root development and enhancing nutrient uptake (Ismael *et al.*, 2021; Paiman *et al.*, 2021; Kalita *et al.*, 2022)^[10, 16, 12]. Zinc application, through soil and foliar methods, increased zinc uptake and concentration in the grain. Zn-solubilizing bacteria enhanced zinc uptake by producing organic acids and phytohormones. Foliar zinc application increased zinc uptake by facilitating direct absorption through leaves. These findings align with previous research by Baskar (2024)^[3], Sitareshmi *et al.* (2024)^[25], Rout *et al.* (2020)^[20], and Ramesh (2024)^[19].

Table 3: Effect of green manuring and zinc fertilization on nutrient uptake of transplanted rice

Treatments	Plant nutrient uptake (kg ha ⁻¹)			Zinc uptake (g ha ⁻¹)	
	N	P	K	Harvest (grain)	Harvest (straw)
T ₁ - Control	128.9	30.9	107.2	23.2	70.2
T ₂ - RDF only	144.2	36.5	118.3	62.1	164.1
T ₃ - T ₂ + GM @ 6.25 t ha ⁻¹ + Soil application of ZnSO ₄ @ 25 kg ha ⁻¹	150.1	40.1	124.8	88.3	217.4
T ₄ - T ₂ + GM @ 6.25 t ha ⁻¹ + Foliar application of 0.2% Nano Zn at 50% flowering, milky and dough stage	152.4	41.9	128.7	99.4	246.8
T ₅ - T ₂ + GM @ 6.25 t ha ⁻¹ + Soil application of 1.0 L ha ⁻¹ Zn solubilizer	147.2	38.3	121.6	77.5	189.6
T ₆ - T ₂ + GM @ 6.25 t ha ⁻¹ + Soil application of ZnSO ₄ @ 25 kg ha ⁻¹ + Foliar application of 0.2% Nano Zn at 50% flowering, milky and dough stage	156.9	45.9	138.7	131.5	312.6
T ₇ - T ₂ + GM @ 6.25 t ha ⁻¹ + Soil application of ZnSO ₄ @ 25 kg ha ⁻¹ + Soil application of 1.0 L ha ⁻¹ Zn solubilizer	154.7	43.8	132.7	112.3	278.6
T ₈ - T ₂ + GM @ 6.25 t ha ⁻¹ + Soil application of ZnSO ₄ @ 25 kg ha ⁻¹ + Soil application of 1.0 L ha ⁻¹ Zn solubilizer + Foliar application of 0.2% Nano Zn at 50% flowering, milky and dough stage	158.9	47.9	143.7	149.5	349.8
SE(m)	0.30	0.17	0.50	1.72	4.20
S.ED	0.78	0.48	1.42	4.85	11.67
CD (P=0.05)	1.69	1.05	3.05	10.50	25.05

Conclusion

The integrated application of RDF, GM, ZnSO₄, foliar Nano-Zn, and Zn solubilizers (T₈) demonstrated superior performance in terms of rice growth, yield attributes and nutrient uptake compared to other treatments. The integrated treatment T₈ effectively addressed the nutritional needs of rice plants, promoting robust growth and development. By providing a balanced supply of essential nutrients, including zinc, the treatment supported optimal photosynthesis, tillering and grain filling. This resulted in increased plant height, tiller number, panicle length and grain weight, ultimately leading to higher yields. Moreover, this approach contributed to improved soil health and nutrient cycling by enhanced soil organic matter content, improved soil structure and promoted nutrient retention. This facilitated efficient nutrient uptake by rice plants, reducing the need for excessive fertilizer applications and minimizing nutrient leaching. This combination of organic and inorganic inputs is highly recommended for lowland rice cultivation as it offers a promising approach to enhance both yield and economic returns.

Reference

1. Ahirwal A. Production potential, soil health, water productivity and economics of rice (*Oryza sativa* L.) based cropping system under different nutrient management.

Jabalpur, Department of Agronomy, College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya; c2022.

2. Baral K, Shivay YS, Prasanna R, Kumar D, Srinivasarao C, Mandi S, Reddy KS. Optimising nitrogen use efficiency of prilled urea through integrated use of Nano-ZnO and green manuring for better productivity, quality and nutritional status of Basmati rice crop. *Front Sustain Food Syst.* 2024;8:1352924.

3. Baskar M. Management of zinc for rice in sodic soils. *Asian J Soil Sci Plant Nutr.* 2024;10(3):310-318.

4. Directorate of Economic and Statistics (DES). Agricultural statistics for 2020-2021 agricultural crop year at a glance. 2021. Available from: desaagri.gov.in.

5. Food and Agriculture Organization (FAO). Annual report 2022. 2022. Available from: www.fao.org.in.

6. Food and Agriculture Organization (FAO). Annual report 2023. 2023. Available from: www.fao.org.in.

7. Farooq M, Ullah A, Rehman A, Nawaz A, Nadeem A, Wakeel A, *et al.* Application of zinc improves the productivity and biofortification of fine grain aromatic rice grown in dry seeded and puddled transplanted production systems. *Field Crops Res.* 2018;216:53-62.

8. Gomez KA, Gomez. Statistical procedures for agricultural research. *Indian J Stat.* 1984;47(2):296-299.

9. Hassan M, Aamer M, Chattha MU, Haiying T, Shahzad B,

- Barbanti L, *et al.* The critical role of zinc in plants facing drought stress. *Agriculture*. 2020;10(9):396.
10. Ismael F, Ndayiragije A, Fangueiro D. New fertilizer strategies combining manure and urea for improved rice growth in Mozambique. *Agronomy*. 2021;11(4):783.
 11. Jalal A, Junior EF, Filho TCM. Interaction of zinc mineral nutrition and plant growth-promoting bacteria in tropical agricultural systems: A review. *Plants*. 2024;13(5):571.
 12. Kalita J, Bhattacharyya HC, Thakuria RK, Bhattacharyya D, Das K. Evaluation of suitable rice (*Oryza sativa*) based cropping systems under rainfed medium land situation of Assam for enhancing farmers' income and soil health. *Crop Res*. 2022;57(1-2):1-7.
 13. Mi K, Yuan X, Wang Q, Dun C, Wang R, Yang S, *et al.* Zinc oxide nanoparticles enhanced rice yield, quality and zinc content of edible grain fraction synergistically. *Front Plant Sci*. 2023;14:1196201.
 14. Mohankumar L, Thiyaharajan M, Venkidusamy KS. The sustainability of fertilizer usage in the rice production system and its influencers evidence from Erode district of Tamil Nadu, India. *Int J Sustain Dev World Ecol*. 2023;30(6):620-632.
 15. Mykhailova E, Protasenko O, Moroz M, Reznichenko A. Analysis of the safety condition of humans, the environment and working conditions during the fertilizers handling. *Municipal Econ Cities*. 2021;4(164):203-214.
 16. Paiman PA. Maximizing the rice yield (*Oryza sativa* L.) using NPK fertilizer. *Open Agric J*. c2021;15.
 17. Palaniswamy KM, Gomez KA. Length-width method for estimating leaf area of rice. *Agron J*. 1974;66(3):430-433.
 18. Peramaiyan P, Craufurd P, Kumar V, Seelan LP, McDonald AJ, Kishore A, *et al.* Agronomic biofortification of zinc in rice for diminishing malnutrition in South Asia. *Sustainability*. 2022;14(13):7747.
 19. Ramesh MNP. Effect of foliar application of nano zinc on nutrient uptake, yield and quality of wheat on zinc deficient and sufficient soils of inceptisol [dissertation]. Mahatma Phule Krishi Vidyapeeth; c2024.
 20. Rout SK. Response of rice (*Oryza sativa* L.) to foliar application of nano zinc [dissertation]. Department of Soil Science and Agricultural Chemistry, OUAT, Bhubaneswar; 2020.
 21. Sathiyabama N, Aruna L, Illakia K, Dhayanithi C, Naresh VSVG, Jayaraghavi R, *et al.* Effect of organic manure on growth and yield of transplanted rice (*Oryza sativa* L.) under coastal Cauvery deltaic region. *Int J Curr Microbiol App Sci*. 2021;10(6):715-728.
 22. Singh A, Shivay YS. Zinc application and green manuring enhances growth and yield in basmati rice (*Oryza sativa* L.). *Indian J Plant Physiol*. 2015;20:289-296.
 23. Singh D, Devi KB, Ashoka P, Bahadur R, Kumar N, Devi N, *et al.* Green manure: aspects and its role in sustainable agriculture. *Int J Environ Climate Change*. 2023;13(11):39-45.
 24. Singh T, Kothari M, Singh AV, Shankhdhar D, Shankhdhar SC. Impact of zinc solubilizing bacteria and microbial consortia on growth and yield of rice (*Oryza sativa* L.). *J Exp Agric Int*. 2024;46(8):611-618.
 25. Sitaresmi T, Pratiwi E, Rohaeni WR, Azis A, Bakar BA, Margaret S, *et al.* Zn content of biofortified rice variety is consistently higher than popular variety under various fertilizers applications. *AIP Conf Proc*. c2024;2957.
 26. Sutardi M, Pertiwi RHP, Praptana M, Anda H, Purwaningsih J, Triastono J, *et al.* Increasing yield and economic value of upland rice using inorganic fertilizer and poultry manure in dryland. *Agronomy*. 2022;12(11):2829.
 27. Ugile SK, Chaudhari AA, Chavan PG, Mane SS, Satpathy A. Soil and foliar application of Zn and Fe impact on growth, grain yield and seed quality of rice (*Oryza sativa* L.). *Asian J Soil Sci Plant Nutr*. 2024;10(2):110-117.
 28. United States Department of Agriculture (USDA). India grain and feed update (Quarterly Update May). Global Agricultural Information Network; c2024. Available from: www.usda.gov.in.