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Evaluating the effect of green manuring and zinc fertilization on yield, economics and post-harvest nutrient status 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 (*Kuruvai*) 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 yield, economics and post-harvest nutrient status of transplanted rice.

Keywords: Green manures, zinc, nano zinc, zinc solubilizers, post-harvest nutrient status

Introduction

Rice (*Oryza sativa* L.) is a staple food for over half the world's population, particularly in Asia, where 90 per cent of global production and cultivation occur. Its widespread cultivation and consumption have earned it the title "global grain". India, the world second-largest rice producer after China, faces significant challenges in meeting the increasing demand for rice while addressing environmental concerns. In India, 47.83 million hectares are used for rice cultivation, with a production of 135.75 million tonnes of grain annually and 2.8 t ha⁻¹ of productivity (MAFW, 2023) [6]. The declining quality and quantity of rice production, coupled with rising environmental issues, necessitates innovative and sustainable agricultural practices. Green manuring, a method of incorporating organic matter into the soil through plant residues, emerges as a promising solution. By enhancing soil fertility, organic carbon content, and nutrient availability, green manuring promotes healthier crop growth and increased yields (Valizadeh *et al.*, 2023) [15].

The most critical concern in rice production is meeting the ever-increasing global demand for rice, particularly without compromising nutritional quality. As the world population continues to grow, so too does the need for this essential staple food. Ensuring that rice production can keep pace with this demand while maintaining its nutritional value is a paramount challenge for agriculture and food security. Zinc deficiency is a major constraint to rice grain yield and a global nutrition concern. As a vital micronutrient involved in various plant physiological processes, zinc plays a crucial role in increasing production, improving plant defense and activating antioxidant enzymes. Combining green manuring with zinc fertilization offers a synergistic approach to sustainable rice production.

This approach not only increases yields and improves nutritional quality but also reduces the environmental impact of agriculture by minimizing the need for synthetic fertilizers and soil degradation (Baral *et al.*, 2024)^[3]

Integrating NPK (nitrogen, phosphorus, potassium) fertilizers, green manures, zinc fertilizers, solubilizers and nano zinc in rice cultivation represents a multifaceted strategy to enhance soil fertility, improve crop yield, and ensure nutrient efficiency. By combining these elements, rice cultivation can achieve a more balanced nutrient profile, improved soil health and greater resilience against nutrient deficiencies, leading to increased productivity and sustainability.

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 yield viz., grain and straw yield and economics were computed. And also the post-harvest nutrient status were also analyzed. Standard agronomic practices were adopted.

The harvested mature crop from the net plot area was subjected to manual threshing, winnowing, and thorough sun drying. The dried grains were weighed, their moisture content was determined to be 14%, and the yield was calculated and expressed in kilograms per hectare (kg ha⁻¹). Additionally, the weight of the dried straw was measured and recorded in kg ha⁻¹. Post-harvest soil samples were collected randomly from the experimental fields to a depth of 15 cm and then pooled together. To assess the available nutrient content, composite soil samples were dried, ground into a fine powder, and sieved through a 2 mm mesh.

The various growth and yield parameters observed during the study were analyzed statistically using the methods outlined by Gomez and Gomez (1984)^[5]. 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'.

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

Treatments	Grain yield (kg ha ⁻¹)	Straw yield (kg ha ⁻¹)
T ₁ - Control	1500	3250
T ₂ - RDF only	3645	6797
T ₃ - T ₂ + GM @ 6.25 t ha ⁻¹ + Soil application of ZnSO ₄ @ 25 kg ha ⁻¹	4409	7493
T ₄ - T ₂ + GM @ 6.25 t ha ⁻¹ + Foliar application of 0.2% Nano Zn at 50% flowering, Milky and dough stage	4621	7835
T ₅ - T ₂ + GM @ 6.25 t ha ⁻¹ + Soil application of 1.0 L ha ⁻¹ Zn solubilizer	4184	7145
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	5355	8560
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	4878	8194
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	5726	8960
SE(m)	33	48
S.ED	93	135
CD (P=0.05)	200	290

Results and Discussion

Yield

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 and 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 grain yield (5726 kg ha⁻¹) and straw yield (8960 kg ha⁻¹) at harvest (Table 1). This increase is primarily attributed to the enhanced nitrogen availability from green manure incorporation, which improves soil structure and microbial activity. Rice yield is directly influenced by nitrogen and phosphorus content, while potassium plays a crucial role in plant stress tolerance (Moe *et al.*, 2019)^[7]. Green manure incorporation provides a sustained release of biologically fixed nitrogen, improving nutrient availability and crop growth. It also enhances plant growth and dry matter accumulation, leading to higher straw yield compared

to the control treatment. These findings were similar with those findings of Sravan *et al.* (2016)^[12] and Winarni *et al.* (2016)^[16]. Crop yield is determined by the interplay between photosynthetic capacity and grain development, with efficient photosynthate translocation and partitioning being crucial. Zinc involvement in enzyme systems, regulatory functions, and its role in auxin synthesis, carbohydrate production, and transport to grain-filling sites are crucial for enhancing crop yield. Zinc plays a pivotal role in enhancing crop yield by acting as a cofactor in numerous enzyme systems, regulating physiological processes, and boosting carbohydrate synthesis and translocation to grain-filling sites (Shukla *et al.*, 2022)^[11]. Zinc is a key micronutrient that significantly enhances rice yield through a complex interplay of physiological processes. By catalyzing the interconversion of CO₂ and HCO₃⁻ through carbonic anhydrase, zinc accelerates photosynthesis, leading to increased biomass accumulation and grain yield. Furthermore, zinc role in stomatal

conductance and anaerobic root respiration is crucial for optimizing water use efficiency and stress tolerance. These physiological enhancements, combined with increased tiller and panicle production, collectively contribute to higher grain yield and improved rice productivity. This findings aligns with those of Rout *et al.* (2020) ^[10]; Akmal *et al.* (2023) ^[11] and Ramesh (2024) ^[9].

Economics

The study demonstrated a significant disparity in economics of the crop examined across various nutrient management practices (Table 2). 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 gross returns (Rs.144892 ha⁻¹), net returns (Rs.75450 ha⁻¹) and BCR (2.00). The improved economic performance of the optimal treatment can be attributed to the enhanced yield resulting from the synchronized release and efficient utilization of nutrients derived from organic and inorganic sources. Additionally, the effective agronomic practices associated with the application of these inputs further boosted grain and straw yield, ultimately reflecting positively on the benefit-cost ratio. Alleviation of zinc deficiency through fertilizer application contributed to increased yield and, consequently, higher net returns (Sucharita *et al.*, 2023) ^[13].

Post-harvest nutrient status

Integrated nutrient management significantly influenced post-harvest nutrient status (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 post-harvest nutrient status (Table 3). This treatment resulted in highest post-harvest soil available N (238.2 kg ha⁻¹), P (23.4 kg ha⁻¹), K (285.5 kg ha⁻¹) and Zn (1.55 mg kg of soil⁻¹).

This is due to the integrated application of inorganic fertilizers, organic manures, and zinc significantly improved soil nutrient content and availability, promoting optimal crop growth and nutrient cycling through root exudates. Organic matter amendments ameliorated soil texture, drainage, and pH, thereby enhancing nutrient solubility and availability. Additionally, the gradual release of micronutrients from organic sources, such as iron, manganese, and copper, reduced nutrient leaching and promoted nutrient retention within the crop soil system. These findings corroborate the research of Devi *et al.* (2022) ^[4] and Sutardi *et al.* (2022) ^[14]. The increased soil zinc concentration observed with Zinc Solubilizing Bacteria (ZSB) application can be attributed to enhanced zinc solubilization and subsequent increased root growth. Nutrient uptake dynamics in rice were intricate, with macro- (N, P, K) and micronutrients (Zn) exhibiting interdependencies. Zinc availability declined progressively throughout the crop cycle due to plant uptake and potential losses. The combined application of ZnSO₄ and zinc-solubilizing bacteria mitigated zinc adsorption, thereby increasing its availability. Notably, *Bacillus* spp., known for their resilience, likely persisted in the rice rhizosphere, contributing to sustained zinc solubilization and increased post-harvest soil zinc levels. This finding aligns with the research of Prathap *et al.* (2022) ^[8] and Ali *et al.* (2023) ^[2].

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

Treatments	Cost of cultivation (Rs. ha ⁻¹)	Gross returns (Rs. ha ⁻¹)	Net returns (Rs. ha ⁻¹)	BCR
T ₁ - Control	52295	40665	-8630	0.77
T ₂ - RDF only	61373	87738	29365	1.42
T ₃ - T ₂ + GM @ 6.25 t ha ⁻¹ + Soil application of ZnSO ₄ @ 25 kg ha ⁻¹	66448	113348	49900	1.70
T ₄ - T ₂ + GM @ 6.25 t ha ⁻¹ + Foliar application of 0.2% Nano Zn at 50% flowering, milky and dough stage	67973	118269	53296	1.73
T ₅ - T ₂ + GM @ 6.25 t ha ⁻¹ + Soil application of 1.0 L ha ⁻¹ Zn solubilizer	65567	104307	41740	1.59
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	70648	136046	68398	1.92
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	68242	125117	59875	1.83
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	72442	144892	75450	2.00

Table 3: Effect of green manuring and zinc fertilization on post-harvest soil available nutrients status of rice

Treatments	Post-harvest soil nutrient (kg ha ⁻¹)			Zinc (mg kg of soil ⁻¹)
	N	P	K	
T ₁ - Control	215.1	17.3	251.2	0.94
T ₂ - RDF only	230.7	18.1	259.7	1.04
T ₃ - T ₂ + GM @ 6.25 t ha ⁻¹ + Soil application of ZnSO ₄ @ 25 kg ha ⁻¹	232.6	19.6	267.2	1.19
T ₄ - T ₂ + GM @ 6.25 t ha ⁻¹ + Foliar application of 0.2% Nano Zn at 50% flowering, milky and dough stage	234.0	20.5	271.1	1.28
T ₅ - T ₂ + GM @ 6.25 t ha ⁻¹ + Soil application of 1.0 L ha ⁻¹ Zn solubilizer	230.7	18.9	263.7	1.12
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	236.8	22.4	280.6	1.46
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	235.4	21.4	276.0	1.36
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	238.2	23.4	285.5	1.55
SE(m)	0.21	0.10	0.32	0.007
S.E.D	0.60	0.27	0.90	0.02
CD (P=0.05)	1.29	0.58	1.94	0.06

Conclusion

The integrated application of RDF, GM, zinc sulphate, nano zinc, and zinc solubilizers in rice cultivation significantly enhanced yield, economic viability, and post-harvest nutrient status. The synergistic interaction of these inputs led to improved soil health, nutrient availability, and crop growth, resulting in higher grain and straw yields.

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