

Effect of Agronomic iron biofortification through integrated nutrient management on soil physico-chemical properties of transplanted rice (*Oryza sativa* L.)

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DOI: [https://doi.org/10.63001/tbs.2026.v21.i03.S.I\(3\).pp01-11](https://doi.org/10.63001/tbs.2026.v21.i03.S.I(3).pp01-11)

KEYWORDS

Agronomic biofortification, FYM, Integrated nutrient management, Iron solubilizing bacteria, Iron Sulphate,

Received on:

03-05-2026

Accepted on:

03-06-2026

Published on:

01-07-2026

Abstract

A field experiment was conducted to study the effect of agronomic iron biofortification through integrated nutrient management on soil physico-chemical properties of transplanted rice (*Oryza sativa* L.) grown on sandy loam soils of Uttar Pradesh at Agronomy Farm, College of Agriculture, Acharya Narendra Deva University of Agriculture and Technology during two consecutive *kharif* seasons of 2024 & 2025. The experiment was laid out in randomized block design with twelve treatments and replicated thrice. The results revealed that, combined application of FYM @ 3 tonnes ha⁻¹, 0.5 % foliar spray of FeSO₄, 0.5 % foliar spray of Fe-EDTA, seedling dip with iron solubilizing bacteria @ 1 gm L⁻¹ of water for 30 minutes along with 100 % RDF (T₁₂) has significant improvement in organic carbon content of the soil of transplanted rice. The study revealed that agronomic iron biofortification through integrated nutrient management practices have improved the nutrient status of the soil.

Introduction

In agriculture, searching for new and sustainable techniques is crucial to guarantee global food security in a constantly changing environment. Rice is the staple food for three fourth of the Indian population and in Asia,

providing on an average of 33 % of total calorie uptake. Rice (*Oryza sativa* L.) belongs to Poaceae family. Rice alone contributes to 42.8 % to food grain production and 48.1 % of cereal production in the country. Globally, rice

cultivation spans approximately 164.06 million hectares, yielding about 759.00 million tonnes annually, In India, rice is grown in 49.38 million hectares with production of 135.29 million tonnes with average productivity of 2810 kg ha⁻¹. The vast majority, about 90 %, of rice grown worldwide is both produced and consumed in Asia. At the current rate of population growth (1.55%) in India, the rice requirement by 2050 would be around 130-135 million tonnes (**Anonymous, 2024-25**).

Globally, it is predictable that more than two billion people suffer from micronutrient deficiencies, also known as a “hidden hunger” (**Prom-u-thai *et al.*, 2020**). These deficiencies are usually dominant in highly developed countries and are more common among growing and developing children, pregnant and breast-feeding women, sportsmen and manual labour and workers. Among micronutrients, zinc, selenium and iron are associated with micronutrient malnutrition world widely. To combat these deficiencies, the biofortification process through agronomic practices offers a sustainable solution, a short-term approach and the easiest way of availability in the diet through the edible parts. The recommended daily dietary intake of Fe for human is 10 -15 mg. Rice plays an important role in food security for its broader adaptability while being a chief food crop for

more than a billion people. However, nutrient-rich aleurone layer and embryo are traditionally removed before human consumption, typically leaving only the starch-rich endosperm as the edible part. Therefore, the resulting polished rice has inadequate amounts of important micronutrients, such as iron and zinc (**Zou *et al.*, 2012**). A slight increase in its nutritive value would be highly beneficial for alleviation of Fe malnutrition.

Agronomic biofortification is method of the application of fertilizers containing micronutrients to soil or plant foliage through basal or foliar application to improve the nutritional quality of the edible parts of food crops. This method is beneficial for improving micronutrients that can be directly absorbed by the plant, such as zinc and iron, but not so for micronutrients that are synthesized in the plant and cannot be absorbed directly by the plant. Out of different management practices, optimum use of fertilizers is an important input and practice to realize maximum possible yields. Sustaining supply of deficient micronutrients along with primary macronutrients (NPK) in appropriate amounts and at right ratio is the key to maximize productivity gains from macronutrients. Soil application of iron fertilizers is often ineffective, because rapidly they are rapidly

converted into insoluble forms. Iron (Fe) is one of the key micronutrients essential for plant growth, yield and quality. Due to its improved nutrient uptake and micronutrient availability in the edible plant parts, foliar fertilization was found superior to soil application. Although Fe is the second most abundant metal element in earth's crust but its low solubility and high fixation in soil reduces its bioavailability to the plant roots. Iron is an essential plant nutrient required for electron transport in photosynthesis. Interveinal chlorosis giving a fine reticulate pattern of younger leaves is the indication of Fe deficiency. Fe plays a major role in redox reactions in metabolic processes such as photosynthesis, respiration and nitrogen assimilation besides being involved in biosynthesis of chlorophyll and hormones. Fe chlorosis is a widespread agricultural problem which reduces productivity as well as nutritional quality of crops. A continuous supply of Fe through roots and its remobilization from older to newly developing leaves is essential for optimum growth and yield. To overcome Fe deficiency in crops, foliar fertilization is one of the most economic and targeted approach. Many fungi are capable of solubilizing metals from insoluble forms thereby increasing their availability to plants. The release of organic

acids that sequester cations and modify the micro environment near roots is thought to be a major mechanism of solubilization by iron solubilizing fungi. The iron solubilizing fungus can solubilize iron from insoluble forms. Promotion of integrated nutrient management is being viewed as a farming practice with distinct advantages such as sustainability of crop production, protection against deteriorating soil, water and environment and as an economic venture. Application of organic manures can result in increased soil concentrations of nutrients and organic matter. Organic manures leave behind sufficient residual nutrients for the subsequent crops. So far, studies on effect of agronomic iron biofortification through integrated nutrient management on growth parameters of transplanted rice is meagre. Considering the reasons stated above and to generate more information, the present experiment is proposed to find out the **“Effect of agronomic iron biofortification through integrated nutrient management on soil properties of transplanted rice (*Oryza sativa* L.)”**.

Material and methods

A field trail was carried out at Agronomy Farm, College of Agriculture, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, during the two

consecutive *kharif* seasons of 2024 and 2025 for two years. The experiment laid out in randomized block design with twelve treatments which replicated thrice consists of Control (T₁), 100 % RDF (T₂), 75 % RDF + FYM @ 6 tonnes ha⁻¹ (T₃), 100 % RDF + foliar spray of FeSO₄ @ 0.5 % at tillering stage (T₄), 100 % RDF + foliar spray of Fe-EDTA @ 0.5 % at panicle initiation stage (T₅), 100 % RDF + seedling dip with Fe solubilizing bacteria @ 1 gm L⁻¹ of water for 30 minutes (T₆), 75 % RDF + FYM @ 6 tonnes ha⁻¹ + foliar spray of FeSO₄ @ 0.5 % at tillering stage + foliar spray of Fe-EDTA @ 0.5 % at panicle initiation stage (T₇), 75 % RDF + FYM @ 6 tonnes ha⁻¹ + seedling dip with Fe solubilizing bacteria @ 1 gm L⁻¹ of water for 30 minutes + foliar spray of FeSO₄ @ 0.5 % at tillering stage (T₈), 75 % RDF + FYM @ 6 tonnes ha⁻¹ + seedling dip with Fe solubilizing bacteria @ 1 gm L⁻¹ of water for 30 minutes + foliar spray of FeSO₄ @ 0.5 % at tillering stage + foliar spray of Fe-EDTA @ 0.5 % at panicle initiation stage (T₉), 100 % RDF + FYM @ 3 tonnes ha⁻¹ + foliar spray of FeSO₄ at tillering stage @ 0.5 % + foliar spray of Fe-EDTA @ 0.5 % at panicle initiation stage (T₁₀), 100 % RDF + FYM @ 3 tonnes ha⁻¹ + seedling dip with Fe solubilizing bacteria @ 1 gm L⁻¹ of water for 30 minutes + foliar spray of FeSO₄ @ 0.5 % at tillering stage (T₁₁) and 100 % RDF + FYM @

3 tonnes ha⁻¹ + seedling dip with Fe solubilizing bacteria @ 1 gm L⁻¹ of water for 30 minutes + foliar spray of FeSO₄ @ 0.5 % at tillering stage + foliar spray of Fe-EDTA @ 0.5 % at panicle initiation stage (T₁₂). The soil of the experimental field was sandy loam in texture, slightly alkaline in reaction (pH 7.6), low in organic carbon (0.38 %), available nitrogen (170.91 kg ha⁻¹) and medium in available phosphorous (10.21 kg ha⁻¹) and available potassium (232.51 kg ha⁻¹). The recommended dose of fertilizers in rice is 120-60-60 kg N, P₂O₅, K₂O ha⁻¹. Fertilizers, FYM and sources of iron were applied as per the treatments. The rice variety of Sarjoo-52 was grown in nursery and transplanted into main field with recommended spacing of 20 × 10 cm and treatments were applied as per the recommended doses. Irrigation was applied as per the requirement by alternate wetting and drying processes. Biometric assessments were done to evaluate growth parameters such as plant height and dry matter accumulation. Grain and straw yields from the net plot were sun dried to achieve a constant weight, with results expressed in kg ha⁻¹. All collected data were subjected to statistical analysis using analysis of variance (ANOVA) for a randomized block design. The significance of results was tested using the F-test at a 5 % level of probability, and

treatment means were compared using the critical difference method as outlined by Gomez (1972); Panse and Sukhatme (1985).

Results

Effect of agronomic iron biofortification through integrated nutrient management on physico-chemical properties of soil after harvest of rice

1. Bulk density (g cm⁻³)

Bulk density is an indicator of soil compaction and health. It affects infiltration, rooting depth, available water capacity, porosity, nutrient availability and microbial activity in soil which in turn influence the soil process and productivity. The bulk density of soil did not differ significantly due to different nutrient

management practices of agronomic iron biofortification during both the years of experimentation (Table 1). The results were in line with the findings of Hussain *et al.* (2001).

2. pH

Data pertaining to soil pH was presented in Table 1. The data indicates that soil pH did not differ significantly due to various nutrient management practices of rice during both the years of experimentation. The results were in line with the findings of Patil *et al.* (2003).

The soil pH ranged from 7.60 to 7.90 and in different treatments during 2024 & 2025, respectively.

Table 1. Effect of agronomic iron biofortification through integrated nutrient management on physico-chemical properties of soil in rice

Treatments	Bulk density (g/cc ⁻³)		pH		EC (dSm ⁻¹)		Organic carbon (%)	
	2024	2025	2024	2025	2024	2025	2024	2025
T ₁	1.37	1.37	7.70	7.80	0.25	0.24	0.39	0.41
T ₂	1.36	1.36	7.80	7.90	0.25	0.25	0.42	0.44
T ₃	1.36	1.36	7.80	7.90	0.24	0.24	0.42	0.44
T ₄	1.36	1.36	7.90	7.90	0.25	0.24	0.43	0.45
T ₅	1.36	1.36	7.70	7.70	0.24	0.23	0.42	0.45

T₆	1.36	1.36	7.60	7.70	0.24	0.23	0.43	0.45
T₇	1.35	1.34	7.80	7.80	0.25	0.24	0.43	0.46
T₈	1.35	1.34	7.70	7.80	0.26	0.25	0.43	0.46
T₉	1.34	1.33	7.70	7.80	0.25	0.24	0.45	0.49
T₁₀	1.34	1.33	7.60	7.60	0.23	0.23	0.44	0.48
T₁₁	1.34	1.33	7.80	7.90	0.24	0.24	0.44	0.48
T₁₂	1.34	1.33	7.70	7.80	0.25	0.24	0.45	0.49
SEm±	0.02	0.01	0.143	0.116	0.006	0.004	0.006	0.007
CD (P=0.05)	NS	NS	NS	NS	NS	NS	0.01	0.02

Treatment details: Control (T₁), 100 % RDF (T₂), 75 % RDF + FYM @ 6 tonnes ha⁻¹ (T₃), 100 % RDF + foliar spray of FeSO₄ @ 0.5 % at tillering stage (T₄), 100 % RDF + foliar spray of Fe-EDTA @ 0.5 % at panicle initiation stage (T₅), 100 % RDF + seedling dip with Fe solubilizing bacteria @ 1 gm L⁻¹ of water for 30 minutes (T₆), 75 % RDF + FYM @ 6 tonnes ha⁻¹ + foliar spray of FeSO₄ @ 0.5 % at tillering stage + foliar spray of Fe-EDTA @ 0.5 % at panicle initiation stage (T₇), 75 % RDF + FYM @ 6 tonnes ha⁻¹ + seedling dip with Fe solubilizing bacteria @ 1 gm L⁻¹ of water for 30 minutes + foliar spray of FeSO₄ @ 0.5 % at tillering stage (T₈), 75 % RDF + FYM @ 6 tonnes ha⁻¹ + seedling dip with Fe solubilizing bacteria @ 1 gm L⁻¹ of water for 30 minutes + foliar spray of FeSO₄ @ 0.5 % at tillering stage + foliar spray of Fe-EDTA @ 0.5 % at panicle initiation stage (T₉), 100 % RDF + FYM @ 3 tonnes ha⁻¹ + foliar spray of FeSO₄ at tillering stage @ 0.5 % + foliar spray of Fe-EDTA @ 0.5 % at panicle initiation stage (T₁₀), 100 % RDF + FYM @ 3 tonnes ha⁻¹ + seedling dip with Fe solubilizing bacteria @ 1 gm L⁻¹ of water for 30 minutes + foliar spray of FeSO₄ @ 0.5 % at tillering stage (T₁₁) and 100 % RDF + FYM @ 3 tonnes ha⁻¹ + seedling dip with Fe solubilizing bacteria @ 1 gm L⁻¹ of water for

30 minutes + foliar spray of FeSO₄ @ 0.5 % at tillering stage + foliar spray of Fe-EDTA @ 0.5 % at panicle initiation stage (T₁₂).

3. Electrical conductivity (dS m⁻¹)

Data on electrical conductivity are presented in Table 1). A glance at the data indicated that effect of different nutrient management practices had no significant influence on electrical conductivity of soil. The soil EC values ranged from 0.23 to 0.26 in different treatments during 2024 & 2025, respectively.

4. Soil organic carbon (%)

Soil organic carbon is defined as soil quality indicator, especially in the surface soils. In this layer, either the addition or removal of organic carbon takes place

through different nutrient management practices. Data pertaining to soil organic carbon after harvest of rice is presented in Table 1. Among the different nutrient management practices, significantly higher soil organic carbon was recorded with the combined application of FYM @ 3 tonnes ha⁻¹, 0.5 % foliar spray of FeSO₄, 0.5 % foliar spray of Fe-EDTA, seedling dip with iron solubilizing bacteria @ 1 gm L⁻¹ of water for 30 minutes along with 100 % RDF (T₁₂) which was statistically on par with 75 % RDF + FYM @ 6 tonnes ha⁻¹ + seedling dip with Fe solubilizing bacteria @ 1 gm L⁻¹ of water for 30 minutes + foliar spray of FeSO₄ @ 0.5 % at tillering stage + foliar spray of Fe-EDTA @ 0.5 % at panicle initiation stage (T₉). However, the lower organic carbon of soil was recorded in control treatment (T₁). This slight increase in organic carbon content in soil might be due to the addition of chemical fertilizers and FYM that attributed to the contribution of biomass to the soil in the form of previous season crop stubbles and residues. The results are in line with the research findings of Tadesse *et al.* (2013).

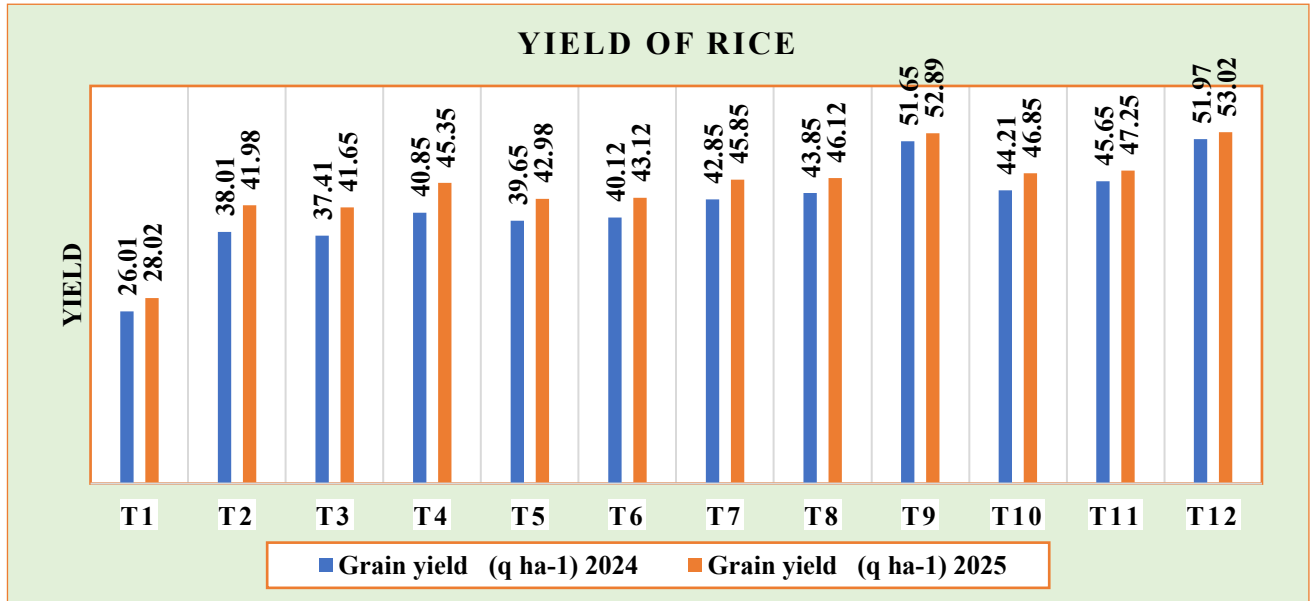
5. Grain yield

Data pertaining to grain yield as influenced by different nutrient management practices of agronomic iron biofortification was

presented in Fig. 1. Combined application of FYM @ 3 tonnes ha⁻¹, 0.5 % foliar spray of FeSO₄, 0.5 % foliar spray of Fe-EDTA, seedling dip with iron solubilizing bacteria @ 1 gm L⁻¹ of water for 30 minutes along with 100 % RDF (T₁₂) resulted in significant increase in grain yield which was statistically at par with 75 % RDF + FYM @ 6 tonnes ha⁻¹ + seedling dip with Fe solubilizing bacteria @ 1 gm L⁻¹ of water for 30 minutes + foliar spray of FeSO₄ @ 0.5 % at tillering stage + foliar spray of Fe-EDTA @ 0.5 % at panicle initiation stage (T₉). However, the lower grain yield was recorded in control treatment (T₁) and was found least effective during the two years of experimentation. Similar trend was recorded during both the years of experimentation. This is in conformity with the findings of Jeyabel (1999); Suresh and Salakinkop (2016) as photosynthetic pathways depend on enzymes and coenzymes which are synthesized by micronutrients. Positive effect of iron application by foliar spray on grain yield of rice might be due to increase in chlorophyll content of leaves of rice which might have increased photosynthesis and resulted in more dry matter, tiller m⁻² and leaf area index hence led to more capture of solar radiation that resulted in enhanced values of growth parameter and yield

attributing characters and finally resulted in higher grain yield.

6. Straw yield



The variations in straw yield of rice, as affected by different nutrient management practices were shown in Fig. 1. The results showed that 100 % RDF + FYM @ 3 tonnes ha⁻¹ + seedling dip with Fe solubilizing bacteria @ 1 gm L⁻¹ of water for 30 minutes + foliar spray of FeSO₄ @ 0.5 % at tillering stage + foliar spray of Fe-EDTA @ 0.5 % at panicle initiation stage (T₁₂) recorded significantly higher straw yield which was statistically on par with 75 % RDF + FYM @ 6 tonnes ha⁻¹ + seedling dip with Fe solubilizing bacteria @ 1 gm L⁻¹ of water for 30 minutes + foliar spray of FeSO₄ @ 0.5 % at tillering stage + foliar spray of Fe-EDTA @ 0.5 % at panicle initiation stage (T₉). However, the lower straw yield was recorded in control treatment. Similar trend was recorded during the two years of experimentation. The results of the present study are concordant with the results obtained from Das *et al.* (2016); Rani and Shamsida (2022) where foliar application of Fe increased herbage yield of teosinte.

Fig.1. Effect of agronomic iron biofortification through integrated nutrient management practices on grain yield (q ha⁻¹) and straw yield (q ha⁻¹) of rice during *kharif* 2024 & 2025

Discussion

Application of RDF, FYM and different sources of iron posed a great increment in

growth over rest of the treatments because of adequate availability of major and minor

nutrients in soil, which in turn favourably influenced physiological processes and building up of photosynthates. Iron, which is indispensable for chlorophyll synthesis and involved in the formation of pyrrole ring, a structural component of chlorophyll increased growth and ultimately yield attributes. Agronomic iron biofortification through integrated nutrient management enhances iron concentration in rice grains and can improve several physico-chemical properties of rice. The combined use of iron fertilizers recommended NPK, organic manures, and biofertilizers promotes better nutrient availability, chlorophyll synthesis, enzymatic activity, and assimilate translocation. As a result, grain filling, test weight, protein content, milling quality, and overall nutritional quality may improve. In addition, INM improves soil organic carbon, nutrient availability, and microbial activity, thereby supporting sustainable rice production and better grain quality. Foliar applications help to maintain nutrient availability throughout the growth cycle, contributing to improved biomass accumulation and increases the crop yield. When both grain and straw yields are enhanced, the overall biomass production increases.

Conclusions

The present study identified the beneficial role of iron through agronomic biofortification and organic sources of nutrients through integrated nutrient management practices in rice cultivation. Moreover, to achieve maximum growth, yield and nutrition, it is mandatory to optimize frequency and rate of application of micronutrients through foliar application has significantly improved the growth and yield. The improved nutrient practices involving micronutrient application in major crops like rice can aid in mitigating the iron deficiency. Biofortification is one of the the most potential solutions which is effective, economical and convenient to combat increasing micronutrient deficiencies in humans. Based on the result of the experiment, it may be concluded that for getting higher grain growth, yield of rice and better soil properties, combined application of RDF, organic sources of nutrients like FYM and foliar application of different iron sources and seedling treatment with microorganisms has significant effect on growth, yield and soil properties of rice.

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