

# INFLUENCE OF IRON AND ZINC BIOFORTIFICATION ON GROWTH AND YIELD OF DRILLED RICE (*ORYZA SATIVA* L.)

## Abstract

A field experiment was carried out with a view to study the “Influence of iron and zinc biofortification on growth and yield of drilled rice (*Oryza sativa* L.)” at the Experimental Farm, Krushi Vigyan Kendra, Navsari Agricultural University, Dediapada, Narmada, during *kharif* 2022 and 2023. The experiment was laid out in randomized block design with ten treatments. On the basis of pooled analysis, almost all the growth attributes, yield attributes and yield were significantly influenced due to soil and foliar application of Zn and Fe. Results of this experiment revealed that all the growth attributes *viz.* periodical plant height, number of tillers plant<sup>-1</sup>, leaf area, leaf area index, dry matter accumulation plant<sup>-1</sup> and yield attributes *viz.*, productive tillers m<sup>-2</sup>, number of filled grains panicle<sup>-1</sup>, number of unfilled grains panicle<sup>-1</sup>, panicle length, weight of panicle and test weight were recorded significantly higher under treatment T<sub>10</sub> (soil ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 25 kg ha<sup>-1</sup> and foliar ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 0.5% at 30 & 60 DAS). Significantly, lowest value of all growth parameters at different growth stages and yield attributes were obtained under absolute control (T<sub>1</sub>). Significantly higher rice grain yield (3035 kg ha<sup>-1</sup>) and straw yield (5336 kg ha<sup>-1</sup>) were also recorded under treatment of Soil ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 25 kg ha<sup>-1</sup> and Foliar ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 0.5% at 30 & 60 DAS (T<sub>10</sub>). However, it remained significantly at par with treatments T<sub>4</sub> (Soil ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 25 kg ha<sup>-1</sup>), T<sub>8</sub> (Soil ZnSO<sub>4</sub> @ 25 kg ha<sup>-1</sup> + Foliar ZnSO<sub>4</sub> @ 0.5% at 30 & 60 DAS), T<sub>9</sub> (Soil FeSO<sub>4</sub> @ 25 kg ha<sup>-1</sup> + Foliar FeSO<sub>4</sub> @ 0.5% at 30 & 60 DAS) and T<sub>2</sub> (Soil ZnSO<sub>4</sub> @ 25 kg ha<sup>-1</sup>).

**Key words:** biofortification, iron, zinc, drilled rice

## 1. INTRODUCTION

Rice (*Oryza sativa* L.) is the world's most staple cereal food crop. It is a good source of calories for approximately 40 percent of the world population (Virdia and Mehta, 2009). Rice is most important food crop for more than two billion people in Asia, provides 27 percent of dietary energy and 20 percent of overall dietary protein (Bashir *et al.*, 2007). Global rough rice demand is estimated to rise from 723 million tons in 2015 and is further expected to increase to 852 million tonnes by 2035 (Brar and Khush, 2018). It is a predominant crop in the lowland ecosystem. Asia is considered the "rice bowl" of the world, producing and consuming more than 90 per cent of the world's rice, but India and China contribute more than half of the world's rice. Rice occupies an area of about 163 million hectares globally with production and productivity of 769 million tonnes and 4717 kg ha<sup>-1</sup>, respectively. India ranks first in acreage (45.77 million hectares) and second in production (186.50 million metric tonnes) after China.

Rice production worldwide has increased to 751.9 million tons (FAO, 2017), with 90% of it produced and consumed in developing nations. However, around 870 million people worldwide suffer from chronic malnutrition (Da Silva, 2013), with the great majority of them living in underdeveloped nations where rice is strongly linked to food security and political stability. As a result, enhancing rice micronutrient status is critical for addressing crucial nutrition and health issues affecting large populations, particularly in poor or developing

nations. Iron and zinc are two micronutrients that are necessary for plant growth and human health. Iron and zinc deficiencies are the sixth and fifth largest health risk factors in developing nations, respectively (Freitas *et al.*, 2016; Sharma *et al.*, 2013), resulting in high mortality rates. As a result, resolving these dietary inadequacies will take time. Furthermore, polished rice contains just 2 mg kg<sup>-1</sup> iron and 12 mg kg<sup>-1</sup> zinc on average (IRRI, 2006), but human Zn and Fe intake recommendations are 12–15 and 10–15 mg, respectively (Welch and Graham, 2004). More than half of the world's population suffers from Fe and Zn deficiency, which can damage immunological function and affect human growth and development (Welch, 2005).

Zinc is an important micronutrient that plays a role in biological metabolism. It is gaining attention around the world as a result of rising reports of zinc inadequacy in food crops and humans, necessitating a food-based approach to address zinc malnutrition. It is involved in a variety of enzymatic and physiological processes, as well as several catalytic functions in the plant system, such as sugar transformation, protein synthesis and chlorophyll synthesis. As a result, a lack of zinc in the soil has a negative impact on plant growth and development. Every year, around 0.8 million individuals worldwide, including nearly 0.45 million children, are in danger of dying due to zinc deficiency (WHO, 2015). Iron deficiency is a widespread nutritional problem in developing countries, causing impairments of cognitive function, immune system and work capacity the increase in infant and maternal mortality represents major health complications associated with Fe deficiency and is the most common cause of anemia globally (Hunt, 2005; Carter *et al.*, 2010). Iron deficiency anemia (IDA) affects 1.62 billion people worldwide, including 293 million preschool children, 56 million pregnant women and 468 million non-pregnant women, according to published statistics (WHO 2008) As iron is the fourth most prevalent element in the earth's crust, it is found in abundance in soils; yet, the majority of iron in soils is unavailable for plant uptake (Meng *et al.*, 2005).

Biofortification is an attractive concept for making full use of a plant's potential for utilization and mobilization of micronutrients and it also helps in revamping the growing conditions of the crop (Zuo and Zhang, 2009). Increasing the bioavailable concentration of essential elements in edible parts of the crop is defined as biofortification (Graham *et al.*, 2001). As compared to brown rice, milled and polished rice become lower in nutritional quality and its zinc content is reduced by 1.83 times (from 33 to 18 parts per million), whereas its iron content is reduced by 2.14 times (from 8.8 to 4.1 parts per million) to 4.75 times (from 19 to 4 parts per million), which may vary according to grain milling processes (Majumder *et al.*, 2019).

## **2. MATERIALS AND METHODS**

The present study was conducted at the Experimental farm, Krushi vigyan kendra, Navsari agricultural university, Dediapada - Narmada during the two consecutive *kharif* seasons of 2022 and 2023. According to agro-climatic conditions, Dediapada is placed in south Gujarat zone II (Agro-ecological situation-I). The climate of this zone is typically tropical, characterized by humid and warm monsoon with heavy rain, a moderately cold winter and a fairly hot summer. The average annual rainfall of the tract is about 1000–1250 mm. The soil in the experimental field was clay in texture, medium in organic carbon (0.52 and 0.54%) and available nitrogen (275.19 and 270.31 kg ha<sup>-1</sup>), medium in available phosphorus (36.60 and 37.15 kg ha<sup>-1</sup>), high in available potassium (428.35 and 421.20 kg ha<sup>-1</sup>), medium available zinc (0.64 and 0.71 mg kg<sup>-1</sup>) and available Fe (7.20 and 7.46 mg kg<sup>-1</sup>). The soil was found to

be slightly alkaline (pH 7.2 and 7.31) with normal electrical conductivity (0.41 and 0.39 dS m<sup>-1</sup>).

In order to study the “Influence of iron and zinc biofortification on growth and yield of drilled rice (*Oryza sativa* L.)” a field experiment was conducted with total ten treatments comprising T<sub>1</sub>: Absolute control (Only RDF), T<sub>2</sub>: Soil ZnSO<sub>4</sub> @ 25 kg ha<sup>-1</sup>, T<sub>3</sub>: Soil FeSO<sub>4</sub> @ 25 kg ha<sup>-1</sup>, T<sub>4</sub>: Soil ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 25 kg ha<sup>-1</sup>, T<sub>5</sub>: Foliar ZnSO<sub>4</sub> @ 0.5% at 30 & 60 DAS, T<sub>6</sub>: Foliar FeSO<sub>4</sub> @ 0.5% at 30 & 60 DAS, T<sub>7</sub>: Foliar ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 0.5% at 30 & 60 DAS, T<sub>8</sub>: Soil ZnSO<sub>4</sub> @ 25 kg ha<sup>-1</sup> + Foliar ZnSO<sub>4</sub> @ 0.5% at 30 & 60 DAS, T<sub>9</sub>: Soil FeSO<sub>4</sub> @ 25 kg ha<sup>-1</sup> + Foliar FeSO<sub>4</sub> @ 0.5% at 30 & 60 DAS, T<sub>10</sub>: Soil ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 25 kg ha<sup>-1</sup> and Foliar ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 0.5% at 30 & 60 DAS with three replications during the *kharif* season of the years 2022 and 2023. Rice cultivar GR-16 (Tapi) was used for this experiment and it was released in 2018 from the Main Rice Research Centre Navsari, Navsari Agricultural University, Vyara. Early maturing upland rice variety GR-16 recorded 2983 kg ha<sup>-1</sup> mean grain yield in Gujarat Crop sown manually at a depth of 3-4 cm in the furrow, in which fertilizer was banded previously on each plot at a spacing of 30 cm x 10 cm. Seeds were covered properly with soil. After two weeks of sowing, the thinning and gap filling were carried out. Crop was grown under rainfed condition and also irrigation was applied as per requirement. The required quantity of fertilizer was worked out as per the unit area and treatment basis. The shallow furrows were opened manually in each plot as per the treatments in dry conditions. Inorganic fertilizers, 50% nitrogen through urea and a full dose of phosphorus through SSP, were applied at the basal just before sowing as a common dose to all treatments. Remaining 50% nitrogen through urea was applied 30 days after sowing when irrigation was applied. Soil applications of Zn and Fe through ZnSO<sub>4</sub> and FeSO<sub>4</sub> were applied at the basal just before sowing as per the treatment basis. Two foliar application of zinc sulphate and ferrous sulphate each at 0.5 percent, mixed with a 0.25 percent lime solution, were sprayed after 30 and 60 DAS as per the treatments. During foliar application, 400 liters in first spray and 500 liters in second spray mixture ha<sup>-1</sup> was used.

## 2.1 Growth Parameters

The plant height of five randomly selected and tagged plants from each net plot was measured by using wooden metre scale. The measurement was made from the base of the plant to the tip of last fully open leaf at 30, 60, 90 DAS and at harvest expressed in centimetre (cm). The progressive tiller count was recorded at 30, 60, 90 DAS and at harvest from five randomly selected plants from each net plot and converted to tillers per plant. Leaf area per plant was worked out following the procedure given by Gomez (1972).

$$\text{Leaf area (cm}^2\text{) of each leaf in middle tiller} = L \times W \times 0.65$$

Where, L = Maximum length of leaf (cm)

W = Maximum width of leaf (cm)

The leaf area index (LAI) was obtained by dividing the actual leaf area obtained per hill with the ground area occupied per hill. From there, the leaf area index was calculated by total leaf area of plant divided by total ground area under plant as proposed by Watson (1952). The dry matter accumulation was recorded at 30, 60, 90 DAS and at harvest for growth analysis from five plant in each gross plot were used for the estimation of dry matter. All the plants were uprooted and allowed to sun dry and finally oven dried at 65 ± 5 °C for recording constant dry weight. The weight thus obtained is expressed as dry weight plant<sup>-1</sup> (g) after dividing the total number of plants in the samples.

## 2.2 Yield parameters

The number of ear bearing tillers from the net plot area with the help of 1 m<sup>2</sup> quadrat from 30 DAS to maturity at every 30 days interval *i.e.*, 30, 60, 90 DAS & at harvest and expressed as number of tillers m<sup>-2</sup>. The number of filled and unfilled grains in all the five selected panicles from the five labelled hills in each treatment were counted and averaged to arrive at number of filled and unfilled grains panicle<sup>-1</sup>. The length of the five randomly selected panicles (cm) from the marked hill was measured in centimeter from the base to the tip of panicle. Weight of panicle was measured in gram from five randomly selected panicles from net plot at the time of harvest. Thousand grain weight (test weight) counted by five grain samples were collected at random from the net plot yield of each treatment. The grain samples were weighed and then the number of grains present in each sample was counted to arrive at test weight per 1000 grains (grams per 1000 grains). Grain and straw yield per plant were measured from randomly selected five plant from net plot and average was calculated. Grains from corresponding net plots were sun dried for 4 to 6 days and the weight of grains in each net plot area was converted and recorded as grain yield kg ha<sup>-1</sup>. Straw yield from the net plot of each treatment was dried in sun to a constant weight and after it convert to straw yield in kg ha<sup>-1</sup>. The harvest index was computed by percentage of economic yield to biological yield of rice and it recorded separately for each treatment.

The statistical analysis of the data of various observations recorded during investigation was carried out under Randomized Block Design through analysis of variance technique as described by Panse and Sukhatme (1978). The significant difference was tested by F-test at five per cent level of significance. The standard error of mean was calculated for all the parameters however, the critical difference were calculated when the difference among treatments were found significant. Further pooled analysis variance of two year workout to study the year effect on treatment and their interaction (Cochran and Cox, 1962).

## 3 RESULTS AND DISCUSSION

Results revealed that growth attributes of rice *i.e.* periodical plant height, number of tillers plant<sup>-1</sup>, leaf area, leaf area index, dry matter accumulation plant<sup>-1</sup> content and yield attributes *viz.*, productive tillers m<sup>-2</sup>, number of filled grains panicle<sup>-1</sup>, number of unfilled grains panicle<sup>-1</sup>, panicle length, weight of panicle, thousand grain weight, grain yield plant<sup>-1</sup>, straw yield plant<sup>-1</sup>, grain yield and straw yield were significantly influenced by different treatments.

### 3.1 Growth Attributes

Plant height is an important expression of plant growth and offers an immediate comparison of the different treatments. Data obtained on the progressive plant height at different stages of growth at 30, 60, 90 DAS and at harvest as affected by different treatments were put to statistical analysis and the results have been summarized and presented in Table 1. Plant height at 30 DAT (day after transplanting) was found nonsignificant.

The maximum plant height was recorded under treatment of soil ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 25 kg ha<sup>-1</sup> and Foliar ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 0.5% at 30 & 60 DAS (T<sub>10</sub>) during both year and pooled study, but it remained at par with treatments T<sub>4</sub>, T<sub>8</sub>, T<sub>9</sub>, T<sub>2</sub> and T<sub>3</sub> during both year. While treatments T<sub>4</sub>, T<sub>8</sub> and T<sub>9</sub> were found statistically at par with T<sub>10</sub> in the pooled result. Whereas, minimum plant height was recorded under treatment T<sub>1</sub> (Absolute control) across both the years of investigation and on a pooled basis, respectively. At 90 days after sowing (Table 1), significantly taller rice plants were observed in treatment T<sub>10</sub> and it was statistically at par with treatments T<sub>4</sub>, T<sub>8</sub> and T<sub>9</sub> during both years. In pooled analysis, T<sub>4</sub> and T<sub>8</sub> were found to be on par with T<sub>10</sub>. However, significantly lower plant height was observed during individual years of study and in pooled results under treatment absolute control (T<sub>1</sub>).

Data in Table 1. clearly indicated that plant height at harvest was recorded significantly higher in treatment Soil ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 25 kg ha<sup>-1</sup> and Foliar ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 0.5% at 30 & 60 DAS (T<sub>10</sub>) during both years, but it remained statistically at par with treatments T<sub>4</sub>, and T<sub>9</sub>. However, data on pooled analysis revealed that treatments T<sub>4</sub> and T<sub>8</sub> (Soil ZnSO<sub>4</sub> @ 25 kg ha<sup>-1</sup> + Foliar ZnSO<sub>4</sub> @ 0.5% at 30 & 60 DAS) were found to be on par with T<sub>10</sub>. The lowest plant height was registered with absolute control (T<sub>1</sub>) during both years and in pooled results at all stages of crop growth.

The data recorded on the number of tillers as influenced by different treatments at 30 day intervals starting from 30 DAS to harvest have been summarized and presented in Table 2. at 30 DAS, number of tillers plant<sup>-1</sup> was not altered due to soil and foliar application of Zn and Fe. However, foliar application of Zn and Fe and recorded a significantly higher maximum number of tillers plant<sup>-1</sup> in treatment soil ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 25 kg ha<sup>-1</sup> and foliar ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 0.5% at 30 & 60 DAS (T<sub>10</sub>) at 60, 90 DAS and at harvest during both year and in pooled results, respectively, which remained statistically at par with T<sub>4</sub>, T<sub>8</sub>, T<sub>9</sub> and T<sub>2</sub>. In pooled results, T<sub>4</sub> and T<sub>8</sub> were found to be on par with T<sub>10</sub>. The significantly lowest number of tillers plant<sup>-1</sup> at 60, 90 DAS and at harvest all stages of growth was observed under absolute control (T<sub>1</sub>).

Leaf area increased with the age of the crop up to 60 DAS and then declined in all treatments. At 30 DAS, there was no significant difference in leaf area with respect to soil and foliar application of Zn and Fe. The interaction effect was also found to be non significant. At 60 and 90 DAS (Table 3), among the different levels of soil and foliar application of Zn and Fe, application of soil ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 25 kg ha<sup>-1</sup> and foliar ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 0.5% at 30 & 60 DAS (T<sub>10</sub>) accounted for significantly higher leaf area over absolute control (T<sub>1</sub>) and was on par with treatments T<sub>4</sub>, T<sub>8</sub>, T<sub>9</sub> and T<sub>2</sub> during both years. Whereas, treatments T<sub>4</sub> (Soil ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 25 kg ha<sup>-1</sup>) and T<sub>8</sub> (Soil ZnSO<sub>4</sub> @ 25 kg ha<sup>-1</sup> + Foliar ZnSO<sub>4</sub> @ 0.5% at 30 & 60 DAS) are on par with treatment treatments T<sub>10</sub> in the pooled study.

The leaf area index is an important plant growth parameter that determines crop yield and the capacity of plants to trap solar energy for photosynthesis. The data presented in Table 4 revealed a remarkably increased leaf area index with an increase in the soil and foliar application of Zn and Fe as the crop aged up to 60 DAS. However, thereafter a decline was noticed. An examination of the data revealed that different treatments of soil and foliar application of Zn and Fe on LAI significantly influenced at all the growth stages, except at 30 DAS during 2022, 2023 and in the combined analysis. The data regarding LAI at 60 and 90 DAS presented in Table 4 showed that significantly higher LAI were recorded with treatment T<sub>10</sub>, but it remained at par with treatments T<sub>4</sub>, T<sub>8</sub>, T<sub>9</sub> and T<sub>2</sub> during both years. However, in the case of pooled analysis, treatment T<sub>4</sub> and T<sub>8</sub> are on par with treatment T<sub>10</sub>. The lower LAI at 60 DAS was obtained with treatment T<sub>1</sub> (Absolute control) during both years and in pooled results.

The results of the experiments on dry matter accumulation plant<sup>-1</sup> of rice graphically depicted in Table 5. An examination of the data revealed that different treatments of soil and foliar application of Zn and Fe on dry matter accumulation plant<sup>-1</sup> significantly influenced it at all the growth stages, except at 30 DAS during 2022, 2023 and in the combined analysis. Application of soil ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 25 kg ha<sup>-1</sup> and foliar ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 0.5% at 30 & 60 DAS (T<sub>10</sub>) recorded significantly higher dry matter accumulation plant<sup>-1</sup> of the rice crop at 60, 90 DAS and at harvest during both years, but it remained at par with treatments T<sub>4</sub>, T<sub>8</sub> and T<sub>9</sub> during both year. Whereas, in pooled results, it remained at par with

treatments T<sub>4</sub> and T<sub>8</sub>. Minimum dry matter accumulation plant<sup>-1</sup> was recorded under treatment T<sub>1</sub> (Absolute control).

The data presented in the Table 9 reveals that plant height, tillers, LAI and dry matter accumulation significantly influenced grain and straw yield of rice and they are highly positively correlated to each other. The results presented in above findings indicated that soil and foliar application of Zn and Fe showed significant effect on crop growth. Among different growth parameters *viz.*, plant height at 60, 90 DAS and at harvest, leaf area, number of tillers and dry matter accumulation plant<sup>-1</sup> at different growth stages of crop varied significantly by soil and foliar application of Zn and Fe.

Most of the photosynthetic pathways depends on enzymes and coenzymes which are synthesized by micronutrients. Increasing in growth parameters due to involvement of Zn and Fe which are involved in the synthesis of growth promoting hormones and the reduction process. Zn and Fe are essential for several enzymes that regulate metabolic activities in plants. Zn helps in auxin production, which led to the higher hormonal activity at critical crop growth stages, which ultimately resulted in better crop growth parameters. While, Fe indispensable for chlorophyll synthesis and involved in the formation of pyrrole ring, which is a structural component of chlorophyll and iron have a stimulating effect to increase the growth attributes. The results are similar findings with Zayed *et al.* (2011), Suresh S. and Salakinkop S. R. (2016), Goverdhan M. (2017), Kadam *et al.* (2018), Balachandrakumar, V. and Sudhagar Rao, G. B. (2018), Rao *et al.* (2019), Janardhan *et al.* (2019), Bharti *et al.* (2020) and Rao *et al.* (2020).

### 3.2 Yield Attributes and Yield

The data on yield attributes and yield *viz.*, productive tillers meter<sup>-2</sup>, number of filled grains panicle<sup>-1</sup>, number of unfilled grains panicle<sup>-1</sup>, panicle length (cm), panicle weight (g), 1000 grain weight (g), grain yield plant<sup>-1</sup> (g plant<sup>-1</sup>), straw yield plant<sup>-1</sup> (g plant<sup>-1</sup>), grain yield (kg ha<sup>-1</sup>), straw yield (kg ha<sup>-1</sup>) and harvest index (%) as influenced by soil and foliar application of Zn and Fe were presented in Table 6, 7 and 8.

The mean data of the number of tillers meter<sup>-2</sup> revealed that treatment T<sub>10</sub> (Soil ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 25 kg ha<sup>-1</sup> and Foliar ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 0.5% at 30 & 60 DAS) produced significantly more panicles during both years and in pooled results, and was statistically equal with T<sub>4</sub>, T<sub>8</sub> and T<sub>9</sub> in the first year. While treatments T<sub>4</sub>, T<sub>8</sub>, T<sub>9</sub> and T<sub>2</sub> were found statistically at par with T<sub>10</sub> during the second year. However, in pooled results, treatments T<sub>4</sub> (Soil Zn + Fe each @ 25 kg ha<sup>-1</sup>) and T<sub>8</sub> (Soil ZnSO<sub>4</sub> @ 25 kg ha<sup>-1</sup> + Foliar ZnSO<sub>4</sub> @ 0.5% at 30 & 60 DAS) remained on par with T<sub>10</sub>. Minimum number of tillers meter<sup>-2</sup> was recorded under treatment T<sub>1</sub> (Absolute control) (Table 6).

An appraisal of the data in Table 6 showed that soil and foliar application of Zn and Fe have a significant effect on the number of filled grains panicle<sup>-1</sup>. An application of soil ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 25 kg ha<sup>-1</sup> and foliar ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 0.5% at 30 & 60 DAS (T<sub>10</sub>) recorded the maximum number of filled grains panicle<sup>-1</sup> during both years and in pooled results. However, it was found to be on par with treatments T<sub>4</sub>, T<sub>8</sub>, T<sub>9</sub>, T<sub>2</sub> and T<sub>3</sub> during both years. While treatments T<sub>4</sub>, T<sub>8</sub> and T<sub>9</sub> were found statistically at par with T<sub>10</sub> in pooled results, Further, significantly the lowest number of filled grains panicle<sup>-1</sup> was recorded with the treatment of T<sub>1</sub> (Absolute control) during both years and in pooled results.

Results of this experiment revealed that various treatments of soil and foliar application of Zn and Fe significantly influenced the number of unfilled grains panicle<sup>-1</sup>. As far as the number of unfilled grains panicle<sup>-1</sup> is concerned, all the treatments under study significantly differ among each other and being minimum in treatment T<sub>10</sub> over absolute control treatment

T<sub>1</sub> which was statistically at par with treatments T<sub>4</sub>, T<sub>8</sub>, T<sub>9</sub> and T<sub>2</sub> (Soil ZnSO<sub>4</sub> @ 25 kg ha<sup>-1</sup>) during first years. While in case of second and in pooled results treatment treatments T<sub>4</sub>, T<sub>8</sub> and T<sub>9</sub> were found statistically at par with T<sub>10</sub>.

A perusal of the data presented in Table 7 revealed that soil ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 25 kg ha<sup>-1</sup> and foliar ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 0.5% at 30 & 60 DAS (T<sub>10</sub>) recorded significantly higher weight of panicle compared to the remaining treatments except Soil ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 25 kg ha<sup>-1</sup> (T<sub>4</sub>). However, significantly light weight of were found with treatment absolute control (T<sub>1</sub>) during both consecutive years and in combined results.

The data presented in Table 7 indicated that the differences in test weight were non-significant due to soil and foliar application of Zn and Fe. However, treatment T<sub>10</sub> recorded a higher value of test weight.

Data in Table 7 revealed that grain yield plant<sup>-1</sup> of rice as influenced by soil and foliar application of Zn and Fe varied significantly during both years and in pooled results. Further, data revealed that soil ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 25 kg ha<sup>-1</sup> and foliar ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 0.5% at 30 & 60 DAS (T<sub>10</sub>) recorded significantly higher grain yield plant<sup>-1</sup> (9.48, 10.06 and 9.77 g plant<sup>-1</sup>, respectively) and remained statistically at par with treatments T<sub>4</sub>, T<sub>8</sub>, T<sub>9</sub>, T<sub>2</sub>, T<sub>3</sub> and T<sub>7</sub>. While in second year and pooled analysis T<sub>4</sub>, T<sub>8</sub>, T<sub>9</sub> and T<sub>2</sub> was found at par with the T<sub>10</sub>. It was also noted that absolute control (T<sub>1</sub>) recorded the significantly lowest grain yield plant<sup>-1</sup> during both years as well as in the pooled analysis.

The sum of the mean data indicated that various treatments lead to a significant increase in straw yield plant<sup>-1</sup> in rice during an individual year, as well as in pooled analysis (Table 8). Treatment T<sub>10</sub> recorded significantly higher straw yield plant<sup>-1</sup> and remained statistically at par with treatments T<sub>4</sub>, T<sub>8</sub>, T<sub>9</sub>, T<sub>2</sub>, T<sub>3</sub> (Soil FeSO<sub>4</sub> @ 25 kg ha<sup>-1</sup>) and T<sub>7</sub> during both years. However, treatment T<sub>4</sub>, T<sub>8</sub>, T<sub>9</sub> and T<sub>2</sub> treatments was found to be statistically equal to T<sub>10</sub> in pooled analysis. Absolute control (T<sub>1</sub>) gave the lowest straw yield plant<sup>-1</sup> g plant<sup>-1</sup>, respectively) during both years as well as in the pooled analysis.

The grain yield is the net result of various agronomic inputs influencing growth and yield attributing characteristics that are altered by the surrounding environment during the life cycle of the crop. A critical examination of the data presented in Table 8. Clearly indicated that rice grain yield was significantly influenced by soil and foliar application of Zn and Fe. Results of grain yield recorded at harvest of the crop as influenced by soil and foliar application of Zn and Fe for the years of 2021, 2022 and on a pooled basis, are presented in Table 8. A perusal of the data showed that the effect of soil and foliar application of Zn and Fe was found to be significant during both the years of experimentation and pooled analysis on the grain yield of rice. Data revealed that significantly higher grain yields (3003, 3067 and 3035 kg ha<sup>-1</sup>, respectively) were obtained under the treatment soil ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 25 kg ha<sup>-1</sup> and foliar ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 0.5% at 30 & 60 DAS (T<sub>10</sub>) during both years and over the pooled results. However, it remained significantly at par with treatments T<sub>4</sub>, T<sub>8</sub>, T<sub>9</sub>, T<sub>3</sub> and T<sub>7</sub> during both years. Wherein, in pooled analysis, T<sub>4</sub> (Soil ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 25 kg ha<sup>-1</sup>), T<sub>8</sub> (Soil ZnSO<sub>4</sub> @ 25 kg ha<sup>-1</sup> + Foliar ZnSO<sub>4</sub> @ 0.5% at 30 & 60 DAS), T<sub>9</sub> (Soil FeSO<sub>4</sub> @ 25 kg ha<sup>-1</sup> + Foliar FeSO<sub>4</sub> @ 0.5% at 30 & 60 DAS) and T<sub>2</sub> (Soil ZnSO<sub>4</sub> @ 25 kg ha<sup>-1</sup>) treatments were found to be statistically equal with T<sub>10</sub>. The significantly lowest grain yield (2435, 2454 and 2445 kg ha<sup>-1</sup>, respectively) was observed under absolute control. The trend of treatments to produce grain yield was T<sub>10</sub>>T<sub>4</sub>>T<sub>8</sub>>T<sub>9</sub>>T<sub>2</sub>>T<sub>3</sub>>T<sub>7</sub>>T<sub>5</sub>>T<sub>6</sub>>T<sub>10</sub>.

Data obtained on the straw yield of summer rice as influenced by different treatments have been statistically analyzed and presented in Table 8. The data revealed that soil and foliar application of Zn and Fe significantly increased the straw yield of rice during both years as

well as in pooled analysis. Among the different treatments examined, significantly higher straw yield (5288, 5384 and 5336 kg ha<sup>-1</sup>, respectively) was recorded under the treatment soil ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 25 kg ha<sup>-1</sup> and foliar ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 0.5% at 30 & 60 DAS (T<sub>10</sub>) during both the years and in the pooled results and it was remained at par with treatments T<sub>4</sub>, T<sub>8</sub>, T<sub>9</sub>, T<sub>2</sub>, T<sub>3</sub> and T<sub>7</sub> during both years. However, treatment T<sub>4</sub>, T<sub>8</sub>, T<sub>9</sub> and T<sub>2</sub> treatments were found to be statistically equal to T<sub>10</sub> in pooled analysis. Absolute control (T<sub>1</sub>) gave the lowest straw yield (4235, 4301 and 4268 kg ha<sup>-1</sup>, respectively) during both years as well as in the pooled analysis.

A critical examination of the data (Table 8) indicated that various soil and foliar applications of Zn and Fe during both years and in the pooled analysis had no significant effect on the harvest index.

The data in Table 10 reveals that productive tillers, panicle length, panicle weight, test weight, grain and straw yield plant<sup>-1</sup> were strongly correlated to the grain yield and straw yield of *kharif* drilled rice. This indicates that yield of rice was significantly influenced by these attributes in a synergistic manner which ultimately enhanced the grain and straw yield of rice. They were positively correlated to each other and to grain and straw yield ultimately indicating increase in yield attributes increase yield in a progressive nature. Understanding this relationship can ultimately help in improving crop productivity by better management of these yield attributes which ultimately reflect in increasing yield.

From the findings mentioned above, soil and foliar application of Zn and Fe showed significant effect on yield attributing characters and yield of drilled rice. Increase in productive tillers meter<sup>-2</sup>, number of filled grains panicle<sup>-1</sup>, number of unfilled grains panicle<sup>-1</sup>, panicle length (cm), panicle weight (g), 1000 grain weight (g), grain yield plant<sup>-1</sup> (g plant<sup>-1</sup>), straw yield plant<sup>-1</sup> (g plant<sup>-1</sup>), grain yield (kg ha<sup>-1</sup>) and straw yield (kg ha<sup>-1</sup>) was noticed as a result of soil and foliar application of Zn and Fe. Zn and Fe are part of the photosynthesis, assimilation and translocation of photosynthates from source to sink. The increase in yield due to zinc and iron application may be attributed to their role in various physiological processes and improvement in growth components better partitioning of carbohydrates from leaf to reproductive parts resulting in increasing yield. It could be ascribed to its improvement in metallo enzymes system regulatory function and growth promoting auxin production especially during the enrichment process to last for a longer time and release the nutrients slowly in the soil system in such a way that nutrients are protected from fixation and made available to the plant root system throughout the crop growth and resulting in yield attributes and yield of rice. These results are in confirmation with Zayed *et al.* (2011), Suresh S. and Salakinkop S. R. (2016), Goverdhan M. (2017), Kadam *et al.* (2018), Balachandrakumar, V. and Sudhagar Rao, G. B. (2018), Rao *et al.* (2019), Janardhan *et al.* (2019), Bharti *et al.* (2020) and Rao *et al.* (2020).

#### 4. CONCLUSION

In the light of the results obtained from two years investigation, it can be concluded that, to obtain better growth and yields of drilled rice *cv.* GR 16 (Tapi), the crop should be fertilized with soil ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 25 kg ha<sup>-1</sup> and foliar ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 0.5% at 30 & 60 DAS along with RDF and soil ZnSO<sub>4</sub> + FeSO<sub>4</sub> each @ 25 kg ha<sup>-1</sup> along with RDF.

#### Disclaimer (artificial intelligence)

V. J. Jinjala/All Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, *etc*) and text-to-image generators have been used

during writing or editing of manuscripts.

## REFERENCES

- Balachandrakumar, V. and Sudhagar Rao, G. B. (2018). Yield and economics of rice as fortification with zinc and iron fertilizer. *Plant Archives.*, **18**: 400-403.
- Bashir, K.; Khan, N. M.; Rasheed, S. and Salim, M. (2007). Indica rice varietal development in Pakistan: an overview. *Paddy and Water Environment*, **5** (2): 73-81.
- Bharti, A.; Prasad, S.; Singh, M. K.; Singh, Y. K.; Behera, S. K. and Pandit, S. K. (2020). Effect of bio-fortification through organic and inorganic sources of zinc and iron on growth, yield and quality of aromatic rice. *International Journal of Current Microbiology and Applied Sciences*. **9** (10): 3487–3494.
- Brar, D. S. and Khush, G. S. (2018). Wild relatives of rice: A valuable genetic resource for genomics and breeding research. *In the Wild Oryza Genomes*, Springer, pp: 1-25.
- Carter, R. C.; Jacobson, J. L.; Burden, M. J.; Armony-Sivan, R.; Dodge, N. C.; Angelilli, M. L.; Lozoff, B. and Jacobson, S. W. (2010). Iron deficiency anemia and cognitive function in infancy. *Pediatrics*, **126**: 427–434.
- Cochron, W. G. and Cox, G. M. (1962). *Experimental Design*. Second Ed. John Willey and Sons Inc.; New York.
- Da Silva, J.G. (2013). Food losses means hunger. The think. Eat. Save. Reduce your footprint-campaign of the save food initiative is a partnership between UNEP, FAO and Messe Dusseldorf. <http://www.unep.org/ourplanet/2013/mav/en/pdf/article3.pdf>. Accessed 8 November 2018.
- FAO (2017). Rice market monitor. <http://www.fao.org/fileadmin/tfemplates/est>.
- Freitas, B. A.; Lima, L. M.; Moreira, M. E.; Priore, S. E.; Henriques, B. D.; Carlos, C. F.; Sabino, J. S. and Franceschini, S do. C. (2016). Micronutrient supplementation adherence and influence on the prevalence of anemia and iron, zinc and vitamin A deficiencies in preemies with a corrected age of six months. *Clinics*, **71** (8): 440-448.
- Gomez, K. A., 1972, Techniques for field experiments with rice. International Rice Research Institute, Manila, Philippines, pp. 39-45.
- Goverdhan, M. (2017). Influence of iron and zinc management on dry matter production and nutrient removal by rice (*Oryza sativa* L.) and soil fertility status under aerobic cultivation. *Chemical Science Review and Letters.*, **6** (24): 2627-2635.

- Graham, R. D.; Welch, R. M. and Bouis, H. E. (2001). Addressing micronutrient malnutrition through enhancing the nutritional quality of staple foods: principles, perspectives and knowledge gaps. *Advances in Agronomy*, **70**: 77–142.
- Hunt, J. R. (2005). Dietary and physiological factors that affect the absorption and bioavailability of iron. *International Journal for Vitamin and Nutrition Research*, **75**: 375–84.
- IRRI (2006). Rice varieties. IRRI Knowledge bank. International Rice Research Institute, Los Banos Philippines.
- Janardhan, S.; Rani, I. U.; Rani, P. P. and Venkateswarlu, B. (2019). Effect of zinc and iron fertilization on growth and yield of direct sown rice. *The Andhra Agricultural Journal*, **66** (1): 121-125.
- Kadam, S. R.; Bhale, V. M.; Chorey, A. B. and Deshmukh, M. R. (2018). Influence of zinc and iron fortification on yield and post-harvest studies of different rice cultivars (*Oryza sativa* L.). *International Journal of Current Microbiology and Applied Sciences*, **7** (1), 1878–1888.
- Majumder, S.; Datta, K. and Datta, S.K. (2019). Rice Biofortification: High Iron, Zinc, and Vitamin-A to Fight against “Hidden Hunger”. *Agronomy*, **9** (12): 803.
- Meng, F.; Wei, Y. and Yang, X. (2005). Iron content and bioavailability in rice. *Journal of Trace Elements in Medicine and Biology*, **18**: 333-338.
- Rao, S. G. B.; Balachandrakumar, V.; Immanuel, R. R.; Nambi, J. and Raj, S. T. (2020). Influence of zinc and iron fortified micronutrients on the growth, yield and economics of rice (*Oryza sativa* L.). *Crop Research*, **55**: (5 & 6).
- Rao, S. G. B.; Immanuel, R. R.; Ramesh. S.; Baradhan, G. and Sureshkumar, S. M. (2019). Effect of zinc and iron fertilization on growth and development of rice. *Plant Archives*, **19** (2): 1877-1880.
- Sharma, B. D.; Chahal, D. S.; Singh, P. K. and Kumar, R. (2013). Forms of iron and their association with soil properties in four soil taxonomy orders of arid and semi-arid soils of Punjab, India. *Communications in Soil Science and Plant Analysis*, **39**: 2550-2567.
- Suresh, S. and Salakinkop, S. R. (2016). Growth and yield of rice as influenced by biofortification of zinc and iron. *Journal of Farm Sciences*, **29** (4): 443-448.
- Viridia, H. M. and Mehta, H. D. (2009). Integrated nutrient management in transplanted rice (*Oryza sativa* L.). *Journal of Rice Research*, **2** (2): 99-104.
- Watson, D. J. (1952). The physiological basis of variation in yield. *Advances in Agronomy*, **4**:101-145.

- Welch, R. M. (2005). Harvesting health, Agricultural linkages for improving human nutrition, Micronutrient in south and south East Asia. 9-16, Nepal.
- Welch, R. M. and Graham, R. (2004), Breeding for micronutrients in staple food crops from a human nutrition perspective. *Journal of Experimental Botany*, **55**: 353-364.
- WHO (2008). Global database on anaemia. World Health Organization, Geneva.
- WHO (2015). Micronutrient deficiency: Iron deficiency-anaemia. World Health Organization, Geneva.
- Zayed, B. A.; Salem, A. K. M. and Sharkawy, H. M. E. (2011). Effect of different micronutrient treatments on rice (*Oryza sativa* L.) growth and yield under saline soil conditions. *World Journal of Agricultural Sciences*, **7** (2): 179-184.
- Zuo, Y. and Zhang, F. (2009). Iron and zinc biofortification strategies in dicot plants by intercropping with gramineous species. *Agronomy for Sustainable Development*, **29**: 63–71.

**Table 1: Plant height of rice as influenced by different treatments**

Treatments		At 30 DAS (cm)			At 60 DAS (cm)			At 60 DAS (cm)			At harvest (cm)		
		2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T <sub>1</sub>		29.88	29.53	29.70	51.98	54.23	53.11	75.56	77.03	76.30	77.05	77.91	77.48
T <sub>2</sub>		30.42	30.76	30.59	61.00	63.12	62.06	85.41	86.36	85.89	86.37	86.92	86.65
T <sub>3</sub>		30.37	30.48	30.43	60.96	61.91	61.43	84.77	85.72	85.25	85.75	86.84	86.29
T <sub>4</sub>		30.51	30.82	30.67	67.46	68.09	67.78	95.99	97.26	96.62	97.28	98.84	98.06
T <sub>5</sub>		30.18	30.20	30.19	57.34	58.31	57.82	81.85	82.01	81.93	82.05	83.12	82.58
T <sub>6</sub>		30.11	30.08	30.09	54.37	56.67	55.52	77.95	80.27	79.11	80.29	80.83	80.56
T <sub>7</sub>		30.26	30.36	30.31	57.99	59.01	58.50	83.19	84.17	83.68	84.19	85.26	84.73
T <sub>8</sub>		30.44	30.89	30.66	67.26	68.01	67.64	91.62	94.43	93.03	94.46	95.67	95.07
T <sub>9</sub>		30.43	30.78	30.61	62.26	63.89	63.08	88.01	89.74	88.88	89.79	90.93	90.36
T <sub>10</sub>		30.67	30.94	30.81	69.28	69.99	69.63	97.35	98.95	98.15	98.99	100.58	99.78
SEm±		1.22	1.25	0.87	3.39	3.37	2.39	3.99	4.15	2.88	4.12	4.26	2.96
CD at 5 %		NS	NS	NS	10.08	10.01	6.86	11.85	12.34	8.26	12.24	12.67	8.51
CV (%)		6.94	7.12	7.03	9.63	9.36	9.49	8.02	8.21	8.12	8.14	8.33	8.24
Year	SEm±	0.39			1.07			1.29			1.33		
	CD (P=0.05)	NS			NS			NS			NS		
Y x T	SEm±	1.23			3.38			4.07			4.19		
	CD (P=0.05)	NS			NS			NS			NS		

**Table 2: Number of tillers plant<sup>-1</sup> of rice as influenced by different treatments**

Treatments		At 30 DAS			At 60 DAS			At 90 DAS			At harvest		
		2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T <sub>1</sub>		3.46	3.52	3.49	7.67	7.70	7.69	7.49	7.65	7.57	7.60	7.76	7.68
T <sub>2</sub>		3.68	3.80	3.74	8.62	8.76	8.69	8.50	8.71	8.61	8.68	8.82	8.75
T <sub>3</sub>		3.63	3.76	3.69	8.45	8.59	8.52	8.33	8.54	8.43	8.51	8.65	8.58
T <sub>4</sub>		3.91	4.07	3.99	9.40	9.52	9.46	9.28	9.47	9.37	9.46	9.58	9.52
T <sub>5</sub>		3.53	3.75	3.64	7.97	8.13	8.05	7.85	8.07	7.96	8.03	8.19	8.11
T <sub>6</sub>		3.50	3.55	3.53	7.85	8.01	7.93	7.73	7.96	7.84	7.91	8.07	7.99
T <sub>7</sub>		3.58	3.70	3.64	8.13	8.28	8.20	8.01	8.22	8.12	8.19	8.34	8.26
T <sub>8</sub>		3.83	3.86	3.85	9.14	9.27	9.20	9.02	9.21	9.11	9.20	9.33	9.26
T <sub>9</sub>		3.75	3.80	3.77	8.84	8.98	8.91	8.72	8.92	8.82	8.90	9.04	8.97
T <sub>10</sub>		3.93	4.07	4.00	9.85	9.96	9.91	9.79	9.94	9.86	9.97	10.02	10.00
SEm±		0.19	0.18	0.13	0.44	0.46	0.32	0.45	0.46	0.32	0.46	0.46	0.33
CD at 5 %		NS	NS	NS	1.32	1.36	0.92	1.32	1.37	0.92	1.38	1.36	0.93
CV (%)		8.85	8.02	8.43	8.97	9.08	9.02	9.10	9.22	9.16	9.27	9.01	9.14
Year	SEm±	0.06			0.14			0.14			0.15		
	CD (P=0.05)	NS			NS			NS			NS		
Y x T	SEm±	0.18			0.45			0.45			0.46		
	CD (P=0.05)	NS			NS			NS			NS		

**Table 3: Leaf area of rice as influenced by different treatments**

Treatments		Leaf Area (cm <sup>2</sup> plant <sup>-1</sup> )								
		At 30 DAS			At 60 DAS			At 90 DAS		
		2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T <sub>1</sub>	124	126	125	976	980	978	714	729	722	
T <sub>2</sub>	131	136	133	1097	1115	1106	811	831	821	
T <sub>3</sub>	130	134	132	1075	1094	1084	794	814	804	
T <sub>4</sub>	140	145	142	1196	1211	1204	885	903	894	
T <sub>5</sub>	126	134	130	1014	1033	1024	749	770	760	
T <sub>6</sub>	125	127	126	999	1019	1009	738	759	749	
T <sub>7</sub>	128	132	130	1034	1053	1043	764	785	774	
T <sub>8</sub>	137	138	137	1162	1178	1170	860	879	869	
T <sub>9</sub>	134	136	135	1124	1142	1133	832	851	841	
T <sub>10</sub>	140	145	143	1253	1268	1260	934	948	941	
SEm±		6.71	6.26	4.59	56.59	58.14	40.56	42.45	44.04	30.58
CD at 5 %		NS	NS	NS	168.13	172.74	116.44	126.14	130.85	87.79
CV (%)		8.85	8.02	8.43	8.97	9.08	9.02	9.10	9.22	9.16
Year	SEm±	2.05			18.14			13.68		
	CD (P=0.05)	NS			NS			NS		
Y x T	SEm±	6.49			57.37			43.25		
	CD (P=0.05)	NS			NS			NS		

**Table 4: Leaf area index of rice as influenced by different treatments**

Treatments		At 30 DAS			At 60 DAS			At 90 DAS		
		2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T <sub>1</sub>		0.41	0.42	0.42	3.25	3.27	3.26	2.38	2.43	2.41
T <sub>2</sub>		0.44	0.45	0.44	3.66	3.72	3.69	2.70	2.77	2.74
T <sub>3</sub>		0.43	0.45	0.44	3.58	3.64	3.61	2.65	2.71	2.68
T <sub>4</sub>		0.47	0.48	0.47	3.99	4.04	4.01	2.95	3.01	2.98
T <sub>5</sub>		0.42	0.45	0.43	3.38	3.44	3.41	2.50	2.57	2.53
T <sub>6</sub>		0.42	0.42	0.42	3.33	3.40	3.36	2.46	2.53	2.50
T <sub>7</sub>		0.43	0.44	0.43	3.45	3.51	3.48	2.55	2.62	2.58
T <sub>8</sub>		0.46	0.46	0.46	3.87	3.93	3.90	2.87	2.93	2.90
T <sub>9</sub>		0.45	0.45	0.45	3.75	3.81	3.78	2.77	2.84	2.80
T <sub>10</sub>		0.47	0.48	0.48	4.17	4.23	4.20	3.11	3.16	3.14
SEm±		0.02	0.02	0.02	0.19	0.19	0.14	0.14	0.15	0.10
CD at 5 %		NS	NS	NS	0.56	0.58	0.39	0.42	0.44	0.29
CV (%)		8.85	8.02	8.43	8.97	9.08	9.02	9.10	9.22	9.16
Year	SEm±	0.01			0.06			0.05		
	CD (P=0.05)	NS			NS			NS		
Y x T	SEm±	0.02			0.19			0.14		
	CD (P=0.05)	NS			NS			NS		

**Table 5: Dry matter accumulation plant<sup>-1</sup> of rice as influenced by different treatments**

Treatments	At 30 DAS			At 60 DAS			At 90 DAS			At harvest (g plant <sup>-1</sup> )		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T <sub>1</sub>	2.22	2.28	2.25	12.04	12.01	12.02	18.72	19.22	18.97	20.65	20.88	20.76
T <sub>2</sub>	2.29	2.30	2.30	13.25	13.62	13.43	22.28	22.68	22.48	24.16	24.90	24.53
T <sub>3</sub>	2.28	2.35	2.31	12.53	13.37	12.95	21.36	21.79	21.57	23.36	23.49	23.43
T <sub>4</sub>	2.39	2.41	2.40	14.23	14.76	14.50	24.47	26.57	25.52	25.92	26.28	26.10
T <sub>5</sub>	2.26	2.31	2.28	12.40	12.60	12.50	19.71	19.91	19.81	22.38	22.29	22.34
T <sub>6</sub>	2.21	2.25	2.23	12.25	12.33	12.29	19.60	19.73	19.66	21.70	21.54	21.62
T <sub>7</sub>	2.24	2.29	2.27	12.47	13.26	12.87	19.79	20.95	20.37	22.79	23.27	23.03
T <sub>8</sub>	2.38	2.40	2.39	13.98	14.56	14.27	23.77	24.32	24.04	25.52	25.96	25.74
T <sub>9</sub>	2.30	2.39	2.35	13.50	13.91	13.71	22.95	23.39	23.17	25.23	25.53	25.38
T <sub>10</sub>	2.44	2.42	2.43	15.30	15.67	15.48	25.93	26.98	26.46	26.34	27.62	26.98
SEm±	0.06	0.10	0.06	0.67	0.65	0.47	1.18	1.11	0.81	1.15	1.14	0.81
CD at 5 %	NS	NS	NS	2.00	1.93	1.34	3.52	3.31	2.33	3.41	3.39	2.32
CV (%)	4.75	7.23	6.14	8.82	8.26	8.54	9.39	8.55	8.97	8.34	8.18	8.26
Year	SEm±	0.03		0.21			0.36			0.36		
	CD (P=0.05)	NS		NS			NS			NS		
Y x T	SEm±	0.08		0.66			1.15			1.14		
	CD (P=0.05)	NS		NS			NS			NS		

**Table 6: Number of productive tillers, number of grains panicle<sup>-1</sup> and number of unfilled grains panicle<sup>-1</sup> of rice as influenced by different treatments**

Treatments		Productive tillers (m <sup>-2</sup> )			No. of filled grains panicle <sup>-1</sup>			No. of unfilled grains panicle <sup>-1</sup>		
		2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T <sub>1</sub>		232	246	239	125.8	127.5	126.6	10.3	9.8	10.0
T <sub>2</sub>		274	283	278	142.6	145.0	143.8	8.2	8.8	8.5
T <sub>3</sub>		267	276	272	139.6	142.1	140.9	8.6	9.3	9.0
T <sub>4</sub>		307	309	308	153.5	162.9	158.2	7.2	7.5	7.3
T <sub>5</sub>		248	262	255	132.4	134.3	133.4	9.3	9.7	9.5
T <sub>6</sub>		244	258	251	129.5	131.7	130.6	10.1	9.7	9.9
T <sub>7</sub>		255	266	260	135.7	134.7	135.2	9.0	9.3	9.2
T <sub>8</sub>		295	300	298	149.1	157.0	153.0	7.3	7.8	7.6
T <sub>9</sub>		282	290	286	148.1	153.5	150.8	7.6	8.3	8.0
T <sub>10</sub>		319	324	321	160.1	166.0	163.1	7.1	7.0	7.1
SEm±		13.07	13.99	9.57	6.94	8.05	5.32	0.46	0.46	0.32
CD at 5 %		38.83	41.56	27.48	20.63	23.92	15.26	1.35	1.37	0.93
CV (%)		8.32	8.61	8.47	8.49	9.59	9.07	9.31	9.15	9.23
Year	SEm±	4.28			2.38			0.14		
	CD (P=0.05)	NS			NS			NS		
Y x T	SEm±	13.54			7.52			0.46		
	CD (P=0.05)	NS			NS			NS		

**Table 7: Panicle length, panicle weight, 1000 grain weight, grain and straw yield plant<sup>-1</sup> of rice as influenced by different treatments**

Treatments	Panicle length (cm)			Panicle weight (g)			1000 grain weight (g)			Grain yield plant <sup>-1</sup> (g)			Straw yield plant <sup>-1</sup> (g)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T <sub>1</sub>	22.07	21.56	21.82	1.75	1.76	1.75	25.32	25.81	25.57	7.54	7.70	7.62	13.28	13.35	13.32
T <sub>2</sub>	25.48	26.35	25.92	2.39	2.56	2.48	27.67	27.83	27.75	8.78	9.04	8.91	15.42	15.59	15.51
T <sub>3</sub>	24.38	25.36	24.87	2.31	2.49	2.40	27.36	27.52	27.44	8.50	8.55	8.52	14.85	15.01	14.93
T <sub>4</sub>	28.40	29.47	28.93	3.25	3.22	3.24	28.45	28.61	28.53	9.37	9.55	9.46	16.47	16.67	16.57
T <sub>5</sub>	23.89	24.52	24.20	2.05	2.01	2.03	26.29	26.45	26.37	8.13	8.10	8.12	14.04	14.17	14.10
T <sub>6</sub>	23.58	23.53	23.55	1.97	1.89	1.93	25.99	26.14	26.07	7.89	7.94	7.91	13.63	13.83	13.73
T <sub>7</sub>	24.24	24.98	24.61	2.20	2.29	2.25	26.71	26.87	26.79	8.29	8.45	8.37	14.34	14.48	14.41
T <sub>8</sub>	27.00	28.31	27.66	2.82	2.88	2.85	28.30	28.46	28.38	9.28	9.43	9.35	16.37	16.56	16.47
T <sub>9</sub>	25.80	26.85	26.32	2.52	2.56	2.54	28.08	28.24	28.16	9.19	9.27	9.23	16.16	16.36	16.26
T <sub>10</sub>	29.96	30.43	30.19	3.43	3.54	3.49	28.97	29.13	29.05	9.48	10.06	9.77	16.63	17.11	16.87
SEm±	1.28	1.45	0.97	0.14	0.14	0.10	1.45	1.51	1.05	0.43	0.47	0.32	0.80	0.83	0.58
CD at 5 %	3.80	4.32	2.78	0.41	0.42	0.28	NS	NS	NS	1.28	1.41	0.92	2.38	2.47	1.66
CV (%)	8.69	9.63	9.19	9.56	9.81	9.69	9.21	9.50	9.36	8.66	9.33	9.01	9.18	9.41	9.30
Year	SEm±	0.43		0.04			0.47			0.14			0.26		
	CD (P=0.05)	NS		NS			NS			NS			NS		
Y x T	SEm±	1.37		0.14			1.48			0.45			0.82		
	CD (P=0.05)	NS		NS			NS			NS			NS		

**Table 8: Grain and straw yield of rice as influenced by different treatments**

Treatments		Grain yield (kg ha <sup>-1</sup> )			Straw yield (kg ha <sup>-1</sup> )			Harvest index		
		2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T <sub>1</sub> : Absolute control (Only RDF)		2435	2454	2445	4235	4301	4268	36.58	36.32	36.45
T <sub>2</sub> : Soil ZnSO <sub>4</sub> @ 25 kg ha <sup>-1</sup>		2816	2869	2842	4927	5030	4979	36.38	36.37	36.37
T <sub>3</sub> : Soil FeSO <sub>4</sub> @ 25 kg ha <sup>-1</sup>		2729	2744	2737	4776	4812	4794	36.36	36.49	36.42
T <sub>4</sub> : Soil ZnSO <sub>4</sub> + FeSO <sub>4</sub> each @ 25 kg ha <sup>-1</sup>		2988	3039	3013	5229	5328	5278	36.54	36.43	36.49
T <sub>5</sub> : Foliar ZnSO <sub>4</sub> @ 0.5% at 30 & 60 DAS		2588	2661	2624	4528	4666	4597	36.42	36.35	36.38
T <sub>6</sub> : Foliar FeSO <sub>4</sub> @ 0.5% at 30 & 60 DAS		2523	2552	2538	4415	4477	4446	36.37	36.32	36.34
T <sub>7</sub> : Foliar ZnSO <sub>4</sub> + FeSO <sub>4</sub> each @ 0.5% at 30 & 60 DAS		2678	2727	2703	4686	4783	4735	36.37	36.35	36.36
T <sub>8</sub> : Soil ZnSO <sub>4</sub> @ 25 kg ha <sup>-1</sup> + Foliar ZnSO <sub>4</sub> @ 0.5% at 30 & 60 DAS		2952	3006	2979	5165	5270	5217	36.45	36.36	36.40
T <sub>9</sub> : Soil FeSO <sub>4</sub> @ 25 kg ha <sup>-1</sup> + Foliar FeSO <sub>4</sub> @ 0.5% at 30 & 60 DAS		2916	2963	2940	5103	5196	5149	36.47	36.32	36.40
T <sub>10</sub> : Soil ZnSO <sub>4</sub> + FeSO <sub>4</sub> each @ 25 kg ha <sup>-1</sup> and Foliar ZnSO <sub>4</sub> + FeSO <sub>4</sub> each @ 0.5% at 30 & 60 DAS		3003	3067	3035	5288	5384	5336	36.21	36.29	36.25
SEm±		129.98	135.30	93.81	231.40	237.69	165.86	1.82	1.89	1.31
CD at 5 %		386.20	402.02	269.29	687.56	706.24	476.13	NS	NS	NS
CV (%)		8.15	8.35	8.25	8.29	8.36	8.33	8.63	8.98	8.81
Year	SEm±	41.95			74.18			0.59		
	CD (P=0.05)	NS			NS			NS		
Y x T	SEm±	132.67			234.57			1.85		
	CD (P=0.05)	NS			NS			NS		

**Table 9: Correlation coefficient between tillers, LAI and Dry matter accumulation readings and yield as influenced by treatments in *kharif* rice at harvest (pooled data)**

<b>P</b>	<b>60PH</b>	<b>90PH</b>	<b>At PH</b>	<b>60 TP</b>	<b>90 TP</b>	<b>At TP</b>	<b>60LAI</b>	<b>90LAI</b>	<b>60DMP</b>	<b>90DMP</b>	<b>At DMP</b>	<b>SY</b>	<b>GY</b>
<b>60PH</b>	1.000	0.987**	0.987**	0.983**	0.982**	0.984**	0.983**	0.981**	0.969**	0.975**	0.981**	0.975**	0.977**
<b>90PH</b>	0.987**	1.000	0.999**	0.988**	0.987**	0.988**	0.988**	0.986**	0.980**	0.984**	0.974**	0.965**	0.967**
<b>At PH</b>	0.987**	0.999**	1.000	0.988**	0.987**	0.987**	0.987**	0.986**	0.981**	0.984**	0.972**	0.962**	0.964**
<b>60 TP</b>	0.983**	0.988**	0.988**	1.000	1.000**	1.000**	1.000**	1.000**	0.993**	0.996**	0.980**	0.961**	0.963**
<b>90 TP</b>	0.982**	0.987**	0.987**	1.000**	1.000	1.000**	1.000**	1.000**	0.994**	0.995**	0.980**	0.960**	0.962**
<b>At TP</b>	0.984**	0.988**	0.987**	1.000**	1.000**	1.000	1.000**	1.000**	0.993**	0.995**	0.981**	0.962**	0.964**
<b>60LAI</b>	0.983**	0.988**	0.987**	1.000**	1.000**	1.000**	1.000	1.000**	0.993**	0.996**	0.981**	0.962**	0.964**
<b>90LAI</b>	0.981**	0.986**	0.986**	1.000**	1.000**	1.000**	1.000**	1.000	0.994**	0.995**	0.978**	0.957**	0.960**
<b>60DMP</b>	0.969**	0.980**	0.981**	0.993**	0.994**	0.993**	0.993**	0.994**	1.000	0.986**	0.970**	0.945**	0.948**
<b>90DMP</b>	0.975**	0.984**	0.984**	0.996**	0.995**	0.995**	0.996**	0.995**	0.986**	1.000	0.976**	0.958**	0.959**
<b>At DMP</b>	0.981**	0.974**	0.972**	0.980**	0.980**	0.981**	0.981**	0.978**	0.970**	0.976**	1.000	0.995**	0.996**

**\* & \*\* - Significant at 5 and 1 percent level of probability, respectively**

**P = Parameters; 60PH = 60 DAS Plant height; 90PH = 90 DAS Plant height; At PH = At harvest plant height; 60 TP = 60 DAS Tiller plant<sup>-1</sup>; 90 TP = 90 DAS Tiller plant<sup>-1</sup>; At TP = At harvest tiller plant<sup>-1</sup>; 60 LAI = 60 DAS LAI; 90 LAI = 90 DAS LAI; 60 DMA = 60 DAS DMA; 90 DMA = 90 DAS DMA; At DMA = At harvest DMA; SY = Straw yield; GY = Grain yield**

**Table 10: Correlation coefficient between yield attributes and yield as influenced by treatments in *kharif* rice at harvest (pooled data)**

<b>P</b>	<b>PT</b>	<b>PL</b>	<b>PW</b>	<b>TW</b>	<b>SYP</b>	<b>GYP</b>	<b>SY</b>	<b>GY</b>
<b>PT</b>	1.000	0.991**	0.990**	0.979**	0.974**	0.983**	0.967**	0.969**
<b>PL</b>	0.991**	1.000	0.989**	0.959**	0.952**	0.970**	0.955**	0.958**
<b>PW</b>	0.990**	0.989**	1.000	0.952**	0.939**	0.956**	0.937**	0.940**
<b>TW</b>	0.979**	0.959**	0.952**	1.000	0.991**	0.994**	0.990**	0.991**
<b>SYP</b>	0.974**	0.952**	0.939**	0.991**	1.000	0.996**	0.994**	0.994**
<b>GYP</b>	0.983**	0.970**	0.956**	0.994**	0.996**	1.000	0.994**	0.995**

**\* & \*\* - Significant at 5 and 1 percent level of probability, respectively**

**P** = Parameters; **PT** = Productive tillers; **PL** = Panicle length; **PW** = Panicle weight; **TW** = Test weight; **SYP** = Straw Yield plant<sup>-1</sup>;

**GYP** = Grain Yield plant<sup>-1</sup>; **SY** = Straw yield; **GY** = Grain yield

UNDER PEER REVIEW