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

## Abstract

A field experiment was conducted during *kharif* 2022 and 2023 to study the effect of iron and zinc biofortification on the growth and yield of drilled rice (*Oryza sativa* L.) at Krushi Vigyan Kendra, Navsari Agricultural University, Dediapada, Gujarat. The experiment was laid out in a randomized block design with ten treatments. Based on pooled analysis, almost all the growth attributes (periodical plant height, number of tillers plant$^{-1}$, leaf area, leaf area index and dry matter accumulation plant$^{-1}$), yield attributes (productive tillers m$^{-2}$, number of filled grains panicle$^{-1}$, panicle length, weight of panicle and 1000 grain weight), grain yield (3035 kg ha$^{-1}$) and straw yield (5336 kg ha$^{-1}$) were recorded significantly higher under treatment $T_{10}$ (soil $ZnSO_4$ + $FeSO_4$ each @ 25 kg ha$^{-1}$ and foliar $ZnSO_4$ + $FeSO_4$ each @ 0.5% at 30 & 60 DAS). Based on the results, it concluded that for achieving higher growth and yield in drilled rice, the crop should be fertilized with soil $ZnSO_4$ + $FeSO_4$ each @ 25 kg ha$^{-1}$ and foliar $ZnSO_4$ + $FeSO_4$ each @ 0.5% at 30 & 60 DAS along with RDF and soil $ZnSO_4$ + $FeSO_4$ each @ 25 kg ha$^{-1}$ along with RDF.

**Key words**: biofortfication, iron, zinc, drilled rice, grain yield

## 1. INTRODUCTION

Rice (*Oryza sativa* L.) is the world's staple cereal crop. It is a good source of calories for approximately 40 percent of the world's population (Virdia and Mehta, 2009). Rice is the most important food crop for more than two billion people in Asia, providing 27 percent of dietary energy and 20 percent of overall dietary protein (Bashir *et al*., 2007). In the 2022/23 crop year, about 520.4 million metric tons of rice were consumed worldwide and it is expected to increase to 852 million tonnes by 2035. 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$^{-1}$, respectively. India ranks first in acreage (45.77 million hectares) and second in production (186.50 million metric tonnes) after China (Anonymous, 2022).

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$^{-1}$ iron and 12 mg kg$^{-1}$ 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. Zn has a crucial role in intracellular metabolic activities as it acts as a cofactor of various enzymes (Sobczyk and Gaunt, 2022). These enzymes mostly act on metabolic reactions Utilized in the breakdown of starch into sugar, chlorophyll synthesis, and the production of some carbohydrates). Additionally, Zn strengthens plant tissue so it may survive in frigid conditions. Zn affects plant water relations, alters stomatal conductance and plays a role in protecting the cell from the damaging effect of reactive oxygen species (White *et al*., 2009, Ghazi *et al*., 2022). Auxins are compounding that aid in growth control and stem elongation and they cannot be produced without zinc (Wairich*et al*., 2022). As a result, a lack of zinc in the soil has a negative impact on plant growth and development. Iron deficiency in rice mainly occurs under upland conditions; particularly in alkaline and calcareous soils. Sometimes severe chlorosis in rice due to Fe deficiency has led to the complete failure of rice crop. In most of the studies, foliar application of Fe has an edge over soil. Iron is easily translocated acropetally and even retranslocated basipetally after foliar application as long as 2+ Fe does not get immobilized. But Fe salts rapidly oxidize upon exposure to ambient air under field conditions. The availability of iron in the plant is involved in chlorophyll biosynthesis and the development of chloroplast and other photosynthetic apparatus. This argument was premised on the fact iron constitutes a vital component of proteins and enzymes involved in most physiological processes (photosynthesis, respiration, electron transportation, *etc*.) that are linked with plant productivity (Graziano and Lamattina 2007).

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 on 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). The biofortification method has the potential to increase the micronutrient content of food crops such as rice. This is a practical and sustainable way to address vitamin deficiencies for people whose diet is mostly rice and who do not have access to other food options, food markets, or proper healthcare (Zhang *et al*., 2023). 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, Gujarat (21.6289° N, 73.5824° E) 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 monsoons 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$^{-1}$), medium in available phosphorus (36.60 and 37.15 kg ha$^{-1}$), high in available potassium (428.35 and 421.20 kg ha$^{-1}$), medium available zinc (0.64 and 0.71 mg kg$^{-1}$) and available Fe (7.20 and 7.46 mg kg$^{-1}$). 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$^{-1}$).

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 $T_1$: Absolute control (Only RDF), $T_2$: Soil $ZnSO_4$ @ 25 kg ha$^{-1}$, $T_3$: Soil $FeSO_4$ @ 25 kg ha$^{-1}$, $T_4$: Soil $ZnSO_4$ + $FeSO_4$ each @ 25 kg ha$^{-1}$, $T_5$: Foliar $ZnSO_4$ @ 0.5% at 30 & 60 DAS, $T_6$: Foliar $FeSO_4$ @ 0.5% at 30 & 60 DAS, $T_7$: Foliar $ZnSO_4$ + $FeSO_4$ each @ 0.5% at 30 & 60 DAS, $T_8$: Soil $ZnSO_4$ @ 25 kg ha$^{-1}$ + Foliar $ZnSO_4$ @ 0.5% at 30 & 60 DAS, $T_9$: Soil $FeSO_4$ @ 25 kg ha$^{-1}$ + Foliar $FeSO_4$ @ 0.5% at 30 & 60 DAS, $T_{10}$: Soil $ZnSO_4$ + $FeSO_4$ each @ 25 kg ha$^{-1}$ and Foliar $ZnSO_4$ + $FeSO_4$ 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$^{-1}$ 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 (Gross plot size: 5.0 m x 4.8 m and Net plot size: 4.2 m x 3.6 m) 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. The crop was grown under rainfed conditions and also irrigation was applied as per requirement. The required quantity of fertilizer was worked out as per the unit area and treatment basis (Recommended dose of fertilizer: 80-30-00 kg ha$^{-1}$ N-P-K). 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. The remaining 50% nitrogen through urea was applied at 30 days after sowing when irrigation was applied. Soil applications of Zn and Fe through $ZnSO_4$ and $FeSO_4$ were applied at the basal just before sowing as per the treatment basis. Two foliar applications 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 the first spray and 500 liters in the second spray mixture ha$^{-1}$ was used.

### 2.1 Growth Parameters

The plant height of five randomly selected and tagged plants from each net plot was measured by using a wooden metre scale. The measurement was made from the base of the plant to the tip of the 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 by the ground area occupied per hill. From there, the leaf area index was calculated by the total leaf area of the plant divided by the total ground area under the plant as proposed by Watson (1952). The dry matter accumulation was recorded at 30, 60, 90 DAS and harvest for growth analysis from five plants in each gross plot was used for the estimation of dry matter. All the plants were uprooted and allowed to sun dry and finally oven dried at 65 ± 5 $^0$C for recording constant dry weight. The weight thus obtained is expressed as dry weight plant$^{-1}$ (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$^2$ quadrat from 30 DAS to maturity at every 30 days interval *i.e.,* 30, 60, 90 DAS and at harvest and expressed as a number of tillers m$^{-2}$. The number of filled and unfilled grains in all the five selected panicles from the five labeled hills in each treatment were counted and averaged to arrive at a number of filled and unfilled grains panicle$^{-1}$. The length of the five randomly selected panicles (cm) from the marked hill was measured in centimeter from the base to the tip of the panicle. The weight of the panicle was measured in grams 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 the test weight (grams per 1000 grains). Grain and straw yield per plant were measured from randomly selected five plants from the net plot and the 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$^{-1}$. Straw yield from the net plot of each treatment was dried in the sun to a constant weight and after it converted to straw yield in kg ha$^{-1}$. The harvest index was computed by the percentage of economic yield to the biological yield of rice and it was recorded separately for each treatment.

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

## 3 RESULTS AND DISCUSSION

Results revealed that growth attributes of rice *i.e.* periodical plant height, number of tillers plant$^{-1}$, leaf area, leaf area index, dry matter accumulation plant$^{-1}$ and yield attributes *viz*., productive tillers m$^{-2}$, number of filled grains panicle$^{-1}$, number of unfilled grains panicle$^{-1}$, panicle length, weight of panicle, thousand grain weight, grain yield plant$^{-1}$, straw yield plant$^{-1}$, 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 $ZnSO_4$ + $FeSO_4$ each @ 25 kg $ha^{-1}$ and Foliar $ZnSO_4$ + $FeSO_4$ each @ 0.5% at 30 & 60 DAS (T10) during both years and pooled study, but it remained at par with treatments $T_4$, $T_8$, $T_9$, $T_2$ and $T_3$ during both year. While treatments $T_4$, $T_8$ and $T_9$ were found statistically at par with $T_{10}$ in the pooled result. Whereas, minimum plant height was recorded under treatment $T_1$ (Absolute control) across both the years of investigation and on a pooled basis. At 90 days after sowing (Table 1), significantly taller rice plants were observed in treatment $T_{10}$ and it was statistically at par with treatments $T_4$, $T_8$ and $T_9$ during both years. In pooled analysis, $T_4$ and $T_8$ were found to be on par with $T_{10}$. However, significantly lower plant height was observed during individual years of study and in pooled results under treatment absolute control ($T_1$). Data in Table 1 clearly indicated that plant height at harvest was recorded significantly higher in treatment Soil $ZnSO_4$ + $FeSO_4$ each @ 25 kg $ha^{-1}$ and Foliar $ZnSO_4$ + $FeSO_4$ each @ 0.5% at 30 & 60 DAS ($T_{10}$) during both years, but it remained statistically at par with treatments $T_4$, and $T_9$. However, data on pooled analysis revealed that treatments $T_4$ and $T_8$ (Soil $ZnSO_4$ @ 25 kg $ha^{-1}$ + Foliar $ZnSO_4$ @ 0.5% at 30 & 60 DAS) were found to be on par with $T_{10}$. The lowest plant height was registered with absolute control ($T_1$) 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, the number of tillers $plant^{-1}$ 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 $plant^{-1}$ in treatment soil $ZnSO_4$ + $FeSO_4$ each @ 25 kg $ha^{-1}$ and foliar $ZnSO_4$ + $FeSO_4$ each @ 0.5% at 30 & 60 DAS ($T_{10}$) at 60, 90 DAS and at harvest during both year and in pooled results, which remained statistically at par with $T_4$, $T_8$, $T_9$ and $T_2$. In pooled results, $T_4$ and $T_8$ were found to be on par with $T_{10}$. The significantly lowest number of tillers $plant^{-1}$ at 60, 90 DAS and at harvest, all stages of growth was observed under absolute control ($T_1$). The availability of nutrients to the crops at various growth stages through agrochemical sources might have increased the number of tillers. Zn and Fe might have accelerated photosynthetic rate, thereby increasing the supply of carbohydrates, resulted in increased cell division, multiplication and elongation leading to an increased number of tillers per plant of field crop. The results were also confirmed with the findings of Ram *et al.* 2020 and Ugile *et al.* 2024.

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 $ZnSO_4$ + $FeSO_4$ each @ 25 kg $ha^{-1}$ and foliar $ZnSO_4$ + $FeSO_4$ each @ 0.5% at 30 & 60 DAS ($T_{10}$) accounted for significantly higher leaf area over absolute control ($T_1$) and was on par with treatments $T_4$, $T_8$, $T_9$ and $T_2$ during both years. Whereas, treatments $T_4$ (Soil $ZnSO_4$ + $FeSO_4$ each @ 25 kg $ha^{-1}$) and $T_8$ (Soil $ZnSO_4$ @ 25 kg $ha^{-1}$ + Foliar $ZnSO_4$ @ 0.5% at 30 & 60 DAS) are on par with treatment treatments $T_{10}$ 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 was recorded with treatment $T_{10}$, but it remained at par with treatments $T_4$, $T_8$, $T_9$ and $T_2$ during both years. However, in the case of pooled analysis, treatment $T_4$ and $T_8$ are on par with treatment $T_{10}$. The lower LAI at 60 DAS was obtained with treatment $T_1$ (Absolute control) during both years and in pooled results.

The results of the experiments on dry matter accumulation plant$^{-1}$ of rice 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$^{-1}$ significantly influenced it at all the growth stages, except at 30 DAS during 2022, 2023 and in the combined analysis. Application of soil $ZnSO_4$ + $FeSO_4$ each @ 25 kg ha$^{-1}$ and foliar $ZnSO_4$ + $FeSO_4$ each @ 0.5% at 30 & 60 DAS ($T_{10}$) recorded significantly higher dry matter accumulation plant$^{-1}$ of the rice crop at 60, 90 DAS and at harvest during both years, but it remained at par with treatments $T_4$, $T_8$ and $T_9$ during both year. Whereas, in pooled results, it remained at par with treatments $T_4$ and $T_8$. Minimum dry matter accumulation plant$^{-1}$ was recorded under treatment $T_1$ (Absolute control).

The results presented in the above findings indicated that soil and foliar application of Zn and Fe showed a 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$^{-1}$ 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 the 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 higher hormonal activity at critical crop growth stages, which ultimately resulted in better crop growth parameters. While, Fe is indispensable for chlorophyll synthesis and involved in the formation of the pyrrole ring, which is a structural component of chlorophyll and iron has a stimulating effect to increase the plant height, leaf area, leaf area index, dry matter accumulation and other 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 and Rao (2018), Rao *et al.* (2019), Janardhan *et al.* (2019), Bharti *et al.* (2020) and Rao *et al.* (2020), Ram *et al*. (2020) and Ugile *et al*. (2024).

### 3.2 Yield Attributes and Yield

The data on yield attributes and yield *viz*., productive tillers meter$^{-2}$, number of filled grains panicle$^{-1}$, number of unfilled grains panicle$^{-1}$, panicle length, panicle weight, 1000 grain weight, grain yield plant$^{-1}$, straw yield plant$^{-1}$, grain yield, straw yield 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$^{-2}$ revealed that treatment $T_{10}$ (Soil $ZnSO_4$ + $FeSO_4$ each @ 25 kg ha$^{-1}$ and Foliar $ZnSO_4$ + $FeSO_4$ each @ 0.5% at 30 & 60 DAS) produced significantly more panicles during both years and in pooled results, and was statistically equal with $T_4$, $T_8$ and $T_9$ in the first year. While treatments $T_4$, $T_8$, $T_9$ and $T_2$ were found statistically at par with $T_{10}$ during the second year. However, in pooled results, treatments $T_4$ (Soil Zn + Fe each @ 25 kg ha$^{-1}$) and $T_8$ (Soil $ZnSO_4$ @ 25 kg ha$^{-1}$ + Foliar $ZnSO_4$ @ 0.5% at 30 & 60 DAS) remained on par with $T_{10}$. Minimum number of tillers meter$^{-2}$ was recorded under treatment $T_1$ (Absolute control) (Table 6). The reason for improving the number of tillers per square meter might be due to the availability of nutrients through soil application to the rice crop Zn and Fe increase plants' tolerance to several abiotic stresses, reduce transpiration and increase nitrate reductase activity, flower longevity and hence, increase in number of tillers. Similar findings were obtained by Ugile *et al*. (2024).

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$^{-1}$. An application of soil $ZnSO_4$ + $FeSO_4$ each @ 25 kg ha$^{-1}$ and foliar $ZnSO_4$ + $FeSO_4$ each @ 0.5% at 30 & 60 DAS ($T_{10}$) recorded the maximum number of filled grains panicle$^{-1}$ during both years and in pooled results. However, it was found to be on par with treatments $T_4$, $T_8$, $T_9$, $T_2$ and $T_3$ during both years. While treatments $T_4$, $T_8$ and $T_9$ were found statistically at par with $T_{10}$ in pooled results, Further, significantly the lowest number of filled grains panicle$^{-1}$ was recorded with the treatment of $T_1$ (Absolute control) during both years and in pooled results. The number of grains per panicle increased due to greater diversion of assimilates towards reproductive organs. For seed development, assimilate transfer to reproductive sinks is essential. The availability and use of assimilates may have an impact on seed set and filling. The combination of traits that contribute to yield, improved photosynthetic efficiency and improved reproductive sink ability to use incoming assimilates as a result of exogenous Zn and Fe application resulted in an increase in the number of grains per panicle. These results are in agreement with the work of Yadav *et al*. (2021) and Ugile *et al*. (2024).

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$^{-1}$. As far as the number of unfilled grains panicle$^{-1}$ is concerned, all the treatments under study significantly differ from each other and being minimum in treatment $T_{10}$ over absolute control treatment $T_1$ which was statistically at par with treatments $T_4$, $T_8$, $T_9$ and $T_2$ during first years. While, in the case of second and in pooled results treatment treatments $T_4$, $T_8$ and $T_9$ were found statistically at par with $T_{10}$.

Significantly higher panicle length (Table 7) was recorded with treatment $T_{10}$ (Soil $ZnSO_4$ + $FeSO_4$ each @ 25 kg ha $^{-1}$ and Foliar $ZnSO_4$ + $FeSO_4$ each @ 0.5% at 30 & amp; 60 DAS), but being at par with treatment $T_4$ (Soil $ZnSO_4$ + $FeSO_4$ each @ 25 kg ha$^{-1}$) and $T_8$ (Soil $ZnSO_4$ @ 25 kg ha$^{-1}$ + Foliar $ZnSO_4$ @ 0.5% at 30 & amp; 60 DAS) during the first year and pooled study. However, in second year treatments $T_4$, $T_8$, $T_9$ and $T_2$ at par with $T_{10}$. However, in pooled study, treatments $T_4$ and $T_8$ were found statistically equal with $T_{10}$. The increase in panicle length might be attributed to the beneficial role of Zn and Fe in improving photosynthetic activity and plant nutrition. The reason for increasing the panicle length might be due to the highly availability of Fe and Zn to rice which increased dry matter and plant assimilates, which directly reflects in the number of tillers plant$^{-1}$ and also higher panicle length. Similarly, results were published by Tripathy and Sahoo (2021) and Ugile *et al*. (2024).

A perusal of the data presented in Table 7 revealed that soil $ZnSO_4$ + $FeSO_4$ each @ 25 kg ha$^{-1}$ and foliar $ZnSO_4$ + $FeSO_4$ each @ 0.5% at 30 & 60 DAS ($T_{10}$) recorded significantly higher weight of panicle compared to the remaining treatments except Soil $ZnSO_4$ + $FeSO_4$ each @ 25 kg ha$^{-1}$ ($T_4$). However, significantly light weight were found with treatment absolute control ($T_1$) 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 $T_{10}$ recorded a higher value of test weight.

Data in Table 7 revealed that grain yield plant$^{-1}$ 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 $ZnSO_4$ + $FeSO_4$ each @ 25 kg ha$^{-1}$ and foliar $ZnSO_4$ + $FeSO_4$ each @ 0.5% at 30 & 60 DAS ($T_{10}$) recorded significantly higher grain yield plant$^{-1}$ and remained statistically at par with treatments $T_4$, $T_8$, $T_9$, $T_2$, $T_3$ and $T_7$. While in the second year and in pooled analysis $T_4$, $T_8$, $T_9$ and $T_2$ were found at par with the $T_{10}$. It was also noted that absolute control ($T_1$) recorded the significantly lowest grain yield plant$^{-1}$ 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$^{-1}$ in rice during an individual year, as well as in pooled analysis (Table 8). Treatment $T_{10}$ recorded significantly higher straw yield plant$^{-1}$ and remained statistically at par with treatments $T_4$, $T_8$, $T_9$, $T_2$, $T_3$ (Soil $FeSO_4$ @ 25 kg ha$^{-1}$) and $T_7$ during both years. However, treatment $T_4$, $T_8$, $T_9$ and $T_2$ treatments was found to be statistically equal to $T_{10}$ in pooled analysis. Absolute control ($T_1$) gave the lowest straw yield plant$^{-1}$ g plant$^{-1}$, 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$^{-1}$, respectively) were obtained under the treatment soil $ZnSO_4$ + $FeSO_4$ each @ 25 kg ha$^{-1}$ and foliar $ZnSO_4$ + $FeSO_4$ each @ 0.5% at 30 & 60 DAS ($T_{10}$) during both years and over the pooled results. However, it remained significantly at par with treatments $T_4$, $T_8$, $T_9$, $T_3$ and $T_7$ during both years. Wherein, in pooled analysis, $T_4$ (Soil $ZnSO_4$ + $FeSO_4$ each @ 25 kg ha$^{-1}$), $T_8$ (Soil $ZnSO_4$ @ 25 kg ha$^{-1}$ + Foliar $ZnSO_4$ @ 0.5% at 30 & 60 DAS), $T_9$ (Soil $FeSO_4$ @ 25 kg ha$^{-1}$ + Foliar $FeSO_4$ @ 0.5% at 30 & 60 DAS) and $T_2$ (Soil $ZnSO_4$ @ 25 kg ha$^{-1}$) treatments were found to be statistically equal with T10. The significantly lowest grain yield (2435, 2454 and 2445 kg ha$^{-1}$, respectively) was observed under absolute control. The trend of treatments to produce grain yield was $T_{10}>T_4>T_8>T_9>T_2>T_3>T_7>T_5>T_6>T_{10}$.

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$^{-1}$, respectively) was recorded under the treatment soil $ZnSO_4$ + $FeSO_4$ each @ 25 kg ha$^{-1}$ and foliar $ZnSO_4$ + $FeSO_4$ each @ 0.5% at 30 & 60 DAS ($T_{10}$) during both the years and in the pooled results and it remained at par with treatments $T_4$, $T_8$, $T_9$, $T_2$, $T_3$ and $T_7$ during both years. However, treatments $T_4$, $T_8$, $T_9$ and $T_2$ treatments were found to be statistically equal to $T_{10}$ in pooled analysis. Absolute control ($T_1$) gave the lowest straw yield (4235, 4301 and 4268 kg ha$^{-1}$, 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.

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$^{-2}$, number of filled grains panicle$^{-1}$, number of unfilled grains panicle$^{-1}$, panicle length (cm), panicle weight (g), 1000 grain weight (g), grain yield plant$^{-1}$ (g plant$^{-1}$), straw yield plant$^{-1}$ (g plant$^{-1}$), grain yield (kg ha$^{-1}$) and straw yield (kg ha$^{-1}$) 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 Rao (2018), Rao *et al.* (2019), Janardhan *et al.* (2019), Bharti *et al.* (2020), Rao *et al.* (2020) and Ugile *et al*. (2024).

## 4. CONCLUSION

In the light of the results obtained from two years investigation, it can be concluded that, to obtain batter growth and yields of drilled rice *cv.* GR 16 (Tapi), the crop should be fertilized with soil $ZnSO_4$ + $FeSO_4$ each @ 25 kg ha$^{-1}$ and foliar $ZnSO_4$ + $FeSO_4$ each @ 0.5% at 30 & 60 DAS along with RDF and soil $ZnSO_4$ + $FeSO_4$ each @ 25 kg ha$^{-1}$ along with RDF.

### Disclaimer (artificial intelligence)

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.

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**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** |
| $T_1$ | | 29.88 | 29.53 | 29.70 | 51.98 | 54.23 | 53.11 | 75.56 | 77.03 | 76.30 | 77.05 | 77.91 | 77.48 |
| $T_2$ | | 30.42 | 30.76 | 30.59 | 61.00 | 63.12 | 62.06 | 85.41 | 86.36 | 85.89 | 86.37 | 86.92 | 86.65 |
| $T_3$ | | 30.37 | 30.48 | 30.43 | 60.96 | 61.91 | 61.43 | 84.77 | 85.72 | 85.25 | 85.75 | 86.84 | 86.29 |
| $T_4$ | | 30.51 | 30.82 | 30.67 | 67.46 | 68.09 | 67.78 | 95.99 | 97.26 | 96.62 | 97.28 | 98.84 | 98.06 |
| $T_5$ | | 30.18 | 30.20 | 30.19 | 57.34 | 58.31 | 57.82 | 81.85 | 82.01 | 81.93 | 82.05 | 83.12 | 82.58 |
| $T_6$ | | 30.11 | 30.08 | 30.09 | 54.37 | 56.67 | 55.52 | 77.95 | 80.27 | 79.11 | 80.29 | 80.83 | 80.56 |
| $T_7$ | | 30.26 | 30.36 | 30.31 | 57.99 | 59.01 | 58.50 | 83.19 | 84.17 | 83.68 | 84.19 | 85.26 | 84.73 |
| $T_8$ | | 30.44 | 30.89 | 30.66 | 67.26 | 68.01 | 67.64 | 91.62 | 94.43 | 93.03 | 94.46 | 95.67 | 95.07 |
| $T_9$ | | 30.43 | 30.78 | 30.61 | 62.26 | 63.89 | 63.08 | 88.01 | 89.74 | 88.88 | 89.79 | 90.93 | 90.36 |
| $T_{10}$ | | 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 per plant of rice as influenced by different treatments**

<table>
<tr><th colspan="2" rowspan="2">Treatments</th><th colspan="3">At 30 DAS</th><th colspan="3">At 60 DAS</th><th colspan="3">At 90 DAS</th><th colspan="3">At harvest</th></tr>
<tr><th>2022</th><th>2023</th><th>Pooled</th><th>2022</th><th>2023</th><th>Pooled</th><th>2022</th><th>2023</th><th>Pooled</th><th>2022</th><th>2023</th><th>Pooled</th></tr>
<tr><td colspan="2">$T_1$</td><td>3.46</td><td>3.52</td><td>3.49</td><td>7.67</td><td>7.70</td><td>7.69</td><td>7.49</td><td>7.65</td><td>7.57</td><td>7.60</td><td>7.76</td><td>7.68</td></tr>
<tr><td colspan="2">$T_2$</td><td>3.68</td><td>3.80</td><td>3.74</td><td>8.62</td><td>8.76</td><td>8.69</td><td>8.50</td><td>8.71</td><td>8.61</td><td>8.68</td><td>8.82</td><td>8.75</td></tr>
<tr><td colspan="2">$T_3$</td><td>3.63</td><td>3.76</td><td>3.69</td><td>8.45</td><td>8.59</td><td>8.52</td><td>8.33</td><td>8.54</td><td>8.43</td><td>8.51</td><td>8.65</td><td>8.58</td></tr>
<tr><td colspan="2">$T_4$</td><td>3.91</td><td>4.07</td><td>3.99</td><td>9.40</td><td>9.52</td><td>9.46</td><td>9.28</td><td>9.47</td><td>9.37</td><td>9.46</td><td>9.58</td><td>9.52</td></tr>
<tr><td colspan="2">$T_5$</td><td>3.53</td><td>3.75</td><td>3.64</td><td>7.97</td><td>8.13</td><td>8.05</td><td>7.85</td><td>8.07</td><td>7.96</td><td>8.03</td><td>8.19</td><td>8.11</td></tr>
<tr><td colspan="2">$T_6$</td><td>3.50</td><td>3.55</td><td>3.53</td><td>7.85</td><td>8.01</td><td>7.93</td><td>7.73</td><td>7.96</td><td>7.84</td><td>7.91</td><td>8.07</td><td>7.99</td></tr>
<tr><td colspan="2">$T_7$</td><td>3.58</td><td>3.70</td><td>3.64</td><td>8.13</td><td>8.28</td><td>8.20</td><td>8.01</td><td>8.22</td><td>8.12</td><td>8.19</td><td>8.34</td><td>8.26</td></tr>
<tr><td colspan="2">$T_8$</td><td>3.83</td><td>3.86</td><td>3.85</td><td>9.14</td><td>9.27</td><td>9.20</td><td>9.02</td><td>9.21</td><td>9.11</td><td>9.20</td><td>9.33</td><td>9.26</td></tr>
<tr><td colspan="2">$T_9$</td><td>3.75</td><td>3.80</td><td>3.77</td><td>8.84</td><td>8.98</td><td>8.91</td><td>8.72</td><td>8.92</td><td>8.82</td><td>8.90</td><td>9.04</td><td>8.97</td></tr>
<tr><td colspan="2">$T_{10}$</td><td>3.93</td><td>4.07</td><td>4.00</td><td>9.85</td><td>9.96</td><td>9.91</td><td>9.79</td><td>9.94</td><td>9.86</td><td>9.97</td><td>10.02</td><td>10.00</td></tr>
<tr><td colspan="2">SEm±</td><td>0.19</td><td>0.18</td><td>0.13</td><td>0.44</td><td>0.46</td><td>0.32</td><td>0.45</td><td>0.46</td><td>0.32</td><td>0.46</td><td>0.46</td><td>0.33</td></tr>
<tr><td colspan="2">CD at 5 %</td><td>NS</td><td>NS</td><td>NS</td><td>1.32</td><td>1.36</td><td>0.92</td><td>1.32</td><td>1.37</td><td>0.92</td><td>1.38</td><td>1.36</td><td>0.93</td></tr>
<tr><td colspan="2">CV (%)</td><td>8.85</td><td>8.02</td><td>8.43</td><td>8.97</td><td>9.08</td><td>9.02</td><td>9.10</td><td>9.22</td><td>9.16</td><td>9.27</td><td>9.01</td><td>9.14</td></tr>
<tr><td rowspan="2">Year</td><td>SEm±</td><td colspan="3">0.06</td><td colspan="3">0.14</td><td colspan="3">0.14</td><td colspan="3">0.15</td></tr>
<tr><td>CD (P=0.05)</td><td colspan="3">NS</td><td colspan="3">NS</td><td colspan="3">NS</td><td colspan="3">NS</td></tr>
<tr><td rowspan="2">Y x T</td><td>SEm±</td><td colspan="3">0.18</td><td colspan="3">0.45</td><td colspan="3">0.45</td><td colspan="3">0.46</td></tr>
<tr><td>CD (P=0.05)</td><td colspan="3">NS</td><td colspan="3">NS</td><td colspan="3">NS</td><td colspan="3">NS</td></tr>
</table>

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

<table>
<tr><th colspan="2" rowspan="3">Treatments</th><th colspan="9">Leaf Area (cm$^2$ plant$^{-1}$)</th></tr>
<tr><th colspan="3">At 30 DAS</th><th colspan="3">At 60 DAS</th><th colspan="3">At 90 DAS</th></tr>
<tr><th>2022</th><th>2023</th><th>Pooled</th><th>2022</th><th>2023</th><th>Pooled</th><th>2022</th><th>2023</th><th>Pooled</th></tr>
<tr><td colspan="2">$T_1$</td><td>124</td><td>126</td><td>125</td><td>976</td><td>980</td><td>978</td><td>714</td><td>729</td><td>722</td></tr>
<tr><td colspan="2">$T_2$</td><td>131</td><td>136</td><td>133</td><td>1097</td><td>1115</td><td>1106</td><td>811</td><td>831</td><td>821</td></tr>
<tr><td colspan="2">$T_3$</td><td>130</td><td>134</td><td>132</td><td>1075</td><td>1094</td><td>1084</td><td>794</td><td>814</td><td>804</td></tr>
<tr><td colspan="2">$T_4$</td><td>140</td><td>145</td><td>142</td><td>1196</td><td>1211</td><td>1204</td><td>885</td><td>903</td><td>894</td></tr>
<tr><td colspan="2">$T_5$</td><td>126</td><td>134</td><td>130</td><td>1014</td><td>1033</td><td>1024</td><td>749</td><td>770</td><td>760</td></tr>
<tr><td colspan="2">$T_6$</td><td>125</td><td>127</td><td>126</td><td>999</td><td>1019</td><td>1009</td><td>738</td><td>759</td><td>749</td></tr>
<tr><td colspan="2">$T_7$</td><td>128</td><td>132</td><td>130</td><td>1034</td><td>1053</td><td>1043</td><td>764</td><td>785</td><td>774</td></tr>
<tr><td colspan="2">$T_8$</td><td>137</td><td>138</td><td>137</td><td>1162</td><td>1178</td><td>1170</td><td>860</td><td>879</td><td>869</td></tr>
<tr><td colspan="2">$T_9$</td><td>134</td><td>136</td><td>135</td><td>1124</td><td>1142</td><td>1133</td><td>832</td><td>851</td><td>841</td></tr>
<tr><td colspan="2">$T_{10}$</td><td>140</td><td>145</td><td>143</td><td>1253</td><td>1268</td><td>1260</td><td>934</td><td>948</td><td>941</td></tr>
<tr><td colspan="2">SEm±</td><td>6.71</td><td>6.26</td><td>4.59</td><td>56.59</td><td>58.14</td><td>40.56</td><td>42.45</td><td>44.04</td><td>30.58</td></tr>
<tr><td colspan="2">CD at 5 %</td><td>NS</td><td>NS</td><td>NS</td><td>168.13</td><td>172.74</td><td>116.44</td><td>126.14</td><td>130.85</td><td>87.79</td></tr>
<tr><td colspan="2">CV (%)</td><td>8.85</td><td>8.02</td><td>8.43</td><td>8.97</td><td>9.08</td><td>9.02</td><td>9.10</td><td>9.22</td><td>9.16</td></tr>
<tr><td rowspan="2">Year</td><td>SEm±</td><td colspan="3">2.05</td><td colspan="3">18.14</td><td colspan="3">13.68</td></tr>
<tr><td>CD (P=0.05)</td><td colspan="3">NS</td><td colspan="3">NS</td><td colspan="3">NS</td></tr>
<tr><td rowspan="2">Y x T</td><td>SEm±</td><td colspan="3">6.49</td><td colspan="3">57.37</td><td colspan="3">43.25</td></tr>
<tr><td>CD (P=0.05)</td><td colspan="3">NS</td><td colspan="3">NS</td><td colspan="3">NS</td></tr>
</table>

**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 |
| $T_1$ | | 0.41 | 0.42 | 0.42 | 3.25 | 3.27 | 3.26 | 2.38 | 2.43 | 2.41 |
| $T_2$ | | 0.44 | 0.45 | 0.44 | 3.66 | 3.72 | 3.69 | 2.70 | 2.77 | 2.74 |
| $T_3$ | | 0.43 | 0.45 | 0.44 | 3.58 | 3.64 | 3.61 | 2.65 | 2.71 | 2.68 |
| $T_4$ | | 0.47 | 0.48 | 0.47 | 3.99 | 4.04 | 4.01 | 2.95 | 3.01 | 2.98 |
| $T_5$ | | 0.42 | 0.45 | 0.43 | 3.38 | 3.44 | 3.41 | 2.50 | 2.57 | 2.53 |
| $T_6$ | | 0.42 | 0.42 | 0.42 | 3.33 | 3.40 | 3.36 | 2.46 | 2.53 | 2.50 |
| $T_7$ | | 0.43 | 0.44 | 0.43 | 3.45 | 3.51 | 3.48 | 2.55 | 2.62 | 2.58 |
| $T_8$ | | 0.46 | 0.46 | 0.46 | 3.87 | 3.93 | 3.90 | 2.87 | 2.93 | 2.90 |
| $T_9$ | | 0.45 | 0.45 | 0.45 | 3.75 | 3.81 | 3.78 | 2.77 | 2.84 | 2.80 |
| $T_{10}$ | | 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 per plant of rice as influenced by different treatments**

| Treatments | | At 30 DAS | | | At 60 DAS | | | At 90 DAS | | | At harvest (g plant$^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **2022** | **2023** | **Pooled** | **2022** | **2023** | **Pooled** | **2022** | **2023** | **Pooled** | **2022** | **2023** | **Pooled** |
| $T_1$ | | 2.22 | 2.28 | 2.25 | 12.04 | 12.01 | 12.02 | 18.72 | 19.22 | 18.97 | 20.65 | 20.88 | 20.76 |
| $T_2$ | | 2.29 | 2.30 | 2.30 | 13.25 | 13.62 | 13.43 | 22.28 | 22.68 | 22.48 | 24.16 | 24.90 | 24.53 |
| $T_3$ | | 2.28 | 2.35 | 2.31 | 12.53 | 13.37 | 12.95 | 21.36 | 21.79 | 21.57 | 23.36 | 23.49 | 23.43 |
| $T_4$ | | 2.39 | 2.41 | 2.40 | 14.23 | 14.76 | 14.50 | 24.47 | 26.57 | 25.52 | 25.92 | 26.28 | 26.10 |
| $T_5$ | | 2.26 | 2.31 | 2.28 | 12.40 | 12.60 | 12.50 | 19.71 | 19.91 | 19.81 | 22.38 | 22.29 | 22.34 |
| $T_6$ | | 2.21 | 2.25 | 2.23 | 12.25 | 12.33 | 12.29 | 19.60 | 19.73 | 19.66 | 21.70 | 21.54 | 21.62 |
| $T_7$ | | 2.24 | 2.29 | 2.27 | 12.47 | 13.26 | 12.87 | 19.79 | 20.95 | 20.37 | 22.79 | 23.27 | 23.03 |
| $T_8$ | | 2.38 | 2.40 | 2.39 | 13.98 | 14.56 | 14.27 | 23.77 | 24.32 | 24.04 | 25.52 | 25.96 | 25.74 |
| $T_9$ | | 2.30 | 2.39 | 2.35 | 13.50 | 13.91 | 13.71 | 22.95 | 23.39 | 23.17 | 25.23 | 25.53 | 25.38 |
| $T_{10}$ | | 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 per panicle and number of unfilled grains per panicle of rice as influenced by different treatments**

| Treatments | | Productive tillers ($m^{-2}$) | | | No. of filled grains panicle$^{-1}$ | | | No. of unfilled grains panicle$^{-1}$ | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2022 | 2023 | Pooled | 2022 | 2023 | Pooled | 2022 | 2023 | Pooled |
| $T_1$ | | 232 | 246 | 239 | 125.8 | 127.5 | 126.6 | 10.3 | 9.8 | 10.0 |
| $T_2$ | | 274 | 283 | 278 | 142.6 | 145.0 | 143.8 | 8.2 | 8.8 | 8.5 |
| $T_3$ | | 267 | 276 | 272 | 139.6 | 142.1 | 140.9 | 8.6 | 9.3 | 9.0 |
| $T_4$ | | 307 | 309 | 308 | 153.5 | 162.9 | 158.2 | 7.2 | 7.5 | 7.3 |
| $T_5$ | | 248 | 262 | 255 | 132.4 | 134.3 | 133.4 | 9.3 | 9.7 | 9.5 |
| $T_6$ | | 244 | 258 | 251 | 129.5 | 131.7 | 130.6 | 10.1 | 9.7 | 9.9 |
| $T_7$ | | 255 | 266 | 260 | 135.7 | 134.7 | 135.2 | 9.0 | 9.3 | 9.2 |
| $T_8$ | | 295 | 300 | 298 | 149.1 | 157.0 | 153.0 | 7.3 | 7.8 | 7.6 |
| $T_9$ | | 282 | 290 | 286 | 148.1 | 153.5 | 150.8 | 7.6 | 8.3 | 8.0 |
| $T_{10}$ | | 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 per plant of rice as influenced by different treatments**

| **Treatments** | | **Panicle length (cm)** | | | **Panicle weight (g)** | | | **1000 grain weight (g)** | | | **Grain yield plant$^{-1}$ (g)** | | | **Straw yield plant$^{-1}$ (g)** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **2022** | **2023** | **Pooled** | **2022** | **2023** | **Pooled** | **2022** | **2023** | **Pooled** | **2022** | **2023** | **Pooled** | **2022** | **2023** | **Pooled** |
| T$_1$ | | 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$_2$ | | 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$_3$ | | 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$_4$ | | 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$_5$ | | 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$_6$ | | 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$_7$ | | 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$_8$ | | 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$_9$ | | 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$_{10}$ | | 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**

<table>
<tr><th colspan="2" rowspan="2">Treatments</th><th colspan="3">Grain yield (kg ha$^{-1}$)</th><th colspan="3">Straw yield (kg ha$^{-1}$)</th><th colspan="3">Harvest index</th></tr>
<tr><th>2022</th><th>2023</th><th>Pooled</th><th>2022</th><th>2023</th><th>Pooled</th><th>2022</th><th>2023</th><th>Pooled</th></tr>
<tr><td colspan="2">$T_1$: Absolute control (Only RDF)</td><td>2435</td><td>2454</td><td>2445</td><td>4235</td><td>4301</td><td>4268</td><td>36.58</td><td>36.32</td><td>36.45</td></tr>
<tr><td colspan="2">$T_2$: Soil $ZnSO_4$ @ 25 kg ha$^{-1}$</td><td>2816</td><td>2869</td><td>2842</td><td>4927</td><td>5030</td><td>4979</td><td>36.38</td><td>36.37</td><td>36.37</td></tr>
<tr><td colspan="2">$T_3$: Soil $FeSO_4$ @ 25 kg ha$^{-1}$</td><td>2729</td><td>2744</td><td>2737</td><td>4776</td><td>4812</td><td>4794</td><td>36.36</td><td>36.49</td><td>36.42</td></tr>
<tr><td colspan="2">$T_4$: Soil $ZnSO_4$ + $FeSO_4$ each @ 25 kg ha$^{-1}$</td><td>2988</td><td>3039</td><td>3013</td><td>5229</td><td>5328</td><td>5278</td><td>36.54</td><td>36.43</td><td>36.49</td></tr>
<tr><td colspan="2">$T_5$: Foliar $ZnSO_4$ @ 0.5% at 30 & 60 DAS</td><td>2588</td><td>2661</td><td>2624</td><td>4528</td><td>4666</td><td>4597</td><td>36.42</td><td>36.35</td><td>36.38</td></tr>
<tr><td colspan="2">$T_6$: Foliar $FeSO_4$ @ 0.5% at 30 & 60 DAS</td><td>2523</td><td>2552</td><td>2538</td><td>4415</td><td>4477</td><td>4446</td><td>36.37</td><td>36.32</td><td>36.34</td></tr>
<tr><td colspan="2">$T_7$: Foliar $ZnSO_4$ + $FeSO_4$ each @ 0.5% at 30 & 60 DAS</td><td>2678</td><td>2727</td><td>2703</td><td>4686</td><td>4783</td><td>4735</td><td>36.37</td><td>36.35</td><td>36.36</td></tr>
<tr><td colspan="2">$T_8$: Soil $ZnSO_4$ @ 25 kg ha$^{-1}$ + Foliar $ZnSO_4$ @ 0.5% at 30 & 60 DAS</td><td>2952</td><td>3006</td><td>2979</td><td>5165</td><td>5270</td><td>5217</td><td>36.45</td><td>36.36</td><td>36.40</td></tr>
<tr><td colspan="2">$T_9$: Soil $FeSO_4$ @ 25 kg ha$^{-1}$ + Foliar $FeSO_4$ @ 0.5% at 30 & 60 DAS</td><td>2916</td><td>2963</td><td>2940</td><td>5103</td><td>5196</td><td>5149</td><td>36.47</td><td>36.32</td><td>36.40</td></tr>
<tr><td colspan="2">$T_{10}$: Soil $ZnSO_4$ + $FeSO_4$ each @ 25 kg ha$^{-1}$ and Foliar $ZnSO_4$ + $FeSO_4$ each @ 0.5% at 30 & 60 DAS</td><td>3003</td><td>3067</td><td>3035</td><td>5288</td><td>5384</td><td>5336</td><td>36.21</td><td>36.29</td><td>36.25</td></tr>
<tr><td colspan="2">SEm±</td><td>129.98</td><td>135.30</td><td>93.81</td><td>231.40</td><td>237.69</td><td>165.86</td><td>1.82</td><td>1.89</td><td>1.31</td></tr>
<tr><td colspan="2">CD at 5 %</td><td>386.20</td><td>402.02</td><td>269.29</td><td>687.56</td><td>706.24</td><td>476.13</td><td>NS</td><td>NS</td><td>NS</td></tr>
<tr><td colspan="2">CV (%)</td><td>8.15</td><td>8.35</td><td>8.25</td><td>8.29</td><td>8.36</td><td>8.33</td><td>8.63</td><td>8.98</td><td>8.81</td></tr>
<tr><td rowspan="2">Year</td><td>SEm±</td><td colspan="3">41.95</td><td colspan="3">74.18</td><td colspan="3">0.59</td></tr>
<tr><td>CD (P=0.05)</td><td colspan="3">NS</td><td colspan="3">NS</td><td colspan="3">NS</td></tr>
<tr><td rowspan="2">Y x T</td><td>SEm±</td><td colspan="3">132.67</td><td colspan="3">234.57</td><td colspan="3">1.85</td></tr>
<tr><td>CD (P=0.05)</td><td colspan="3">NS</td><td colspan="3">NS</td><td colspan="3">NS</td></tr>
</table>