NUSANTARA BIOSCIENCE
Vol. 14, No. 2, pp. 182-187
November 2022

ISSN: 2087-3948
E-ISSN: 2087-3956
DOI: 10.13057/nusbiosci/n140208

Effect of foliar zinc application on growth and yield of rice (*Oryza sativa*) in the Indo-Gangetic Plains of India

RAHUL SAIKH, KANU MURMU♥, ARUP SARKAR, RAMYAJIT MONDAL, KALYAN JANA
Department of Agronomy, Bidhan Chandra Krishi Viswavidyalaya. P.O-Krishi Viswavidyalaya, Mohanpur 741252, Nadia, West Bengal, India.
♥email: kanumurmu@gmail.com

Manuscript received: 18 May 2022. Revision accepted: 4 September 2022.

Abstract. *Saikh R, Murmu K, Sarkar A, Mondal R, Jana K. 2022. Effect of foliar zinc application on growth and yield of rice (*Oryza sativa*) in the Indo-Gangetic Plains of India. Nusantara Bioscience 14: 182-187.* A field experiment was conducted on rice cv. Satabdi (IET-4768) to investigate the effect of foliar zinc application at different stages during the post-Kharif season of 2019. The field experiment was carried out at 'C' block farm of (B.C.K.V), Kalyani, India, with eight different foliar 0.5% 0.5% $ZnSO_4$ ($ZnSO_4$) are T_1: Control (without foliar application), T_2: Foliar application of 0.5% $ZnSO_4$ at Panicle Initiation, T_3: Foliar application of 0.5% $ZnSO_4$ at Booting, T_4: Foliar application of 0.5% $ZnSO_4$ at Panicle Initiation and 1 week after flowering, T_5: Foliar application of 0.5% $ZnSO_4$ at Panicle at 1 week after Flowering, T_6: Foliar application of 0.5% $ZnSO_4$ at Panicle at 2 weeks after flowering, T_7: Foliar application of 0.5% $ZnSO_4$ at Panicle at 1 week and 2 weeks after flowering and T_8: Foliar application of 0.5% $ZnSO_4$ at Panicle Initiation, Booting, 1 week and 2 weeks after flowering respectively in randomized complete block design with three replication. The result of the experiment revealed that rice plants treated with the combination of T_4i.e. Foliar application of 0.5% $ZnSO_4$ at Panicle Initiation and 1 week after flowering have resulted in the highest grain yield of 5.09 t/ha, which was 50.59% higher (3.38 t/ha) than the T_1i.e. the control. Furthermore, residual nutrient status was also highest in the plot treated with T_4i.e. Foliar application of 0.5% $ZnSO_4$ at Panicle Initiation and 1 week after flowering.

Keywords: Foliar application, rice, seed zinc, seedling growth, $ZnSO_4$

INTRODUCTION

Cereals are the prime contributor of Zn to the world's population, particularly for rural communities, which is an essential source for most of the cereal-based food products that are quite deficient in meeting human demands (Juliano 1993; Siahpoush and Darvishnia 2019). Among the cereals, rice (*Oryza sativa* L.) is the principal food source, contributing to a major dietary energy requirement of more than 90% of the global population consumed (Jana et al. 2020). A foliar spray of Zn is the most effective way, rather than soil application, to improve the quality production of crops (Yuan et al. 2013). On average, about 30% of arable lands in West Bengal are under deficiency of available Zn (Singh 2009). Zinc deficiency is most commonly adjusted through zinc sulfate ($ZnSO_4.7H_2O$) because of its high solubility and low cost (Mollah et al. 2009; Fageria et al. 2011). Based on the discussion above, providing Zn to plants (for example, by applying Zn-fertilizers to soil and/or to foliar) appears vital to ensure breeding efforts' success in boosting zinc concentration in grains. Zn's Foliar applications improve grain quality significantly (Mondal et al. 2019). Foliar application is linked with the advantage of fast and effective utilization of nutrients, reduction of losses through leaching, fixation, and regulating the nutrient uptakes of plants. Foliar nutrition is regarded as an essential approach to fertilization at appropriate growth stages as the applied nutrients can easily penetrate through leaf cuticles that can improve the better utilization of the crop, causing rapid utilization of nutrients to reduce the cost of cultivation and minimize crop production. Therefore, applying nutrients such as foliar spray has great potential in enhancing the higher content of this nutritionally important element, and assessing their Zn use efficiencies upon different modes of Zn fertilization has become high-priority research for overcoming Zn-related nutritional disorders in humans and plants. Developing rice variety with high Zn content through the process of "biofortification" aims to combine high mineral content with grain quality (Prasad et al. 2012), improving yield as well as resistance to pests and disease (Graham et al. 2001). Finally, it is the most economical way to achieve quality production and yield, especially when sink competition for carbohydrates occurs while nutrient uptake is restricted.

MATERIALS AND METHODS

Experimental site and weather data

The field experiment was conducted in the post-Kharif season of 2019 at 'C' Block Farm of Bidhan Chandra Krishi Viswavidyalaya (B.C.K.V.), Kalyani, Nadia, West Bengal, India, to study on "Effect of foliar zinc application at different growth stages on seed zinc concentration and yield of rice." The farm where the experiment was conducted is situated in the New Alluvial Zone (NAZ) of West Bengal. The farm is situated at 22°57′ N latitude and 88°20′E longitude with an altitude of 9.75 m above mean sea level, and the ecosystem is on medium land. The farm is situated in the New Alluvial Zone of West Bengal under the sub-tropical climate with high summer temperature, erratic rainfall, high humidity, and short-mild winter. The Monthly weather phenomenon of rice (*O. sativa*) during the growing period is presented in Figure 1. The long-term average annual rainfall is about 1,396 mm; 70-80% comes from the southwest monsoon, with its onset in the region during the second week of June.

Treatments details

Foliar application of zinc was applied with 0.5% zinc sulfate ($ZnSO_4.7H_2O$) solution in rice at different growth stages. The solution was prepared by dissolving $ZnSO_4$ powder with triple distilled deionized (TDI) water. The solution was poured into the sprayer and applied to the whole plant during the morning hours. The rate of applications was 900-1,000 L ha^{-1}.

The treatments are T_1: Control, T_2: Foliar application of 0.5% $ZnSO_4$ at Panicle Initiation, T_3: Foliar application of 0.5% $ZnSO_4$ at Booting, T_4: Foliar application of 0.5% $ZnSO_4$ at Panicle Initiation and 1 week after Flowering, T_5: Foliar application of 0.5% $ZnSO_4$ at Panicle at 1 week after Flowering, T_6: Foliar application of 0.5% $ZnSO_4$ at Panicle at 2 weeks after flowering, T_7: Foliar application of 0.5% $ZnSO_4$ at Panicle at 1 week and 2 weeks after Flowering and T_8: Foliar application of 0.5% $ZnSO_4$ at Panicle Initiation, Booting, 1 week and 2 weeks after flowering.

Crop and soil management

The Rice variety Satabdi (IET-4786) was taken for the entire field experiment. A 100% RDF (120 kg N, 60 kg P_2O_5, and 60 kg K_2O per ha) or 75% of it was given to the respective plots as per the treatments. The entire dose of phosphate, potash, and ½ N was applied at basal, and the remaining ½ of N was top-dressed in two equal splits at 30 and 60 days after transplanting (DAT). Urea, single super phosphate, and muriate of potash were used to supply nitrogen, phosphorus, and potassium, respectively. Soil pH was determined from soil-water suspension in 1:2.5 ratios with the help of a systronics processor-based pH meter (Model-361) described by Jackson (1973). Organic carbon of soil was estimated by oxidizing the soil with a mixture of 1(N) $K_2Cr_2O_7$ and concentrated H_2SO_4 and back-titrating the excess $K_2Cr_2O_7$ with standard ferrous ammonium sulfate solution using diphenylamine indicator following the wet digestion method of Walkley and Black (1934) as outlined by Jackson (1973). The available nitrogen content of the soil was determined using hot alkaline potassium permanganate for oxidative hydrolysis of the soil organic matter, and liberated ammonia was then absorbed and condensed in boric acid and titrated against standard 0.02 (N) H_2SO_4 following the method as proposed by Subbiah and Asija (1956). The available phosphorus content of the soil was extracted with 0.5 (M) $NaHCO_3$ solution at pH 8.5 following Olsen's method (Olsen et al. 1954). The available potassium in the soil was determined by shaking 5 g of the soil sample with 25 mL neutral 1 (N) ammonium acetate solution for 5 minutes. The soil-extractant suspension was leached through Whatman No.1 filter paper.

Statistical analysis

All the data were statistically analyzed following the standard procedures Gomez and Gomez (1984) described. In addition, the data were treated for analysis of variance and least significant difference (P=0.05) to compare the effect of foliar zinc application on the growth and yield of rice.

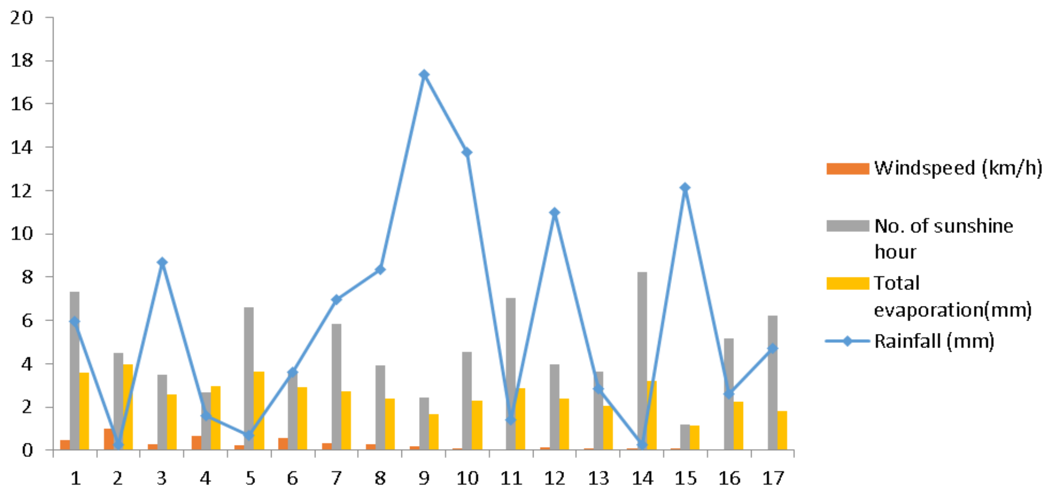

Figure 1. Monthly weather phenomenon of rice (*Oryza sativa*) during the growing period **(*** Source: AlCRlP on Agro-Meteorology. Directorate of Research, BCKV. Kalyani, Nadia)

RESULT AND DISCUSSION

Growth attributes

The height is greatly influenced by the foliar application of 0.5% $ZnSO_4$ at different growth stages of rice plants (Table 1). A maximum plant height of 93.00 cm was observed in the T_4 treatment (Panicle initiation+1week after flowering). The increase in growth parameters might be ascribed to an adequate supply of zinc that might have increased the availability and uptake of other essential nutrients and thereby resulted in improved crop growth. The minimum plant height (82.27 cm) was recorded in the control. At harvesting (100 DAT), the maximum dry matter accumulated in the case of treatment T_4 (983.66 g/m^2) followed by T_8 (952.93 g/m^2) treatment. Dry matter production was very poor (825.06 g/m^2) in the control situation, i.e., where no fertilization was done. Muthukumararaja et al. (2012) reported that maximum dry matter production of (2.98 gm per pot) at tillering and (40.93 gm per pot) at panicle initiation was obtained with the application of 5 mg Zn per kg, which was about 44 to 60% greater as compared with the treatment that did not receive zinc. Notable changes were also reflected in the Crop Growth Rate (CGR) of Kharif rice from 60 DAT to harvest with the different times of foliar management. The crop growth rate of rice at the stage of 60 to 100 DAT varied from 11.77 to 13.34 g/m^2/day, with a variation of 13.33%. The maximum crop growth rate (13.34 g/m^2/day) was observed in $T_{4,}$ and the lowest CGR (11.77 g/m^2/day) was recorded in the control treatment (T_1), but the treatments were non-significant. At harvesting (100 DAT), there was a significant difference between the LAI of rice under different treatments. The maximum LAI of rice (2.44) was recorded at treatment $T_{5,}$ followed by T_8 treatment. The lowest value of LAI was recorded from treatment T1, i.e., the control obtained a value of 1.95. At harvesting (100 DAT), there was a significant difference between the root length of rice under different treatments.

Foliar zinc application resulted in a significant impact on root length over control plots. The maximum root length of rice (25.73 cm) was recorded at treatment T4 followed by T_8 treatment (Panicle initiation + Booting + 1 week and 2 weeks after flowering). The root volume of the rice crop was found to vary from 20.34 to 25.82 cc/hill, with a variation of 26.94%. Amongst all treatments, the T_4 treatment (Panicle initiation + 1 week after flowering) recorded a maximum root volume of 25.82 cc/hill, whereas the control treatment recorded the least value of root volume. At harvesting (100 DAT), there was a significant difference between root volumes of rice under different treatments. Foliar zinc application resulted in a significant impact on root volume over control plots. The maximum root volume of rice (31.12 cc per hill) was recorded at treatment T_4 followed by T_8 treatment (Panicle initiation + Booting + 1 week and 2 weeks after flowering. At harvesting (100 DAT), there was a significant difference between the root dry weight of rice under different treatments. Foliar zinc application resulted in a significant impact on root dry weight over the control plots. The maximum root dry weight of rice (10.64 gm) was recorded at treatment T_8 followed by T_4 treatment (Panicle initiation + 1 week after flowering). The lowest root value by dry weight of rice (4.23gm) was recorded from T_1i.e the control.

The increase in growth parameters might be ascribed to an adequate supply of zinc that might have increased the availability and uptake of other essential nutrients, thereby resulting in improved crop growth in rice. Foliar Zn application significantly increased Zn concentration in rice seeds of paddy and other crops. This result is in good agreement with the previous studies in wheat, during which seed Zn concentration was increased by foliar Zn application up to 3 times compared with no Zn application (Yilmaz et al. 1997; Karim et al. 2012). Foliar Zn applied is well absorbed and transported through the phloem, as shown in wheat using radiolabeled Zn (65Zn), especially in plants grown under low Zn supply (Erenoglu et al. 2002). Although xylem transport of Zn has been indicated to be more important for Zn accumulation in rice grain than re-translocation of Zn from the leaves (Palmgren et al. 2008), the results of this study, however, suggested that phloem transport of Zn from leaf and stem tissue may additionally play a greater role in the enrichment of grains with Zn.

Yield attributes and yield

All yield attributes and yield are presented in (Table 2). The most important yield component of rice in terms of panicle per square meter area was found to be statistically significant as influenced by different times of foliar zinc application during the Kharif season. It has been observed that the panicles/m^2 was to tune 182.33 to 270 with a variation of 48.08% among the treatments. The highest number of panicles/ m^2 was recorded at T_4 (270 /m^2), followed by treatment T_8 (267/m^2) which were statistically at par. The lowest number of effective tiller /m^2 was observed in the T_1i.e., the control treatment (182.33/m^2). It has been observed that the panicle length of rice varied from 23.52 to 26.06 cm with a variation of 13.09% over the control. The maximum panicle length (26.06cm) was achieved in the T_5 treatment, i.e., 1 week after flowering, followed by the T_2 treatment, i.e., Panicle Initiation (23.52 cm). The control treatment observed a very short panicle length (23.52 cm). The inflorescence length of rice, called panicle, was significantly different from the treatment. It has been observed that the panicle length of rice varied from 23.52 to 26.06 cm with a variation of 13.09% over the control. The maximum panicle length (26.06cm) was achieved in the T_5 treatment, i.e., 1 week after flowering, followed by the T_2 treatment, i.e., Panicle Initiation (23.52 cm). The control treatment observed a very short panicle length (23.52 cm).

However, the number of filled grains/panicles varied from 91.08 to 116, and the variation was recorded at 27.06%. The number of filled grains/panicle was maximum in T_8 treatment, i.e., panicle initiation+ Booting + 1 week and 2 weeks after flowering (116). The lowest number of filled grains/panicles was obtained in the T_1 treatment (91.08), which was the control plot. The other treatments significantly differ from each other. Foliar zinc application at different growth stages significantly improved rice grain yield due to the improvement in yield attributing characters. The grain yield of rice cv. IET 4786 (Satabdi) varied to the range of 3.38 to 5.09 t/ha, and the variation was recorded by 50.59%. The highest grain yield (5.09 t/ha) was recorded in the T_4 treatment Panicle initiation + 1 week after flowering, which was significantly higher than other treatments. The control plot recorded the lowest yield (3.38 t/ha). The straw yield of rice significantly increased from 5.56 to 6.88 t/ ha, and the variation was recorded by 23.74%. Application at Panicle initiation + 1 week after flowering (T_4) recorded the highest straw yield of 6.88 t/ha, followed by T_8 (6.86 t/ha) and T_7 (6.82 t/ha). The lowest straw yield was recorded in the control plot (5.56 t/ ha). The harvest index of rice increased from 37.80% to 42.52%. The harvest index differed significantly among different treatments. However, treatment T_4 (Panicle initiation + 1 week after flowering) gave the highest value of harvest index (42.52%) compared to the rest of the treatment combinations. The lowest value of 37.80 was recorded in T_1. The higher harvest index values indicated the greater translocation of photosynthates from source to sink and better portioning towards reproductive growth.

It seems obvious that only a small amount of foliar-applied Zn is translocated into paddy rice after early foliar application, while a greater amount of Zn is translocated into paddy rice grain and enters into brown rice after the late foliar application of Zn. This result agrees with Phattarakul et al. (2012), who showed that a foliar Zn spray applied at late growth to rice grown under field conditions caused a greater increase in grain Zn than a foliar Zn spray before the flowering stage. Similar results were also found in field-grown-wheat (Cakmak et al. 2010). Furthermore, Abid et al. (2002) observed that the growth and rice yield were significantly enhanced by applying Zn, Fe, and Mn alone or in various combinations.

Table 1. Effect of foliar zinc application on growth parameters at different growth stages of rice (*Oryza sativa*)

Treatment	Plant height (cm)	Dry matter accumulation (g/m^2)	Crop growth rate (g/m^2/day)	Leaf area index	Root length (cm)	Root volume (cc/hill)	Root dry wt.(gm)
T_1	82.27	825.06	11.77	1.95	22.02	26.58	4.23
T_2	89.36	948.38	12.95	2.24	22.45	27.46	5.03
T_3	83.02	844.53	12.22	2.02	23.38	28.56	6.38
T_4	93.00	983.66	13.34	2.15	25.73	31.12	10.30
T_5	86.96	882.60	12.74	2.44	21.25	29.29	8.50
T_6	91.44	925.60	12.92	2.32	22.86	28.45	6.82
T_7	84.36	933.47	13.31	2.37	23.24	29.76	8.28
T_8	84.34	952.93	12.30	2.45	23.74	29.90	10.64
SD	4.02	55.75	0.55	0.19	1.34	1.44	2.32
CD at 5%	NS	3.45	NS	0.03	0.05	0.32	2.41

Note: T_1: the Control, T_2: Foliar application of 0.5% $ZnSO_4$ at Panicle Initiation, T_3: Foliar application of 0.5% $ZnSO_4$ at Booting, T_4: Foliar application of 0.5% $ZnSO_4$ at Panicle Initiation and 1 week after flowering, T_5: Foliar application of 0.5% $ZnSO_4$ at Panicle at 1 week after flowering, T_6: Foliar application of 0.5% $ZnSO_4$ at Panicle at 2 weeks after flowering, T_7: Foliar application of 0.5% $ZnSO_4$ at Panicle at 1 week and 2 weeks after flowering and T_8: Foliar application of 0.5% $ZnSO_4$ at Panicle Initiation, Booting, 1 week and 2 weeks after flowering

Table 2. Effect of foliar zinc application on yield parameters at different growth stages of rice (*Oryza sativa*)

Treatment	No. of panicle/m^2	No. of filled grain/panicle	Panicle length (cm)	Grain yield (t/ha)	Straw yield (t/ha)	Harvest Index (%)
T_1	182.33	91.08	23.53	3.38	5.56	37.80
T_2	263.00	96.73	25.51	4.60	6.65	40.88
T_3	212.00	93.00	25.27	4.26	5.96	41.68
T_4	270.00	110.33	25.00	5.09	6.88	42.53
T_5	240.00	104.00	26.06	4.58	6.22	42.40
T_6	247.00	101.00	24.29	4.55	6.77	40.19
T_7	252.00	105.00	25.16	4.68	6.82	40.69
T_8	267.00	116.00	24.77	4.72	6.86	40.75
SD	30.33	8.51	0.77	0.50	0.50	1.50
CD at 5%	3.36	1.81	1.06	0.02	0.01	0.09

Note: T_1: the Control, T_2: Foliar application of 0.5% $ZnSO_4$ at Panicle Initiation, T_3: Foliar application of 0.5% $ZnSO_4$ at Booting, T_4: Foliar application of 0.5% $ZnSO_4$ at Panicle Initiation and 1 week after flowering, T_5: Foliar application of 0.5% $ZnSO_4$ at Panicle at 1 week after flowering, T_6: Foliar application of 0.5% ZnSO4 at Panicle at 2 weeks after flowering, T_7: Foliar application of 0.5% $ZnSO_4$ at Panicle at 1 week and 2 weeks after flowering and T_8: Foliar application of 0.5% $ZnSO_4$ at Panicle Initiation, Booting, 1 week and 2 weeks after flowering

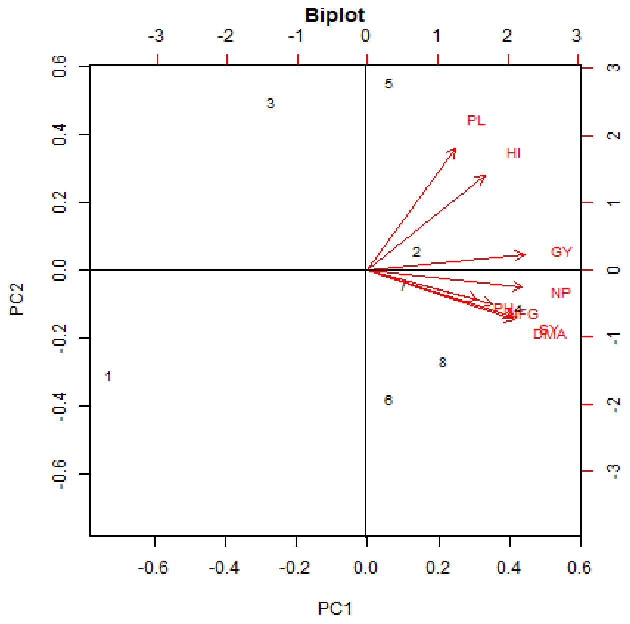

Figure 2. PCA graphs of 8 treatments for yield, yield components, and agronomic traits of the experiment. PH: plant height; DMA: dry matter accumulation; NP: numbers of panicle m-2; NFG: numbers of filled grain per panicle; PL: panicle length; GY: grain yield; SY: seed yield; HI: harvest index; (1-8) denotes (T1-T8)

Table 3. Effect of foliar zinc application on soil nutrient status at post-harvest soil

Treatment	Available N (kg/ha)	Available P_2O_5 (kg/ha)	Available soil K_2O (kg/ha)
T_1	162.41	25.81	167.41
T_2	188.01	37.19	207.77
T_3	204.62	40.45	208.61
T_4	215.53	44.93	219.56
T_5	208.27	42.34	213.19
T_6	189.25	38.54	185.02
T_7	192.40	37.65	191.00
T_8	186.64	37.51	183.36
SD	16.43	5.64	17.98
CD at 5%	2.32	2.10	2.51

Note: T_1: the Control, T_2: Foliar application of 0.5% $ZnSO_4$ at Panicle Initiation, T_3: Foliar application of 0.5% $ZnSO_4$ at Booting, T_4: Foliar application of 0.5% $ZnSO_4$ at Panicle Initiation and 1 week after Flowering, T_5: Foliar application of 0.5% $ZnSO_4$ at Panicle at 1 week after Flowering, T_6: Foliar application of 0.5% $ZnSO_4$ at Panicle at 2 weeks after Flowering, T_7: Foliar application of 0.5% $ZnSO_4$ at Panicle at 1 week and 2 weeks after Flowering and T_8: Foliar application of 0.5% $ZnSO_4$ at Panicle Initiation, Booting, 1 week and 2 weeks after flowering

Principal Component Analysis (PCA)

The PCA comprising two principal components (PC1 and PC2) explained 86.49% of the total variation in the experiment (Figure 2). In the experiment, PC1 explained 69.81%, and PC2 explained 16.68% of the total variation. A strong correlation was observed between various components, yield, plant height, dry matter accumulation, panicle number, filled grain per panicle, panicle length, stover yield, and harvest index. Superimposition of 8 treatments on rice yield and yield components revealed that foliar application of 0.5% $ZnSO_4$ at panicle initiation and 1 week after flowering with RDF on rice cv Satabdi (IET 4786) produced the highest values for the given attributes and showed significant correlation with these parameters (Figure 2).

Soil nutrient status

After harvesting Kharif rice, available soil nitrogen, phosphorus, and potassium varied significantly with different treatments (Table 3). The available nitrogen in the soil varied from 162.41 to 215.53 kg/ha with a variation of 32.70%. The available nitrogen was more (215.53 kg/ha) in the plot fertilized with foliar management at Panicle initiation + 1 week after flowering (T4), followed by the plot fertilized with foliar management at (T5). The lowest available nitrogen (162.41 kg/ha) was recorded in the control plot. Conversely, the soil's phosphorus availability varied from 25.81 to 44.93, with a variation of 74.07%. The highest available phosphorus was recorded in treatment T4,i.e., Panicle initiation + 1 week after flowering, followed by treatment T5 and T3, and the lowest available phosphorus was recorded in the control plot (T1). The treatments significantly differ from each other. The available potassium in the soil varied from 167.41 to 219.56 kg/ha with a variation of 31.15%. The highest available potassium was obtained from the T4 treatment, i.e., Panicle initiation + 1 week after flowering (219.56 kg /ha) followed by T5 (1 week after flowering) treatment (213.86 kg /ha), and the lowest data was obtained in the control plot where no foliar were applied (167.41 kg/ ha). The highest value of available N, P_2O_5, and K_2O was found in T4 treatment, maybe because they can improve soil properties and structure, leading to an increase in soil fertility. The results are close finding with Murmu et al. (2013).

In conclusion, the effect of foliar zinc application at different growth stages significantly influenced the growth as well as yield and yield attributes of rice cv. Satabdi (IET-4786) grew in the post-Kharif situation. Therefore, Zn in rice grain can be effectively raised by foliar Zn application, particularly when Zn is sprayed after flowering. Therefore, considering values and based on the results obtained in the present study, it may be concluded that foliar application of 0.5% $ZnSO_4$ at Panicle Initiation, Booting, 1 week and 2 weeks after flowering and foliar application of 0.5% $ZnSO_4$ at Panicle Initiation and 1 week after flowering, could be recommended due to better grain and straw yield obtaining values of 4.72t/ha and 6.88t/ha respectively.

REFERENCES

Abid M, Ahmad N, Jahangir M, Ahmad I. 2002. Effect of zinc, iron and manganese on growth and yield of rice (*Oryza sativa* L.). Pak J Agric Sci 39: 177-180.

Cakmak I, Kalayci M, Kaya Y et al. 2010. Biofortification and localization of zinc in wheat grain. J Agric Food Chem 58: 9092-9102. DOI: 10.1021/jf101197h.

Erenoglu B, Nikolic M, Romheld V, Cakmak I. 2002. Uptake and transport of foliar applied zinc (65Zn) in bread and durum wheat cultivars differing in zinc efficiency. Plant Soil 241: 251-257. DOI: 10.1023/A:1016148925918.

Fageria NK, Dos Santos AB, Cobucci T. 2011. Zinc nutrition in lowland rice. Commun Soil Sci Plant Anal 42 (1): 719-727. DOI: 10.1080/00103624.2011.584591.

Gomez KA, Gomez AA. 1984. Statistical Procedure for Agricultural Research. An International Rice Research Institute Book, John Wiley and Sons, New Jersey.

Graham RD, Welch, RM, Bouis HE. 2001. Addressing micronutrient malnutrition through enhancing the nutritional quality of staple foods: Principles, perspectives and knowledge gaps. Adv Agron 70: 77-142. DOI: 10.1016/s0065-2113(01)70004-1.

Jackson ML. 1973. Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd., New Delhi.

Jana K, Mondal R, Mallick Gk. 2020. Grain yield of hybrid rice varieties as influenced by seed rates under aerobic direct seeded situation. Intl J Curr Microbiol Appl Sci 7 (10): 2839-2845. DOI: 10.21275/ART20193790.

Juliano BO. 1993. Rice in Human Nutrition. Prepared in Collaboration with FAO, Food and Agriculture Organization of the United Nations, Rome.

Karim R, Zhang Y, Zhao R, Chen X, Zhang F, Zou C. 2012. Alleviation of drought stress in winter wheat by late foliar application of zinc, boron, and manganese. J Plant Nutr Soil Sci 175: 142-151. DOI: 10.1002/jpln.201100141.

Mollah MZI, Talukder NM, Islam MN, Ferdous Z. 2009. Effect of nutrients content in rice as influenced by zinc fertilization. World Appl Sci J 6 (8): 1082-1089. DOI: 10.1.1.415.5182.

Mondal R, Goswami S, Mandi SK, Goswami SB. 2019. Quality seed production of rice (*Oryza sativa* L.) as influenced by nutrient management during kharif season in the lower Indo-Gangetic plains. Environ Ecol 37 (1A): 274-280. DOI: 10.35709/ory.2020.57.1.6.

Murmu K, Swain DK, Ghosh BC. 2013. Comparative assessment of conventional and organic nutrient management on crop growth and yield and soil fertility in tomato-sweet corn production system. Aust J Crop Sci 7 (11): 1617-1626.

Muthukumararaja M, Wajid SA, Hussain A. 2012. Growth and yield response of Basmati 385 (*Oryza sativa* L) to zinc sulphate application. Pak J Biol Sci 1632-1633. DOI: 10.3923/pjbs.1999.1632.1633.

Olsen SR, Cole C, Watanabe CV, Dean LA. 1954. Estimation of available phosphorus in soils by extraction with sodiumbicarbonate. USDA Circular No. 939.

Palmgren MG, Clemens S, Williams L, Kramer U, Borg S, Schjorring K, Sanders D. 2008. Zinc biofortification of cereals: Problems and solutions. Trends Plant Sci 13: 464-473. DOI: 10.1016/j.tplants.2008.06.005.

Phattarakul N, Rerkasem B, Li LJ et al. 2012. Biofortification of rice grain with zinc through zinc fertilization in different countries. Plant Soil 361: 131-141. DOI: 10.1007/s11104-012-1211-x.

Prasad R, Shivay YS, Kumar D. 2012. Biofortification/fertifortification of rice (*Oryza sativa*) and wheat (*Triticum aestivum*) for ameliorating zinc malnutrition of humans and animals in India. Indian J Agron 57 (3rd IAC Special Issue): 195-98.

Siahpoush S, Darvishnia M. 2019. Short Communication: Genetic diversity among *Fusarium* isolates from cereals in Iran assessed using RAPD marker. Biodiversitas 20: 292-296. DOI: 10.13057/biodiv/d200133.

Singh MV. 2009. Micronutrient nutritional problems in soils of India and improvement for human and animal health. Indian J Fertilizers 5 (4): 11-16.

Walkley AJ, Black IA. 1934. Estimation of soil organic carbon by the chromic acid titration method. Soil Sci 37: 29-38. DOI: 10.1097/00010694-193401000-00003.

Yilmaz A, Ekiz H, Torun B, Gultekin I, Karanlik S, Bagci SA, Cakmak I. 1997. Effect of different zinc application methods on grain yield and zinc concentration in wheat cultivars grown on zinc-deficient calcareous soils. J Plant Nutr 20: 461-471. DOI: 10.1080/01904169709365267.

Yuan E , Wilson CE JR, Ntamatungiro S, Norman RJ, Boothe DL. 2013: Evaluation of zinc seed treatments for rice. Agron J 93: 157-163. DOI: 10.2134/agronj2001.931152x.