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Growth and yield of rice as influenced by biofortification of zinc and iron

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Abstract: A field experiment was conducted during *kharif* 2014 in Main Agricultural Research Station (MARS), Dharwad to study the biofortification of zinc and iron on growth and yield of rice. The experiment consisted of two factors *viz.,* soil and foliar application of zinc sulphate and ferrous sulphate. Factor-1 consisted of six soil applications *viz.,* S_1: Control (No application of $ZnSO_4$ and $FeSO_4$), S_2: $ZnSO_4$ and $FeSO_4$ application each @ 10 kg ha^{-1}, S_3: $ZnSO_4$ and $FeSO_4$ application each @ 15 kg ha^{-1}, S_4: $ZnSO_4$ and $FeSO_4$ application each @ 20 kg ha^{-1}, S_5: $ZnSO_4$ and $FeSO_4$ application each @ 25 kg ha^{-1}, S_6: $ZnSO_4$ and $FeSO_4$ application each @ 30 kg ha^{-1} and factor-2 consisted of foliar applications *viz.,* F_1: No spray of $ZnSO_4$ and $FeSO_4$, F_2: Foliar spray of $ZnSO_4$ and $FeSO_4$ each @ 0.5 %. Combined soil application of $ZnSO_4$ and $FeSO_4$ each @ 25 kg ha^{-1} and foliar spray of $ZnSO_4$ and $FeSO_4$ each @ 0.5 % recorded significantly higher yield attributing characters like productive tillers per meter row length, number of filled grains per panicle, grain yield (3739 kg ha^{-1}), straw yield (5539 kg ha^{-1}) and growth attributes like number of tillers per meter row length, LAI, SPAD value and dry matter production which were on par with that of treatment receiving soil application of $ZnSO_4$ and $FeSO_4$ each @ 20 and 30 kg ha^{-1} with foliar spray $ZnSO_4$ and $FeSO_4$ each @ 0.5 per cent.

Key words: Biofortification, Ferrous sulphate, Rice, Straw, Zinc sulphate

Introduction

Rice (*Oryza sativa* L.) is one of the most important food crop in the world which serves as staple food for more than half of the global population. Asia accounts for 60 per cent of the global population, about 92 per cent of the world rice production and 90 per cent of global rice consumption (Anon., 2012). Rice provides 30 to 75 per cent of the total calories to more than 3 billion Asians (Khush, 2004). Rice production in India is 106.19 m t from an area of 43.95 m ha with a productivity of 2416 kg ha^{-1}. In Karnataka rice is grown in an area of 1.54 m ha with an annual production of 4.19 m t and productivity is 2719 kg ha^{-1} (Anon., 2014).

Biofortification is the process of creating micronutrient denser staple food crops with increased bioavailable concentrations through agronomic intervention or genetic selection. Biofortification works for twin objective of increasing the concentration of the micronutrients in the grains and simultaneously improving the bioavailability of micronutrients in the grains to alleviate the micronutrient deficiency in human beings and also animals. The traditional strategies, such as supplementation or food fortification cannot always be universally successful. Agronomic biofortification has gained importance compared with other methods such as supplementation and food fortification. Hence the biofortification of zinc and iron can be done through seed treatment, soil and foliar applications.

Agronomic biofortification strategy appears to be essential in keeping sufficient amount of available zinc and iron in soil solution and maintaining adequate zinc and iron transport to the seeds during reproductive stage, agronomic biofortification would be a very attractive and useful strategy in solving zinc and iron deficiency related health problems globally and effectively. Applying Zn and Fe fertilizers to soil and or through foliar to the plants appears to be important to ensure success of breeding efforts for increasing Zn and Fe concentration in grain. Depending on the application method, Zn and Fe fertilizers can increase grain Zn and Fe concentration up to three to four fold. The most effective method for increasing Zn and Fe in grain was the soil + foliar application method that resulted in about three and half fold increase in the grain Zn and Fe concentration. The highest increase in grain yield was obtained with soil, soil+foliar and seed+foliar applications (Cakmak, 2008).

Material and methods

A field experiment was conducted during *kharif* season 2014 in Main Agricultural Research Station, Dharwad, Karnataka at 15°30'6'' North latitude and at longitude of 74° 59'12.4'' East and at an altitude of 678 m above MSL. The experiment consisted of two factors *viz.,* soil and foliar application of zinc sulphate and ferrous sulphate. Factor-1 consisted of six soil applications *viz.,* S_1: Control (No soil application of $ZnSO_4$ and $FeSO_4$), S_2: $ZnSO_4$ and $FeSO_4$ application each @ 10 kg ha^{-1}, S_3: $ZnSO_4$ and $FeSO_4$ application each @ 15 kg ha^{-1}, S_4: $ZnSO_4$ and $FeSO_4$ application each @ 20 kg ha^{-1}, S_5: $ZnSO_4$ and $FeSO_4$ application each @ 25 kg ha^{-1}, S_6: $ZnSO_4$ and $FeSO_4$ application each @ 30 kg ha^{-1} and factor-2 consists of two foliar applications *viz.,* F_1: No spray of $ZnSO_4$ and $FeSO_4$, F_2: Foliar spray of $ZnSO_4$ and $FeSO_4$ each @ 0.5 %. The experiment was laid out in factorial RCBD with three replications.

The soil of the experimental site was medium deep black soil having pH 7.02, electrical conductivity 0.27 dS m^{-1}, carbon 0.53 %, available N 257.3 kg ha^{-1}, P_2O_5 25.4 kg ha^{-1}, K_2O 278.7 kg ha^{-1} and micronutrients *viz.,* Zn, Fe, Cu and Mn, 0.61, 5.28, 1.98 and 8.34 ppm, respectively. The rainfall during the cropping period (July- December) was 679.2 mm which was well distributed during crop growth period. There was no soil moisture deficit upto panicle emergence. Later four irrigations were given between panicle emergence to grain development stage.

The land was ploughed and cultivated once with mould-board plough and harrowed twice to bring the soil to a fine tilth. Small bunds were formed around each plot to avoid movement of water from one plot to another. Plots were laid out as per the plan of the experiment. The rice variety BPT-5204 was sown with seed rate of 100 kg ha^{-1} in spacing of 20 x 10 cm. Fertilizers were applied as recommended (100:50:50 N: P_2O_5: K_2O kg ha^{-1}, respectively) for drill sown rice crop. At the time of sowing, complete dose of P_2O_5 and K_2O were applied and N was applied in three equal splits at 20, 40 days after sowing and at panicle initiation stage as top dressing in all treatments. The levels of $ZnSO_4$ and $FeSO_4$ were applied as per treatments. The nutrients were applied in the form of urea, diammonium phosphate, muriate of potash, zinc sulphate and ferrous sulphate. Before sowing, seeds were treated with 1% $ZnSO_4$ and 1% $FeSO_4$ mixed with 1 % lime solution for 12 hours and shade dried for 5 hours. One foliar application of zinc sulphate and ferrous sulphate each @ 0.5 per cent mixed with 0.25 per cent lime solution was made at panicle emergence as per treatments. Biometric observations were taken at different growth stages (30, 60, 90, 120 DAS and at harvest). Leaf area was computed by length and breadth method. It was multiplied by factor 0.65 and expressed in dm^2 by following the procedure given by Gomez (1972). Leaf area index was calculated as per procedure. The data collected from the experiment at different growth stages and at harvest was subjected to statistical analysis as described by Gomez and Gomez (1984).

Results and discussion

Effect of soil application on growth and yield of rice

The variation in yield and yield attributes could be traced back to the improved growth parameters *viz.,* number of tillers per meter row length, leaf area, LAI, chlorophy1 contents and total dry matter production. Zinc is required for the synthesis of tryptophan, which is a precursor for formation of indole acetic acid (IAA) and increased amount of tryptophan in plants was supplied with the zinc manure. There seemed to be a suitable nutritional condition that increased the growth of crop. Significantly more number of tillers per m row length at 90, 120 and at harvest stages (84.19, 78.80 and 72.35 respectively) (Table 1) were recorded with soil application of $ZnSO_4$ and $FeSO_4$ each @ 25 kg ha^{-1}. This was due to the availability of optimum quantity of micronutrients which

Table 1. Growth parameters at different growth stages of rice as influenced by soil and foliar application of zinc and iron

Treatments	Number of tillers per meter row length					Leaf area index per plant				
	30 DAS	60 DAS	90 DAS	120 DAS	At harvest	30 DAS	60 DAS	90 DAS	120 DAS	At harvest
Factor - I (Soil application)										
S_1- Control (No application of $ZnSO_4$ and $FeSO_4$)	44.60	64.01	69.59	66.70	0.943	0.334	1.181	2.294	1.208	0.471
S_2- $ZnSO_4$ and $FeSO_4$ each @ 10 kg/ha	45.55	68.31	73.30	71.43	1.055	0.359	1.703	2.852	1.749	0.528
S_3- $ZnSO_4$ and $FeSO_4$ each @ 15 kg/ha	47.91	71.11	78.18	72.69	1.357	0.367	1.832	2.998	1.878	0.678
S_4- $ZnSO_4$ and $FeSO_4$ each @ 20 kg/ha	47.96	72.65	82.11	76.96	1.763	0.398	2.122	3.311	2.125	0.882
S_5- $ZnSO_4$ and $FeSO_4$ each @ 25 kg/ha	51.67	74.85	84.19	78.80	1.889	0.471	2.319	3.538	2.393	0.944
S_6- $ZnSO_4$ and $FeSO_4$ each @ 30 kg/ha	48.85	77.86	82.29	78.23	1.794	0.435	2.162	3.562	2.531	0.897
S.Em ±	1.66	1.99	0.79	0.91	0.063	0.032	0.068	0.145	0.163	0.032
C.D. (0.05)	NS	5.8	2.3	2.6	0.18	NS	0.20	0.42	0.47	0.09
Factor - II (Foliar application)										
F_1- No spray of $ZnSO_4$ and $FeSO_4$	47.52	71.08	77.10	72.30	1.358	0.395	1.872	2.902	1.804	0.679
F_2- Foliar spray of $ZnSO_4$ and $FeSO_4$ each @ 0.5 %	47.99	71.85	79.46	75.96	1.575	0.393	1.900	3.283	2.157	0.788
S. Em ±	0.96	1.15	0.46	0.53	0.036	0.018	0.039	0.084	0.094	0.018
C.D. (0.05)	NS	NS	1.34	1.55	0.107	NS	NS	0.24	0.27	0.05
Interaction										
S_1F_1	44.33	63.25	68.27	66.04	0.921	0.328	1.237	2.256	1.194	0.460
S_1F_2	44.86	64.77	70.91	67.35	0.964	0.340	1.125	2.333	1.221	0.482
S_2F_1	45.88	67.18	72.72	69.16	1.006	0.358	1.592	2.701	1.590	0.503
S_2F_2	45.22	69.43	73.87	73.70	1.105	0.359	1.813	3.003	1.908	0.552
S_3F_1	47.40	71.32	78.44	70.32	1.067	0.361	1.867	2.908	1.780	0.534
S_3F_2	48.41	70.90	77.93	75.06	1.646	0.373	1.796	3.087	1.976	0.823
S_4F_1	47.82	72.18	79.95	75.55	1.725	0.408	2.073	3.187	2.009	0.863
S_4F_2	48.09	73.12	84.27	78.38	1.801	0.387	2.171	3.434	2.240	0.901
S_5F_1	51.30	77.05	82.69	76.46	1.731	0.463	2.350	3.123	2.162	0.866
S_5F_2	52.04	75.51	85.70	81.14	2.047	0.478	2.288	3.839	2.695	1.023
S_6F_1	48.41	74.18	80.52	76.30	1.697	0.450	2.115	3.236	2.091	0.849
S_6F_2	49.30	78.68	84.06	80.16	1.890	0.421	2.208	4.001	2.900	0.945
S.Em ±	2.34	2.82	1.12	1.29	0.089	0.045	0.097	0.205	0.230	0.045
C.D. (0.05)	NS	NS	3.27	3.79	0.26	NS	NS	0.60	0.67	0.13

Table 2. Chlorophyl content (SPAD value) and dry matter production (g/plant) at different growth stages of rice as influenced by soil and foliar application of zinc and iron

Treatments	SPAD value (Chlorophyll content of rice leaf)					Dry matter production (g/plant)				
	30 DAS	60 DAS	90 DAS	120 DAS	At harvest	30 DAS	60 DAS	90 DAS	120 DAS	At harvest
Factor - I (Soil application)										
S_1- Control (No application of $ZnSO_4$ and $FeSO_4$)	25.92	28.90	36.63	32.15	1.80	0.60	4.71	7.94	9.28	12.83
S_2- $ZnSO_4$ and $FeSO_4$ each @ 10 kg/ha	27.12	31.41	38.46	34.48	1.91	0.63	5.12	8.06	10.22	14.01
S_3- $ZnSO_4$ and $FeSO_4$ each @ 15 kg/ha	28.77	32.76	40.29	34.92	2.17	0.65	5.41	8.38	11.00	14.48
S_4- $ZnSO_4$ and $FeSO_4$ each @ 20 kg/ha	29.61	34.19	41.13	35.64	2.53	0.66	5.63	9.98	11.57	15.73
S_5- $ZnSO_4$ and $FeSO_4$ each @ 25 kg/ha	30.96	36.64	42.36	36.11	2.64	0.71	5.82	11.23	12.81	17.08
S_6- $ZnSO_4$ and $FeSO_4$ each @ 30 kg/ha	30.63	34.87	42.03	36.46	2.58	0.67	6.59	10.59	12.03	16.42
S.Em ±	1.22	0.98	0.39	0.31	0.03	0.03	0.33	0.42	0.42	0.46
C.D. (0.05)	NS	2.87	1.13	0.91	0.10	NS	0.98	1.24	1.23	1.34
Factor - II (Foliar application)										
F_1- No spray of $ZnSO_4$ and $FeSO_4$	28.82	33.16	39.20	34.50	2.18	0.65	5.55	8.56	10.65	14.55
F_2- Foliar spray of $ZnSO_4$ and $FeSO_4$ each @ 0.5 %	28.85	33.10	41.10	35.42	2.36	0.66	5.55	10.17	11.65	15.63
S.Em ±	0.71	0.57	0.22	0.18	0.02	0.02	0.19	0.24	0.24	0.26
C.D. (0.05)	NS	NS	0.65	0.52	0.06	NS	NS	0.72	0.71	0.77
Interaction										
S_1F_1	26.11	28.41	35.96	31.91	1.77	0.59	4.62	7.93	9.12	12.68
S_1F_2	25.72	29.40	37.30	32.39	1.83	0.61	4.81	7.96	9.43	12.97
S_2F_1	26.65	30.93	37.12	34.32	1.86	0.62	5.07	8.02	9.97	13.64
S_2F_2	27.59	31.90	39.80	34.64	1.95	0.63	5.17	8.11	10.47	14.37
S_3F_1	28.71	32.92	39.61	34.61	2.04	0.65	5.44	8.37	10.78	13.93
S_3F_2	28.83	32.60	40.96	35.22	2.30	0.64	5.38	8.40	11.22	15.02
S_4F_1	29.49	34.41	39.97	35.07	2.44	0.66	5.74	8.42	10.88	15.08
S_4F_2	29.72	33.97	42.29	36.22	2.62	0.67	5.52	11.55	12.27	16.37
S_5F_1	31.18	36.80	41.35	35.71	2.51	0.70	6.58	9.32	11.71	16.12
S_5F_2	30.74	36.48	43.37	36.86	2.76	0.72	5.78	13.14	13.90	18.05
S_6F_1	30.75	35.46	41.15	35.37	2.45	0.68	5.85	9.29	11.45	15.83
S_6F_2	30.51	34.29	42.91	37.21	2.71	0.66	6.60	11.89	12.61	17.00
S.Em ±	1.73	1.38	0.55	0.44	0.05	0.04	0.47	0.60	0.59	0.65
C.D. (0.05)	NS	NS	1.53	1.28	NS	NS	NS	1.75	1.74	1.90

facilitated more number of tillers at all the growth stages of the crop (Mustafa *et al.,* 2013). Soil application of $ZnSO_4$ and $FeSO_4$ each @ 25 kg ha^{-1} recorded significantly higher leaf area index at 60 DAS and at harvest stage (2.32 and 0.94 respectively) over control due to corresponding increase in leaf area (4.638 and 1.889 dm^2 per plant, respectively) compared to control (2.362 and 0.943 dm^2 per plant, respectively). Higher SPAD value (36.64, 42.36 and 2.64 at 60, 90 DAS and at harvest) compared to control with soil application of $ZnSO_4$ and $FeSO_4$ each @ 25 kg ha^{-1} was due to higher uptake of nutrients which could have accelerated the magnitude of chlorophy1content and photosynthetic ability of the crop. The similar observations were made by Mustafa *et al.* (2013).

The pre requisite for getting higher yield in any crop mainly depends on higher total dry matter production coupled with maximum translocation of photosynthates to sink. The amount of dry matter produced depends upon the production of sufficient number of tillers and leaf area which are influenced by adequate availability of Zn and Fe. Similarly, total dry matter production depends upon photosynthetic ability of the plant. Significantly higher dry matter production at 60, 90, 120 DAS and at harvest (5.82. 11.23, 12.81 and 17.08 g plant^{-1} respectively) was recorded with soil application of $ZnSO_4$ and $FeSO_4$ each @ 25 kg ha^{-1} which was on par with 20 and 30 kg ha^{-1} Zn and Fe application increased the growth of crops due to its effects on photosynthetic rate and nutrient uptake. It increased the photosynthetic rate and accelerated nutrient uptake from soil, these effects stimulate the dry matter production in plants. The role of Zn in synthesis of auxin can also be a factor that stimulates the growth of plants.

Soil application of $ZnSO_4$ and $FeSO_4$ each @ 25 kg ha^{-1} recorded significantly higher grain and straw yield (3575 kg ha^{-1} and 5299 kg ha^{-1}, respectively) compared to lower levels of $ZnSO_4$ and $FeSO_4$ each @ 10,15 and 20 kg ha^{-1} and control (2878 and 3718 kg ha^{-1}, respectively) (Table 3). Increased yield due to Zn and Fe application was attributed to better performance of growth and yield parameters through adequate availability of major and micro nutrients in soil, which in turn, favourably influenced physiological processes and build up of photosynthates (Tabassum *et al.,* 2013). There was increased grain yield of 16.5 per cent upon application of 2.5 kg Zn ha^{-1}; while 15 per cent upon application of 5.0 kg Zn ha^{-1} in rice (Rahman *et al.,* 2006). These findings are consistence with previous researches that indicated combination of zinc with other elements improved the photosynthetic attributes and had a positive effect on reproductive organs to produce more grain and straw yield (Zayed, 2011). Moreover, by supplying plants with micronutrients through soil application, there was increased yield and quality as well as macronutrient use efficiency.

The variation in yield was due to the variation of yield components *viz.,* number of production tillers per meter row length, number of filled grains per panicle, panicle weight and test weight. The increased yield of rice due to soil application of $ZnSO_4$ and $FeSO_4$ each @ 25 kg ha^{-1} was mainly due to significant increase in number of productive tillers per m row length (66.6), number of filled grains per panicle (96.1), panicle weight (3.4 g), test weight (18.3 g) compared to lower levels of $ZnSO_4$ and $FeSO_4$ and control (49.5, 71.2, 1.4 g and 17.0 g respectively). The increase in yield attributes due to supply of S, Zn and Fe to plants as they take part in energy formation and translocation from source to sink. Higher grain weight in rice was obtained with zinc, copper, iron, manganese and boron which were applied in combination (Jat *et al.,* 2011).

Effect of foliar application on growth and yield of rice

Foliar application of $ZnSO_4$ and $FeSO_4$ resulted in higher growth and yield parameters. Foliar application of $ZnSO_4$ and $FeSO_4$ each @ 0.5% recorded significantly improved growth parameters at 90, 120 DAS and at harvest *viz.,* number of tillers per meter row length (79.46, 75.96 and 69.58 respectively), leaf area (6.566, 4.313 and 1.575 dm^2 per $plant^{-1}$ respectively) LAI (3.28, 2.16 and 0.79, respectively), SPAD value (41.10, 35.42 and 2.36 respectively) and total dry matter production (10.17, 11.65 and 15.63 respectively). These results are in agreement with the findings of Zayed *et al.* (2011). Most of the photosynthetic pathways depends on enzymes and coenzymes which are synthesized by micronutrients. Zn and Fe are essential for several enzymes that regulate metabolic activities in plants. They involve in auxin production, transformation of carbohydrate and regulation of sugar in plants. Increase in growth attributes was mainly due to Zn and Fe application which are involved in the synthesis of growth promoting hormones and the reproduction process of many plants which are vital for grain formation (Ramana *et al.,* 2006).

Foliar application of $ZnSO_4$ and $FeSO_4$ significantly influenced the grain yield of rice. Foliar application of $ZnSO_4$ and $FeSO_4$ each @ 0.5% accounted for significantly higher grain and straw yield (3409 and 4871 kg ha^{-1} respectively) over no foliar spray (3182 and 4482 kg ha^{-1}) due to increased growth and yield attributes. Increase in the grain yield was due to significantly higher yield components *viz.,* number of productive

Table 3. Yield and yield parameters of rice as influenced by soil and foliar application of zinc and iron

Treatments	Productive tillers per meter row length	No.of filled grains $panicle^{-1}$	Panicle weight (g)	1000 grain weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
Factor - I (Soil application)						
S_1- Control (No application of $ZnSO_4$ and $FeSO_4$)	49.56	71.22	1.45	17.00	2878	3718
S_2- $ZnSO_4$ and $FeSO_4$ each @ 10 kg/ha	54.96	78.38	2.00	17.22	3081	4226
S_3- $ZnSO_4$ and $FeSO_4$ each @ 15 kg/ha	57.54	82.38	2.35	17.74	3210	4521
S_4- $ZnSO_4$ and $FeSO_4$ each @ 20 kg/ha	64.21	92.47	3.03	18.08	3491	5087
S_5- $ZnSO_4$ and $FeSO_4$ each @ 25 kg/ha	66.66	96.17	3.48	18.30	3575	5299
S_6- $ZnSO_4$ and $FeSO_4$ each @ 30 kg/ha	64.70	99.68	3.29	18.42	3539	5209
S.Em ±	0.85	2.59	0.07	0.12	34.03	73.11
C.D. (0.05)	2.49	7.60	0.20	0.35	99.81	214.43
Factor - II (Foliar applications)						
F_1- No sprayof $ZnSO_4$ and $FeSO_4$	57.34	81.71	2.33	17.63	3182	4482
F_2- Foliar spray of $ZnSO_4$ and $FeSO_4$ each @ 0.5 %	61.87	91.72	2.87	17.96	3409	4871
S.Em ±	0.49	1.50	0.04	0.07	19.65	42.21
C.D. (0.05)	1.44	4.39	0.11	0.20	57.63	123.80
Interaction						
S_1F_1	48.46	69.49	1.34	16.94	2850	3694
S_1F_2	50.66	72.94	1.55	17.06	2906	3741
S_2F_1	53.04	76.46	1.81	17.18	3027	4131
S_2F_2	56.89	80.30	2.19	17.26	3135	4320
S_3F_1	55.52	77.00	1.94	17.55	3072	4140
S_3F_2	59.56	87.76	2.77	17.94	3348	4901
S_4F_1	60.60	85.61	2.66	17.82	3338	4879
S_4F_2	67.82	99.32	3.39	18.35	3643	5295
S_5F_1	63.87	91.70	3.21	18.17	3412	5058
S_5F_2	69.44	102.34	3.74	18.50	3739	5539
S_6F_1	62.53	89.99	3.00	18.11	3396	4988
S_6F_2	66.86	107.67	3.59	18.66	3683	5431
S.Em ±	1.20	3.66	0.10	0.17	48.13	103.39
C.D. (0.05)	3.52	10.74	0.28	NS	141.16	303.25

tillers per meter row length (61.87), number of filled grains per panicle (91.72), panicle weight (2.87 g), test weight (17.96 g) over no foliar spray (57.34, 81.71, 2.33 and 17.63 g, respectively.

Interaction effect on growth and yield of rice

Higher grain yield was obtained when zinc, copper, iron, manganese and boron were applied in combination (soil and foliar). Moreover, by supplying plants with micronutrients, either through soil application, foliar spray or seed treatment, there was increased yield and quality as well as macronutrient use efficiency (Jat *et al.,* 2011). Combined soil ($ZnSO_4$ and $FeSO_4$ each @ 25 kg ha^{-1}) and foliar (each @ 0.5 %) application recorded significantly improved growth parameters at 90, 120 DAS and at harvest *viz.,* number of tillers per m row length (85.70, 81.14 and 74.64, respectively), leaf area (7.679, 5.390 and 2.047 dm^2 $plant^{-1}$, respectively) LAI (3.839, 2.695 and 1.023, respectively), SPAD value (43.37 and 36.86 respectively) and total dry matter production (13.14, 13.90 and 18.05 g $plant^{-1}$, respectively) compared to control. Improvement in plant growth was due to proper nourishment of crop with nutrient supply and also increased activity of meristematic cells and cell elongation with combined soil and foliar application of Zn and Fe as they are known to have favorable effect on metabolic process (Pooniya and Shivay, 2013).

Combined soil ($ZnSO_4$ and $FeSO_4$ each @ 25 kg ha^{-1}) and foliar ($ZnSO_4$ and $FeSO_4$ each @ 0.5%) application recorded significantly higher grain and straw yield (3739 and 5539 kg ha^{-1} respectively) which were on par with soil application of $ZnSO_4$ and $FeSO_4$ each @ 20 and 30 kg ha^{-1} with foliar spray $ZnSO_4$ and $FeSO_4$ each @ 0.5%. Therefore, it can be opined that soil plus foliar application of Zn and Fe is very effective than individual application. The similar observation were noticed by Yadav *et al.* (2013b). The higher grain yield with Zn and Fe application could be attributed to increased total dry matter production (Zayed *et al.,* 2011) due to better uptake of Zn and Fe and their translocation to reproductive parts.

Economic yield is expressed as a function of factors that contribute to yield, which are known as yield attributes. The variation in yield due to treatments could be attributed to variation in the yield attributing parameters. Combined soil application soil application of $ZnSO_4$ and $FeSO_4$ each @ 25 kg ha^{-1} with foliar application each @ 0.5% recorded significantly improved yield attributes *viz.,* number of productive tillers per mater row length (69.44), number of filled grains per panicle (102.34), panicle weight (3.74 g) and test weight (18.50 g) of rice compared to control. Application of micronutrients (Zn^{+2} , Fe^{+2} and Mn^{+2}) in single or combination (Zn^{+2} + Fe^{+2} + Mn^{+2}) as soil and foliar spray improved the rice yield parameters (Zayed *et al.,* 2011). The difference of performance in the yield attributes due to variation in translocation of photosynthates from vegetative to reproductive parts. Improvement in soil fertility and productivity due to combined soil and foliar application of $ZnSO_4$ and $FeSO_4$ have supported more number of productive tiller per meter row length, number of filled grains per panicle, panicle weight and test weight. The similar observations were recorded by Yadav *et al.* (2011).

Conclusion

Combined soil ($ZnSO_4$ and $FeSO_4$ each @ 25 kg ha^{-1}) and foliar ($ZnSO_4$ and $FeSO_4$ each @ 0.5%) application recorded significantly improved growth parameters *viz.,* number of tillers per m row length, leaf area, LAI, SPAD value and total dry matter production compared to rest of the treatments. Similarly significantly higher grain yield, straw yield and yield attributing parameters *viz.,* number of productive tillers per row length, number of filled grain per panicle, panicle weight and test weight were recorded in combined soil ($ZnSO_4$ and $FeSO_4$ each @ 25 kg ha^{-1}) and foliar ($ZnSO_4$ and $FeSO_4$ each @ 0.5%) application.

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