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Influence of Nano Zinc Oxide and Nano Ferric Oxide on Growth and Yield of Rice under Aerobic Condition (*Oryza sativa* L.)

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ABSTRACT

A field study was conducted during *kharif* 2019 and 2020 at Zonal Agricultural Research Station, GKVK, UAS, Bengaluru to know the effect of nano zinc oxide and nano ferric oxide particles on growth and yield of aerobic rice. In field, nine treatments were laid out in RCBD with three replications and the cultivar used was MAS-946-1. The results revealed that seed priming with 800 ppm of nano zinc oxide for 30 minutes and foliar application of nano ZnO and nano Fe_2O_3 @ 800 ppm recorded significantly higher plant height at 60, 90 DAS and harvest (49.18, 61.96 and 62.28 cm, respectively), leaf area at 60 and 90 DAS (1628 and 3436 cm^2 $hill^{-1}$, respectively), higher grain yield (4927 kg ha^{-1}) and straw yield (5383 kg ha^{-1}) in pooled data. This treatment was also found on par with seed treatment of 800 ppm of nano ZnO and nano Fe_2O_3 for 30 minutes and foliar application of nano ZnO and nano Fe_2O_3 at 600 ppm and seed treated with 800 ppm of nano ZnO and nano Fe_2O_3 for 30 minutes and foliar application of nano ZnO and nano Fe_2O_3 @ 400 ppm. Significantly lower plant height, leaf area, grain yield and straw yield were recorded with soil application of $ZnSO_4$ @ 25 kg ha^{-1} and of $FeSO_4$ @ 12.5 kg ha^{-1} (T_9).

Keywords: Nano zinc oxide, Nano ferric oxide, Rice, Aerobic condition

RICE (*Oryza sativa* L.) is one of the most important staple food crops as it helps to sustain two thirds of the world's population. Rice cultivation occupies almost one fifth of the total land area covered under cereals. It is grown in a wide range of locations and under a variety of climatic conditions from the wettest areas in the world to the driest deserts. Although rice is grown in 112 countries, spanning an area from 53 degree latitude north to 35 degree south, about 95 per cent of the crop is grown and consumed in Asia. It is semi-aquatic annual in nature. India occupies the largest cropped area of 43.39 m ha with an annual production of 104.32 million tonnes with a productivity of 2404 kg ha^{-1}. This gives an indication that, we need to increase the productivity by 4.03 t ha^{-1} to meet the growing demand of 130 m tonnes of milled rice by 2030 to maintain the present level of food self-sufficiency. Increasing the rice production can solve the food-deficit problem. The major rice-growing states in the country are West Bengal, Andhra Pradesh, Chhattisgarh, Tamil Nadu, Karnataka, Assam, Maharashtra, Orissa, Punjab and Gujarat. In Karnataka, rice is being grown in an area of 14 lakh ha with an annual production of 41.68 lakh tonnes (Anonymous, 2020).

Zinc (Zn) is one of the essential micronutrient elements which play an important role in auxin production, enzyme production, preferential accumulation of chlorophyll protein synthesis and starch metabolism. Therefore, deficiency of zinc in soils adversely affects the growth and development of crops. In rice, Zn deficiency is referred to as Khaira disease where in plants show appearance of dusty brown spots on upper leaves, stunted growth of plants, decreased tillering ability and spikelet sterility. Zn deficiency is a serious agricultural problem as around one-half of the cereal-growing soils in the world contain low Zn in the soil (Graham and Welch, 1996). The critical concentration of Fe and Zn in soil is 6.95 ppm and <0.6 ppm, respectively while for plant this concentration is <50 ppm and 20 ppm, respectively.

Iron (Fe) deficiency in aerobic rice mainly occurs under limited moisture condition, particularly under alkaline and calcareous soils. One or more of the following can cause Fe deficiency in rice, *viz.,* low concentration of soluble iron, high pH, wide P/Fe ratio, fast oxidation of ferrous iron, immobilization in the roots and excessive concentration of other metallic cations and low potential of rice cultivars for excretion of organic acids (Mori *et al.,* 1991), responsible for Fe solubilization. The aerobic rice system relies on the adequate supply of plant nutrients particularly iron (Fe), which may become deficient under aerobic condition. Sometimes severe chlorosis in rice due to Fe-deficiency has led to complete failure of the crop.

The metal oxide nanoparticles, ZnO and Fe_2O_3 attracted more attention for their uses in agriculture. The smaller size, high specific area and reactivity of nano particulate Fe and Zn oxides compared to bulk Fe and Zn oxides may affect solubility, diffusion and hence availability to plants. Interaction of nanoparticles with plants causes many physiological, biochemical changes and increase uptake of nutrients depending upon the properties of nano particles like chemical composition, surface area and their releasing patterns of nutrients. In view of above facts, the present investigation 'Studies on effect of nano zinc oxide and nano ferric oxide on growth and yield of rice under aerobic condition (*Oryza sativa* L.)' is planned with the following objectives.

1. To study the effect of nano zinc oxide and nano ferric oxide on growth and yield of rice under aerobic condition
2. To assess the effect of nano zinc oxide and nano ferric oxide on uptake of macro and micro nutrients by rice under aerobic condition
3. To known the effect of nano zinc oxide and nano ferric oxide on available soil nutrient status with respect to macro and micro nutrients
4. To workout the economics of nano zinc oxide and nano ferric oxide in rice under aerobic condition

Material and Methods

A field experiment was conducted in two *kharif* seasons during 2019 and 2020 in Randomized Block Design which consists of nine treatments with three replications at Zonal Agricultural Research Station, University of Agricultural Sciences, GKVK, Bengaluru which is situated in the Eastern Dry Zone (Zone-5) of Karnataka. The experimental site was located at 12º51'N Latitude and 77º 35'E Longitude, at an altitude of 930 m above mean sea level (MSL).

The aerobic rice variety MAS-946 developed by the University of Agricultural Sciences, Bangalore was used for the experiment. The land was prepared by using a tractor drawn disc plough once followed by cultivator twice. Healthy and viable seeds of MAS-946-1 rice hybrid were hand dibbled at the rate of two per hill by maintaining the intra and inter row spacing of 25 cm with seed rate of 5 kg ha^{-1}. Immediately after sowing the seeds were covered with soil with the help of wooden plank. FYM was applied before 15 days of sowing to all the treatment plots at the rate of 10 tonnes ha^{-1}. Fertilizers were applied as per the recommendation. Out of 100:50:50 N, P_2O_5 and K_2O kg ha^{-1} nutrients, 50 per cent N and the entire dose of P and K were applied as basal and remaining 50 per cent N in two equal splits at 30 and 60 DAS. All plots were irrigated with a depth of 5 cm immediately after sowing and subsequent irrigation were given at a depth of 4 cm at 5 days interval throughout the crop growth period. Depending upon rainfall the irrigation was given.

The experimental data were analyzed using ANOVA technique. The significance of the treatment effect was judged with the help of 'F' table and tested at 5 per cent probability level.

Nanoparticle Suspension Preparation

The nano particles were suspended in double distilled water (DDW) directly and scattered by utilizing magnetic stirrer for 30 min. Small magnetic beeds were set in the suspensions for blending before use to avoid aggregation of the particles. The nano iron suspension was prepared by dissolving hot water. The treatments included in the study are T_1 : Seed priming with nano ZnO @800 ppm and nano Fe_2O_3 @ 800 ppm 30 minutes, T_2 : T_1+ Foliar application of nano ZnO @ 200 ppm and nano Fe_2O_3 @ 200 ppm, T_3 : T_1+ Foliar application of nano ZnO @400 ppm and nano Fe_2O_3 @ 400 ppm, T_4 : T_1+ Foliar application of nano ZnO

@ 600 ppm and nano Fe_2O_3 @ 600 ppm, T_5 : T_1+ Foliar application of nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm, T_6 : T_1 + Foliar application of $ZnSO_4$ @ 0.5 per cent and of $FeSO_4$ @ 0.5 per cent, T_7 : T_1+- Soil application of $ZnSO_4$ @ 25 kg/ha and of $FeSO_4$ @ 12.5 kg/ha, T_8 : Foliar application of $ZnSO_4$ @ 0.5 per cent and of $FeSO_4$ @ 0.5 per cent and T_9 : Soil application of $ZnSO_4$ @ 25 kg ha^{-1} and of $FeSO_4$ @ 12.5 kg ha^{-1}.

Results and Discussion

Plant Height (cm)

The data pertaining to plant height as influenced by the different treatments is presented in the Table 1.

At 30 DAS, significantly higher plant height was noticed in seed priming of nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm for 30 minutes followed by foliar application of nano ZnO @ 400 ppm and nano Fe_2O_3 @ 400 ppm in pooled analysis (27.0 cm). This treatment was found on par with seed treatment of nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm for 30 minutes followed by foliar application of nano ZnO @ 600 ppm and nano Fe_2O_3 at 600 ppm (26.08 cm) and seed treated of nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm for 30 minutes followed by foliar application of nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm (24.81 cm).

From 60 DAS to harvest, significantly higher plant height was recorded in seed treatment of nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm for 30 minutes followed by foliar application of nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm at 30 DAS (49.18, 61.96 and 62.28 cm at 60, 90 DAS and harvest, respectively) in pooled analysis. This treatment was found on par with seed treatment of nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm for 30 minutes followed by foliar application of nano ZnO and nano Fe_2O_3 at 600 ppm (47.46, 60.01 and 61.46 cm at 60, 90 DAS and harvest, respectively) and seed treated of nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm for 30 minutes followed by foliar application of nano ZnO @ 400 ppm and nano Fe_2O_3 @ 400 ppm (45.77, 56.81 and 56.73 cm at 60, 90 DAS and harvest, respectively). Significantly lower plant height was recorded in soil application of $ZnSO_4$ @ 25 kg ha^{-1} and $FeSO_4$ @ 12.5 kg ha^{-1} (39.81, 49.56 and 51.58 cm at 60, 90 DAS and harvest, respectively). The similar trend was noticed during both the years of study.

Higher plant height in seed treatment with 800 ppm of nano ZnO and nano Fe_2O_3 for 30 minutes and foliar application of nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm was due to increased seedling vigour by zinc and iron nutrition. This leads to higher nutrient uptake, greater cell division and elongation. The increased plant height was also due to adequate supply of zinc and iron which accelerated the activity of many enzymes and chlorophyll content there by increases the auxin metabolism in the plant system (Nithya *et al*., 2018).

Leaf Area per Plant (cm^2 $plant^{-1}$)

The data on leaf area of aerobic rice as influenced by nano zinc oxide and nano ferric oxide particles at different growth stages are presented in (Table 2).

At 30 DAS, significantly higher leaf area per plant (244.4 cm^2 $plant^{-1}$) was noticed in seed priming of nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm for 30 minutes followed by foliar application of nano ZnO @ 400 ppm and nano Fe_2O_3 @ 400 ppm in pooled analysis. This treatment was found on par with seed treatment of nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm for 30 minutes followed by foliar application of nano ZnO @ 600 ppm and nano Fe_2O_3 @ 600 ppm (229.4 cm^2 $plant^{-1}$) and seed treated of nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm for 30 minutes followed by foliar application of nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm (214.9 cm^2 $plant^{-1}$).

Whereas at 60 and 90 DAS, significantly higher leaf area per plant was recorded in seeds treated with nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm for 30 minutes followed by foliar application of nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm at 30 DAS (1628 and 3436 cm^2 $plant^{-1}$ at 60 and 90 DAS, respectively) in pooled analysis. This treatment is found on par with seed treatment of nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm for 30 minutes followed

TABLE 1

Effect of nano zinc oxide and nano ferric oxide particles on plant height at different growth stages of aerobic rice

Treatments	30 DAS			60 DAS			90 DAS			At harvest		
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled
T_1	24.44	23.04	23.74	45.62	42.34	43.98	55.92	52.02	53.97	55.64	52.97	54.31
T_2	24.42	22.71	23.57	46.75	43.09	44.20	56.90	54.75	55.83	56.74	54.54	55.64
T_3	28.09	25.90	27.00	47.06	44.47	45.77	57.38	56.24	56.81	57.81	55.66	56.73
T_4	27.89	24.27	26.08	50.02	44.90	47.46	63.48	56.53	60.01	63.93	59.00	61.46
T_5	25.99	23.62	24.81	52.13	46.23	49.18	64.32	59.61	61.96	64.93	59.63	62.28
T_6	24.40	22.17	23.29	44.49	41.93	43.21	55.04	51.90	53.47	54.97	52.68	53.82
T_7	23.82	22.06	22.94	43.42	41.87	42.65	54.80	51.88	53.34	54.93	51.91	53.42
T_8	22.57	21.65	22.11	44.30	38.18	41.24	51.90	49.82	50.86	54.91	50.80	52.85
T_9	22.37	19.97	21.17	42.22	37.39	39.81	50.76	48.36	49.56	54.34	48.82	51.58
F-test	*	*	*	*	*	*	*	*	*	*	*	*
S.Em±	1.04	1.05	1.03	1.89	1.74	1.77	2.30	2.23	2.22	2.36	2.24	2.25
CD @ 5%	3.12	3.14	2.97	5.66	5.22	5.08	6.88	6.67	6.38	7.09	6.71	6.47

Treatments

T_1 : Seed priming with nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm 30 minutes

T_2 : T_1+ Foliar application of nano ZnO @ 200 ppm and nano Fe_2O_3 @ 200 ppm

T_3 : T_1+ Foliar application of nano ZnO @ 400 ppm and nano Fe_2O_3 @ 400 ppm

T_4 : T_1+ Foliar application of nano ZnO @ 600 ppm and nano Fe_2O_3 @ 600 ppm

T_5 : T_1+ Foliar application of nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm

T_6 : T_1+ Foliar application of $ZnSO_4$ @ 0.5% and of $FeSO_4$ @ 0.5%

T_7 : T_1+- Soil application of $ZnSO_4$ @ 25 kg/ha and of $FeSO_4$ @ 12.5 kg/ha

T_8 : Foliar application of $ZnSO_4$ @ 0.5% and of $FeSO_4$ @ 0.5%

T_9 : Soil application of $ZnSO_4$ @ 25 kg/ha and of $FeSO_4$ @ 12.5 kg/ha

TABLE 2

Effect of nano zinc oxide and nano ferric oxide particles on leaf area (cm^2 plant^{-1}) at different growth stages of aerobic rice

Treatments	30 DAS			60 DAS			90 DAS		
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled
T_1	198.9	215.0	207.5	1393	1425	1409	3031	3125	3078
T_2	195.5	212.6	204.1	1401	1433	1417	3079	3203	3141
T_3	244.6	244.3	244.4	1428	1528	1478	3119	3228	3173
T_4	234.8	224.1	229.4	1431	1532	1482	3220	3398	3309
T_5	211.6	218.3	214.9	1577	1679	1628	3380	3493	3436
T_6	193.0	211.2	202.1	1319	1398	1358	2961	3105	3033
T_7	188.6	193.4	191.0	1318	1367	1343	2934	3011	2972
T_8	187.5	192.8	190.1	1302	1343	1322	2835	2934	2884
T_9	183.0	187.8	185.4	1076	1316	1196	2775	2826	2800
F-test	*	*	*	*	*	*	*	*	*
S.Em±	7.74	9.81	9.12	52	55	55	108.23	127.59	121.95
CD @ 5%	23.22	29.10	26.21	156	166	159	324.48	382.50	350.49

Treatments

T_1 : Seed priming with nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm 30 minutes
T_2 : T_1 + Foliar application of nano ZnO @ 200 ppm and nano Fe_2O_3 @ 200 ppm
T_3 : T_1 + Foliar application of nano ZnO @ 400 ppm and nano Fe_2O_3 @ 400 ppm
T_4 : T_1 + Foliar application of nano ZnO @ 600 ppm and nano Fe_2O_3 @ 600 ppm
T_5 : T_1 + Foliar application of nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm
T_6 : T_1 + Foliar application of $ZnSO_4$ @ 0.5% and of $FeSO_4$ @ 0.5%
T_7 : T_1 + Soil application of $ZnSO_4$ @ 25 kg/ha and of $FeSO_4$ @ 12.5 kg/ha
T_8 : Foliar application of $ZnSO_4$ @ 0.5% and of $FeSO_4$ @ 0.5%
T_9 : Soil application of $ZnSO_4$ @ 25 kg/ha and of $FeSO_4$ @ 12.5 kg/ha

by foliar application of nano ZnO @ 600 ppm and nano Fe_2O_3 @ 600 ppm at 30 DAS (1482 and 3309 cm^2 plant^{-1} at 60 and 90 DAS, respectively) and seed treated with nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm for 30 minutes followed by foliar application of nano ZnO @ 400 ppm and nano Fe_2O_3 @ 400 ppm at 30 DAS (1478 and 3173 cm^2 plant^{-1} at 60 and 90 DAS, respectively). Significantly lower leaf area was recorded in treatment with soil application of $ZnSO_4$ @ 25 kg ha^{-1} and of $FeSO_4$ @ 12.5 kg ha^{-1} (1199 and 2800 cm^2 plant^{-1} at 60 and 90 DAS, respectively). The same trend was noticed during both the years.

Application of nano zinc and nano iron as seed priming increased CGR (crop growth rate) at initial stages due to positive role in root growth that improves early growth. Whereas, at later stages, foliar application particularly these micronutrients (Zn and Fe) increases the biomass production, green leaves per plant and leaf area. Because iron act sas important component of chlorophyll and play a vital role in many enzymes like cytochrome of electron transport chain this helps in increasing photosynathates accumulation intern increases leaf area. The results are in line with the findings of Singh and Kumar (2017), Zhu *et al*. (2012), Beeresha (2018) and Vanitha and Dass (2014).

Yield Parameters of Rice

The data pertaining to yield parameters due to application of nano zinc oxide and nano ferric oxide

TABLE 3

Effect of nano zinc oxide and nano ferric oxide particles on yield components of aerobic rice

Treatments	Productive tillers (No. plant^{-1})			Panicle length (cm)			1000 grain weight (g)		
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled
T_1	16.63	19.08	17.85	22.0	22.9	22.4	22.00	23.01	22.52
T_2	17.33	20.28	18.80	22.4	23.1	22.7	22.23	23.16	22.82
T_3	17.53	21.51	19.52	23.3	23.6	23.4	23.82	23.31	23.56
T_4	19.03	21.52	20.28	23.4	23.9	23.6	23.83	24.00	23.92
T_5	20.53	25.72	23.13	25.5	25.4	25.4	24.70	25.72	25.21
T_6	15.33	18.23	16.78	21.6	22.6	22.4	21.70	22.97	22.33
T_7	15.20	17.44	16.32	20.8	22.3	21.6	21.56	22.67	22.11
T_8	14.87	16.93	15.90	20.2	22.1	21.1	21.23	21.75	21.49
T_9	14.73	16.33	15.53	19.7	20.9	20.3	20.27	20.69	20.48
F-test	*	*	*	*	*	*	*	*	*
S.Em±	0.90	1.78	1.49	0.96	0.76	0.88	0.82	0.81	0.80
CD @ 5%	2.71	5.34	4.27	2.89	2.26	2.53	2.46	2.44	2.30

Treatments

T_1 : Seed priming with nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm 30 minutes

T_2 : T_1 + Foliar application of nano ZnO @ 200 ppm and nano Fe_2O_3 @ 200 ppm

T_3 : T_1 + Foliar application of nano ZnO @ 400 ppm and nano Fe_2O_3 @ 400 ppm

T_4 : T_1 + Foliar application of nano ZnO @ 600 ppm and nano Fe_2O_3 @ 600 ppm

T_5 : T_1 + Foliar application of nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm

T_6 : T_1 + Foliar application of $ZnSO_4$ @ 0.5% and of $FeSO_4$ @ 0.5%

T_7 : T_1 + Soil application of $ZnSO_4$ @ 25 kg/ha and of $FeSO_4$ @ 12.5 kg/ha

T_8 : Foliar application of $ZnSO_4$ @ 0.5% and of $FeSO_4$ @ 0.5%

T_9 : Soil application of $ZnSO_4$ @ 25 kg/ha and of $FeSO_4$ @ 12.5 kg/ha

as seed treatment and foliar spray was presented in (Table 3).

Significantly higher number of productive tillers (per hill) and panicle length (cm) was recorded in seed treatment of @ 800 ppm of nano ZnO and @ 800 ppm nano Fe_2O_3 for 30 minutes and foliar application of nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm (23.13 and 25.4) which was found on par with seed treatment of 800 ppm of nano ZnO and nano Fe_2O_3 for 30 minutes and foliar application of nano ZnO and nano Fe_2O_3 @ 600 ppm (20.28 and 23.6) and seed treatment of 800 ppm of nano ZnO and nano Fe_2O_3 for 30 minutes and foliar application of nano ZnO and nano Fe_2O_3 @ 400 ppm (19.52 and 23.4) and significantly lower number of productive tillers (per hill) and panicle length (cm) was recorded in soil application of $ZnSO_4$ @ 25 kg ha^{-1} and of $FeSO_4$ @ 12.5 kg ha^{-1} (15.53 and 20.3).

The improvement in yield parameters with application of nano zinc and nano ferric oxide was due to increased leaf area and total dry matter partitioning and there by increases source to sink ratio and in turn increases the number of productive tillers (per hill), panicle length (cm) and thousand grain weight (g) may be due to enhancement in photosynthetic activity and these resulted in the translocation of photosynthates and amino acids from the leaves and culms to the grain and these results are in accordance with findings of

TABLE 4

Effect of nano zinc oxide and nano ferric oxide particles on grain yield and straw yield of aerobic rice

Treatments	Grain yield (kg ha^{-1})			Straw yield (kg ha^{-1})		
	2019	2020	Pooled	2019	2020	Pooled
T_1	4225	4257	4241	4817	4857	4837
T_2	4340	4543	4442	4839	4900	4870
T_3	4501	4737	4619	5078	5237	5157
T_4	4657	4812	4735	5127	5267	5197
T_5	4812	5042	4927	5321	5446	5383
T_6	4099	4119	4109	4814	4762	4788
T_7	3889	3937	3913	4662	4529	4596
T_8	3724	3819	3771	4489	4498	4494
T_9	3692	3786	3739	4366	4386	4376
F-test	*	*	*	*	*	*
S.Em±	151	165	155	159	178	175
CD @ 5%	452	493	445	476	534	503

Treatments

T_1 : Seed priming with nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm 30 minutes

T_2 : T_1+ Foliar application of nano ZnO @ 200 ppm and nano Fe_2O_3 @ 200 ppm

T_3 : T_1+ Foliar application of nano ZnO @ 400 ppm and nano Fe_2O_3 @ 400 ppm

T_4 : T_1+ Foliar application of nano ZnO @ 600 ppm and nano Fe_2O_3 @ 600 ppm

T_5 : T_1+ Foliar application of nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm

T_6 : T_1 + Foliar application of $ZnSO_4$ @ 0.5% and of $FeSO_4$ @ 0.5%

T_7 : T_1+ Soil application of $ZnSO_4$ @ 25 kg/ha and of $FeSO_4$ @ 12.5 kg/ha

T_8 : Foliar application of $ZnSO_4$ @ 0.5% and of $FeSO_4$ @ 0.5%

T_9 : Soil application of $ZnSO_4$ @ 25 kg/ha and of $FeSO_4$ @ 12.5 kg/ha

Yoseftabar *et al.* (2013). Higher tillers per hill in these treatments can be attributed to zinc induced enzyme activity and auxin metabolism in plants and beneficial effects. So, higher tillering was mainly due to more uptake of nitrogen as influenced by zinc. These results are in line with the findings of Ghani *et al.* (1990).

Grain Yield Straw Yield (kg ha^{-1})

The data pertaining to grain and straw yield due to application of nano zinc oxide and nano ferric oxide as seed treatment and foliar spray was presented in (Table 4).

Grain yield differed significantly among the treatments. Aerobic rice cultivation with seed treatment of 800 ppm of nano ZnO and nano Fe_2O_3 for 30 minutes and foliar application of nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm recorded significantly higher grain yield (4927 kg ha^{-1}) in pooled data. This treatment was found on par with seed treatment of 800 ppm of nano ZnO and nano Fe_2O_3 for 30 minutes and foliar application of nano ZnO and nano Fe_2O_3 @ 600 ppm (4735 kg ha^{-1}) and seed treated with 800 ppm of nano ZnO and nano Fe_2O_3 for 30 minutes and foliar application of nano ZnO and nano Fe_2O_3 @ 400 ppm (4619 kg ha^{-1}). The lower grain yield was recorded in soil application of $ZnSO_4$ @ 25 kg ha^{-1} and of $FeSO_4$ @ 12.5 kg ha^{-1} (3739 kg ha^{-1}). The increase in grain yield was mainly due increased growth and yield attributes. The results in agreement with the findings of Uma, *et al.* (2019).

Grain yield is a function of yield components *viz.*, productive tillers, panicles, test weight, chaffiness and grain yield per plant. Nano zinc resulted in significant increase in the grains per panicle which is directly related to grain yield per hill. Fischer and Kohn (2006) have also reported higher grain per panicle with nano zinc oxide application and reported highest grain weight with nano zinc oxide application @ 20 and 40 ppm at panicle initiation and full heading stage Ghasemi *et al.* (2014).

Significant difference for straw yield (kg ha^{-1}) was observed due to seed treatment of 800 ppm of nano ZnO and nano Fe_2O_3 for 30 minutes and foliar application of nano ZnO @ 800 ppm and nano Fe_2O_3 @ 800 ppm recorded significantly higher straw yield (5383 kg ha^{-1}) in pooled data and similar trend was observed in first and second year. This treatment was found on par with seed treatment of 800 ppm of nano ZnO and nano Fe_2O_3 for 30 minutes and foliar application of nano ZnO and nano Fe_2O_3 at 600 ppm (5197 kg ha^{-1}) and seed treated with 800 ppm of nano ZnO and nano Fe_2O_3 for 30 minutes and foliar application of nano ZnO and nano Fe_2O_3 @ 400 ppm (5157 kg ha^{-1}) only for pooled data. The lower grain yield was recorded in soil application of $ZnSO_4$ @ 25 kg ha^{-1} and of $FeSO_4$ @ 12.5 kg ha^{-1} (4376 kg ha^{-1}). Increase in straw yield in the present study can be attributed to significant increase in the growth parameters *viz.,* plant height, number of leaves, leaf area and dry matter accumulation.

It could be observed from the experiment that nano technology plays a prominent role in aerobic rice production by overcoming the deficiencies of micronutrients particularly zinc and iron. Application of nano fertilizers in the form of seed treatment and foliar application of nano fertilizers like nano zinc oxide and nano ferric oxide improves the growth attributes like plant height, leaf area (cm^2 $plant^{-1}$) and yield components like productive tillers, panicle length and 1000 grain weight that intern increases grain and straw yield of aerobic yield.

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