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Research Article

Influence of Iron and Zinc Management on Drymatter Production and Nutrient Removal by Rice (*Oryza Sativa* L.) and Soil Fertility Status under Aerobic Cultivation

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Abstract

Under aerobic conditions, oxidation of iron sources from ferrous to ferric form impedes the plants to absorb iron and iron deficiency is a serious problem, even though the soil has sufficient iron. Similarly aerobic conditions regulate the amount of zinc dissolved in soil solution, thereby exhibit large impact on its availability in soils and transport within plants. Results of the field experiment conducted during 2015-16, at PJTSAU, Rajendranagar under aerobic situations indicated that application of recommended NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS is a better nutrient management practice for higher total dry matter production, uptake of nutrients like nitrogen, phosphorus, potassium zinc and iron throughout the crop growth period and at harvest. Soil application of $ZnSO_4$ as basal application had helped in increasing the available zinc status in soil while basal application of iron did not show significant increase in soil available status.

Keywords: Rice, Aerobic cultivation, Iron, Zinc, Drymatter production, Nutrient uptake, Nutrient availability

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Introduction

Rice (*Oryza sativa L.*) is the world's second most important cereal crop and staple food for about three billion people across the globe and the demand for food continue to increase as the population is increasing at faster rate. Transplanting is the common method of establishment of rice in India. However, this method is not much profitable due to requirement of huge labour force, large quantity of water, drudgery to farm worker, high production cost, etc. Water scarcity is becoming severe in many rice growing areas in the world, but introduction of aerobic rice can reduce water use in rice production as much as 60% less than that of lowland rice [1]. Nevertheless, direct-seeded aerobic rice is subject to more severe weed infestation and nutrient deficiencies like iron and zinc than transplanted lowland rice. Under aerobic conditions, due to the oxidation of iron sources from ferrous to ferric form plants were unable to absorb iron, even though it is present in sufficient quantities in soil. Similarly, under aerobic conditions soil properties regulate the amount of zinc dissolved in soil solution, thereby exhibit large impact on its availability in soils and transport within plants. The consequences of these changes require applying fertilizers to correct iron and zinc deficiencies and increase grain yield [2]. To make aerobic rice more remunerative there is a need to standardize agro techniques in particular with reference to macro and micronutrient management practices.

Material and Methods

A field experiment was conducted during *kharif*, 2015 at Rice Section, Agricultural Research Institute, Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad to study the effect of iron and zinc nutrient management on growth and yield of aerobic rice. This experiment was laid out in a Randomised Block Design with 10 treatments replicated thrice. The treatments were recommended NPK (120:60:40 kg ha^{-1}); FYM @12 t ha^{-1}; Recommended NPK + $FeSO_4$ soil application @ 50 kg ha^{-1}; Recommended NPK + $ZnSO_4$ soil application @ 50 kg ha^{-1}; Recommended NPK + 0.5 % $FeSO_4$ foliar spray at 20, 40 and 60 DAS; Recommended NPK + 0.2 %

$ZnSO_4$ foliar spray at 2O, 40 and 60 DAS, recommended NPK + $FeSO_4$ (25 kg ha^{-1}) + $ZnSO_4$ (25 kg ha^{-1}) soil application followed by their foliar spray *i.e.*, $FeSO_4$ @ 0.5% and $ZnSO_4$ @ 0.2% at 20, 40 and 60 DAS, FYM (12 t ha^{-1}) + foliar spray of 0.5 % $FeSO_4$ at 20, 40 and 60 DAS; FYM (12 t ha^{-1}) + foliar spray of 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS and recommended NPK + FYM @12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS.

Plant samples were collected at regular intervals (20, 40, 60, 80 and harvest) and shade dried and then oven dried at 70 C^0 for 72 hours until constant weight. Dry weight of samples was recorded and dry matter production ha^{-1} was calculated and expressed in kg ha^{-1}. Samples collected for recording dry matter production at different stages were used for estimation of N, P, K and micronutrients to workout uptake of nutrients. The nitrogen content was estimated using the micro kjeldahl method [3] while P and K contents were estimated as per the method described by Stanford and English (1949)[4]. Micro nutrients (Iron, Zinc, Manganese and Copper) content (ppm) in the plant samples were estimated by using Atomic absorption spectrophotometer [5]. The total uptake of N, P and K nutrients was calculated by multiplying the nutrient content (%) with dry matter production and expressed in kg ha^{-1}.

Pre-experimental composite sample and post harvest soil samples in each treatment were collected from 0-15 cm depth using core sampler to determine the soil properties. Samples were air dried and passed through 2 mm sieve for further analyses. Air dried samples were used for estimating organic carbon by Walkley and Black modified method [6], available N by Alkaline permanganate method [7], available P Olsen’s extractant method [8] and available K by extracting with neutral normal ammonium acetate and using Flame photometer [9]. Micro nutrients (Iron, Zinc, Manganese and Copper) content were estimated using DTPA reagent and was determined using Atomic absorption spectrophotometer as described by Lindsay and Norvell (1978)[5] and expressed as mg kg^{-1}.

Results and Discussion

Dry matter (g) at 20, 40, 60, 80 DAS and at harvest

The quantum of dry matter produced is an indication of overall utilization of available resources by the plant. The dry matter of aerobic rice increased progressively with age of the crop and was higher at harvest (**Table 1**) and varied significantly due to iron and zinc nutrient management practices at 20, 40, 60, 80 DAS and at harvest.

Table 1 Dry matter production (kg ha^{-1}) of aerobic rice as influenced by iron and zinc management

T. No	Treatment	Dry matter production (kg ha^{-1})				
		20 DAS	40 DAS	60 DAS	80 DAS	Harvest
T1	Recommended NPK (120:60:40 kg ha^{-1})	69.9	315	1575	3123	7274
T2	FYM @12 t ha^{-1}	55.3	251	1336	2225	5371
T3	Recommended NPK + basal application of $FeSO_4$ @ 50 kg ha^{-1}	75.2	391	1733	3499	8584
T4	Recommended NPK + basal application of $ZnSO_4$ @ 50 kg ha^{-1}	73.3	370	1605	3329	7829
T5	Recommended NPK + foliar spray of 0.5 % $FeSO_4$ at 20, 40 and 60 DAS	70.5	423	1821	3403	8349
T6	Recommended NPK + foliar spray of 0.2 % $ZnSO_4$ at 2O, 40 and 60 DAS	70.7	384	1640	3267	7802
T7	Recommended NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5% $FeSo_4$ and 0.2% $ZnSo_4$ at 20, 40 and 60 DAS	73.5	519	2041	3955	10009
T8	FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ at 20, 40 and 60 DAS	58.0	299	1518	2960	6903
T9	FYM @ 12 t ha^{-1} + foliar spray of 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS	57.7	283	1404	2790	5829
T10	Recommended NPK + FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS	74.5	453	1841	3520	8958
	SE(m) ±	2.2	15	69	115	233
	CD (p=0.05)	6.6	45	204	343	692

At 20 DAS, highest dry matter production (75.2 kg ha^{-1}) was recorded with application of recommended NPK along with basal application of $FeSO_4$ @ 50 kg ha^{-1} which was on par with T_{10} (74.5 kg ha^{-1}) *fb* T_7 (73.5 kg ha^{-1}) *fb* T_4 (73.3 kg ha^{-1}) *fb* T_6 (70.7 kg ha^{-1}) *fb* T_5 (70.5 kg ha^{-1}) *fb* T_1 (69.9 kg ha^{-1}). These treatments were significantly different from rest of the treatments which have no NPK fertilizers in their treatment composition. But at 40 DAS, application

of recommended NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_7) recorded highest dry matter (519 kg ha^{-1}) which was significantly different from the rest of the treatments. The next best treatment was application of recommended NPK + FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_{10}-453 kg ha^{-1}) which was at par with application of recommended NPK + foliar spray of 0.5 % $FeSO_4$ at 20, 40 and 60 DAS (T_5-423 kg ha^{-1}) and significantly superior over rest of the treatments. Likewise at 60 DAS (2041 kg ha^{-1}), 80 DAS (3955 kg ha^{-1}) and at harvest (10009 kg ha^{-1}), total dry matter production continued to be maximum with application of recommended NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T7) and significantly superior than rest of the treatments. The next best result at harvest was observed with application of recommended NPK + FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (8958 kg ha^{-1}) and it was at par with T_3 (8584 kg ha^{-1}) *fb* T_5 (8349 kg ha^{-1}). The superiority of T_7 might be due to availability of sufficient amount of NPK nutrients along with iron and zinc in both basal and foliar forms which enhanced the photosynthetic activity of the crop and ultimately enhanced the dry matter production. These results were in accordance with the results of Sunil and Shankaralingappa (2014)[10].

Nutrient uptake by aerobic rice at 20, 40, 60 DAS and at harvest

Nitrogen uptake

Nitrogen uptake by aerobic rice significantly varied with iron and zinc management practices. The data pertaining to the nitrogen uptake by aerobic rice at 20, 40, 60 DAS and at harvest is represented in **Table 2**. At 20 DAS, nitrogen uptake by aerobic rice was highest (0.58 kg ha^{-1}) with application of recommended NPK + basal application of $FeSO_4$ @ 50 kg ha^{-1} however it was at par with T_7 (0.56 kg ha^{-1}), T_{10} (0.56 kg ha^{-1}), T_5 (0.55 kg ha^{-1}), T_6 (0.54 kg ha^{-1}) and T_4 (0.53 kg ha^{-1}). At this stage nitrogen uptake was lowest (0.32 kg ha^{-1}) with application of FYM @12 t ha^{-1} alone. With the progress of age, at 40 DAS (5.38 kg ha^{-1}) and 60 DAS (35.7 kg ha^{-1}) nitrogen uptake by aerobic rice was highest with application of recommended NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_7). Only at 40 DAS, the highest nitrogen removal by T7 treatment was at par with application of recommended NPK + FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (5.13 kg ha^{-1}) but at 60 DAS it was significantly superior over the rest of the treatments. At harvest, grain and straw uptakes were computed separately. Highest grain (56.6 kg ha^{-1}) and straw (40.6 kg ha^{-1}) uptake was recorded with application of recommended NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSo_4$ at 20, 40 and 60 DAS (T_7) and was significantly superior over rest of the treatments. The next best treatment was application of recommended NPK + FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_{10}) with 48.4 kg ha^{-1} uptake by grain and 36.9 kg ha^{-1} by straw. Lowest nutrient removal was noticed with application of FYM @12 t ha^{-1} (T_2-19.4 kg ha^{-1}). These results were in agreement with the results of Yadav *et al*. (2011) who mentioned that among the different levels and times of application, the application of 50 kg $FeSO_4.7H_2O$ as basal + 2 foliar sprays of 2 % $FeSO_4.7H_2O$ recorded significantly higher N uptake. The results of the present study were also in line with the results of Malamsuri *et al*.(2014) [11] and Jadhav *et al*. (2014)[12].

Phosphorous uptake

At 20 DAS, phosphorous uptake by aerobic rice was ranging from 0.2 to 0.35 kg ha^{-1}. Among all the treatments highest (0.33 kg ha^{-1}) amount of uptake was observed with application of recommended NPK + FYM @12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_{10}) which was at par with application of recommended NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSo_4$ at 20, 40 and 60 DAS (T_7-0.32 kg ha^{-1}). Uptake by these treatments was significantly superior with rest of the treatments. At 40 DAS, phosphorous uptake by aerobic rice was in the range of 1.25 to 3.48 kg ha^{-1} and highest (3.48 kg ha^{-1}) amount of phosphorous uptake was observed with the same treatment as that 20 DAS and significantly higher over rest of the treatments. At this stage lowest values were observed with application of FYM @12 t ha^{-1} (T_2 -1.25 kg ha^{-1}). At 60 DAS also the crop receiving the treatment T7 continued to remove more phosphorus (14.9 kg ha^{-1}) which was at par with application of recommended NPK + FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_{10} with 13.7 kg ha^{-1}) and significant over rest of the treatments. The trend continued at harvest also with highest phosphorous uptake by rice grain (21.7 kg ha^{-1}) and straw (30.7 kg ha^{-1}) with application of recommended NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSo_4$ at 20, 40 and 60 DAS (T_7) which was at par with application of recommended NPK + FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_{10})

with 19.5 kg ha^{-1}of grain and 27.5 kg ha^{-1}straw uptake and was significantly superior over rest of the treatments. The data revealed that the uptake in treatments with NPK applications was significantly more over FYM applied treatments at all the stages of crop growth. These results were in line with Jadhav *et al*. (2014) [12] who reported highest uptake of P by aerobic rice grain and straw with application of 35 kg ha^{-1} of P in the form of DAP along with 5 kg ha^{-1} of Zn in the form of $ZnSO_4$.

Table 2 Macronutrient (N, P and K) uptake (kg ha^{-1}) by aerobic rice as influenced by iron and zinc management

T. No	Treatment	Nitrogen uptake (kg ha^{-1})					Phosphorous uptake (kg ha^{-1})				
		20 DAS	40 DAS	60 DAS	Harvest Straw	Harvest Grain	20 DAS	40 DAS	60 AS	Harvest Grain	Harvest Straw
T1	Recommended NPK (120:60:40 kg ha^{-1})	0.48	2.84	22.9	26.4	37.4	0.25	2.02	11.1	6.55	13.1
T2	FYM @12 t ha^{-1}	0.32	1.84	18.0	19.4	24.8	0.20	1.25	7.8	4.65	8.5
T3	Rec.NPK + basal application of $FeSO_4$ @ 50 kg ha^{-1}	0.58	3.54	26.5	29.2	45.5	0.31	2.43	12.5	7.76	17.3
T4	Recommended NPK + basal application of $ZnSO_4$ @ 50 kg ha^{-1}	0.53	3.26	24.9	30.7	40.6	0.31	2.26	11.2	7.02	15.0
T5	Rec. NPK + foliar spray of 0.5 % $FeSO_4$ at 20, 40 and 60 DAS	0.55	3.67	28.4	33.7	43.5	0.26	2.79	12.5	7.48	16.9
T6	Rec. NPK + foliar spray of 0.2 % $ZnSO_4$ at 2O, 40 and 60 DAS	0.54	3.36	25.5	30.7	40.8	0.25	2.45	11.2	6.99	14.8
T7	Rec. NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5% $FeSo_4$ and 0.2% $ZnSo_4$ at 20, 40 and 60 DAS	0.56	5.38	35.7	40.6	56.6	0.32	3.48	14.9	8.92	21.7
T8	FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ at 20, 40 and 60 DAS	0.38	2.43	21.9	26.7	34.7	0.22	1.62	9.6	6.01	11.9
T9	FYM @ 12 t ha^{-1} + foliar spray of 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS	0.36	2.37	18.9	21.1	28.7	0.20	1.47	8.8	5.03	9.5
T10	Rec. NPK + FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS	0.56	5.13	30.9	36.9	48.4	0.33	3.16	13.7	8.04	19.5
	SE(m) ±	0.03	0.25	1.5	1.5	1.9	0.01	0.11	0.6	0.34	1.0
	CD (p=0.05)	0.09	0.76	4.4	4.3	5.7	0.04	0.34	1.7	1.01	2.9

Table 2 Continued…

T. No	Treatment	Potassium uptake (kg ha^{-1})				
		20 DAS	40 DAS	60 DAS	Harvest Grain	Harvest Straw
T1	Recommended NPK (120:60:40 kg ha^{-1})	0.50	2.36	12.5	28.5	43.3
T2	FYM @12 t ha^{-1}	0.29	1.76	9.9	18.6	28.8
T3	Rec.NPK + basal application of $FeSO_4$ @ 50 kg ha^{-1}	0.56	3.15	14.6	33.0	53.0
T4	Recommended NPK + basal application of $ZnSO_4$ @ 50 kg ha^{-1}	0.55	3.03	13.4	28.9	48.0
T5	Rec. NPK + foliar spray of 0.5 % $FeSO_4$ at 20, 40 and 60 DAS	0.53	3.31	15.4	31.6	51.1
T6	Rec. NPK + foliar spray of 0.2 % $ZnSO_4$ at 2O, 40 and 60 DAS	0.51	3.03	13.3	28.5	47.1
T7	Rec. NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5% $FeSo_4$ and 0.2% $ZnSo_4$ at 20, 40 and 60 DAS	0.56	4.37	17.7	39.4	66.0
T8	FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ at 20, 40 and 60 DAS	0.33	1.94	11.6	23.3	39.2
T9	FYM @ 12 t ha^{-1} + foliar spray of 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS	0.32	1.88	10.5	20.5	31.6
T10	Rec. NPK + FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS	0.55	3.61	16.2	35.8	58.2
	SE(m) ±	0.02	0.15	0.8	1.6	2.4
	CD (p=0.05)	0.07	0.43	2.4	4.7	7.0

Potassium uptake

Data regarding the potassium uptake by aerobic rice at 20, 40, 60 DAS and at harvest is presented in Table 2. At 20 DAS, potassium uptake by aerobic rice was in the range of 0.29 to 0.56 kg ha^{-1}. Treatments applied with NPK nutrients recorded significantly higher uptake compared to the treatments applied with FYM. All the treatments having recommended NPK were on par with each other. Among these treatments highest (0.56 kg ha^{-1}) amount of uptake was recorded with application of recommended NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5 % $FeSo_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_7) and application of recommended NPK + basal application of $FeSO_4$ @ 50 kg ha^{-1} (T_3). At 40 DAS, potassium uptake by aerobic rice continued to be highest (4.37 kg ha^{-1}) with application of recommended NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_7) which was significantly more over rest of the treatments. The next best treatment was application of recommended NPK + FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_{10} with 3.61 kg ha^{-1}) which was at par with application of recommended NPK + foliar spray of 0.5 % $FeSO_4$ at 20, 40 and 60 DAS (T_5 with 3.31 kg ha^{-1}). At 60 DAS, potassium uptake by aerobic rice followed similar trend with highest (17.7 kg ha^{-1}) uptake in T_7 which was at par with T_{10} (16.2 kg ha^{-1}) and T_5 (15.4 kg ha^{-1}). At harvest, total potassium uptake (grain + straw) by aerobic rice was highest (105.4 kg ha^{-1}) with application of recommended NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_7) which was significantly more than rest of the treatments. The next best treatment was application of recommended NPK + FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_{10} with 93.9 kg ha^{-1}) which was at par with application of recommended NPK + basal application of $FeSO_4$ @ 50 kg ha^{-1} (T_3 with 86.0 kg ha^{-1}). Lowest amount of Potassium uptake was recorded with FYM @12 t ha^{-1} (T_2 with 18.6 kg ha^{-1}).

At all the stages treatments having recommended NPK application were significantly superior over sole FYM applied treatments either alone or in combination with Fe and Zn. Among all the treatments the superiority of T_7 might be due to synergetic effect of combined application of iron and zinc nutrients in basal and foliar forms along with NPK nutrients. These results were in line with the results of Mahajan and Khurana (2014)[13] and Yadav *et al.* (2011)[14].

Iron uptake

At 20 DAS, iron uptake by aerobic rice was highest (5.33 g ha^{-1}) with application of recommended NPK + basal application of $FeSO_4$ @ 50 kg ha^{-1} (T_3) which was at par with application of recommended NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_7 with 5.20 g ha^{-1}) and significantly more than rest of the treatments (**Table 3**). Among the remaining treatments, recommended NPK applied treatments were on par with each other and significantly superior over rest of the FYM applied treatments. At 40 DAS, iron uptake by aerobic rice continued to be highest (39.8 g ha^{-1}) with application of recommended NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_7) which was significantly superior over rest of the treatments. The next best treatment was application of recommended NPK + FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_{10} with 32.8 g ha^{-1}) which was at par with recommended NPK + basal application of $FeSO_4$ @ 50 kg ha^{-1} (T_3-30.4 g ha^{-1}). Among the remaining treatments, application of recommended NPK + foliar spray of 0.5 % $FeSO_4$ at 20, 40 and 60 DAS (T_5 with 27.4 g ha^{-1}) recorded statistically significant uptake over rest of the treatments. Treatment T_8 with foliar spray of 0.5 % $FeSO_4$ at 20 DAS along with FYM (22.5 g ha^{-1}) was significant than other FYM applied treatments (T_2 and T_9). At 60 DAS, iron uptake by aerobic rice followed a similar trend with highest in T7 (201.2 g ha^{-1}) followed by T_{10} with 170.1 g ha^{-1} which was at par with T_5 (164.0 g ha^{-1}) and T_3 (163.5 g ha^{-1}). These treatments were significant over rest of the treatments. Among FYM applied treatments, T_8 (139.9 g ha^{-1}) was at par with T_9 (126.2 g ha^{-1}) and significantly superior over T_2 (119.4 g ha^{-1}) due to inclusion of foliar spray of 0.5 % $FeSO_4$ at 20, 40 DAS.

Iron uptake by aerobic rice grain at harvest was highest (109.3 g ha^{-1}) with application of recommended NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_7) and was significantly superior over rest of the treatments. The next best treatment was application of recommended NPK + FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_{10} with 93.0 g ha^{-1}) which was at par with T_3 (87.9 g ha^{-1}) and T_5 (85.2 g ha^{-1}). Uptake in these treatments was significantly more than rest of the treatments. Among FYM applied treatments, T_8 (70.5 g ha^{-1}) was significantly superior over T_9 (55.5 g ha^{-1}) and T_2 (49.8 g ha^{-1}) due to foliar spray of 0.5% $FeSO_4$ at 20, 40 DAS. Iron uptake by aerobic rice straw at harvest followed similar trend as that of grain recording highest uptake (507.5 g ha^{-1}) with application of recommended NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_7) and was significantly superior over rest of the treatments. It was closely followed by application of recommended NPK + FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_{10}-424.9 g ha^{-1}) which was at par with T_3 (408.1 g ha^{-1}) and T_5 (393.4 g ha^{-1}). These treatments were significantly superior over rest of the treatments. Among FYM applied treatments, T_8 (333.3 g ha^{-1}) was superior over T_9 (252.1 g ha^{-1}) and T_2 (232.8 g ha^{-1}) due to foliar spray of 0.5 % $FeSO_4$ at 20, 40 DAS. The superiority of T_7 might be ascribed to combined application of iron and zinc nutrients as basal and foliar applications along with NPK nutrients through which required nutrients were available to the crop throughout the growth period and enhanced the iron uptake. These findings were in agreement with the results of Yadav *et al*. (2011) who mentioned that the application of 50 kg $FeSO_4.7H_2O$ as basal + 2 foliar sprays of 2 % $FeSO_4.7H_2O$ was recorded significantly higher Fe uptake over other methods and levels of iron application. Our results were also in line with those of Sunil and Shankaralingappa (2014)[10] and Mahajan and Khurana (2014)[13].

Table 3 Micronutrient (Iron and zinc) uptake (g ha^{-1}) by aerobic rice as influenced by iron and zinc management

T. No	Treatment	Iron uptake (g ha^{-1})					Zinc uptake (g ha^{-1})				
		20 DAS	40 DAS	60 DAS	Harvest		20 DAS	40 DAS	60 AS	Harvest	
					Straw	Grain				Straw	Grain
T1	Recommended NPK (120:60:40 kg ha^{-1})	4.22	20.8	131.4	306.4	51.0	0.93	4.70	27.0	62.5	39.2
T2	FYM @12 t ha^{-1}	3.63	17.6	119.4	232.8	49.8	0.86	4.32	24.8	50.4	30.9
T3	Rec.NPK + basal application of $FeSO_4$ @ 50 kg ha^{-1}	5.33	30.4	163.5	408.1	87.9	1.01	6.12	29.8	74.7	46.5
T4	Recommended NPK + basal application of $ZnSO_4$ @ 50 kg ha^{-1}	4.55	24.7	133.3	322.4	54.0	1.27	7.48	33.3	73.5	49.1
T5	Rec. NPK + foliar spray of 0.5 % $FeSO_4$ at 20, 40 and 60 DAS	4.49	27.4	164.0	393.4	85.2	0.98	6.19	31.2	72.1	46.1
T6	Rec. NPK + foliar spray of 0.2 % $ZnSO_4$ at 2O, 40 and 60 DAS	4.27	24.7	139.2	305.4	52.1	0.96	6.61	33.0	73.7	49.9
T7	Rec. NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5% $FeSo_4$ and 0.2% $ZnSo_4$ at 20, 40 and 60 DAS	5.20	39.8	201.2	507.5	109.3	1.23	9.60	42.5	94.6	65.0
T8	FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ at 20, 40 and 60 DAS	3.76	22.5	139.9	333.3	70.5	0.88	5.45	28.3	59.5	40.3
T9	FYM @ 12 t ha^{-1} + foliar spray of 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS	3.72	19.7	126.2	252.1	55.5	0.91	4.86	29.2	55.2	36.0
T10	Rec. NPK + FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS	4.68	32.8	170.1	424.9	93.0	1.10	7.78	37.4	81.1	56.7
	SE(m) ±	0.21	0.9	6.7	14.3	4.6	0.05	0.29	1.5	2.6	2.4
	CD (p=0.05)	0.62	2.6	19.8	42.4	13.5	0.14	0.85	4.6	7.9	7.2

Zinc uptake

Zinc uptake by aerobic rice at 20, 40, 60 DAS and at harvest is presented in Table 3. At 20 DAS, zinc uptake by aerobic rice was highest with application of recommended NPK + basal application of $ZnSO_4$ @ 50 kg ha^{-1} (T_4-1.27 g ha^{-1}) and was at par with application of recommended NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_7 with 1.23 g ha^{-1}) and significantly superior over rest of the treatments. Among the remaining treatments, recommended NPK applied treatments were on par with each other and significantly higher over rest of the FYM applied treatments (T_2, T_8 and T_9). At 40 DAS, zinc uptake by aerobic rice was higher (9.60 g ha^{-1}) with application of recommended NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_7) which was significantly superior over rest of the treatments. The next best treatment was application of recommended NPK + FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_{10} with 7.78 g ha^{-1}) and was on par with recommended NPK + basal application of $ZnSO_4$ @ 50 kg ha^{-1} (T_4 with 7.48 g ha^{-1}). Among the remaining treatments, application of recommended NPK + foliar spray of 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_5-6.61 g ha^{-1}) was superior over rest of the treatments. Among FYM applied treatments T_8 (5.45 g ha^{-1}) was superior over rest of the FYM treatments (T_2 and T_9). The trend continued at 60 DAS with highest uptake (42.5 g ha^{-1}) on application of recommended NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_7) which was significantly superior over rest of the treatments. The next best treatment was application of recommended NPK + FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_{10}-37.4 g ha^{-1}) which was at par with T_4 (33.3 g ha^{-1}) and T_6 (33 g ha^{-1}). Uptake in these treatments was significantly more than rest of the treatments. Among FYM applied treatments, T_9 (29.2 g

ha^{-1}) was superior over T_8 (28.3 g ha^{-1}) and T_2 (24.8 g ha^{-1}).

Zinc uptake by grain (65.0 g ha^{-1}) and straw (94.6 g ha^{-1}) at harvest was highest with application of recommended NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_7) and significantly superior than rest of the treatments. The next best treatment was application of recommended NPK + FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS with 56.7 g ha^{-1} and 81.1 g ha^{-1} grain and straw uptake respectively and at par with T_6 (49.9 g ha^{-1}). These treatments were superior with rest of the treatments. These treatments were superior over rest of the treatments. The superiority of T_7 treatment might be due to combined application of iron and zinc nutrients as basal and foliar applications along with NPK nutrients through which nutrients were available to the crop throughout the growth period at required quantities and enhanced the zinc uptake. These results were in line with the results of Jadhav *et al*. (2014)[14] and Ghoneim (2016)[15] and highest Zn content in rice grain was observed in treatment with foliar Zn application, followed by soil application of Zn.

Soil nutrient availability as influenced by iron and zinc management in aerobic rice

Available macronutrients (kg ha^{-1})

Data regarding the availability of macronutrients (N, P and K) in soil (kg ha^{-1}) at harvest is presented in **Table 4**. Available nitrogen at harvest had shown slight variation from the initial status (220 kg ha^{-1}) and was in the range of 221 to 230 kg ha^{-1} in different treatments. However, the variations were not statistically significant. The highest amount of available nitrogen (230 kg ha^{-1}) was observed with application of recommended NPK (T_1) and the lowest amount was noticed with application of FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ at 20, 40 and 60 DAS (T_8-221 kg ha^{-1}). Available phosphorous was in the range of 70.1 to 75.7 kg ha^{-1} and had shown very slight variation from the initial available phosphorous in soil (71 kg ha^{-1}). The treatments were statistically on par with each other. Available potassium in soil was in the range of 433 to 456 kg ha^{-1} in various treatments and variation from the initial status (431 kg ha^{-1}) was very narrow. The treatments were statistically on par with each other.

Table 4 Macro and micro nutrient availability in soil at harvest as influenced by iron and zinc management in aerobic rice

T. No	Treatment	Nutrient availability				
		N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	Iron (ppm)	Zinc (ppm)
T1	Recommended NPK (120:60:40 kg ha-1)	230	75.7	456	12.4	0.90
T2	FYM @12 t ha^{-1}	222	70.7	434	13.1	0.92
T3	Recommended NPK + basal application of $FeSO_4$ @ 50 kg ha^{-1}	229	72.9	434	13.3	0.91
T4	Recommended NPK + basal application of $ZnSO_4$ @ 50 kg ha^{-1}	226	75.4	458	12.6	1.10
T5	Recommended NPK + foliar spray of 0.5 % $FeSO_4$ at 20, 40 and 60 DAS	226	72.0	438	12.5	0.91
T6	Recommended NPK + foliar spray of 0.2 % $ZnSO_4$ at 2O, 40 and 60 DAS	222	75.0	446	12.5	0.91
T7	Recommended NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5% $FeSo_4$ and 0.2% $ZnSo_4$ at 20, 40 and 60 DAS	224	71.6	433	13.0	1.03
T8	FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ at 20, 40 and 60 DAS	221	71.1	444	13.0	0.92
T9	FYM @ 12 t ha^{-1} + foliar spray of 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS	223	70.1	445	13.1	0.92
T10	Recommended NPK + FYM @ 12 t ha^{-1} + foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS	228	74.2	445	12.8	0.92
	SE(m) ±	3.24	1.93	7.89	0.3	0.01
	CD (p=0.05)	NS	NS	NS	NS	0.03
	Initial	220	71.0	431	12.9	0.90

Available micronutrients (Iron and Zinc-ppm)

Available iron in soil prior to experimentation was 12.9 ppm and at harvest it was in the range of 12.4 to 13.3 ppm in different treatments. The variations in the treatments were statistically not significant. The highest amount of available iron in soil (13.3 ppm) was observed with application of recommended NPK + basal application of $FeSO_4$ @ 50 kg ha^{-1} (T_3). Similarly, the lowest amount of available iron in soil was noticed with application of recommended NPK alone (T_1-12.4 ppm). Oxidation of soil in upland situation might have resulted in lower available Fe although applied through soil application.

Availability of zinc in soil was significantly influenced by nutrient management practices (Table 4). Available zinc in soil prior to experimentation was 0.90 ppm and at harvest it ranged from 0.90 to 1.10 ppm in different treatments. The highest amount of available zinc in soil (1.10 ppm) was observed with application of recommended NPK + basal application of $ZnSO_4$ @ 50 kg ha^{-1} (T_4) which was significantly higher than rest of the treatments. The treatment with application of recommended NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS (T_7- 1.03 ppm), being closely followed the former was significantly superior over rest of the treatments. Soil application of $ZnSO_4$ as basal application had helped in increasing the available zinc status in soil. The lowest amount of available zinc in soil was noticed with application of recommended NPK (T_1-0.90 ppm). Ghoneim (2016)[15] reported significantly that basal application of zinc hadincreased Zn content of soil at harvest when compared with no application. Highest Zn content was recorded in soil applied Zn treatment. In contrary, Paramesh *et al.* (2013)[16] and Jadhav *et al*. (2014)[17] observed non significant changes in available N, P, K, Fe and Zn status of soil due to application of NPK or NPK + FYM with Zn and/or Fe either through soil or foliar spray, this might be attributed to loss of applied nutrients through various processes viz., denitrification, volatilization, leaching and fixation.

Conclusion

Results of the study under aerobic situations indicated that application of recommended NPK + basal application of $FeSO_4$ @ 25 kg ha^{-1} + $ZnSO_4$ @ 25 kg ha^{-1} *fb* foliar spray of 0.5 % $FeSO_4$ and 0.2 % $ZnSO_4$ at 20, 40 and 60 DAS is a better nutrient management practice for higher total dry matter production, uptake of nutrients like nitrogen, phosphorus, potassium zinc and iron by rice throughout the crop growth period and at harvest.

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