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Research Article

Physiological response and productivity of aerobic rice (*Oryza sativa* L.) to iron fertilization in typic Ustifluvents soil

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Abstract
Aerobic rice is projected as a sustainable rice production technology for the immediate future to address water scarcity and environmental safety. Micronutrient deficiency, particularly iron is one of the main factors responsible for low productivity in aerobic rice. With this perspective, a field experiment was conducted at farmer's field in 2022 at Kuttalam, Mayladuthurai district, Tamilnadu, in sandy clay loam (Padugai Series – Typic Ustifluvents) to predict the response of aerobic rice (*Oryza sativa*) to iron nutrition. The experiment was laid out in randomised block design with eleven treatments (Recommended dose of fertilizers (RDF) NPK only (control)(T_1), (RDF) + $FeSO_4$ @ 25 kg ha^{-1} (SA) (T_2), RDF + $FeSO_4$ 37.5 kg ha^{-1} (SA)(T_3),RDF+ $FeSO_4$ @ 50 kg ha^{-1} (SA)(T_4), RDF+ $FeSO_4$ @ 25 kg ha^{-1} (SA) + $FeSO_4$ @ 1% (FS)(T_5), RDF+ $FeSO_4$ 37.5 kg ha^{-1} (SA) + $FeSO_4$ @ 1% (FS)(T_6) , RDF+ $FeSO_4$ @ 50 kg ha^{-1} (SA) + $FeSO_4$ @ 1% (FS)(T_7), RDF+ $FeSO_4$ @ 25 kg ha^{-1}(SA) + Fe-EDTA @ 0.5% (FS) (T_8), RDF+ $FeSO_4$ 37.5 kg ha^{-1} (SA) + Fe-EDTA @ 0.5% (FS)(T_9), RDF+ $FeSO_4$ @ 50 kg ha^{-1} (SA) + Fe-EDTA @ 0.5% (FS) (T_{10}) and RDF + Seed priming 0.05M Fe-EDTA(T_{11})) and replicated thrice. The results revealed that application of $FeSO_4$ @ 50 kg ha^{-1} (SA) + Fe-EDTA @ 0.5% (FS) with RDF recorded the highest growth and yield parameters and the highest grain (3438 kg ha^{-1}) and straw yield (5078 kg ha^{-1}) compared to other treatments including control. This study concluded that iron fertilization through the soil and foliar application could enhance aerobic rice productivity.

Keywords: Aerobic rice, Growth parameters, Iron fertilization, Yield attributes, Yield

INTRODUCTION

Rice (*Oryza sativa* L.) is the world's second most important cereal crop. Rice accounts for about 59.5% of food grain production and 39.5% of cereal production in India. India produced 275.68 million tonnes of food grains with a major contribution from rice, i.e. 110.15 million tonnes (Pradhan *et al.,* 2020) but the productivity of milled rice is still much low, i.e. 2,404 kg/ha Water gets depleted in many rice growing countries due to the removal of excess water particularly in China and India, where competing and increasing demands for freshwater are coming from other sectors In the idea of efficient resource use hierarchy, water crisis threatens the lowland rice production and necessitates the adoption of water saving irrigation technology. There is a need to economise water usage in rice production. The aerobic rice system (ARS) is a new production system in which rice is grown under non-puddled, non-flooded and non-saturated soil conditions as other upland crops

(Prasad, 2011; Bouman, 2001; Tuong and Bouman, 2003).

For sustainable aerobic rice cultivation, there is a need to find effective micronutrient management, especially iron (Fe). Iron is an important micronutrient because it plays a crucial role in the metabolic processes, DNA synthesis, respiration and photosynthesis. It is involved in the synthesis of chlorophyll and the maintenance of chlorophyll structure.(Gyana et al., 2015;Gangadi Kalyan et al.,2020). Iron can act as electron carriers in the enzyme systems, bringing about oxidation-reduction reactions in rice (Jones and Benton, 2012; Meghana et al.,2019). Iron deficiency is major concern and critical to yield realization of aerobic rice ecosystem (Soumya et al. 2017); and rice grown in problem soils (Gao et al.,2022). The presence of micronutrient deficiency renders it impossible to gain maximum benefit from NPK fertilizers application in aerobic rice production. With this background, the present investigation was carried out to study the effect of iron nutrition on growth, yield attributes and yield of aerobic rice (*Oryza sativa* L.) in iron-deficient sandy clay loam soil.

MATERIALS AND METHODS

A field experiment was conducted in the farmer's field at Kuttalam, Tamil Nadu, in 2022 in sandy clay loam (Padugai Series- Typic Ustifluvents) in *navarai* season (January - May) to assess the iron nutrition on growth, yield attributes and yield in aerobic rice (O. sativa). The experimental soil was sandy clay loam (Typic Ustifluvents). The treatments consisted of T_1- NPK only (control), T_2- RDF + $FeSO_4$ @ 25 kg ha^{-1} (SA), T_3- RDF + $FeSO_4$ 37.5 kg ha^{-1} (SA), T_4- RDF+ $FeSO_4$ @ 50 kg ha^{-1} (SA), T_5- RDF+ $FeSO_4$ @ 25 kg ha^{-1} (SA) + $FeSO_4$ @ 1% (FS), T_6- RDF+ $FeSO_4$ 37.5 kg ha^{-1} (SA) + $FeSO_4$ @ 1% (FS) , T_7 - RDF+ $FeSO_4$ @ 50 kg ha^{-1} (SA) + $FeSO_4$ @ 1% (FS), T_8 - RDF+ $FeSO_4$ @ 25 kg ha^{-1}(SA) + Fe-EDTA @ 0.5% (FS), T_9- RDF+ $FeSO_4$ 37.5 kg ha^{-1} (SA) + Fe-EDTA @ 0.5% (FS), T_{10}- RDF+ $FeSO_4$ @ 50 kg ha^{-1} (SA) + Fe-EDTA @ 0.5% (FS) and T_{11}- RDF + Seed priming 0.05M Fe-EDTA. The experiment was laid out in a randomized block design with three replications.. The initial soil sample was with pH (6.9), EC (0.23), available nitrogen (232.3 kg ha^{-1}), available phosphorus (16.1 kg ha^{-1}), available potassium (270.5 kg ha^{-1}) and available iron (2.6 mg kg^{-1}).

The experimental field was initially ploughed to remove all the weeds and other plant residues of the previous crop. The second ploughing was done 15 days after the first ploughing and light irrigation was applied to the field to enhance the germination of weed seeds and seeds of the previous crop. The third ploughing was done 3 days before sowing to destroy the weeds and previous crop. Level the field with leveller in order to prepare good seed bed for the smooth germination of rice seeds. All the plots received uniform doses of NPK (100: 50:50 kg ha^{-1}). Iron sulphate was applied as basal as per the treatment schedule. Foliar spray of FeSO4 @ 1 % and Fe-EDTA @ 0.5% was applied thrice per the treatment schedule at tillering, pre-flowering and flowering stages, respectively. The seeds were soaked in a wet gunny bag for 24 hours for sprouting. The seed priming was done for the respective treatment Fe-EDTA @ 0.05 M. The sprouted seeds were broadcasted in respective plots.

Irrigation for the field was provided to maintain saturation conditions and to overcome water stress, especially during critical growth stages of the crop. Irrigation was done once a week to keep the soil moist. The ~~bracket~~pre-emergence herbicide 3.3 lit/ha of Pendimethalin @ 1 kg a.i ha^{-1} 30 EC was applied 2 days after sowing. Bispyribac sodium @ 0.025 kg a.i ha^{-1} (250 ml ha^{-1}) was sprayed 15 days after sowing. Hand weeding was done at 35 DAS. The plant samples were collected at 35 DAS, 75 DAS and harvest stages to observe the growth parameters. The yield attributes, grain and straw yield, were recorded at the harvest stage of aerobic rice (*Oryza sativa* L.)

RESULTS AND DISCUSSION

Physiological responses

Application of iron through soil alone or soil and foliar significantly (p=0.05) increased the growth parameters and yield attributes over control (Table 1, 2). Among the different levels of iron application, the highest growth parameters viz., plant height (64.2 cm), no. of tillers/hill(10.3), leaf area index (LAI) of 3.40, chlorophyll content (36.8 SPAD), crop growth rate (CGR) 8.20 g m^{-2} d^{-1},relative growth rate of (RGR)23.07 mg g^{-1} d^{-1} ,net assimilation rate(NAR) of 1.17 g dm^{-2} d^{-1}, drymatter production(DMP) of 4180 kg ha^{-1}, and yield components *viz.,* number of panicles m^{-2}(187.9) , number of grains $panicle^{-1}$(124.9) and panicle length (21.5 cm) were recorded in RDF+ $FeSO_4$ @ 50 kg ha^{-1} (T_4) in aerobic rice. The efficient iron management with nitrogen might have helped in inducing vegetative growth leading to better interception of photosynthetically active radiation and greater photosynthesis by rice crop resulted in highest number of tillers $hill^{-1}$ (Suresh and Salakinkop, 2016; Pradhan *et al.,* 2020). The increase in the panicle length might be due to higher photosynthates sinking due to higher chlorophyll content facilitated by iron nutrition.

The application of iron through soil + foliar recorded higher growth parameters and yield attributes than soil application alone. The highest growth parameters viz., plant height (81.4cm), no. of productive tillers/hill(14.1), chlorophyll content(47.5 SPAD value), CGR (10.44 g

Table 1. Effect of iron fertilization on growth parameters in aerobic rice

Treatments	Plant height (cm)	No. of productive tillers/hill	LAI	Chlorophyll content (SPAD)	CGR ($g\ m^{-2}\ d^{-1}$)	RGR ($mg\ g^{-1}\ d^{-1}$)	NAR ($g\ dm^{-2}\ d^{-1}$)	DMP $kg\ ha^{-1}$
T_1 - NPK only (control)	52.6	8.0	2.16	31.4	6.88	20.53	1.08	3408
T_2 - RDF+$FeSO_4$ @ 25 kg ha^{-1} (SA)	59.6	9.4	2.92	34.8	7.35	21.49	1.14	3784
T_3 - RDF+$FeSO_4$ @ 37.5 kg ha^{-1} (SA)	61.3	9.6	3.01	35.2	7.57	21.91	1.15	3879
T_4 - RDF+$FeSO_4$ @ 50 kg ha^{-1} (SA)	64.2	10.3	3.40	36.8	8.20	23.07	1.17	4180
T_5 - RDF+$FeSO_4$ @ 25 kg ha^{-1} (SA) + $FeSO_4$ @ 1% (FS)	67.0	10.8	3.73	38.5	8.53	23.63	1.19	4381
T_6 - RDF+$FeSO_4$ @ 37.5 kg ha^{-1} (SA) + $FeSO_4$ @ 1% (FS)	72.7	11.8	4.43	41.7	9.16	24.78	1.23	4855
T_7 - RDF+$FeSO_4$ @ 50 kg ha^{-1} (SA) + $FeSO_4$ @ 1% (FS)	78.4	12.7	5.11	45.1	9.78	25.62	1.27	5147
T_8 - RDF+$FeSO_4$ @ 25 kg ha^{-1} (SA) + Fe-EDTA 0.5% (FS)	69.9	11.3	4.07	42.9	8.93	24.31	1.21	4614
T_9 -RDF+$FeSO_4$@ 37.5 kg ha^{-1}(SA)+Fe-EDTA@0.5% (FS)	76.6	12.4	5.18	44.3	9.58	25.31	1.25	5022
T_{10} - RDF+$FeSO_4$ @50kg ha^{-1} (SA)+Fe-EDTA@0.5% (FS)	81.4	14.1	6.39	47.5	10.44	26.55	1.31	5453
T_{11} - RDF + Seed priming @ 0.05M Fe-EDTA	55.4	8.6	2.46	33.5	7.12	21.02	1.11	3592
C.D (p= 0.05)	2.61	0.49	0.17	1.24	0.23	0.45	0.012	151.5

RDF – Recommended dose of fertilizer; SA- Soil application; FS- Foliar sprays; LAI- Leaf area index; CGR- Crop growth rate; RGR- Relative growth rate; NAR-Net assimilation rate; DM- Dry matter production

Table 2. Effect of iron fertilization on yield attributes in aerobic rice

Treatments	Number of panicles m^{-2}	Number of grains $panicle^{-1}$	Panicle length (cm)
T_1 - NPK only (control)	177.4	106.8	18.5
T_2 - RDF+$FeSO_4$ @ 25 kg ha^{-1} (SA)	183.4	116.7	20.1
T_3 - RDF+$FeSO_4$ @ 37.5 kg ha^{-1} (SA)	185.1	119.1	20.7
T_4 - RDF+$FeSO_4$ @ 50 kg ha^{-1} (SA)	187.9	124.9	21.5
T_5 - RDF+$FeSO_4$ @ 25 kg ha^{-1} (SA) + $FeSO_4$ @ 1% (FS)	190.8	130.6	22.3
T_6 - RDF+$FeSO_4$ @ 37.5 kg ha^{-1} (SA) + $FeSO_4$ @ 1%(FS)	197.2	142.6	23.9
T_7 - RDF+$FeSO_4$ @ 50 kg ha^{-1} (SA) + $FeSO_4$ @ 1% (FS)	202.4	150.8	25.1
T_8 - RDF+$FeSO_4$ @ 25 kg ha^{-1}(SA) + Fe-EDTA @ 0.5% (FS)	194.6	136.6	23.1
T_9 -RDF+$FeSO_4$ @37.5 kg ha^{-1} (SA) + Fe-EDTA @0.5%(FS)	200.6	148.3	24.6
T_{10} - RDF+$FeSO_4$ @50 kg ha^{-1} (SA)+ Fe-EDTA @ 0.5%(FS)	205.6	156.3	25.8
T_{11} - RDF + Seed priming @ 0.05M Fe-EDTA	180.8	110.9	19.2
C.D(p= 0.05)	2.36	3.63	0.61

* RDF – Recommended dose of fertilizer; SA- Soil application; FS- Foliar sprays at tillering, preflowering and flowering stages

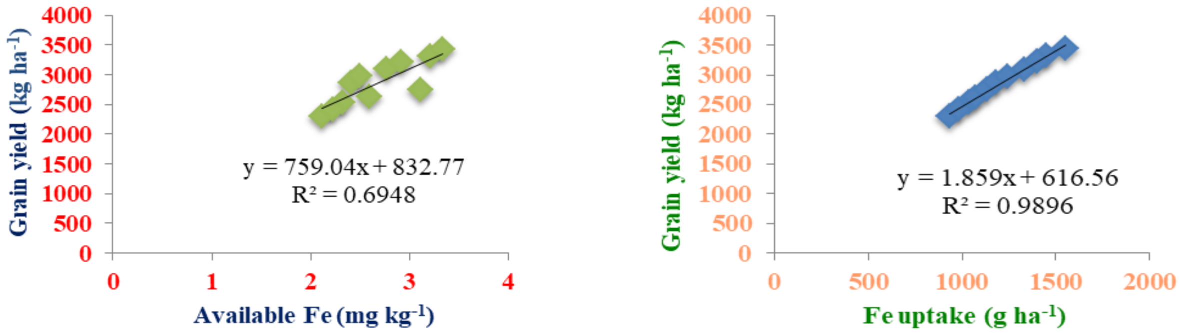

Fig. 1. *Linear relationship between nutrient uptake with grain yield*

m^{-2} d^{-1}), RGR(26.55 mg g^{-1} d^{-1}) , NAR(1.31 g dm^{-2} d^{-1}), DMP(5453 kg ha^{-1}), yield components *viz.,* number of panicles m^{-2}(205.6) , number of grains $panicle^{-1}$(156.3) and panicle length (25.8 cm) were registered in $FeSO_4$ @ 50 kg ha^{-1} (SA) + Fe-EDTA @ 0.5% (FS) with RDF (T_{10}). The increase in the plant height might be owing to an adequate quantity of iron supplied to crops as per need during the critical stage through soil and foliar. Higher plant height attained may be due to better internode elongation and good vegetative growth throughout the crop cycle (Das *et al.* 2016). Iron is involved in many enzymatic reactions as a catalyst in various growth processes, hormone production and protein synthesis, which might have resulted in more grains $panicle^{-1}$(Baishya *et al*. 2016). The application of iron increased the enzymatic reaction and improvement of chlorophyll content which facilitated the higher CGR, RGR and NAR in rice. Dry matter production (DMP) at various growth stages increased with the iron application (Rakesh *et al.,* 2012) which may be due to the involvement of iron in rice metabolism.

Better enhancement of the metabolic activity of rice that helps in flower initiation in many tillers and increased synthesis of organic compounds by the increased photosynthesis, plants use these organic compounds for cell division and multiplication that in turn resulted in increased yield parameters (Meghana *et al.,* 2019). The increased growth parameters might be attributed to the higher response of rice to iron fertilization involved in electron transport in photosynthesis and as a constituent of porphorins and ferredoxins (Vikash Kumar *et al.,* 2015). Iron fertilization may have significantly improved plant growth by enhancing photosynthesis and root growth. This improved plant growth might be the reason for higher values of yield attributes with iron fertilization. The results obtained in the present study were confirmed by a significant positive correlation between plant height r=(0.834**), tillering count r=(0.841**), LAI r=(0.832**), chlorophyll content r=(0.781**). CGR (r=0.828**), RGR (r=0.824**) and NAR (r=0.842**) DMP r=(0.824**) with available iron. Similarly positive correlation between iron uptake with number of panicles m^{-2} r=(0.996**), number of grains $panicle^{-1}$ r=(0.995**) and

Table 3. Effect of iron fertilization on grain and straw yield (kg ha^{-1}) in aerobic rice

Treatments	Grain yield (kg ha^{-1})	% increase over control	Straw yield (kg ha^{-1})	% increase over control
T_1 - NPK only (control)	2293	-	3552	-
T_2 - RDF +$FeSO_4$ @ 25 kg ha^{-1} (SA)	2538	10.7	3855	8.5
T_3 - RDF+$FeSO_4$ @ 37.5 kg ha^{-1} (SA)	2624	14.4	3987	12.3
T_4 - RDF+$FeSO_4$ @ 50 kg ha^{-1} (SA)	2748	19.8	4145	16.7
T_5 - RDF+$FeSO_4$ @ 25 kg ha^{-1} (SA) + $FeSO_4$ @ 1% (FS)	2864	24.9	4304	21.2
T_6 - RDF+$FeSO_4$ @ 37.5 kg ha^{-1} (SA) + $FeSO_4$ @ 1% (FS)	3098	35.1	4624	30.2
T_7 - RDF+$FeSO_4$ @ 50 kg ha^{-1} (SA) + $FeSO_4$ @ 1% (FS)	3321	44.8	4909	38.2
T_8 - RDF+$FeSO_4$ @ 25 kg ha^{-1}(SA) + Fe-EDTA @ 0.5% (FS)	2980	30.0	4461	25.6
T_9 - RDF+$FeSO_4$ @ 37.5 kg ha^{-1} (SA)+ Fe-EDTA @ 0.5%(FS)	3217	40.3	4773	34.4
T_{10} - RDF+$FeSO_4$ @ 50 kg ha^{-1} (SA) + Fe-EDTA @ 0.5%(FS)	3438	49.9	5078	43.0
T_{11} - RDF + Seed priming @ 0.05M Fe-EDTA	2416	5.4	3701	4.2
C.D(p= 0.05)	110.5	-	143.4	-

* RDF – Recommended dose of fertilizer; SA- Soil application; FS- Foliar sprays at tillering, preflowering and flowering stages

panicle length r=(0.991**).

Rice yield

Application of iron either through soil or soil and foliar significantly increased the grain and straw yield over control (Table 3). Among the different levels of iron application through soil alone, the highest grain (2748 kg ha^{-1}) and straw yield(4145 kg ha^{-1}) was noticed in $FeSO_4$ @ 50 kg ha^{-1} (T_4) caused 19.8% and 16.7% increase over control in grain and straw yield respectively. The treatment (T_3) $FeSO_4$ @ 37.5 kg ha^{-1} was on par with (T_2) $FeSO_4$ @ 25 kg ha^{-1}. Better response of rice to iron application was due to low initial status in the experimental site. Soil application of iron @ 50 kg ha^{-1} to rice with RDF could be advantageous for profuse vegetative and root growth which activates higher absorption of nutrients from soil. Further improved metabolic activity due to iron application reflected in higher grain and straw yield in rice. In addition to that, higher absorption due to the foliar application of iron and loading of the iron nutrient into the edible parts of the plants, and higher translocation of Fe to economic parts may be attributed to higher grain yield (Prom U Thai *et al.,* 2020).

Grain yield of the rice plant increased further with soil and foliar application than with soil alone. Among different levels and sources of foliar application of iron, the highest grain yield (3438 kg ha^{-1}) and (5078 kg ha^{-1}) was noticed in $FeSO_4$ @ 50 kg ha^{-1} + Fe-EDTA (FS) @ 0.5% (T_{10}), 3 foliar sprays at tillering, pre-flowering and flowering stages which were significantly superior over rest of the treatments. The best treatment caused 49.9 % and 43.0% increase over control in grain and straw yield, respectively. Applying iron through foliar spray with chelates resulted in a faster supply of soluble iron than soil application alone, which ultimately resulted in higher grain yield. Applying iron in aerobic rice improved the DMP, eventually leading to increased straw yield (Vikashkumar *et al.,* 2015). Higher grain and straw yield with iron nutrition was mainly due to higher crop growth with more number of effective tillers, a higher number of filled grains, more panicle length, thousand-grain weight and an increased supply of photosynthates from source to sink (Soumya *et al.,* 2017; Shaygany *et al.,* 2012; Yadav *et al.,* 2013). It was confirmed by a significant positive correlation of grain yield with available iron r=(0.834**). Similarly, there was a significant positive linear relationship between available iron and iron uptake with grain yield (Fig.1).

Conclusion

Based on the findings of this study, it can be concluded that to attain higher productivity in aerobic rice, *O. sativa*, the application of iron through $FeSO_4$ @ 50 kg ha^{-1} + Fe-EDTA (FS) @ 0.5%(T_{10}) may be recommended. The increase in the grain yield in combined treatments may be due to the general improvement in the nutritional state of the plant along with major nutrients. However, applying iron through the soil and foliar can be a better choice than soil alone to attain higher growth, yield attributes and yield of aerobic rice, *O. sativa* in iron-deficient sandy clay loam soil.

Conflict of interest

The authors declare that they have no conflict of interest.

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