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Effect of Iron Nutrition on Growth and Productivity of Aerobic Rice (*Oryza sativa*)

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ABSTRACT

A field experiment was conducted during *kharif* seasons (June–October) of 2012 and 2013 at College Farm, College of Agriculture, Professor Jayashankar Telangana State Agricultural University, Hyderabad, Telengana, India to evaluate the response of rice cultivars and iron nutrition on growth and yield of aerobic rice. Experiment comprising of three rice cultivars (Tellahamsa, MTU 1010 and KRH 2) and twelve sources and modes of iron nutrition i.e. control (no iron), basal application of iron sulphate @ 25 kg ha^{-1}, basal application of Iron chelate @ 25 kg ha^{-1}, 3 foliar sprays of 2% iron sulphate @ 7 days interval, 3 foliar sprays of 2% iron sulphate @ 10 days interval and 3 foliar sprays of 2% iron sulphate @ 15 days interval. Next 3 treatments were three foliar sprays of 2% iron sulphate in conjunction with basal application of iron sulphate @ 25 kg ha^{-1}. Subsequent treatments were three foliar sprays of 2% iron sulphate with basal combination of iron chelate @ 25 kg ha^{-1}. Results indicated that among rice cultivars KRH 2 gave significantly better agronomic performance with respect to growth parameters and yield. Iron nutrition treatments significantly affected the plant height, tillers, dry matter accumulation and yield of aerobic rice. Basal application of iron chelate @ 25 kg ha^{-1} with 3 foliar sprays of iron sulphate at 7 days interval produced tallest plants, maximum number of tillers, accumulated highest dry matter and produced maximum yield during both the years.

KEYWORDS: Aerobic rice, growth, iron nutrition, rice cultivars, yield

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1. INTRODUCTION

Rice is a staple food for more than half of the world population and generally grown by transplanting seedlings into a puddled soil in Asia (Kumar and Ladha, 2011, Singh and Banjara, 2021). Transplanted rice production is a major source of methane and nitrous oxide emission contributing 48% and 52% respectively, of total greenhouse gases emitted by agricultural sources (Majumdar, 2003, Win et al., 2020). Moreover, lowland rice cultivation requires large quantity of water and for producing one kg of rice, about 3000-5000 L of water is required under irrigated conditions (Bouman and Tuong, 2001, Geethalakshmi et al., 2011). As water crisis threatens the sustainability of the irrigated rice ecosystem across the globe cultivation of aerobic rice (Farooq et al., 2011) is gradually catching the imagination of people and efforts are being made to increase the productivity of this system.

The aerobic rice is a new production system in which rice is cultivated in non-puddled, non-flooded fields (Singh et al., 2008, Rajakumar et al., 2009, Kadiyala et al., 2015) like upland crop with adequate inputs and supplementary irrigation when rainfall is insufficient (Mahapatra et al., 2021). Aerobic rice can be rainfed or irrigated, should be responsive to high inputs and tolerate occasional flooding. Thus in aerobic rice, soils are kept aerobic almost throughout the rice growing season. The expected yields in aerobic rice are somewhat lower than those obtained under lowland flooded conditions, but double or triple of that obtained under upland conditions. The major gain is saving in water, which may be 50–60% less water required in aerobic rice as compared to lowland rice (Bouman et al. 2005, Prasad, 2011). Despite the usefulness of aerobic rice, there are still many constraints that restrict its adoption by rice farmers. The major constraint in aerobic rice is unavailability of cultivars specifically bred for it (Atlin et al., 2006, Vikash et al., 2017), cultivars used in aerobic rice production were developed by genetic recombination of lowland and upland varieties from different eco geographic origins (Lafitte et al., 2002). Although some cultivars with high yield potential have been released to farmers, aerobic rice often suffers from micronutrient deficiency and especially Fe leading to reduced yield and quality (Kreye et al., 2009).

Iron deficiency in rice mainly occurs under upland conditions, particularly in alkaline and calcareous soils (Sasaki et al., 2010). In acid soils the problem of Fe deficiency is far less. The iron chlorosis is most severe when the coarse textured soils are brought into wider rice cultivation for the first time (Sadana and Nayyar, 2000). Sometimes severe chlorosis due to Fe deficiency can lead to complete failure of the rice crop (Katyal and Sharma, 1980, Nogiya et al., 2019). This happens despite the fact that total Fe content in soils is extraordinary high but the amount of plant usable Fe is rather low to moderate (Mahender et al., 2009) and depends on soil properties, cropping pattern and prevalent environmental condition. Compare to other graminaceous plants, rice secretes a very low amount of deoxy-mugineic acids as a phytosiderophore even under Fe deficiency, which is the main cause for the high sensitivity of rice to Fe deficiency (Kobayashi and Nishizawa, 2012, Kobayashi et al., 2014). For sustainable aerobic rice cultivation there is a need to find out the ways and means of effective iron management through soil application besides foliar nutrition. In view of the above facts, the present experiment was carried out to study the response of rice cultivars to different sources and modes of iron application.

2. MATERIALS AND METHODS

The field experiment was carried out during the *kharif* seasons (June–October) of 2012 and 2013 at College Farm, Professor Jayashankar Telangana State Agricultural University (PJTSAU), Rajendranagar, Hyderabad, Telengana, India. The experimental site was sandy clay loam in texture, slightly alkaline in reaction (pH 7.2), low in organic carbon (0.45%) as well as available nitrogen (210 kg ha^{-1}), medium in available phosphorus (22.6 kg ha^{-1}) and available potassium (250 kg ha^{-1}). The iron is sufficient in the experimental site (4.18 mg kg^{-1}).

Experiment was carried out with three rice cultivars i.e. Tellahamsa (M_1), MTU 1010 (M_2) and KRH 2 (M_3) as main treatments and twelve iron nutrition treatments i.e., control (S_1), basal application of iron sulphate @ 25 kg ha^{-1} (S_2), basal application of iron chelate @ 25 kg ha^{-1} (S_3), 3 foliar sprays of iron sulphate from 21 DAS @ 7 days interval (S_4), 3 foliar sprays of iron sulphate from 21 DAS @ 10 days interval up to maximum tillering (S_5), 3 foliar sprays of iron sulphate from 21 DAS @ 15 days interval up to panicle initiation stage (S_6), basal application of iron sulphate @ 25 kg ha^{-1}+3 foliar sprays of iron sulphate from 21 DAS @ 7 days interval (S_7), basal application of iron sulphate @ 25 kg ha^{-1}+3 foliar sprays of iron sulphate from 21 DAS @ 10 days interval up to maximum tillering (S_8), basal application of iron sulphate @ 25 kg ha^{-1}+3 foliar sprays of iron sulphate from 21 DAS @ 15 days interval up to panicle initiation stage (S_9), basal application of iron chelate @ 25 kg ha^{-1}+3 foliar sprays of iron sulphate from 21 DAS @ 7 days interval (S_{10}), basal application of iron chelate @ 25 kg ha^{-1}+3 foliar sprays of iron sulphate from 21 DAS @ 10 days interval up to maximum tillering (S_{11}), basal application of iron chelate @ 25 kg ha^{-1}+3 foliar sprays of iron sulphate from 21 DAS @ 15 days interval up to panicle initiation stage (S_{12}) as sub treatments laid out in split plot design replicated thrice.

Recommended nitrogen @ 120 kg ha^{-1} was applied in three equal splits i.e., at sowing, maximum tillering and panicle initiation stage of the crop, in the form of urea. Phosphorus and potassium were applied basally as per the recommended dose of 60 kg each of P_2O_5 and K_2O ha^{-1} in the form of SSP and MOP respectively. Iron sulphate and chelate @ 25 kg ha^{-1} were applied at the time of sowing as per the treatments. These fertilizers were applied as bands in the seed furrow. Three foliar sprays of Iron sulphate @ 2%+citric acid 2.0 g l^{-1} of water were sprayed starting from 21 DAS at weekly, 10 days interval and 15 days interval as per the treatments.

Plant height of the aerobic rice was measured from the ground to the tip of the top most leaf (or) panicle was recorded. Numbers of tillers were recorded by counting from the sampling unit. Dry matter production obtained from uprooting the border row plants. Leaf area index was calculated as per the formula suggested by Watson (1952). 10 panicles were sampled for measurement of mean panicle length, panicle weight and number of filled grains panicle^{-1}. The 1,000 filled grains, taken from sampled panicles and then weighed to compute the 1,000 grain weight. After harvesting, threshing, cleaning and drying, the grain yield was recorded at 14% moisture. Straw yield was obtained by subtracting grain yield from the total biomass yield. The pooled data were statistically analysed using the *F*-test as per the procedure given by Gomez and Gomez (1984). CD values at p=0.05 were used to determine the significance of difference between treatment means.

3. RESULTS AND DISCUSSION

3.1. Effect of cultivars

3.1.1. On Growth

Plant height gradually increased with successive growth stages up to 90 days at a faster rate, and slowed down at maturity stage. However, the maximum plant height was recorded at the harvest stage. Among the cultivars, KRH 2 recorded significantly higher plant height of 99 cm than MTU 1010 (85 cm) and Tellahamsa (74 cm). KRH 2 being a hybrid established earlier to varieties and progressed faster and attained good growth in terms of plant height. The differences in plant height due to genotypes may be attributed to their inherent characteristics. Dry matter accumulation also increased with plant age and highest was noticed at maturity stage. However, in case of tillers production and leaf area index highest was at 90 DAS, there is a slight decline at harvest due to the death of newly emerged tillers which can't withstand the competition from matured tillers. KRH 2 maintained its superiority in all growth parameters followed by MTU 1010 and Tellahamsa. Higher dry matter accumulation in KRH 2 could be due to increased plant height and leaf area that enabled higher assimilation rate and in turn increased dry matter production. These results are also supported by Sridhara et al. (2012).

3.1.2. On yield attributes and yield

Number of effective tillers m^{-2} is the result of the number of tillers produced and the proportion of effective tillers which survived to produce panicle, thereby contributing to the yield. Among cultivars, KRH 2 produced 282 effective tillers and maintained its significant superiority. The difference in number of effective tillers of these cultivars could be attributed to the higher tillering ability and conversion of total tillers into reproductive tillers. Similar results were reported by Kannan et al. (2015).

In case of panicle length, panicle weight and grains panicle^{-1} KRH 2 maintained its superiority over other two cultivars. Variation in panicle length and weight of cultivars is associated with genetic characters of rice cultivars. However, Tellahamsa recorded lower spikelet sterility (6.38%) compared to MTU 1010 (8.17%) and KRH 2 (7.92%) during investigation. KRH 2 maintained higher test weight of 22.7 g compared to other two cultivars. Test weight of grains is mostly the varietal character and less influenced by other factors. Such variability for test weight among rice cultivars under aerobic condition was also reported by Borah and Pathak (2022).

KRH 2 cultivar produced significantly higher grain yield (5726 kg ha^{-1}) and straw yield (6881 kg ha^{-1}) followed by MTU 1010. The lowest grain and straw yield was obtained with Tellahamsa. Difference in yield among the cultivars might be attributed due to better response of hybrid over the two cultivars resulting in increased number of effective tillers, better panicle length and more number of filled grains with higher test weight. The difference in the yield and yield attributes may also be attributed due to their genetic constitution. Similar results were also reported by Reddy and Padmaja (2013).

3.2. Effect of iron nutrition

3.2.1. On growth

Among iron nutrition treatments significantly higher plant height at 90 DAS and harvest (88, 99 cm) was produced with the basal application of iron chelate @ 25 kg ha^{-1}+3 foliar sprays $FeSO_4$ at 7 days interval (S_{10}) followed by S_{11} and S_{12}. Next best treatment combinations observed with foliar sprays of iron sulphate in combination with basal application of iron sulphate i.e. S_7, S_8 and S_9 which were significantly superior to only foliar sprays of iron sulphate i.e. S_4, S_5 and S_6. S_1 (control) produced least plant height but significantly differed with basal application of iron sulphate @ 25 kg ha^{-1} and basal application of iron chelate @ 25 kg ha^{-1}. The higher plant height due to combined application of iron nutrition through soil and foliage might be ascribed to availability of nutrients in adequate amount with balanced proportion, which helped in cell multiplication and enlargement and led to substantial increase in crop growth and better root development. These results are in conformity with the findings of Kumar et al. (2015).

In case of other growth parameters like total tiller m^{-2}, dry matter production and leaf area index similar trend was observed. Combined application of iron fertilizers through soil and foliar methods had helped in enhanced availability of iron throughout crop growing period and resulted in better accumulation of photosynthates in the form of dry matter and thereby enhanced leaf number and leaf expansion. These results are in agreement with the findings of Pal et al. (2008) (Table 1).

3.2.2. *On yield attributes and yield*

Among the sources and mode of iron application, soil

Table 1: Plant height, dry matter production, total tiller number and leaf area index of aerobic rice as influenced by cultivars and iron nutrition

Treatments		Plant height @ 90 DAS (cm)	Plant height @ harvest (cm)	DMP @ 90 DAS (g m^{-2})	DMP @ Harvest (g m^{-2})	Total tiller number (m^{-2}) @ 90 DAS	Total tiller number (m^{-2}) @ harvest	LAI @ 90 DAS	LAI @ harvest
Main plots (M)									
M_1		67	74	518	657	297	269	3.56	2.36
M_2		74	85	779	1010	350	305	4.22	2.73
M_3		90	99	933	1226	384	336	4.79	3.34
SEm±		0.4	0.5	16	27	3	2	0.06	0.05
CD (p=0.05)		1.4	2.1	61	105	13	9	0.23	0.19
Sub plots (S)									
S_1		67	73	569	732	272	239	2.68	1.35
S_2		69	77	587	756	288	255	2.85	1.52
S_3		70	78	604	777	298	262	2.98	1.65
S_4		76	84	729	948	338	300	3.99	2.57
S_5		73	82	681	886	322	284	3.53	2.24
S_6		72	81	658	855	316	276	3.36	2.05
S_7		82	92	848	1102	379	337	5.06	3.72
S_8		79	89	794	1026	362	320	4.70	3.27
S_9		78	87	776	1009	353	313	4.53	3.14
S_{10}		88	99	928	1206	413	364	5.93	4.36
S_{11}		85	96	880	1144	395	348	5.44	3.99
S_{12}		84	94	868	1129	388	342	5.26	3.85
SEm±		0.7	0.7	13	21	4	3	0.11	0.09
CD (p=0.05)		1.9	1.9	37	60	11	8	0.30	0.25
Interaction									
Main at sub	SEm±	1.2	1.1	23	37	7	5	0.18	0.15
	CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Sub at main	SEm±	1.2	1.2	27	44	7	5	0.19	0.15
	CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

M_1: Tellahamsa; M_2: MTU 1010; M_3: KRH 2; S_1: Control (No Iron); S_2: BA of IS @ 25 kg ha^{-1}; S_3: BA of IC @ 25 kg ha^{-1}; S_4: 3 FS of IS from 21 DAS @ 7 DI; S_5: 3 FS of IS from 21 DAS @ 10 DI; S_6: 3 FS of IS from 21 DAS @ 15 DI; S_7: BA of IS @ 25 kg ha^{-1}+3 FS of IS from 21 DAS @ 7 DI; S_8: BA of IS @ 25 kg ha^{-1}+3 FS of IS from 21 DAS @ 10 DI; S_9: BA of IS @ 25 kg ha^{-1}+3 FS of IS from 21 DAS @ 15 DI; S_{10}: BA of IC @ 25 kg ha^{-1}+3 FS of IS from 21 DAS @ 7 DI; S_{11}: BA of IC @ 25 kg ha^{-1}+3 FS of IS from 21 DAS @ 10 DI; S_{12}: BA of IC @ 25 kg ha^{-1}+3 FS of IS from 21 DAS @ 15 DI ; BA: Basal application; IS: Iron Sulphate; IC: Iron Chelate; FS: Foliar spray, DI: Days interval application of iron did not prove effective in improving yield attributes of aerobic rice. However soil and foliar application of iron proved more effective. Higher panicle length and weight were recorded with S_{10}, S_{11} and S_{12} i.e. basal application of iron chelate @ 25 kg ha^{-1} along with foliar sprays of iron sulphate at 7, 10 and 15 days interval. Iron sulphate @ 25 kg ha^{-1} as basal application together with foliar sprays of iron sulphate at 7 (S_7), 10 (S_8) and 15 (S_9) days interval, further showed reduced panicle length and weight. Only foliar sprays iron sulphate i.e. S_4, S_5 and S_6 recorded lower panicle length and weight compared to combined application of iron nutrition through soil and foliar methods (S_7–S_{12} treatments). The panicle length and weight might have been increased with supply of photosynthates to sink, due to higher chlorophyll content and photosynthesis due to more availability of micronutrients by iron nutrition. The similar observations were recorded by Suresh and Salakinkop (2016) (Table 2).

In case of 1000 grain weight higher was recorded with S_{10} which was at par with S_{11} and S_{12}. In treatments S_7, S_8 and S_9 1000 grain weight further reduced and they could not show any significant variation. Treatments with only foliar sprays of iron sulphate S_4, S_5 and S_6 recorded lower 1000 grain weight compared to combined application of iron nutrition through soil and foliar methods. Lowest test weight noticed in S_1, S_2 and S_3. The higher test weight in treatments with combined application of soil and foliar iron may be attributed to steady supply of nutrients which enhanced dry matter production and translocation of photosynthates to sink resulting in bold seeds which in turn increased the test weight. Similar increase in 1000 grain weight was also reported by Shaygany et al. (2012). Higher filled grains inturn lower spikelet sterility were noticed in S_{10}, S_{11} and S_{12} followed by S_7, S_8 and S_9. In control and only basal application of iron sources resulted in lower filled grains and high spikelet sterility. Combined application of iron nutrition through soil and foliar methods decreased the spikelet sterility, this was mainly due to early establishment of crop and higher translocation of photosynthates to grains. Similar results were also reported by Baishya et al. (2016) (Table 3).

Higher grain yield of 6044 kg ha^{-1} was produced with basal application of iron chelate @ 25 kg ha^{-1}+three foliar sprays of 2.0 % FeSO4 from 21 DAS at 7 days interval (S_{10}) followed by S_{11} and was at par with S_{12}. The next order of treatments which produced higher grain yield were basal application of iron sulphate+3 foliar sprays of iron sulphate at 7, 10 and 15 days interval i.e. S_7, S_8 and S_9. Among the foliar sprays of iron sulphate, 7 days interval sprays i.e., S_4 registered higher grain yield followed by sprays at 10 days interval i.e. S_5 and was at par with 15 days interval sprays (S_6). In case of straw yield also similar trend observed. Adequate supply of iron

Table 2: Effective tillers, panicle length and panicle weight of aerobic rice as influenced by cultivars and iron nutrition

Treatments		Effective tillers (m^{-2})	Panicle length (cm)	Panicle weight (g)
Main plots (M)				
M_1		221	18.8	1.72
M_2		261	20.5	2.61
M_3		282	22.5	3.41
SEm±		3.1	0.2	0.14
CD (p=0.05)		12.4	0.7	0.57
Sub plots (S)				
S_1		194	17.1	2.14
S_2		209	18.2	2.32
S_3		217	18.6	2.31
S_4		251	20.5	2.49
S_5		237	19.8	2.57
S_6		231	19.5	2.33
S_7		284	21.9	2.79
S_8		269	21.3	2.66
S_9		263	21.0	2.59
S_{10}		314	23.7	2.96
S_{11}		298	22.9	2.96
S_{12}		290	22.6	2.83
SEm±		3.5	0.4	0.09
CD (p=0.05)		10	1.2	0.24
Interaction				
Main at sub	SEm±	6.1	0.7	0.15
	CD (p=0.05)	NS	NS	NS
Sub at main	SEm±	6.7	0.7	0.20
	CD (p=0.05)	NS	NS	NS

fertilization to meet the required nutrient uptake which inturn resulted in increased plant growth and photosynthetic rate which resulted in higher translocation of dry matter and thus increasing grain yield. Similar findings were also reported by Sakariyawo et al. (2020) (Table 4).

Harvest index was influenced by iron nutrition and found significant. Highest harvest index recorded with S_{10} i.e. iron chelate as basal @ 25 kg ha^{-1}+3 foliar sprays of iron sulphate at 7 days interval (46.45%) and on par with S_{11}, S_{12}, S_7, S_8 and S_9 during experimentation. Further, these treatments were followed by only foliar application of iron sulphate i.e. S_4, S_5 and S_6. Lowest harvest index recorded with control (S_1). However, basal application of 25 kg ha^{-1} iron sulphate (S_2)

Table 3: Total grains panicle-1, filled grains panicle-1, Spikelet sterility and 1000 grain weight of aerobic rice as influenced by cultivars and iron nutrition

Treatments		Total grains panicle-1	Filled grains panicle-1	Spikelet sterility (%)	1000 grain weight (g)
Main plots (M)					
M_1		100	94	6.38	19.6
M_2		116	107	8.17	21.8
M_3		130	120	7.92	22.7
SEm±		3	3	0.24	0.3
CD (p=0.05)		10	10	0.96	1.4
Sub plots (S)					
S_1		101	90	11.05	18.8
S_2		102	92	10.18	19.4
S_3		104	94	9.92	19.9
S_4		115	106	7.79	21.4
S_5		111	101	8.83	21.1
S_6		109	99	9.14	20.8
S_7		123	116	5.62	22.3
S_8		118	111	6.28	22.1
S_9		117	109	6.75	21.9
S_{10}		132	126	4.17	23.4
S_{11}		127	121	4.94	22.8
S_{12}		125	119	5.25	22.7
SEm±		4	4	0.36	0.4
CD (p=0.05)		12	12	1.02	1.1
Interaction					
Main at sub	SEm±	7	7	0.62	0.7
	CD (p=0.05)	NS	NS	NS	NS
Sub at main	SEm±	7	7	0.65	0.7
	CD (p=0.05)	NS	NS	NS	NS

Table 4: Grain yield, straw yield and harvest index of aerobic rice as influenced by cultivars and iron nutrition

Treatments		Grain yield (kg ha-1)	Straw yield (kg ha-1)	Harvest index
Main plots (M)				
M_1		2714	3786	41.38
M_2		4556	5789	43.34
M_3		5726	6881	44.96
SEm±		90	46	0.75
CD (p=0.05)		353	183	NS
Sub plots (S)				
S_1		2866	4548	37.93
S_2		3079	4565	40.02
S_3		3214	4680	40.46
S_4		4105	5334	43.45
S_5		3724	5067	42.18
S_6		3595	4961	41.99
S_7		5117	6034	45.31
S_8		4708	5745	44.88
S_9		4525	5649	44.20
S_{10}		6044	6683	46.45
S_{11}		5609	6347	46.10
S_{12}		5396	6209	45.81
SEm±		148	75	1.16
CD (p=0.05)		418	211	3.27
Interaction				
Main at sub	SEm±	256	130	2.00
	CD (p=0.05)	NS	NS	NS
Sub at main	SEm±	261	133	2.06
	CD (p=0.05)	NS	NS	NS

and 25 kg ha^{-1} iron chelate (S_3) found superior to control but statistically on par (Table 4).

All the yield attributes (effective tillers m^{-2}, panicle weight, panicle length, number of grains per panicle and 1000 grain weight) had a positive impact on grain yield of rice (Table

Table 5: Correlation between yield attributes and grain yield of aerobic rice

	Grain yield (kg ha-1)	1000 Grain weight	Grains panicle-1	Panicle length (cm)	Panicle weight (g)	Effective tillers m-2
Grain yield (kg ha-1)	1					
1000 Grain weight	0.901*	1				
Grains panicle-1	0.970*	0.851*	1			
Panicle length (cm)	0.930*	0.884*	0.919*	1		

Table 5: Continue...

	Grain yield (kg ha^{-1})	1000 Grain weight	Grains $panicle^{-1}$	Panicle Length (cm)	Panicle weight (g)	Effective tillers m^{-2}
Panicle weight (g)	0.921*	0.764*	0.888*	0.823*	1	
Effective tillersm^{-2}	0.932*	0.945*	0.884*	0.950*	0.784*	1

*Correlation coefficient (r) is significant at the 0.01 level (2-tailed)

5). Among the yield attributes, grains $panicle^{-1}$ (r=0.970*, *significant at 1% level) is highly correlated with grain yield followed by effective tillers m^{-2} (r=0.932*) and panicle length (r=0.93*). Panicle weight (r=0.921*) and 1000 grain weight (r=0.90*) also shown a positive correlation with grain yield of rice.

4. CONCLUSION

KRH 2 was superior in registering higher growth and yield. Among twelve iron nutrition treatments, basal application of iron chelate @ 25 kg ha^{-1}+3 foliar sprays of iron sulphate from 21 DAS @ 7 days interval was ideal for realizing higher growth parameters and yield.

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