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Research Paper

Effect of iron fertilization on dry-matter production, yield and economics of aerobic rice (*Oryza sativa*)

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ABSTRACT

A field experiment was conducted during the rainy (*kharif*) seasons of 2011 and 2012 at the research farm of the Indian Agricultural Research Institute, New Delhi, to study the effect of iron fertilization on dry-matter production, yield and economics of aerobic rice (*Oryza sativa* L.) varieties. The experiment was laid out in a randomized block design with 3 replications. Treatments comprised 2 rice varieties ('PRH 10' and 'PS 5') and 8 sources and modes of iron fertilization–control (no iron), iron sulphate @ 50 kg/ha + 1 foliar spray of 2.0% iron sulphate, iron sulphate @ 50 kg/ha + 1 foliar spray of 0.5% iron chelate, iron sulphate @ 100 kg/ha, 2 foliar sprays of 2.0% iron sulphate, 3 foliar sprays of 2.0% iron sulphate, 2 foliar sprays of 0.5% iron chelate and 3 foliar sprays of 0.5% iron chelate. Variety 'PRH 10' showed significantly higher dry-matter, yield attributing characters and yield than 'PS 5'. Highest dry-matter accumulation and number of effective tillers/m^2 and grain yield were recorded with 3 foliar sprays of 2.0% iron sulphate followed by 3 foliar sprays of 0.5% iron chelate. Grain yield differed significantly among the 2 varieties of rice. Variety 'PRH 10' gave significantly higher grain yield than 'PS 5'. The highest grain yield was recorded from the 3 foliar sprays of 2.0% iron sulphate followed by 3 foliar sprays of 0.5% iron chelate, 2 foliar sprays of 2.0% iron sulphate and two foliar sprays of 0.5% iron chelate, whereas the lowest grain yield was recorded in the control plot (no iron). The benefit: cost ratio was recorded the highest with 3 foliar sprays of 2.0% iron sulphate followed by 2 foliar sprays of 2.0% iron sulphate and found significantly higher over all other treatments.

Key words **:** Aerobic rice, Dry-matter, Economics, Iron fertilizaion, Yield, Yield attributes

Rice is the staple food for three-fourths of the Indian population. The total foodgrain production (2012–13) of the country was 255.4 million tonnes with major contribution from rice (104.4 million tonnes) and wheat (92.46 million tonnes) crops (DES, 2013). Though the productivity of both rice and wheat is still low, i.e. 2,462 and 3,118 kg/ha respectively (DES, 2013). To safeguard the food security in India, it is quite important to raise the productivity levels of rice, particularly under the decreased water availability.

Scarcity of water for agricultural production is becoming a major problem in many countries, particularly the world's leading rice-producing countries, China and India, where competing and growing demands for freshwater are coming from other sectors. Rice farmers need technologies to cope with water shortage and ways must be sought to grow rice with less water (Tuong and Bouman, 2002). Also, rainfall reductions and variability create problems for farmers even if only a cyclical rather than a permanent constraint. Rainfall patterns in many areas are becoming more unreliable, with extremes of drought and flooding occurring at unexpected times. Being able to economize on water use for irrigated rice production is thus becoming more important. Transplanted puddled rice production system is labour, water and energy-intensive which proved less profitable (Kumar and Ladha, 2011). The alarming rate of groundwater depletion and increasing labour scarcity are major threats to future rice production in North West India (Yadav *et al.*, 2012). Efforts are therefore underway to develop water-saving technologies such as system of rice intensification (SRI) and aerobic rice system (ARS), because irrigated rice production is the leading consumer of water in the agricultural sector, and rice is the world's most widely consumed staple crop, finding ways

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to reduce the need for water to grow irrigated rice should benefit both producers and consumers.

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 (Bouman, 2001; Tuong and Bouman, 2003; Prasad, 2011). Thus in ARS, soils are kept aerobic almost throughout the rice-growing season. In addition to lesser water availability, other factors in ARS include soil mechanical impedance, increased oxygen supply to roots, accumulation of ethylene and carbon dioxide in root tissue and availability of nitrogen as nitrate in place of ammonium (the dominant N ion under flooded conditions) and a changed soil fauna (Vosenek and Van der Veen, 1994). But Despite the usefulness of ARS, there are still many constraints that restrict its adoption by rice farmers. The major constraints in ARS are unavailability of varieties specifically bred for it, severe weed and nematode infestation, and of course, the iron deficiency.

Iron is an essential plant nutrient required for electron transport in photosynthesis. Increasing cropping intensity and accompanying changes in the soil and fertilizer management practices have altered the iron status and availability, especially in the Indo-Gangetic plains of India where on large areas rice–wheat cropping system is being practiced. Further, the iron deficiency is more severe in calcareous soils with low-Fe availability due to high soil *p*H. Cropping systems of 200 to 300% intensity deplete the soil iron more due to higher production. This Fe deficiency is aggravated further as farmers do not apply it externally and its mining occurs. However, application of iron fertilizers may overcome its deficiency in soil, increase crop yields which will subsequently increase crops productivity and income of the farmers. Furthermore, identification of efficient Fe-utilizing varieties would also help in coping the iron deficiency. In view of the above facts an experiment was carried out to study the effect of iron fertilization on dry-matter production, yield and economics of aerobic rice

MATERIALS AND METHODS

The field experiment was conducted during the rainy (*kharif*) seasons of 2011–2012, New Delhi, (28^{o} 40' N, 77^{o}12' E, 228.6 m above the mean sea-level). A composite representative soil sample was collected from the experimental field prior to start of the experimentation and analysed for physico-chemical properties. The soil was sandy clay loam and alkaline (*p*H value 7.4 with 1:2.5 soil and water ratio). Soil had 212 kg/ha available N (Subbiah and Asija, 1956), 18.9 kg/ha available P (Olsen *et al*., 1954), 283 kg/ha available K (Hanway and Heidel, 1952), 0.57 % organic carbon (Walkley and Black, 1934) and 4.7 ppm Fe (Prasad *et al*., 2006). The rice–wheat cropping system has been adopted continuously in the experimental area for the last 3 years. The treatments (16) were combinations of 2 rice varieties ('PRH 10' and 'PS 5') and 8 sources and mode of application (control, iron sulphate @ 50 kg/ha + 1 foliar spray of 2.0% iron sulphate, iron sulphate @ 50 kg/ha + 1 foliar spray of 0.5% iron chelate, iron sulphate @ 100 kg/ha, 2 foliar sprays of 2.0% iron sulphate, 3 foliar sprays of 2.0% iron sulphate, 2 foliar sprays of 0.5% iron chelate and 3 foliar sprays of 0.5% iron chelate). The treatments were randomly allocated to different plots using random number table of Fisher and Yates (1963), in a randomized block design with 3 replicates.

The field was irrigated, ploughed and made ready for sowing. Iron was applied as per treatment through various Fe sources. The amount of sulphur contributed by iron fertilization in different treatments was adjusted through elemental sulphur in plots which did not receive it. Recommended doses of N (150), P_2O_5 (60) and K_2O (50) kg/ha were applied to crops during both the years in all the plots. Half dose of nitrogen and full doses of P and K were applied basal at the time of sowing and remaining N was applied in 2 equal splits, i.e. at tillering and panicle-initiation stages. Irrigations to the crop were provided so as to keep soil near field capacity. Other crop-management practices were followed as per the recommendations. The crop was sown on 21 June and 17 June during 2011 and 2012, respectively, using seed rate of 40 kg/ha, with a row-to-row spacing of 20 cm. The individual plot size was 4.25 m × 3.25 m. The crop was harvested on 11 October in 2011 and 8 October in 2012. Plant samples from 50 cm row length were harvested from the ground level for estimation of dry matter at different growth stages. These sampled plants were sun-dried for 2–3 days and later oven-dried at 60±2°C for 24 hrs and dry weight (g/m^2) was recorded 30, 60, 90 days after sowing (DAS) and at harvesting. At harvesting the numbers of panicles/m row length was counted and converted to panicles/m^2 in each plot. Length of the panicle was measured from a sample of 10 panicles drawn randomly from the marked 10 plants. The length was measured from neck to the tip of the panicle and average length was then computed. The selected 10 panicles were also used to record the mean weight of the panicle.The total number of filled grains from the randomly selected 10 panicles from each plot was counted and their average was computed. The 1,000-filled grains, taken from sampled panicles, were first counted by a seed counter and then weighed to compute the 1,000-grain weight. The net plots (leaving 2 border rows on each side and 0.5 m from each side of the length) were harvested and sun-dried and then the total biomass yield was recorded. After threshing, cleaning and drying, the grain yield was recorded and reported at 14% moisture content. Straw yield was obtained by subtracting grain yield from the total biomass yield. Harvest index (HI) was computed by using the expression given by Singh and Stoskofif, 1971.

Cost of cultivation was computed based on the prevailing market prices of the inputs during the respective crop seasons. Gross returns were computed based on the grain and straw yields and their prevailing market prices during the respective crop seasons. Net returns were computed by subtracting cost of cultivation from gross returns. Net benefit: cost ratio was computed by dividing net returns with cost of cultivation.

All the data were analyzed statistically using the *F*-test as per Gomez and Gomez (1984). Critical difference (CD at P=0.05) was used to determine the significance of difference between treatment means.

RESULTS AND DISCUSSION

Dry-matter

In general, dry matter increased substantially and quadratically with the advancement of crop age (Fig. 1). The highest dry-matter accumulation was recorded at harvesting stage. However, dry-matter accumulated by the 2 varieties differed significantly. 'PRH 10' accumulated significantly higher dry matter across all the stages over 'PS 5'. Sources and mode of iron application also had a significant effect on dry matter production. The lowest dry-matter accumulation was recorded with the control plot which was significantly lower than 2 and 3 foliar sprays of 2.0% iron sulphate and 0.5% iron chelate at all the stages. However, dry-matter produced by the application of iron sulphate @ 100 kg/ha, iron sulphate @ 50 kg/ha + 1 foliar spray of 2.0% iron sulphate and iron sulphate @ 50 kg/ha + 1 foliar spray of 0.5% iron chelate was at par with the control. Xiaoyun *et al.* (2012) also reported a significant increase in shoot dry weight by Fe application under both aerobic and flooded plots. Similarly, plant dry matter g/m^2 at various growth stages (active tillering, panicle initiation, flowering and at harvesting) increased with iron application (Rakesh *et al*., 2012).

Yield attributes

The yield of rice crop is primarily governed by the yield-contributing attributes. The higher values of such attributes indirectly indicate the potential yield or these values can be used to estimate the yield in advance. 'PRH 10' rice recorded significantly higher values of effective tillers/m^2, panicle weight, panicle length, grains/panicle and 1,000-grain weight than 'PS 5' (Table 1). Hence, the cultivar 'PRH 10' therefore had upper edge with respect to yield attributes. In fact 'PRH 10' is a hybrid and 'PS 5' a pureline variety, and therefore the former cultivar showed superior growth than the later. Further, the significant differences in dry-matter accumulation of 2 cultivars might have caused a significant difference in yield attributes, particularly in favour of the 'PRH 10'.

Among the sources and mode of iron application, soil application of iron did not prove effective in improving yield attributes of aerobic rice. However, foliar application of iron proved more effective. Highest number of effective tillers/m^2 was recorded from 3 foliar sprays of 2.0% iron sulphate followed by 3 foliar sprays of 0.5% iron chelate. In fact the former 2 treatments produced significantly higher number of effective tillers/m^2 than the control, iron sulphate @ 50 kg/ha + 1 foliar spray of 2.0% iron sulphate, iron sulphate @ 50 kg/ha + 1 foliar spray of 0.5% iron chelate and iron sulphate @ 100 kg/ha. Also, the panicle weight, panicle length, grains/panicle and 1,000-

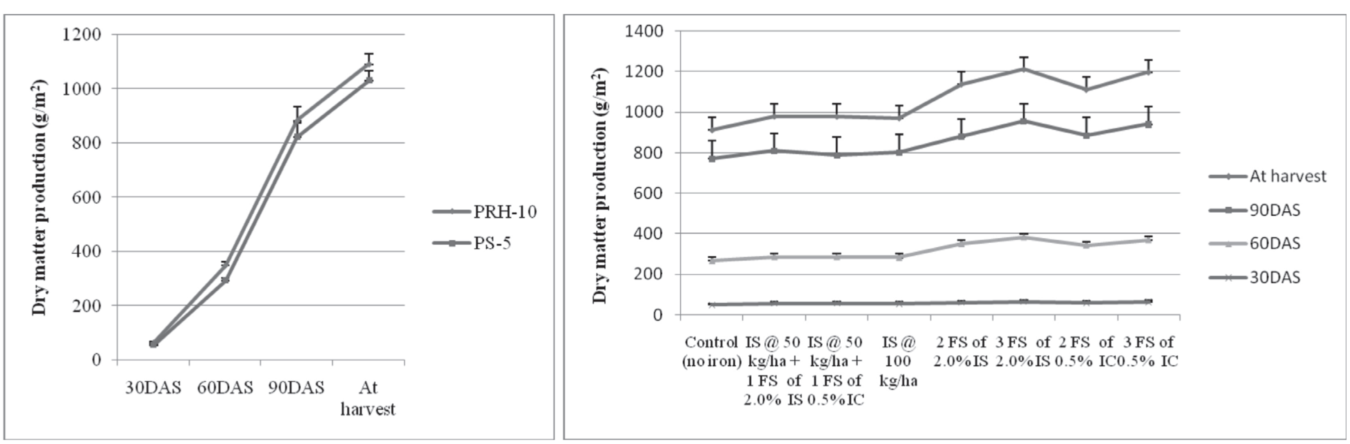

Fig. 1. Dry-matter production (g/m^2) of aerobic rice at different growth stages as influenced by varieties and iron fertilization (mean data of 2 years)
(DAS, Days after sowing; FS, foliar spray; IC, iron chelate; IS, iron sulphate)

grain weight were the highest with 3 foliar sprays of 2.0% iron sulphate, followed by 3 foliar sprays of 0.5% iron chelate, which was significantly higher than the control, iron sulphate @ 50 kg/ha + 1 foliar spray of 2.0% iron sulphate, iron sulphate @ 50 kg/ha + 1 foliar spray of 0.5% iron chelate and iron sulphate @ 100 kg/ha. Iron is required for the synthesis of chlorophyll, which is an essential pigment for photosynthesis. It also improves the root-systems of rice and the growth and leaf areas of rice (Fageria, 2014). Hence, the iron fertilization may have significantly improved the 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. Our results confirm the findings of Yadav *et al*. (2012).

Grain and straw yields

Varieties and iron fertilization significantly influenced the grain yield of aerobic rice (Table 1). Rice hybrid 'PRH 10' gave significantly higher grain yield than 'PS 5' owing to contribution of higher values of yield attributes. The amount of grain obtained per unit area in rice is actually a function of yield attributes. The higher values of these attributes would obviously result in higher grain yield. Since the values of most yield attributes were significantly higher in 'PRH 10' than 'PS 5', the grain yield was also significantly higher in the former variety. Straw yield also differed significantly between 2 varieties. 'PRH 10' gave significantly higher straw yield than 'PS 5', mainly owing to their significant differences in dry-matter production ability.

Iron fertilization of aerobic rice proved useful in enhancing the grain yield. The mean grain yield aerobic rice over 2 year rose from 4.32 in the control to 5.24 t/ha in 3 foliar sprays of 2.0% iron sulphate. The highest grain yield was recorded from the 3 foliar sprays of 2.0% iron sulphate, followed by 3 foliar sprays of 0.5% iron chelate, 2 of 2.0% iron sulphate and 2 foliar sprays of 0.5% iron chelate. All these former treatments gave statistically similar yields, being significantly higher than the control. Duraisamy and Mani (2001) also reported that iron application either alone or in combination with Mo increased the grain yield over the control, irrespective of the levels and modes of application and foliar application was found more effective than soil application. Rakesh *et al.* (2012) from Andhra Pradesh, reported that effective tillers/m^2, panicle length (cm), filled grains/panicle, test weight (g), grain yield and straw yield (kg/ha) were increased with iron application.

In the present investigation the iron, depending on the treatment, was applied in soil, through foliar spray and their combinations. In general, application of iron in soil was less effective than sole foliar spray in the present study, indicating superiority of foliar application of iron sulphate over soil application alone. Foth and Ellis (1988) suggested that correcting iron deficiency is very difficult because it is caused by changes in chemical conditions of soil and not by low levels of iron. If soluble iron is added to soil, it is very quickly precipitated and becomes unavailable to plants (Fageria, 2014). Hence, we did not get any

Table 1. Effect of varieties and iron fertilization on yield attributes and yield of aerobic rice (mean data of 2 years)

Treatment	Effective tillers/m^2	Weight/ panicle (g)	Length/ panicle (cm)	Grains/ panicle	1,000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)
Variety								
'PS 5'	306.3	3.3	24.7	119.5	21.9	4.58	7.71	37.2
'PRH 10'	331.4	3.5	25.5	129.9	22.6	4.96	7.89	38.6
SEm±	4.4	0.1	0.2	1.0	0.1	0.06	0.05	0.3
CD (P=0.05)	12.7	0.1	0.6	2.8	0.4	0.18	0.14	0.9
Sources and mode of iron application								
Control (no iron)	264.2	3.1	24.1	116.8	21.1	4.32	7.60	36.2
IS @ 50 kg/ha + 1 FS of 2.0% IS	300.2	3.3	24.8	120.1	21.9	4.59	7.71	37.3
IS @ 50 kg/ha + 1 FS of 0.5% IC	293.3	3.3	24.7	119.4	21.6	4.56	7.72	37.1
IS @ 100 kg/ha	273.8	3.2	24.5	118.7	21.7	4.44	7.67	36.6
2 FS of 2.0% IS	354.5	3.5	25.6	129.7	22.6	5.00	7.93	38.5
3 FS of 2.0% IS	366.2	3.7	26.1	136.0	23.4	5.24	7.93	39.7
2 FS of 0.5% IC	340.2	3.5	25.3	125.4	22.6	4.95	7.92	38.5
3 FS of 0.5% IC	358.5	3.7	26.0	131.2	22.9	5.05	7.91	38.9
SEm±	7.2	0.1	0.4	1.6	0.2	0.10	0.08	0.5
CD (P=0.05)	20.7	0.2	1.0	4.6	0.7	0.30	0.23	1.5

FS, Foliar spray; IC, iron chelate; IS, iron sulphate response to soil application of iron. In the present study, 2 iron sources, viz. iron sulphate (2%) and iron chelate (0.5%) were compared at 2 and 3 foliar sprays. Though the concentration of 2 iron sources differed for foliar spray, but their response was similar when used at same frequency, i.e. at 2 or 3 foliar sprays. It indicates that either of the 2 sources could be used at their respective concentration for foliar spray. But now the economics would come into picture and decide which source needs to be used. Fageria (2014) has also opined that important criterion in selecting a Fe source is its cost and solubility in water. He stated further that iron chelates are good sources and also soluble in water, but their cost is very high compared with other options.

Almost all the yield attributes were highly correlated with grain yield (Table 2). The mean effective tillers/m^2 (r = 0.986), mean panicle length (r = 0.985), mean number of grains/panicle (r = 0.976), mean panicle weight (r = 0.962) and mean test weight (r = 0.988) have shown a highly significant and positive correlation with grain yield.

Iron fertilization also affected the straw yield significantly. Among the iron sources and modes of application the lowest straw yield was recorded in the control plot. Control plot gave significantly lower straw yield than 3 foliar sprays of 2.0% iron sulphate, 3 foliar sprays of 0.5% iron chelate, 2 foliar sprays of 2.0% iron sulphate and 2 foliar sprays of 0.5% iron chelate. Two and three foliar sprays of 2.0% iron sulphate and 0.5% iron chelate gave statistically at similar straw yield. Application of iron in aerobic rice improved the dry-matter yield which eventually may have led to the increased straw yield.

Harvest index

Rice varieties and sources and modes of iron application differed significantly in harvest index. Variety 'PRH 10' had better harvest index than 'PS 5'. The higher harvest index with former variety is attributed to production of higher economic yield compared to later. Among the

Table 2. Correlation matrix among yield attributes and grain yield of aerobic rice (mean data of 2 years)

	ET	PL	GP	PW	TW	GY
ET	1					
PL	0.985996*	1				
GP	0.958524*	0.976940*	1			
PW	0.940466*	0.979129*	0.962996*	1		
TW	0.967269*	0.986013*	0.974442*	0.976751*	1	
GY	0.986317*	0.985328*	0.976124*	0.962852*	0.988155*	1

ET, Effective tiller; PL, panicle length; GP, grains/panicle; TW, 1,000-grain weight; GY, grain yield;
*Correlation matrix is significant at P=0.05

Table 3. Economics of aerobic rice as affected by varieties and iron fertilization (mean data of 2 years)

Treatment	Cost of cultivation ($\times 10^3$ ₹/ha)	Gross returns ($\times 10^3$ ₹/ha)	Net returns ($\times 10^3$ ₹/ha)	Net Benefit: Cost ratio
Variety				
'PS 5'	38.2	85.6	47.3	1.24
'PRH 10'	39.8	89.4	49.5	1.25
SEm±	-	1.0	1.0	0.03
CD (P=0.05)	-	2.8	NS	NS
Sources and mode of iron application				
Control (no iron)	36.9	81.4	44.5	1.21
IS @ 50 kg/ha + 1 FS of 2.0% IS	37.8	85.0	47.2	1.25
IS @ 50 kg/ha + 1 FS of 0.5% IC	39.9	84.7	44.8	1.13
IS @ 100 kg/ha	38.4	83.1	44.7	1.16
2 FS of 2.0% IS	37.2	90.7	53.5	1.44
3 FS of 2.0% IS	37.4	93.5	56.1	1.50
2 FS of 0.5% IC	41.4	90.1	48.7	1.18
3 FS of 0.5% IC	43.2	91.2	48.0	1.11
SEm±	-	1.6	1.6	0.05
CD (P=0.05)	-	4.5	4.5	0.12

FS, Foliar spray; IC, iron chelate; IS, iron sulphate sources and modes of iron application, the highest harvest index recorded with 3 foliar sprays of 2.0% iron sulphate, followed by 3 foliar sprays of 0.5% iron chelate, 2 of 2.0% iron sulphate and 2 of 0.5% iron chelate. All these treatments produced statistically significantly higher harvest index over the control owing to significantly higher production of grain yields.

Economics

The total cost of cultivation of aerobic rice was higher with 'PRH 10' than 'PS 5' mainly owing to the high seed cost of the former variety than the later. 'PRH 10' produced significantly higher gross returns than 'PS 5'. Net returns were also found higher in 'PRH 10' over 'PS 5' but the difference was non-significant. In both the varieties, the difference in net benefit: cost ratio was found non-significant though it was found slightly higher in 'PRH 10'. Sources and mode of iron application significantly affected the economics of aerobic rice. The lowest cost of cultivation was recorded in the control plot, while it was the highest in 3 foliar sprays of 0.5% iron chelate, followed by 2 foliar sprays of 0.5% iron chelate and iron sulphate @ 50 kg/ha + 1 foliar spray of 0.5% iron chelate. Gross returns were the highest with the 3 foliar sprays of 2.0% iron sulphate which were significantly higher over the control, iron sulphate @ 50 kg/ha + 1 foliar spray of 2.0% iron sulphate, iron sulphate @ 50 kg/ha + 1 foliar spray of 0.5% iron chelate and iron sulphate @ 100 kg/ha, but the net returns were found significantly higher with 3 foliar sprays of 2.0% iron sulphate over rest of the treatments except 2 foliar sprays of 2.0% iron sulphate

Duraisamy and Mani (2001) computed the economics and observed that the net returns were higher in foliar spray than the soil application and the control. The application of $FeSO_4$ significantly affected the cost of cultivation, net returns and benefit: cost ratio of aerobic rice (Yadav *et al*., 2012). The net benefit: cost ratio was also highest with 3 foliar sprays of 2.0% iron sulphate which was found significantly higher over all the other treatments except 2 foliar sprays of 2.0% iron sulphate. The lowest net benefit: cost ratio was found with 3 foliar sprays of 0.5% iron chelate. Though the gross returns with the sprays of iron chelate were at par with the sprays of iron sulphate, but the net benefit: cost ratio with the iron chelate was significantly lower than iron sulphate because of high cost of chelated iron.

Based on 2 year field study we conclude that hybrid 'PRH 10' had better agronomic performance than 'PS 5' in aerobic rice environment, as it exhibited better growth, higher values of most yield attributes, greater grain yields and lastly better profits. The soil application of iron did not prove effective in improving the dry-matter production, yield or economics of aerobic rice. However, foliar application of iron either through iron sulphate or iron chelate proved more effective than soil application in enhancing the growth and yield of aerobic rice. Two or three foliar sprays of either chelated iron or ferrous sulphate gave statistically similar grain yields. But considering the economics, iron sulphate was relatively a better iron source than chelated iron.

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