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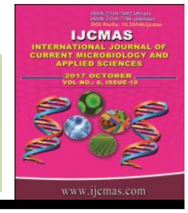

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Study of Aerobic Rice under Varying Fertility Levels in Relation to Iron Application

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A B S T R A C T

A field experiment was conducted at Agricultural Research Station, Kampasagar, Nalgonda, during *kharif*, 2011 withMTU-1010 variety, to find out the optimum nutrient requirement for aerobic rice cultivation. The experiment comprising of two nitrogen levels (120 and 180 kg N ha^{-1}), two phosphorus levels (60 and 90 kg P ha^{-1}), two potassium levels (40 and 60 kg K ha^{-1}) and two iron levels (0 and 25 kg Fe ha^{-1}) were laid in ten plots replicated thrice. The results revealed that application of 180:90:60:25 kg N, P, K and Fe ha^{-1} registered higher number of tillers and panicles (491 and 381 m^{-2}), filled grains panicle^{-1} (86.3), 1000-grain weight (26.97 g), grain and straw yields (4960 and 6034 kg ha^{-1} respectively) than the application of (120:60:40 kg N, P and K ha^{-1}). However, it was on par with (180:90:60 kg N, P and K ha^{-1}) which registered similar number of tillers, panicles (483 and 375 m^{-2}),filled grains panicle^{-1} (84.7), 1000-grain weight (26.47 g), grain and straw yields (4873 and 5814 kg ha^{-1} respectively).

Introduction

Rice requires approximately 3000-5000 litres of water to grow one kilogram of rice traditionally. It is mostly grown under flooded conditions and consumes up to 43% of the world's developed irrigation resources (Bouman *et al.*, 2007). About 22 million hectares of irrigated dry season rice experience "economic water scarcity" in South and Southeast Asia (Tuong and Bouman, 2002). The availability of water for agriculture is declining steadily due to urbanization and rapid increase in population (Xue *et al.*, 2008).Therefore, in coming decades, farmers all over the world will face severe water scarcity and everlasting competition for water exists in irrigated rice systems that will ultimately have an impact on overall production. Considering the future population growth, competition from non-agricultural uses of water and increasing demand for agricultural products, available water needs to be used efficiently. To reduce the share of water in rice cultivation, it is imperative to develop new way of growing rice that uses less water, while maintaining high yields. So, it was felt that there is a need to save water in rice cultivation, which led to development of aerobic rice.

Aerobic rice is water saving production system in which potentially high yielding, fertilizer responsive adapted rice varieties are grown in fertile aerobic soils that are non-puddled and have no standing water.

Supplementary irrigation, however, can be supplied in the same way as to any other upland cereal crop (Wang *et al.*, Bouman *et al.,* 2005). The main driving force behind aerobic rice is the increasing water scarcity, which threatens the sustainability of lowland rice production. Aerobic rice is unique in its characteristics to withstand both flooding and dry soil conditions, which make it an ideal crop for areas prone to surface flooding where other crops would suffer or fail.

The low and unstable yields of aerobic rice were mainly due to nutrient stresses. Nutrients are delivered to roots primarily by mass flow and diffusion but the delivery rate decreases as the moisture content of the soil decreases. The lower soil moisture content in aerobic rice cultivation therefore reduces nutrients supply to the roots and resulted in the lower rate of plant uptake. Understanding of nutrient uptake and response to fertilization effects are also urgently required to establish optimized crop management technology. As, rice is much more susceptible to iron deficiency than other cereals, presumably because it does not have an inducible ferric chelate reductase activity, as do plants that use the reduction strategy to generate ferrous iron from the more abundant ferric iron found in aerobic soils (Mori *et al.,* 1991). So, there is an urgent need for formulating optimum dose of fertilizers for increasing the yields of aerobic rice. Considering the above facts, field experiment was conducted at ARS, Kampasagar to study the response of aerobic rice to varying fertility levels in relation to iron application.

Materials and Methods

The field experiment was conducted during *kharif*, 2011 under aerobic conditions at Agricultural Research Station, Kampasagar, Nalgonda district of Andhra Pradesh, situated at an altitude of 136.0 m above MSL on 16^{o}51'.12.5" N latitude and 79^{o}28'.28.4" E longitude. It is in the Southern Telangana agro-climatic zone of Andhra Pradesh. The experiment was conducted in sandy clay loam soil with moderate drainage. The soil was low in available nitrogen (125.44 kg ha^{-1}), medium in available phosphorus (24.84 kg ha^{-1}) and medium in available potassium (164.84 kg ha^{-1}) contents. The pH of the soil was 6.38. A medium slender grain type variety, MTU-1010 of 110-120 days duration was grown. The experiment was laid out in randomized block design with ten treatments [T_1–(120:60:40 kg NPK ha^{-1}), T_2–(180:60:40 kg NPK ha^{-1}), T_3–(180:60:60 kg NPK ha^{-1}), T_4–(180:90:40 kg NPK ha^{-1}), T_5-(180:90:60 kg NPK ha^{-1}), T_6–(120:60:40:25 kg NPK and $FeSO_4$ ha^{-1}), T_7–(180:60:40:25 kg NPK and $FeSO_4$ ha^{-1}), T_8–(180:60:60:25 kg NPK and $FeSO_4$ ha^{-1}), T_9–(180:90:40:25 kg NPK and $FeSO_4$ ha^{-1}) and T_{10} –(180:90:60:25 kg NPK and $FeSO_4$ha^{-1})] with three replications.

Results and Discussion

Tiller production

The data pertaining to tiller production was recorded at active tillering, panicle initiation, flowering stages and at maturity stage are presented in Table 1.

The tiller number was decreased from active tillering to harvest in all treatments (T_1-T_{10}). At all the stages of aerobic rice highest number of tillers m^{-2} (537, 523, 509 and 491 at active tillering, panicle initiation, flowering and harvest stages respectively) were recorded with the application of 180: 90: 60:25 kg NPK and $FeSO_4$ ha^{-1} (T_{10}). However, there was no significant difference in tiller number with varying fertility levels in relation to iron application.

Lower number of tillers m^{-2} (423, 395, 363 and 353 at active tillering, panicle initiation, flowering and harvest stages respectively) was recorded with 120:60:40 kg NPK ha^{-1} (T_1). Addition of 25 kg $FeSO_4$ ha^{-1} (T_6) resulted in the increase of tiller number m^{-2} by 6.6, 8.8, 14.3 and 12.2 % over the T_1 at different growth stages of aerobic rice. Additional dose of 60 kg N ha^{-1} (T_2) to T_1 resulted in improvement of tiller number by (53, 67, 88 and 85 m^{-2}) at active tillering, panicle initiation, flowering and harvest stages of aerobic rice. Inclusion of 25 kg ha^{-1} further enhanced tiller number m^{-2} by (13, 15, 9 and 6) and finally resulted in the tiller number of (489. 477, 460 and 444 m^{-2}) at active tillering, panicle initiation, flowering and harvest stages of aerobic rice.

Successive increase in the levels of fertilizers applied to aerobic rice has showed positive response on number of tillers m^{-2}, though they had not reached the level of significance. Increase in the fertility levels increased the tiller production at all the stages of aerobic rice. The increased tiller number is due to availability of nutrients in sufficient quantities during the critical stages of crop growth. These findings are in accordance with the reports of Venugopal (2005), Alam and Azmi (1989), Raju *et al.,* (1992), Sarkar *et al.,* (1995) and Krishnappa *et al.,* (1990).

Application of $FeSO_4$ in aerobic rice has failed to claim significant effect on tiller number m^{-2}. This might be due to involvement of Fe in plant physiochemical activity but it might not be a strong element to induce a drastic change in the plant growth. These findings are in accordance with the findings of Voigt *et al.,* (1982), Kasana and Chaudry (1983) and Singh (1992).

Dry matter accumulation

The data pertaining to plant dry matter production which was recorded at active tillering, panicle initiation, flowering and harvest stages were presented in Table 2.

Study of the data pertaining to dry matter accumulation presented in table revealed that there was an increase in the dry matter production from active tillering to harvest in all the treatments (T_1 to T_{10}). The plant dry matter production at active tillering stage was maximum with the application of 180: 90: 60:25 kg NPK and $FeSO_4$ ha^{-1} (T_{10}), as it recorded highest plant dry matter m^{-2} (68.7 g) and it was followed by 180:90:60 kg NPK ha^{-1} (T_5-65.6 g m^{-2}). The next two best results were recorded by 180:60:60:25 kg N, P, K and Fe ha^{-1} (T8-63.7 g) and 180:60:60 kg NPK ha^{-1} (T_3-61.2 g).

At panicle initiation the influence of varying fertility levels in relation to iron application on plant dry matter was more pronounced. The application of 180: 90: 60:25 kg NPK and $FeSO_4$ ha^{-1} (T_{10}) had significant influence on dry matter production (524 g m^{-2}) over 120:60:40 kg NPK ha^{-1} (T_1-388 g m^{-2}) and it was on par with 180:90:60 kg NPK ha^{-1} (T_5-514 g m^{-2}). The next two best treatments were T_8 (504 g m^{-2}) and T_3 (475 g m^{-2}) where 180:60:60:25 kg NPK and $FeSO_4$ ha^{-1} and 180:60:60:0 kg NPK and $FeSO_4$ ha^{-1} were applied respectively.

At both flowering and harvest stages the response of aerobic rice to varying fertility levels in relation to iron application on plant dry matter production was not significant though the application of 180: 90: 60:25 kg NPK and $FeSO_4$ ha^{-1} (T_{10}) recorded highest plant dry matter of 919 and 1600 g m^{-2} at flowering and harvest stages over 120:60:40 kg NPK ha^{-1} (T_1-652 and 1232 g m^{-2}). Application of 25 kg $FeSO_4$ ha^{-1} to T_1 (T_6) increased the plant dry matter by 46 and 29 g m^{-2} at flowering and harvest stages respectively.

Enhanced nutrient application increased dry matter production at all stages. Increased nutrient availability at higher doses of fertilizers was responsible for profuse tillering and ultimately higher plant dry matter production. Excluding panicle initiation stage, the influence of varying fertility levels in relation to iron application was not significant. These findings are in accordance with Laxminarayana (2003); Venugopal (2005); Sashikumar *et al.*, (1995); Rao *et al.*, (1991); Raju *et al.*, (1999) and Thakur and Patel (1998).

Application of $FeSO_4$ in aerobic rice has failed to claim significant effect on DMP. This might be due to involvement of iron in plant physiological activity but it might not be a strong element to induce a drastic change in plant growth. These findings are in accordance with Voigt *et al.*, (1982), Kasana and Chaudry (1983) and Singh (1992).

Yield Attributes

The data on yield attributing characters like productive tillers m^{-2}, panicle length, total grains $panicle^{-1}$, filled grains per panicle, unfilled grains per panicle and 1000 grain weight are presented in Table 3.

Effective tillers m^{-2}

A critical analysis of the data brings out the fact that the varying fertility levels in relation to iron application had failed to claim significant influence on effective tillers of aerobic rice. However, the highest number of effective tillers m^{-2} (381) was recorded where the maximum amount of the nutrients (180:90:60 kg NPK ha^{-1}) were applied along with 25 kg $FeSO_4$ ha^{-1} (T_{10}). This was closely followed by application of same quantity of fertilizers except $FeSO_4$ (T_5- 375 m^{-2}).

Application of 120:60:40 kg NPK ha^{-1} (T_1) recorded less number of effective tillers m^{-2} (331) in aerobic rice and with additional [60 kg N ha^{-1} (T_2); 60, 20 kg NK ha^{-1} (T_3); 60, 30 kg NP ha^{-1} (T_4); 60, 30, 20kg NPK ha^{-1} (T_5); 60, 30, 20kg NPK and 25 kg $FeSO_4$ ha^{-1} (T_{10})] application of nutrients resulted in the yield improvements of 2.1, 10.6, 5.4, 13.3 and 15.1 % respectively over T_1.

Application of $FeSO_4$ @ 25 kg ha^{-1} only improved the number of effective tillers m^{-2} of aerobic rice (T_6 to T_{10}) marginally when compared to their respective nutrient levels (T_1 to T_5). Addition of 25 kg $FeSO_4$ ha^{-1} to 120:60:40 kg NPK ha^{-1} (T_6) recorded an additional 4 effective tillers m^{-2} over no application of $FeSO_4$ (T_1) to the same nutrients.

Efficient utilization of applied nitrogen as well as other major nutrients has resulted in more number of effective tillers at higher levels. These findings are in close agreement with the reports of Shekar *et al.*, (2005), Kundu *et al.*, (2004), Singh and Namdeo (2004), Dwivedi *et al.*, (2006), Sarmah (1998) and Sathiya Bama and Selvakumari (2005).

Panicle length

Though there was an increase in panicle length with varying fertility levels in relation to iron application, their influence was not much pronounced on the length of panicle. However, application of 180:90:60:25 kg NPK and $FeSO_4$ ha^{-1} (T_{10}) recorded the maximum panicle length of (20.7 cm) followed by the application of same fertilizers except $FeSO_4$ (T_5-20.42 cm).

Application of 120:60:40 kg NPK ha^{-1} (T_1) recorded the minimum panicle length of 19.21 cm. Addition of 25 kg $FeSO_4$ ha^{-1} to T_1 improved the panicle length by 2.1%. Addition of 60, 30, 20 kg NPK and 25 kg $FeSO_4$ (T_{10}) to T_1 enhanced the panicle length by 1.5 cm.

These findings are in accordance with the works of Laxminarayana, 2003; Venugopal, 2005; Ramamurthy and Shivashankar, 1996 and Ram *et al.,* 1997.

Total grains panicle^{-1}

Varying fertility levels in relation to iron application has failed to claim significant influence on total grains panicle^{-1} of aerobic rice. However, application of 180:90:60:25 kg NPK and $FeSO_4$ ha^{-1} (T_{10}) recorded highest number of grains panicle^{-1} (91) followed by the application of 180:90:60 kg NPK ha^{-1} (T_5-88).

Lowest number of grains panicle^{-1} (78) was recorded with the application of 120:60:40 kg NPK ha^{-1} (T_1). Addition of 60, 20 kg NK ha^{-1} to T_1 (T_3) recorded more number of grains panicle^{-1} (85) than the addition of 60, 30 kg NP ha^{-1} to T_1 (T_4-83). Addition of 25 kg $FeSO_4$ ha^{-1} to T_1 (T_6) recorded an increase of 2.6 % in the number of grains panicle^{-1}.

Number of filled grains panicle^{-1}

There was no significant difference in the number of filled grains panicle^{-1} due to varying fertility levels in relation to iron application. Though maximum number of filled grains panicle^{-1} (83) were recorded with the application of 180: 90: 60:25 kg NPK and $FeSO_4$ ha^{-1} (T_{10}) and 180:90:60 kg NPK ha^{-1} (T_5-81), the percent transformation of total grains panicle^{-1} to filled grains panicle^{-1} was more pronounced with the application of 120:60:40 kg NPK ha^{-1} (T_1-94 %) than with the application of 180:90:60:25 kg NPK and $FeSO_4$ ha^{-1} (T_{10}-91 %).

Number of unfilled grains panicle^{-1}

The response of aerobic rice to varying fertility levels in relation to iron application has failed to claim significant influence on number of unfilled grains panicle^{-1}. Unfilled grain percentage was increased with the increasing NPK and $FeSO_4$ from 6.41 % (120:60:40:25 kg ha^{-1}) to 8.79 % (180:90:60:25 kg ha^{-1})

Increase in the total number of grains panicle^{-1} at higher NPK and $FeSO_4$ levels might have caused severe competition for carbohydrates thus resulted in increased hollow grain percentage. In lower NPK and $FeSO_4$ levels, insufficient nutrients for filling of grains led to diminished grain number panicle^{-1}; thus in this state, lower competition is the cause of decreased hollow grain percentage in panicle. These results are in accordance with the findings of Esfehani *et al.,* 2005 and Mondal *et al.,* (1987).

Test weight

There was no significant difference in test weight due to varying fertility levels in relation to iron application. However, the test weight was increased with increase in nutrient levels. Maximum test weight (26.97 g) was recorded with the application of180: 90: 60:25 kg N, P, K and Fe ha^{-1} (T_{10}) followed by the application of 180:90:60 kg N, P and K ha^{-1} (T_5-26.47 g). The next two best treatments are T_8 (26.2 g) and T_3 (25.3 g) where 180:60:60:25 kg NPK and $FeSO_4$ ha^{-1} and 180:60:60 kg NPK ha^{-1} were applied respectively. Minumum test weight (24.16 g) was recorded from the application of 120:60:40 kg NPK ha^{-1} (T_1). Addition of 25 kg $FeSO_4$ ha^{-1} to T_1 increased the test weight marginally by 0.21 g.

The efficacy of the fertilizers applied to aerobic rice was reflected in yield attributing characters like productive tillers m^{-2}, panicle length, total grains panicle^{-1}, filled grains per panicle, unfilled grains per panicle and 1000 grain weight, though they had not reached the level of significance. Increase in fertility levels increased the yield attributing characters of aerobic rice. The increase in yield attributes were mainly due to availability of nutrients in sufficient quantities during critical stages of crop growth which resulted in better growth characters and finally resulted in the growth of yield components of aerobic rice. These findings are in accordance with Shekhar *et al.*, (2005), Kundu *et al.*, (2004), Madhavi Latha (2001) and Raju *et al.*, (1999).

Application of ferrous sulphate even upto 25 kg ha^{-1} as soil application has failed to influence the yield attributes of aerobic rice. It is clear that the role of Fe in rice plant is unparallel, but the amount of $FeSo_4$ supplied to aerobic rice in the form of soil application might not be sufficient during the whole period of crop growth, thus resulting in the poor response of aerobic rice to ferrous sulphate application.

These observations are in close agreement with the findings of Sakal and Singh (1983), Tandon (1984) and Ghosh and Jena (1989).

Table.1 Influence of varying fertility levels in relation to iron application on tiller number m^{-2} at various stages of aerobic rice

Treatments (Nutrient levels (kg ha^{-1}))	**Tiller number m^{-2}**			
	Active tillering	**Panicle initiation**	**Flowering**	**Harvest**
$T_1(N_{120}P_{60} K_{40})$	423	395	363	353
T_2 $(N_{180}P_{60}K_{40})$	476	462	451	438
T_3 $(N_{180}P_{60}K_{60})$	506	491	475	462
T_4 $(N_{180}P_{90}K_{40})$	491	482	459	442
T_5 $(N_{180}P_{90}K_{60})$	528	513	501	483
T_6 $(N_{120}P_{60} K_{40}FeSO_{4\ 25})$	451	430	415	396
T_7 $(N_{180}P_{60}K_{40}FeSO_{4\ 25})$	489	477	460	444
T_8 $(N_{180}P_{60}K_{60}FeSO_{4\ 25})$	516	497	483	470
T_9 $(N_{180}P_{90}K_{40}FeSO_{4\ 25})$	498	485	470	456
T_{10} $(N_{180}P_{90}K_{60}FeSO_{4\ 25})$	537	523	509	491
CD (P = 0.05)	N.S.	N.S	N.S.	N.S.
SE(m)	26.6	46.6	37.7	35.7
CV (%)	9.4	16.8	14.1	13.9

Table.2 Influence of varying fertility levels in relation to iron application on plant dry matter g m^{-2} at various stages of aerobic rice

Treatments [Nutrient levels (kg ha^{-1})]	**Plant dry matter g m^{-2}**			
	Active tillering	**Panicle initiation**	**Flowering**	**Harvest**
$T_1(N_{120}P_{60} K_{40})$	53.3	388	652	1232
T_2 $(N_{180}P_{60}K_{40})$	54.4	440	791	1285
T_3 $(N_{180}P_{60}K_{60})$	61.2	475	833	1411
T_4 $(N_{180}P_{90}K_{40})$	56.4	449	780	1383
T_5 $(N_{180}P_{90}K_{60})$	65.6	514	909	1555
T_6 $(N_{120}P_{60} K_{40}FeSO_{4\ 25})$	54	414	698	1261
T_7 $(N_{180}P_{60}K_{40}FeSO_{4\ 25})$	59.5	451	793	1287
T_8 $(N_{180}P_{60}K_{60}FeSO_{4\ 25})$	63.7	504	899	1492
T_9 $(N_{180}P_{90}K_{40}FeSO_{4\ 25})$	59.9	454	797	1408
T_{10} $(N_{180}P_{90}K_{60}FeSO_{4\ 25})$	68.7	524	919	1600
CD (P = 0.05)	N.S.	48	N.S.	N.S.
SE(m)	6.5	15.9	57.6	164.8
CV (%)	19.0	6.0	12.4	20.5

Table.3 Influence of varying fertility levels in relation to iron application on yield attributes of aerobic rice

Treatments (Nutrient levels (kg ha^{-1}))	Effective tillers m^{-2}	Panicle length(cm)	Number of grains Panicle^{-1}	Number of filled grains Panicle^{-1}	Number of unfilled grains Panicle^{-1}	Test weight (g)
$T_1(N_{120}P_{60}K_{40})$	331	19.21	78	73	5	24.16
$T_2 (N_{180}P_{60}K_{40})$	338	19.67	81	74	7	24.49
$T_3 (N_{180}P_{60}K_{60})$	366	20	85	78	7	25.28
$T_4 (N_{180}P_{90}K_{40})$	349	19.87	83	77	6	24.7
$T_5 (N_{180}P_{90}K_{60})$	375	20.42	88	81	7	26.47
$T_6 (N_{120}P_{60}K_{40}FeSO_{4\ 25})$	335	19.61	80	75	5	24.37
$T_7 (N_{180}P_{60}K_{40}FeSO_{4\ 25})$	346	19.73	84	78	6	24.6
$T_8 (N_{180}P_{60}K_{60}FeSO_{4\ 25})$	374	20.17	86	81	5	26.2
$T_9 (N_{180}P_{90}K_{40}FeSO_{4\ 25})$	354	19.88	85	79	6	24.83
$T_{10} (N_{180}P_{90}K_{60}FeSO_{4\ 25})$	381	20.7	91	83	8	26.97
CD (at 5%)	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
SE(m) ±	21.9	0.32	5.9	2.65	0.7	0.86
CV (%)	10.7	2.8	12.2	5.9	19.7	5.94

Table.4 Influence of varying fertility levels in relation to iron application on grain and straw yield (kg ha^{-1}) of aerobic rice

Treatments	Grain yield	Straw yield	Harvest index
(Nutrient levels (kg ha^{-1}))	(kg ha^{-1})	(kg ha^{-1})	(%)
$T_1(N_{120}P_{60}K_{40})$	4281	4924	0.47
$T_2 (N_{180}P_{60}K_{40})$	4465	5253	0.46
$T_3 (N_{180}P_{60}K_{60})$	4767	5530	0.45
$T_4 (N_{180}P_{90}K_{40})$	4552	5336	0.46
$T_5 (N_{180}P_{90}K_{60})$	4873	5814	0.45
$T_6 (N_{120}P_{60}K_{40}FeSO_{4\ 25})$	4399	5143	0.46
$T_7 (N_{180}P_{60}K_{40}FeSO_{4\ 25})$	4534	5327	0.46
$T_8 (N_{180}P_{60}K_{60}FeSO_{4\ 25})$	4811	5812	0.45
$T_9 (N_{180}P_{90}K_{40}FeSO_{4\ 25})$	4584	5424	0.46
$T_{10} (N_{180}P_{90}K_{60}FeSO_{4\ 25})$	4960	6034	0.45
CD (P = 0.05)	N.S.	N.S.	N.S.
SE(m)	169.9	253.3	0.01
CV (%)	6.4	8.03	3.70

Table.5 Influence of varying fertility levels in relation to iron application on nitrogen uptake (kg ha $^{-1}$) at different crop growth stages of aerobic rice

Treatments [Nutrient levels (kg ha^{-1})]	Nitrogen uptake (kg ha^{-1})			
	Active tillering	Harvest		
		Grain	Straw	Total
$T_1(N_{120}P_{60}K_{40})$	8.2	31.3	23	54.3
$T_2 (N_{180}P_{60}K_{40})$	9.8	41.5	27	68.5
$T_3 (N_{180}P_{60}K_{60})$	10.3	46	34.8	80.8
$T_4 (N_{180}P_{90}K_{40})$	10.3	42.3	30.2	72.5
$T_5 (N_{180}P_{90}K_{60})$	11.4	50.6	38.4	89
$T_6 (N_{120}P_{60}K_{40}FeSO_{4\ 25})$	8.8	38	26.3	64.3
$T_7 (N_{180}P_{60}K_{40}FeSO_{4\ 25})$	10.3	42.4	28.9	71.3
$T_8 (N_{180}P_{60}K_{60}FeSO_{4\ 25})$	10.4	45.5	33.5	79
$T_9 (N_{180}P_{90}K_{40}FeSO_{4\ 25})$	10.3	42.6	32.4	75
$T_{10} (N_{180}P_{90}K_{60}FeSO_{4\ 25})$	11.6	52.2	39.1	91.3
CD (P = 0.05)	N.S.	N.S.	N.S.	
SE(m)	1.33	5.5	4.02	
CV (%)	22.7	22.1	22.2	

Table.6 Influence of varying fertility levels in relation to iron application on phosphorus uptake (kg ha $^{-1}$) at different crop growth stages of aerobic rice

Treatments [Nutrient levels (kg ha^{-1})]	Phosphorus uptake (kg ha-1)			
	Active tillering	Harvest		
		Grain	Straw	Total
$T_1(N_{120}P_{60}K_{40})$	1.36	11.4	5	16.4
$T_2 (N_{180}P_{60}K_{40})$	1.56	12.5	5.4	17.9
$T_3 (N_{180}P_{60}K_{60})$	2.18	14	6.9	20.9
$T_4 (N_{180}P_{90}K_{40})$	1.79	13.3	6.2	19.5
$T_5 (N_{180}P_{90}K_{60})$	2.42	15.2	7.6	22.8
$T_6 (N_{120}P_{60}K_{40}FeSO_{4\ 25})$	1.49	12.3	5.3	17.6
$T_7 (N_{180}P_{60}K_{40}FeSO_{4\ 25})$	1.64	13.1	5.9	19
$T_8 (N_{180}P_{60}K_{60}FeSO_{4\ 25})$	2.19	13.5	6.4	19.9
$T_9 (N_{180}P_{90}K_{40}FeSO_{4\ 25})$	2.16	13.2	6.7	19.9
$T_{10} (N_{180}P_{90}K_{60}FeSO_{4\ 25})$	2.73	16.2	8.7	24.9
CD (P = 0.05)	0.8	2.2	N.S.	
SE(m)	0.26	0.74	0.76	
CV (%)	22.8	9.5	20.5	

Table.7 Influence of varying fertility levels in relation to iron application on potassium uptake (kg ha $^{-1}$) at different crop growth stages of aerobic rice

Treatments [Nutrient levels (kg ha^{-1})]	Potassium uptake (kg ha^{-1})			
	Active tillering	Harvest		
		Grain	Straw	Total
$T_1(N_{120}P_{60}K_{40})$	5.3	9.1	39.9	49
$T_2(N_{180}P_{60}K_{40})$	5.9	9.9	44	53.9
$T_3(N_{180}P_{60}K_{60})$	6.6	11	51.5	62.5
$T_4(N_{180}P_{90}K_{40})$	6.1	10.3	47.3	57.6
$T_5(N_{180}P_{90}K_{60})$	7.1	11.7	52.8	64.5
$T_6(N_{120}P_{60}K_{40}FeSO_{4\,25})$	5.5	10.3	44.4	54.7
$T_7(N_{180}P_{60}K_{40}FeSO_{4\,25})$	6.0	10.1	45.5	55.6
$T_8(N_{180}P_{60}K_{60}FeSO_{4\,25})$	6.7	10.8	48.1	58.9
$T_9(N_{180}P_{90}K_{40}FeSO_{4\,25})$	6.1	10.4	49.1	59.5
$T_{10}(N_{180}P_{90}K_{60}FeSO_{4\,25})$	7.3	12	54.7	66.7
CD (P = 0.05)	N.S.	N.S.	7.2	
SE(m)	0.7	0.7	2.4	
CV (%)	19.8	11.8	8.8	

Table.8 Influence of varying fertility levels in relation to iron application on iron uptake (g ha $^{-1}$) at different crop growth stages of aerobic rice

Treatments [Nutrient levels (kg ha^{-1})]	Iron uptake (kg ha^{-1})			
	Active tillering	Harvest		
		Grain	Straw	Total
$T_1(N_{120}P_{60}K_{40})$	8.3	9.5	14.8	24.3
$T_2(N_{180}P_{60}K_{40})$	13.4	10.8	18.2	29
$T_3(N_{180}P_{60}K_{60})$	20	13.4	24.3	37.7
$T_4(N_{180}P_{90}K_{40})$	16.4	12.4	19.9	32.3
$T_5(N_{180}P_{90}K_{60})$	25.4	14.6	25.6	40.2
$T_6(N_{120}P_{60}K_{40}FeSO_{4\,25})$	13.5	10.5	17.8	28.3
$T_7(N_{180}P_{60}K_{40}FeSO_{4\,25})$	15.4	11.3	19.4	30.7
$T_8(N_{180}P_{60}K_{60}FeSO_{4\,25})$	23.6	13.5	22.2	35.7
$T_9(N_{180}P_{90}K_{40}FeSO_{4\,25})$	18.8	12.6	22.2	34.8
$T_{10}(N_{180}P_{90}K_{60}FeSO_{4\,25})$	30.9	15.6	27	42.6
CD (P = 0.05)	N.S.	N.S.	N.S.	
SE(m)	4.5	2.2	4.1	
CV (%)	41.7	30.1	33.2	

Table.9 Economics of varying fertility levels in relation to iron application in aerobic rice

Treatment [Nutrient levels (kg ha^{-1})]	Cost of cultivation (Rs. ha^{-1})	Gross returns (Rs. ha^{-1})	Net returns (Rs. ha^{-1})	B:C ratio
$T_1(N_{120}P_{60} K_{40})$	16982	52337	35355	3.08
$T_2 (N_{180}P_{60}K_{40})$	17716	54763	37047	3.09
$T_3 (N_{180}P_{60}K_{60})$	18247	58349	40102	3.20
$T_4 (N_{180}P_{90}K_{40})$	18691	55800	37109	2.99
$T_5 (N_{180}P_{90}K_{60})$	19222	59888	40666	3.12
$T_6 (N_{120}P_{60} K_{40}FeSO_{4\ 25})$	20982	54608	33626	2.60
$T_7 (N_{180}P_{60}K_{40}FeSO_{4\ 25})$	21716	55598	33882	2.56
$T_8 (N_{180}P_{60}K_{60}FeSO_{4\ 25})$	22247	59234	36987	2.66
$T_9 (N_{180}P_{90}K_{40}FeSO_{4\ 25})$	22691	56268	33577	2.48
$T_{10} (N_{180}P_{90}K_{60}FeSO_{4\ 25})$	23222	61131	37909	2.63

Grain yield

A critical analysis of the data brings out the fact that the varying fertility levels in relation to iron application had failed to claim significant influence on grain yield of aerobic rice. However, the highest grain yield (4960 kg ha^{-1}) was recorded where the maximum amount of the nutrients (180:90:60 kg NPK ha^{-1}) were applied along with 25 kg $FeSO_4$ ha^{-1} (T_{10}). This was closely followed by application of same quantity of fertilizers except $FeSO_4$ (T_5- 4873 kg ha^{-1}). Application of 120:60:40 kg NPK ha^{-1} (T_1) recorded grain yield of 4281 kg ha^{-1} in aerobic rice and with additional [60 kg N ha^{-1} (T_2); 60, 20 kg NK ha^{-1} (T_3); 60, 30 kg NP ha^{-1} (T_4) and 60, 30, 20 kg NPK ha^{-1} (T_5); 60, 30, 20 kg NPK and 25 kg $FeSO_4$ ha^{-1} (T_{10})] enhancement in dosages of nutrients resulted in the yield improvements of 4.29, 11.3, 6.3, 13.8 and 15.9 % respectively over T_1.

Application of $FeSO_4$ @ 25 kg ha^{-1} only improved the grain yield of aerobic rice (T_6 to T_{10}) marginally when compared to their respective nutrient levels (T_1 to T_5). Addition of 25 kg $FeSO_4$ ha^{-1} to 120:60:40 kg NPK ha^{-1} (T_6) recorded an additional grain yield of 118 kg ha^{-1} over no application of $FeSO_4$ (T_1) to the same nutrients.

The efficacy of the fertilizers applied to aerobic rice was reflected in grain yields though they had not reached the level of significance. Increase in fertility levels increased the grain yields of aerobic rice.

The increase in grain yields were mainly due to availability of nutrients in sufficient quantities during critical stages of crop growth which resulted in better growth characters and yield components and finally on yield of aerobic rice. These findings are in accordance with Yogeshwar *et al.,* (1980); Sharma and Prasad (1982); Raju and Rao (1987); Dalal and Dixit (1987); Patel *et al.,* (1997) and Reddy and Kumar (1999)

$FeSO_4$ application to the aerobic rice has failed to claim a significant influence on grain yield. This might be due to insufficient amount of iron in the experimental plots which has resulted into low grain yields. The results are in agreement with the results reported by Singh *et al.,* (1987); Zhang (1991) and Tandon (1996).

N uptake by crop

The data on N uptake at active tillering and at harvest by grain and straw is presented in Table 1.

The N uptake was increased from active tillering to harvest in all treatments (T_1-T_{10}). At both the stages of aerobic rice, highest N uptake of (11.6, 52.2 and 39.1 kg ha^{-1} at active tillering and at harvest (grain and straw) respectively) were recorded with the application of 180: 90: 60:25 kg N, P, K and Fe ha^{-1} (T_{10}). However, there was no significant difference in tiller number with varying fertility levels in relation to iron application.

Lowest N uptake of (8.2, 31.3 and 23 kg ha^{-1} at active tillering and harvest (grain and straw) stages respectively) were recorded with 120:60:40 kg NPK ha^{-1} (T_1). Addition of 25 kg $FeSO_4$ ha^{-1} (T_6) resulted in the increase of N uptake by 7.3 and 18.4 % over the T_1 at both (active tillering and harvest) stages of aerobic rice. Additional dose of 60 kg N ha^{-1} (T_2) to T_1 resulted in improvement of N uptake by (1.6, 10.2 and 4 kg ha^{-1}) at active tillering and harvest (grain and straw) stages of aerobic rice respectively. Inclusion of 25 kg $FeSO_4$ ha^{-1} (T_7) further enhanced N uptake by (0.5, 0.9 and 1.9 kg ha^{-1} at actine tillering and harvest stages) over T_2.

The efficacy of the fertilizers applied to aerobic rice was reflected in N uptake though they had not reached the level of significance. Increase in N levels increased the N uptake of aerobic rice. The increase in N uptake was mainly due to availability of N in sufficient quantities during critical stages of crop growth which resulted in better uptake of this nutrient and better accumulation of it in the plant tissues of aerobic rice. The enhanced fertility levels favoured the crop growth and finally resulted in higher grain yield and more uptake of nitrogen. These findings are in accordance with the reports of Sreedevi and Thangamuthu (1991), Krishnakumar and Subramanian (1992), Thakur (1993), Pandey *et al.*, (1993), Pradeep *et al.*, (1994), Laxminarayana (2003) and Venugopal (2005).

P uptake by crop

The data on P uptake at active tillering and at harvest by grain and straw is presented in Table 2.

The P uptake was increased from active tillering to harvest in all treatments (T_1-T_{10}). At both the stages of aerobic rice, highest P uptake of (2.73, 16.2 and 8.7 kg ha^{-1} at active tillering and at harvest (grain and straw) respectively) were recorded with the application of 180:90:60:25 kg NPK and $FeSO_4$ ha^{-1} (T_{10}). The influence of varying fertility levels in relation to iron application on P uptake was more pronounced at active tillering and harvest (grain) stages of aerobic rice as there was significant difference between the treatments.

At active tillering the influence of varying fertility levels in relation to iron application on P uptake was more pronounced. The application of 180:90:60:25 kg NPK and $FeSO_4$ ha^{-1} (T_{10}) had significant influence on P uptake (2.73 kg ha^{-1}) over 120:60:40 kg NPK ha^{-1} (T_1-1.36 kg ha^{-1}) and it was on par with 180:90:60 kg NPK ha^{-1} (T_5-2.42 kg ha^{-1}). The next two best treatments were T_8 (2.19 kg ha^{-1}) and T_3 (2.18 kg ha^{-1}) where 180:60:60:25 kg NPK and $FeSO_4$ ha^{-1} and 180:60:60:0 kg NPK and $FeSO_4$ ha^{-1} were applied respectively.

At harvest (grain) the influence of varying fertility levels in relation to iron application on P uptake was more pronounced. The application of 180: 90: 60:25 kg NPK and $FeSO_4$ ha^{-1} (T_{10}) had significant influence on P uptake (16.2 kg ha^{-1}) over 120:60:40 kg NPK ha^{-1} (T_1-11.2 kg ha^{-1}) and it was on par with 180:90:60 kg NPK ha^{-1} (T_5-15.2 kg ha^{-1}). Application of 60, 30 kg NP to the T_1 (T_4) increased the P uptake by 16.7 %. The uptake of P by crop was not significantly affected by varying fertility levels at harvest (straw). The results indicated that the P uptake was lower in straw than the grain. However, the highest P uptake in straw was recorded from the application of 180:90:60:25 kg NPK and $FeSO_4$ ha^{-1} (T_{10}-8.7 kg ha^{-1}).

The efficacy of the fertilizers applied to aerobic rice was reflected in P uptake. Increase in P levels increased the P uptake of aerobic rice. The increase in P uptake was mainly due to availability of P in sufficient quantities during critical stages of crop growth which resulted in better uptake of this nutrient and better accumulation of it in the plant tissues of aerobic rice. The enhanced fertility levels favoured the crop growth and finally resulted in higher grain yield and more uptake of phosphorus. These findings are in accordance with the reports of Pandey *et al.,* (1995) and Paliwal *et al.,* (1997).

K uptake by crop

The data on K uptake by active tillering and at harvest by grain and straw is presented in Table 3. The K uptake was increased from active tillering to harvest in all treatments (T_1-T_{10}). At both the stages of aerobic rice, highest K uptake of (7.3, 12 and 52.8 kg ha^{-1} at active tillering and at harvest (grain and straw) respectively) were recorded with the application of 180: 90: 60:25 kg NPK and $FeSO_4$ ha^{-1} (T_{10}). The influence of varying fertility levels in relation to iron application on K uptake was more pronounced at harvest (straw) stage of aerobic rice than at active tillering and harvest (grain) as there was no significant difference between the treatments at these stages.

At active tillering and harvest (grain) stages the influence of varying fertility levels in relation to iron application on K uptake was not significant. However, the application of 180:90:60:25 kg NPK and $FeSO_4$ ha^{-1} (T_{10}) has recorded highest K uptake of (7.3 and 12 kg ha^{-1} at active tillering and harvest (grain) stages respectively) over 120:60:40 kg NPK ha^{-1} (T_1-5.3 and 9.1 kg ha^{-1}) followed by application of 180:90:60 kg NPK ha^{-1} (T_5-7.1 and 11.7 kg ha^{-1}). The next two best treatments were T_8 (6.7and 10.8 kg ha^{-1}) and T_3 (6.6 and 11 kg ha^{-1}) where 180:60:60:25 kg NPK and $FeSO_4$ ha^{-1} and 180:60:60:0 kg NPK and $FeSO_4$ ha^{-1} were applied respectively.

At harvest (straw) the influence of varying fertility levels in relation to iron application on K uptake was more pronounced. The application of 180: 90: 60:25 kg NPK and $FeSO_4$ ha^{-1} (T_{10}) had significant influence on K uptake (54.7 kg ha^{-1}) over 120:60:40 kg NPK ha^{-1} (T_1-39.9 kg ha^{-1}) and it was on par with 180:90:60 kg NPK ha^{-1} (T_5-52.8 kg ha^{-1}). Application of 60, 20 kg NK to T_1 (T_3) increased the K uptake by 20.5% and further addition of 25 kg $FeSO_4$ to T_3 (T_8) increased the K uptake by 7.1 %.

The efficacy of the fertilizers applied to aerobic rice was reflected in K uptake. Increase in K levels increased the K uptake of aerobic rice. The increase in K uptake was mainly due to availability of K in sufficient quantities during critical stages of crop growth which resulted in better uptake of this nutrient and better accumulation of it in the plant tissues of aerobic rice. The enhanced fertility levels favoured the crop growth and finally resulted in higher grain yield and more uptake of phosphorus. These findings are in accordance with the reports of Selvakumari *et al.,* (1983), Singha and Das (1991), Prasad, (1993), Sudipta *et al.,* (1994), Pandey *et al.,* (1993), Sorour *et al.,* (1998) and Singh *et al.,* (1999).

Fe uptake by crop

The data on Fe uptake by active tillering and at harvest by grain and straw is presented in Table 4.

The Fe uptake was increased from active tillering to harvest in all treatments (T_1-T_{10}). At both the stages of aerobic rice, highest Fe uptake of (30.9, 15.6 and 27 g ha^{-1} at active tillering and at harvest (grain and straw) respectively) were recorded with the application of 180: 90: 60:25 kg N, P, K and Fe ha^{-1} (T_{10}). However, there was no significant difference in Fe uptake with varying fertility levels in relation to iron application.

Lowest Fe uptake of (8.3, 9.5 and 14.8 kg ha^{-1} at active tillering and harvest (grain and straw) stages respectively) were recorded with 120:60:40 kg NPK ha^{-1} (T_1). Application of $FeSO_4$ @ 25 kg ha^{-1} only improved the Fe uptake of aerobic rice (T_6 to T_{10}) marginally when compared to their respective nutrient levels (T_1 to T_5). Addition of 25 kg $FeSO_4$ ha^{-1} (T_6) resulted in the increase of Fe uptake by 62.6 and 16.5 % over the T_1 at both (active tillering and harvest) stages of aerobic rice.

It is obvious because supply of 25 kg $FeSO_4$ ha^{-1} through soil application might have increased the available soil Fe which facilitated the aerobic rice to utilize as much as it could. Similar findings have also been reported by Gupta and Gupta (1984) and Kulandaivel (2002).

The uptake of Fe by crop was not significantly affected by enhanced nutrient levels at active tillering and at harvest (both by grain and straw). The results indicated that the application of 180: 90: 60:25 kg NPK and $FeSO_4$ ha^{-1} (T_{10}) recorded maximum Fe uptake of 30.9, 15.6 and 27 kg ha^{-1}at active tillering and at harvest (grain and straw) respectively, followed by application of 180:90:60 kg NPK ha^{-1} (T_5-25.4, 14.6 and 25.6 g m^{-2} at these stages). The next two best treatments were T_8 (23.6, 13.5 and 22.2 g m^{-2} at active tillering and at harvest (grain and straw) stages respectively) and T_3(20, 13.4 and 24.3 g m^{-2} during the same stages) where 180:60:60:25 and 180:60:60:0 kg NPK and $FeSO_4$ were applied. Among all treatments T_1–(120:60:40 kg NPK ha^{-1}) recorded minimum Fe uptake of 8.3, 9.5 and 14.8 kg ha^{-1} at active tillering and at harvest (grain and straw) respectively, followed by the application of 120:60:40:25 kg NPK and $FeSO_4$ (T_6- 13.5, 10.5 and 17.8). The enhanced fertility levels favoured the crop growth and finally resulted in higher grain yield and more uptake of Iron.

Economics

The data on economics is presented in Table 4.

A critical analysis of the data brings out the fact that the varying fertility levels in relation to iron application have a considerable effect on the economics of aerobic rice (Tables 5 and 6).

The cost of cultivation was increased with increase in nutrient levels. The cost of cultivation was highest (Rs 23,222) with the application of 180:90:60:25 kg NPK and $FeSO_4$ ha^{-1} (T_{10}) followed by the application of 180:90:40:25 kg NPK and $FeSO_4$ ha^{-1} (T_9-Rs 22,691). The cost of cultivation was lowest with the application of 120:60:40 kg NPK ha^{-1} (T_1-Rs.16,982).

The highest gross returns of Rs.61131 were obtained from the application of 180: 90: 60:25 kg NPK and $FeSO_4$ ha^{-1} (T_{10}) followed by the application of 180:90:60 kg NPK ha^{-1} (T_5-Rs.59888). The next two best treatments were T_8 (Rs. 59,234) and T_3 (Rs. 58,349) where 180:90:60:25 and 180:90:60:0 kg NPK and $FeSO_4$ ha^{-1} were applied respectively. Among all treatments application of 120:60:40 kg NPK ha^{-1} (T_1) recorded lowest gross returns of Rs.52,337 followed by the application of 120:60:40:25 kg NPK and

$FeSO_4$ ha^{-1} (T_6- Rs. 54,608). The highest net returns of Rs. 40,666 were obtained from the application of 180:90:60 kg NPK ha^{-1} (T_5) followed by the application of 180:60:60 kg NPK ha^{-1} (T_3-Rs. 40,102). Application of 180:90:60:25 kg NPK and $FeSO_4$ ha^{-1} (T_{10}) recorded the next highest net returns of Rs. 37,909. Application of 180:90:40:25 kg NPK and $FeSO_4$ ha^{-1} (T_9) recorded the lowest net returns of Rs. 33,577 (Tables 7 and 8).

The benefit cost ratio was highest (3.20) with the application of 180:60:60 kg NPK ha^{-1} (T_3) followed by the application of (T_5-3.12) and (T_2-3.09) where 180:90:60 and 180:60:40 kg NPK ha^{-1} were applied respectively. Application of 120:60:40 kg NPK ha^{-1} (T_1) also recorded a benefit cost ratio of 3.08 (Table 9). Though the gross returns were higher with the treatments containing $FeSO_4$ (T_6 to T_{10}), these treatments had recorded lowest B: C ratios because of high cultivation costs due to application of $FeSO_4$. These findings are in accordance with the findings of Pujari *et al.*, (1989), Wahab and Jayaprakash (1995), Srinivasa *et al.*, (1999) and Ikramullah and Mohita (2004).

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