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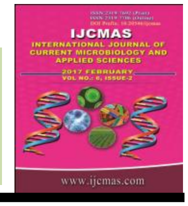

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Effect of Zn, Fe and FYM on Interaction between Zn and Fe on Nutrient Content, Uptake and Yield of Different Varieties of Rice (*Oryza sativa* L.)

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A B S T R A C T

The field experiment were carried out using split plot design with three replication during *kharif* 2006-07 and 2007-08 to investigate the effect of varieties and Zn, Fe and FYM on nutrient content, uptake and yield of rice (*Oryza sativa*). The experiment consisted of two level of varieties (V_1:NDR-359, V_2:HUBR-2-1) and two fertilizer source (F_1:RFD_{100}, F_2:RFD_{75}+FYM_{25}) in main plot and nine level of micronutrient combination (M_0:0, M_1:Zn-$EDTA_1$, M_2:Zn-EDTA0.5, M_3:Fe-$EDTA_1$, M_4:Fe-$EDTA_{0.5}$, M_5:Zn-$EDTA_1$+Fe-$EDTA_1$, M_6:Zn-$EDTA_{0.5}$+Fe-$EDTA_{0.5}$, M_7:Zn-$EDTA_1$+Fe-$EDTA_{0.5}$, M_8:Fe-$EDTA_1$+Zn-$EDTA_{0.5}$) allotted in sub-plot. Among the different testing varieties, V1:(NDR-359) recorded highest yield and NPK content in grain, while significant content of Zn and Fe recorded in HUBR-2-1. Among different fertilizer sources, nutrient supplied through RFD_{75}+FYM_{25} was record improvement in Zn and Fe content and uptake in grain and straw of rice. The significantly high content of Zn and their uptake in grain recorded under supply through the micronutrient level M_7 (Zn:$EDTA_1$+Fe-$EDTA_{0.5}$). Whereas foliar application of M_4:Fe-$EDTA_{0.5}$ at 15 DAT and 50% panicle initiation significantly increased Fe content and uptake in grain and straw. Interaction effect of HUBR-2-1 and RFD_{75}+FYM_{25} with single application of Zn-$EDTA_1$ through soil recorded significant zinc content in grain. It can be concluded that the NDR-359 was found the high yielding rice cultivar responding to RFD_{75}+FYM_{25} along with supply of micronutrient as Zn-$EDTA_1$+Fe-$EDTA_{0.5}$ in alluvial soil of Uttar Pradesh.

Introduction

Rice (*Oryza sativa* L.) cultivated in 114 of the 193 countries of the world *and* considers one of the most important cereal crops in India. The amount needed from it is greater than that locally produced. Therefore, increasing its productivity as well as cultivated area is highly recommended. Plants require specific amount of certain nutrients in specific form at appropriate time, for their growth and development. In India rice productivity is still very low. During the last few decades, though country has witnessed some increase in productivity but to meet our expected demand of 140 MT by the end of 2020, it warrants further intensified efforts to increase the production and productivity of the crops. However, imbalanced use of nutrients, giving much emphasis to supplement the soil with the micronutrients, may lead to widespread deficiencies of other nutrients, particularly micronutrients under intensive cultivation. The deficiency of micronutrients has become major constraints to productivity, stability, sustainability and fertility of soil. Large variation in the content of iron and zinc in grains of rice varieties, have been observed.

The aromatic cultivars have consistently higher concentration of iron and zinc in grain than the non-aromatic types (Graham *et al.*, 1997). In general iron density in rice varied from 7-24 mg kg^{-1} and that of zinc between 16-58 mg kg^{-1}. However, nearly in all the widely grown varieties content of Zn and Fe remained 12 and 22 mg kg^{-1} for iron and zinc respectively (Senadhira and Graham, 1999). Red rice genotypes showed higher iron and zinc concentration as compared to white rice. The role of N nutrition in biofortification of grain with Zn and Fe is a highly relevant issue in terms of designing new fertilizer programs for increasing Zn and Fe content in grain. Improving N nutrition of plants may contribute to grain Zn and Fe concentrations by affecting the levels of Zn-or Fe-chelating nitrogenous compounds required for transport of Zn and Fe within plants and/or the abundance of Zn and Fe transporters needed for root uptake and phloem loading of Zn and Fe. Finally, the results indicate that nitrogen management represents an effective agronomic tool to contribute to grain Zn and Fe concentrations (Ismail Cakmak, 2010).

Zinc-iron interaction has been reported in many crops. Lee *et al.*, (1969) observed that completion sites exists between Fe^{+3} and Zn^{+2} while Brar and Sekhon (1976) reported that inhibitory effect of Fe on Zn absorption was non-competitive and translocation of Zn decreased with increased Fe levels. However, postulated that Zn may be bound in the soil through Fe/Al phosphate bridges, which are not readily available to plants. Few of such studies, refer to rice which, being physiologically different, responds differently to nutrient interactions. Under reduced conditions, increased availability of Fe and deficiency of Zn have been reported due to decreased absorption of Zn by plants (Rashid *et al.*, 1976). Such soils are widely distributed in the states of Uttar Pradesh of these soils occasionally show toxic concentrations of available Fe and marginal concentrations of available Zn for rice and under such a situation liming is generally recommended to raise rice crop successfully. However, the effects of high content of Fe and application of lime on Zn availability in such soils are not fully known, particularly for upland conditions. Therefore, an attempt has been made in this paper to study interaction effects of rice for Zn and Fe on grain and straw yields and on Zn and Fe content in upland rice.

Under such conditions, soil application of micronutrients can be very expensive. The macro and micro-nutrients added to the soil, their availability will be affected by the soil environmental factors. Foliar feeding technique, as a particular way to supply these nutrients could avoid these factors and results in rapid absorption. Foliar feeding of micronutrients generally is more effective and less costly. It is well known that soil application of NPK fertilizers may lead to some losses of these fertilizers. The reported experiment was undertaken to study the effect of soil and foliar application of micronutrients on interaction between Zn and Fe content and uptake of rice crop to improve the nutritional status of plants.

Materials and Methods

The field experiments were conducted in SPD design during *kharif* 2006-07 and 2007-08, at the Department of Agronomy, Agricultural Research Farm, Institute of Agricultural Science, Banaras Hindu University Varanasi. The experiment consisted of two levels of varieties (V_1:NDR-359, V_2:HUBR-2-1), two level of fertilizer source (F_1:RFD_{100},

F_2:RFD_{75}+FYM_{25}) arranged in main plot and nine level of micronutrient supply through soil and foliar application viz. M_0:0 (control), M_1:Zn-$EDTA_1$ (Zn as soil application through Zn-EDTA at 1.00 kg ha^{-1}), M_2:Zn-$EDTA_{0.5}$ (Zn as foliar application through Zn-EDTA at 0.5 kg ha^{-1}), M_3:Fe-EDTA1 (Fe as soil application through Fe-EDTA at 1.00 kg ha^{-1}), M_4:Fe-$EDTA_{0.5}$ (Fe as foliar application through Fe-EDTA at 0.5 kg ha^{-1}), M_5:Zn-$EDTA_1$+Fe-$EDTA_1$ (Zn as soil application through Zn-EDTA at 1.00 kg ha^{-1} + Fe as soil application through Fe-EDTA at 1.00 kg ha^{-1}), M_6:Zn-$EDTA_{0.5}$+Fe-$EDTA_{0.5}$ (Zn as foliar application through Zn-EDTA at 0.5 kg ha^{-1} followed by Fe as foliar application through Fe-EDTA at 0.5 kg ha^{-1}), M_7:Zn-EDTA+Fe-$EDTA_{0.5}$ (Zn as soil application through Zn-EDTA at 1.00 kg ha^{-1} followed by Fe as foliar application through Fe-EDTAat 0.5 kg ha^{-1}), M_8:Fe-$EDTA_1$+Zn-$EDTA_{0.5}$ (Fe as soil application through Fe-EDTA at 1.00 kg ha^{-1} followed by Zn as foliar application through Zn-EDTA at 0.5 kg ha^{-1}) allotted in sub-plot design. There were 36 treatment combinations, each replicated for three times. One hundred eight plots were prepared and planted test crop on a spacing of 20 x 10 cm with two seedling hill-1.

For which the nursery beds was prepared on leveled and slightly raised ground (5 cm high) having a small plot of 22 m2 for growing rice seedling. The healthy seed of test cultivar NDR-359 and HUBR-2-1 (Malviya Basmati-1) were sown separately by broad casting method at 25-30 kg ha^{-1}. As source of nutrients, 75% of recommended dose of 120 kg Nitrogen 60 kg P_2O_5 and 60 Kg K_2O from the source of urea, diammonium phosphate and muriate of potash respectively, and 50 Qtl FYM (25% N though organic manure. While Zn-EDTA and Fe-EDTA at 1 kg ha^{-1} were incorporated thoroughly mixed into the soil whereas 0.5 kg ha^{-1} Zn-EDTA and Fe-EDTA were applied as foliar application as per treatment. Half of N, total of quantity of phosphorus, potassium, FYM and Zn-EDTA, Fe-EDTA (as soil application) were applied as basal at the time of transplanting and the remaining half was top dressed in two equal amounts at maximum tillering and at flowering stages. The foliar application of Zn-EDTA and Fe-EDTA each at 0.5 kg ha^{-1} were applied in two splits at 15 days after transplanting and at 50% at panicle initiation stage.

Soil of experimental field was alluvium, neutral in pH (7.3), low in available nitrogen (190.56 kg ha^{-1}), medium in available phosphorus (20.58 kg ha^{-1}) and exchangeable K (223.87 kg ha^{-1}). While content of Zn (0.89 kg ha^{-1}), and Fe (20.67 kg ha^{-1}) were deficient. Observation on nutrient content and uptake (Zn and Fe) were done at 90 days after transplanting. Estimation of N, P, K, Zn and Fe, respectively were done by the methods given by Zn and Fe (L'vov, 2005).

Results and Discussion

Data revealed that variety NDR-359 produced significantly higher grain yield and straw yield. Slight varietal differences were observed in N, P and K content of grain. Variety NDR-359 recorded higher N and P content than HUBR 2-1, but it recorded significantly higher K content in grain. In non-aromatic rice varieties, about 73% of N was translocated to grain and rest remained in the straw while in aromatic cultivars translocation of N to grain was only 47% (De *et al.*, 2002). Application of N, P, K with micronutrients Zn and Fe are known to increase the uptake or content of N, P, K, Zn and Fe (Ganghaih *et al.*, 1999). However, micronutrient (Zn and Fe) content of variety HUBR 2-1 proved significantly superior to NDR-359 (Table 1 and Fig. 1). Variety, HUBR 2-1 recorded maximum zinc and iron in grains because it is aromatic in nature which supported the fact that zinc and iron concentrations remain higher in grains due to aromatic nature of the variety. These findings are strongly supported by Babu *et al*., 2005).

It is well known that the application of N,P, K, micronutrients along with FYM in proper combinations might increase and synthesize, various volatile aromatic compound found in rice, responsible for its aroma. Among which 2-Acetyle-1-Pyrroline (2-AP) is the most significant. Considerable improvement in grain quality of aromatic rice was recorded under combined use of organic and inorganic fertilizers as compared to 100% RFD through inorganic fertilizers (Sahu *et al.,* 2007).

Application of 75% RFD through inorganic + 25% N through FYM recorded significantly higher grain yield of 5.40 t ha^{-1} over 100% RFD through inorganic (4.97 t ha^{-1}) (Table 2). Application of 75% RFD+25% N through FYM sources of fertilizers also produced relatively higher straw yield (7.54 t ha^{-1}) as compared to 100% recommended fertilizer dose sources of fertilizers at crop harvest (Table 2). It may be due to slow release of nutrients for a longer period after decomposition of FYM, which favored better plant growth and improved the yield components of rice. Improvement in all above yield attributes and yield has also been reported by Gupta *et al*., (2009). Application of 75% RFD through inorganic sources + 25% N through FYM proved significantly superior in increasing P, K, Zn and Fe content in grain over 100% RFD through inorganics whereas N content remained statistically at par with 100% recommended fertilizer dose (Table 3). The present results are in agreement with the findings of Srivastava *et al*., (2008) and Chandrapala *et al.,* (2010). Organic sources also improved the content of Fe by supplying chelating agents, which helps in maintaining the solubility of micro-nutrients including Fe. The response of organic matter showed profound influence on the solubility of Fe in waterlogged soil by providing resistance to Fe chlorosis (Singh *et al.,* 2010 and Das *et al.,* 2010). It is thus apparent that application and maintenance of organic matter in the soil translates adequate long term availability of Fe. Improving N nutrition of plants may contribute to increase Zn and Fe concentration in grain by affecting the levels of Zn or Fe-chelating nitrogenous compound, required for transport of Zn and Fe within plants, which increased Zn and Fe transporters needed for its uptake by root and phloem loading. It indicates that nitrogen management is an effective agronomic tool to enhance grain Zn and Fe concentrations. The present results are in agreement with the findings of Cakmak (2010).

Application of Zn and Fe in combination with FYM and recommended dose of N, P, K significantly influenced the yield (Table 2; Fig. 2). Similarly combined application of Zn-EDTA at 1.00 Kg ha^{-1} followed by Fe-EDTAat 0.5 Kg ha^{-1} applied as foliar recorded significantly higher grain and straw yield over the single or combined application of Zn-EDTA and Fe-EDTA. Participation of Zn in biosynthesis of indole acetic acid (IAA) and its role in initiation of primordial reproductive parts and partitioning of photosynthates towards them are responsible for increased yield (Takaki and Kushizaki, 1970). The favorable influence of applied Zn on yield may be due to its catalytic or stimulatory effect on most of the physiological and metabolic process of plants (Mandal *et al.,* 2009). Iron as a constituent of the electron transport enzymes, like cytochromes and ferredoxin are actively involved in photosynthesis and mitochondrial respiration. It is also a constituent of the enzymes catalase and peroxidase, which catalyze the breakdown of H_2O_2 (peroxide released during photorespiration) into H_2O and O_2, preventing H_2O_2 toxicity. Iron along with molybdenum, is an element of the nitrite and nitrate reductase enzymes. Thus, iron helps in the utilization of nitrogen. All these physiological processes proved instrumental in increasing yield by application of iron. Incorporation of micronutrient (Zn-EDTA and Fe-EDTA) proved significantly superior to control in increasing N, P, K content in grains of rice (Table 3). Application of Zn-EDTA at 1 Kg ha^{-1} in soil followed by Fe-EDTA at 0.5 Kg ha^{-1} as foliar spray in two splits recorded maximum N, P and K content in grain of rice and proved superior over other treatments whereas, it remained at par with Zn-EDTA at 0.5 Kg ha^{-1} followed by at 0.5 Kg ha^{-1} Fe-EDTA as foliar application. Rest of the treatment combinations remained almost on par. Increase in nutrient uptake with the increased fertility levels could be attributed to better availability of nutrients and their transport to the plant from the soil. Incorporation of Zn-EDTA at 1.00 Kg ha^{-1} as soil application showed significant superiority over all treatments in increasing Zn content in grain. The zinc and iron content in rice grains were recorded maximum with their separate application and minimum under control, whereas combined and sequential applications of Zn-EDTA and Fe-EDTA slightly decreased Zn and Fe concentrations in grains as compared to their separate applications reported by Verma and Tripathi (1983). Jana *et al.*, (2010) also observed that soil application of Zn-EDTA led to higher content and uptake of N, P, K and Zn in grain and straw of rice. Alvarez *et al.*, (2001) reported that when Zn was added as Zn-EDTA, the amounts of the most labile fractions (water-soluble plus exchangeable and organically complexed Zn) increased throughout the entire soil profile column, which enhanced the root-cell membrane function. Activity of carbonic anhydrase (CA) is closely related to Zn content in C3 plants (Pearson *et al.*, 1995). Under extreme Zn deficiency, carbonic anhydrase activity remained almost absent. The labeled Zn rapidly accumulated in the roots of cereal crops upon immersion into the isotope solution. Root uptake and root-to-shoot transport of zinc and particularly internal utilization of zinc are equally important mechanism involved in the expression of zinc efficiency in cereal crops varieties. Since flag leaves are one of the sources of remobilized metals for developing seeds, the identification of the molecular players that might contribute to the process of metal transport from flag leaves to the seeds may be useful for biofortification purposes in relation to Zn and Fe (Sperotto *et al.*, 2010). Foliar application of Fe in two splits produced highest Fe content in grain and proved significantly superior to all other combinations. Concurrently, incorporation of Zn-EDTA at 1 Kg ha^{-1} in soil and foliar application of Fe- EDTA at 0.5 Kg ha^{-1} showed next best affectivity in increasing Fe content over other treatments. Uptake of Zn or Fe, however, was reduced in combined soil as well as foliar applications of Zn and Fe which remarkably increased when applied to soil individually. This indicated antagonism between these two micronutrients when applied in combination. Further, Fe content improved due to application of N through organic sources which might be due to maintenance of better soil aeration and the solubility of micronutrients. Based on overall findings, it may be concluded that Zn-EDTA as soil and Fe-EDTA as foliar applied in rice contributed marked increase in yield associated with grain micronutrient content (Zn and Fe) along with their uptake as compared to other treatments and finally significantly balancing in ionic composition.

Interaction effect between variety, fertilizer and micronutrient content in grain

On Zn content

The significant interaction between variety and Zn content (V×M) was recorded in grain of rice (Table 1).

Table.1 Effect of Zn, Fe and FYM on grain yield and straw yield of rice

Treatments	**Grain yield (q ha^{-1})**			**Straw yield (qha^{-1})**		
	2006	**2007**	**Pooled**	**2006**	**2007**	**Pooled**
Varieties						
V_1: NDR – 359	54.50	55.61	55.05	73.78	76.25	75.01
V_2: HUBR 2-1	47.22	50.27	48.75	70.93	73.76	72.34
SEm±	1.22	0.92	1.06	0.69	0.71	0.70
CD (P = 0.05)	4.23	3.18	3.66	2.39	2.47	2.42
Fertilizers						
F_1: %RFD 100	49.37	50.13	49.75	70.58	73.33	71.96
F_2: RFD 75 + FYM25	52.35	55.76	54.06	74.13	76.69	75.41
SEm±	1.22	0.92	1.06	0.69	0.71	0.70
CD (P = 0.05)	NS	3.18	3.66	2.39	2.47	2.42
Micro-nutrient (Zn and Fe)						
M_0: Control	42.89	44.13	43.49	64.72	65.14	65.83
M_1: Zn-EDTA at 1.00 kg ha^{-1} (S)	52.20	54.33	53.25	72.88	76.41	74.65
M_2: Zn-EDTA at 0.5 kg ha^{-1} (F)	50.27	52.84	51.60	70.88	75.34	73.11
M_3: Fe-EDTA at 1.00 kg ha^{-1} (S)	49.36	52.07	50.71	70.55	74.01	72.28
M_4: Fe-EDTA at 0.5 kg ha^{-1} (F)	51.81	53.62	52.72	72.73	76.05	74.39
M_5: Zn-EDTA at 1.00 kg ha^{-1} (S) + Fe-EDTA at 1.00kg (S) ha^{-1}	51.89	53.80	52.85	73.61	76.23	74.92
M_6: Zn-EDTA at 0.5 kg ha^{-1} (F) fb Fe-EDTA at 0.5 kg ha^{-1} (F)	52.39	54.57	53.48	74.64	76.51	75.58
M_7: Zn-EDTA 1.00 kg ha^{-1} (S) fb Fe-EDTA at 0.5 kg ha^{-1} (F)	55.26	57.28	56.27	77.57	79.46	78.52
M_8: Fe-EDTA at 1.00 kg ha^{-1}(S) fb Zn-EDTA at0.5 kg ha^{-1} (F)	51.68	53.84	52.76	73.60	75.93	74.77
SEm±	0.89	0.79	0.83	0.64	0.67	0.65
CD (P = 0.05)	2.52	2.24	2.35	1.80	1.90	1.84

*RFD-Recommended Fertilizers Dose, S-Soil application, F-foliar application, fb-Followed by, NS-Non-significant

Table.2a Interaction effect between variety and micronutrient (Zn and Fe) on zinc content (ppm) by grain of rice during 2006 and 2007

Zn and Fe Application (V x M)	2006		2007	
	V_1 (NDR-359)	V_2 (HUBR 2-1)	V_1 (NDR-359)	V_2 (HUBR 2-1)
M_0: Control	142.17	149.66	147.58	154.06
M_1: Zn-EDTA at 1.00 kg ha^{-1} (S)	158.65	186.11	169.70	191.85
M_2: Zn-EDTA at 0.5 kg ha^{-1} (F)	157.10	178.19	162.75	184.35
M_3: Fe-EDTA at 1.00 kg ha^{-1} (S)	142.64	168.77	147.94	174.71
M_4: Fe-EDTA at 0.5 kg ha^{-1} (F)	150.63	167.75	163.38	164.42
M_5: Zn-EDTA at 1.00 kg ha^{-1} (S) + Fe-EDTA at 1.00kg (S) ha^{-1}	152.14	171.76	171.87	181.49
M_6: Zn-EDTA at 0.5 kg ha^{-1} (F) fb Fe-EDTA at 0.5 kg ha^{-1} (F)	155.73	170.77	163.33	172.79
M_7: Zn-EDTA at 1.00 kg ha^{-1} (S) fb Fe-EDTA at 0.5 kg ha^{-1} (F)	157.22	174.21	162.27	178.28
M_8: Fe-EDTA at 1.00 kg ha^{-1} (S) fb Zn-EDTA at 0.5 kg ha^{-1} (F)	144.95	154.15	150.98	172.38
SEm±	SEm±	CD (P = 0.05)	SEm±	CD (P = 0.05)
M at same level of V	1.76	4.98	1.85	5.22
V at same or different level of M	2.18	6.75	2.28	7.05

Table.2b Interaction effect between fertilizer and micronutrient on zinc content of rice grain (ppm) 2007

Zn and Fe Application (F x M)	F_1	F_2
M_0: Control	143.02	158.63
M_1: Zn-EDTA at 1.00 kg ha^{-1} (S)	174.78	184.77
M_2: Zn-EDTA at 0.5 kg ha^{-1} (F)	168.70	175.40
M_3: Fe-EDTA at 1.00 kg ha^{-1} (S)	153.49	169.16
M_4: Fe-EDTA at 0.5 kg ha^{-1} (F)	159.47	169.38
M_5: Zn-EDTA at 1.00 kg ha^{-1} (S) + Fe-EDTA at 1.00kg (S) ha^{-1}	170.46	178.56
M_6: Zn-EDTA at 0.5 kg ha^{-1} (F) fb Fe-EDTA at 0.5 kg ha^{-1} (F)	161.60	177.03
M_7: Zn-EDTA at 1.00 kg ha^{-1} (S) fb Fe-EDTA at 0.5 kg ha^{-1} (F)	164.74	182.31
M_8: Fe-EDTA at 1.00 kg ha^{-1} (S) fb Zn-EDTA at 0.5 kg ha^{-1} (F)	157.21	168.06
M at same level of F	1.85	5.23
F at same or different micronutrient (M)	2.28	7.05

Table.2c Interaction between variety, fertilizer and micronutrient (Zn and Fe) on Zn content (ppm) by rice grain during 2006

Zn and Fe Application (V×F×M)	V_1F_1	V_1F_2	V_2F_1	V_2F_2
M_0: Control	135.630	148.710	141.490	157.830
M_1: Zn-EDTA at 1.00 kg ha^{-1} (S)	153.540	163.760	180.370	191.850
M_2: Zn-EDTA at 0.5 kg ha^{-1} (F)	151.350	162.840	170.840	185.530
M_3: Fe-EDTA at 1.00 kg ha^{-1} (S)	139.620	145.660	155.960	181.570
M_4: Fe-EDTA at 0.5 kg ha^{-1} (F)	136.420	164.830	161.680	173.820
M_5: Zn-EDTA at 1.00 kg ha^{-1} (S) + Fe-EDTA at 1.00kg (S) ha^{-1}	145.580	158.690	168.330	175.180
M_6: Zn-EDTA at 0.5 kg ha^{-1} (F) fb Fe-EDTA at 0.5 kg ha^{-1} (F)	147.890	163.560	168.700	172.840
M_7: Zn-EDTA at 1.00 kg ha^{-1} (S) fb Fe-EDTA at 0.5 kg ha^{-1} (F)	145.780	168.650	169.720	178.690
M_8: Fe-EDTA at 1.00 kg ha^{-1} (S) fb Zn-EDTA at 0.5 kg ha^{-1} (F)	137.990	151.910	145.730	162.570
M at same level of V F	2.49	7.04		
V F at same or different level of M	3.09	9.54		

Table.3a Interaction effect between variety and micronutrient on Fe content (ppm) in grain of rice during 2006 and 2007

Zn and Fe Application (V × M)	2006		2007	
	V_1 (NDR-359)	**V_2 (HUBR 2-1)**	**V_1 (NDR-359)**	**V_2 (HUBR 2-1)**
M_0: Control	35.74	39.06	39.00	42.55
M_1: Zn-EDTA at 1.00 kg ha^{-1} (S)	40.85	45.64	43.50	47.41
M_2: Zn-EDTA at 0.5 kg ha^{-1} (F)	56.27	55.10	63.21	57.78
M_3: Fe-EDTA at 1.00 kg ha^{-1} (S)	42.53	49.74	48.35	51.46
M_4: Fe-EDTA at 0.5 kg ha^{-1} (F)	66.25	85.68	73.34	95.31
M_5: Zn-EDTA at 1.00 kg ha^{-1} (S) + Fe-EDTA at 1.00kg (S) ha^{-1}	53.80	59.24	59.55	60.97
M_6: Zn-EDTA at 0.5 kg ha^{-1} (F) fb Fe-EDTA at 0.5 kg ha^{-1} (F)	58.15	67.31	62.41	71.37
M_7: Zn-EDTA at 1.00 kg ha^{-1} (S) fb Fe-EDTA at 0.5 kg ha^{-1} (F)	53.38	76.91	55.35	82.27
M_8: Fe-EDTA at 1.00 kg ha^{-1} (S) fb Zn-EDTA at 0.5 kg ha^{-1} (F)	51.61	67.71	56.29	70.72
M at same level of V	0.65	1.84	0.70	1.98
V at same or different level of M	0.78	2.40	0.84	2.59

Table.3b Interaction effect between fertilizers and micronutrient (Zn and Fe) on Fe content (ppm) by rice grain during 2006 and 2007

Zn and Fe Application (F × M)	2006		2007	
	F_1	F_2	F_1	F_2
M_0: Control	35.20	39.60	39.57	41.98
M_1: Zn-EDTA at 1.00 kg ha^{-1} (S)	39.79	46.70	40.90	50.02
M_2: Zn-EDTA at 0.5 kg ha^{-1} (F)	48.67	62.70	53.02	67.97
M_3: Fe-EDTA at 1.00 kg ha^{-1} (S)	44.19	48.09	47.38	52.42
M_4: Fe-EDTA at 0.5 kg ha^{-1} (F)	69.18	82.75	74.37	94.28
M_5: Zn-EDTA at 1.00 kg ha^{-1} (S) + Fe-EDTA at 1.00kg (S) ha^{-1}	54.32	58.72	58.28	62.24
M_6: Zn-EDTA at 0.5 kg ha^{-1} (F) fb Fe-EDTA at 0.5 kg ha^{-1} (F)	57.20	68.25	57.71	76.07
M_7: Zn-EDTA at 1.00 kg ha^{-1} (S) fb Fe-EDTA at 0.5 kg ha^{-1} (F)	59.56	70.73	61.79	75.84
M_8: Fe-EDTA at 1.00 kg ha^{-1} (S) fb Zn-EDTA at 0.5 kg ha^{-1} (F)	56.06	63.26	59.61	67.40
M at same level of F	0.65	1.84	0.70	1.98
F at same or different level of M	0.78	2.40	0.84	2.59

Table.3c Interaction effect between variety, fertilizers and micronutrient (Zn and Fe) on Fe content (ppm) by rice grain during 2006

Zn and Fe Application (V×F× M)	2006			
	V_1F_1	V_1F_2	V_2F_1	V_2F_2
M_0: Control	33.650	37.830	36.750	41.370
M_1: Zn-EDTA at 1.00 kg ha^{-1} (S)	37.820	43.870	41.750	49.520
M_2: Zn-EDTA at 0.5 kg ha^{-1} (F)	45.860	66.670	51.470	58.730
M_3: Fe-EDTA at 1.00 kg ha^{-1} (S)	40.480	44.580	47.890	51.590
M_4: Fe-EDTA at 0.5 kg ha^{-1} (F)	62.530	69.970	75.830	95.530
M_5: Zn-EDTA at 1.00 kg ha^{-1} (S) + Fe-EDTA at 1.00kg (S) ha^{-1}	51.960	55.640	56.680	61.800
M_6: Zn-EDTA at 0.5 kg ha^{-1} (F) fb Fe-EDTA at 0.5 kg ha^{-1} (F)	53.520	62.770	60.880	73.7300
M_7: Zn-EDTA at 1.00 kg ha^{-1} (S) fb Fe-EDTA at 0.5 kg ha^{-1} (F)	50.940	55.810	68.180	85.640
M_8: Fe-EDTA at 1.00 kg ha^{-1} (S) fb Zn-EDTA at 0.5 kg ha^{-1} (F)	48.330	54.880	63.780	71.630
M at same level of V F	0.92		2.61	
VF at same or different level of M	1.11		3.39	

Table.3d Interaction effect between variety, fertilizers and micronutrient (Zn and Fe) on Fe content (ppm) by rice grain during 2007

Zn and Fe Application (V×F× M)	2007			
	V_1F_1	V_1F_2	V_2F_1	V_2F_2
M_0: Control	37.560	40.430	41.570	43.530
M_1: Zn-EDTA at1.00 kg ha^{-1} (S)	38.220	48.780	43.570	51.250
M_2: Zn-EDTA at0.5 kg ha^{-1} (F)	51.780	74.630	54.250	61.310
M_3: Fe-EDTA at1.00 kg ha^{-1} (S)	44.840	51.850	49.920	52.990
M_4: Fe-EDTA at0.5 kg ha^{-1} (F)	66.350	80.330	82.380	108.230
M_5: Zn-EDTA at1.00 kg ha^{-1} (S) + Fe-EDTA at1.00kg (S) ha^{-1}	57.690	61.400	58.860	63.080
M_6: Zn-EDTA at0.5 kg ha^{-1} (F) fb Fe-EDTA at0.5 kg ha^{-1} (F)	56.320	68.500	59.100	83.630
M_7: Zn-EDTA at1.00 kg ha^{-1} (S) fb Fe-EDTA at0.5 kg ha^{-1} (F)	54.490	56.210	69.080	95.460
M_8: Fe-EDTA at1.00 kg ha^{-1}(S) fb Zn-EDTA at0.5 kg ha^{-1} (F)	51.130	61.440	68.080	73.360
M at same level of V F	0.99		2.80	
V F at same or different level of M	1.19		3.36	

Table.3e Interaction effect between variety, fertilizers and micronutrient (Zn and Fe) on total Fe uptake (kgha-1) by rice during 2006.

Zn and Fe Application (V×F×M)	2006			
	V_1F_1	V_1F_2	V_2F_1	V_2F_2
M_0: Control	1.007	1.117	1.151	1.260
M_1: Zn-EDTA at 1.00 kg ha^{-1} (S)	1.337	1.632	1.444	2.028
M_2: Zn-EDTA at 0.5 kg ha^{-1} (F)	1.184	1.591	1.412	1.683
M_3: Fe-EDTA at 1.00 kg ha^{-1} (S)	1.435	1.561	1.535	2.417
M_4: Fe-EDTA at 0.5 kg ha^{-1} (F)	1.673	1.998	2.250	2.886
M_5: Zn-EDTA at 1.00 kg ha^{-1} (S) + Fe-EDTA at 1.00kg (S) ha^{-1}	1.376	1.624	1.855	2.197
M_6: Zn-EDTA at 0.5 kg ha^{-1} (F) fb Fe-EDTA at 0.5 kg ha^{-1} (F)	1.475	1.837	2.086	2.623
M_7: Zn-EDTA at 1.00 kg ha^{-1} (S) fb Fe-EDTA at 0.5 kg ha^{-1} (F)	1.485	1.786	2.378	2.779
M_8: Fe-EDTA at 1.00 kg ha^{-1}(S) fb Zn-EDTA at 0.5 kg ha^{-1} (F)	1.316	1.699	1.676	2.517
M at same level of V F	0.01	0.04		
V F at same or different level of M	0.02	0.05		

Table.3f Interaction effect between variety, fertilizers and micronutrient (Zn and Fe) on total Fe uptake (kg ha-1) by rice during 2007.

Zn and Fe Application (V×F× M)		**2007**			
		V_1F_1	**V_1F_2**	**V_2F_1**	**V_2F_2**
M_0:	Control	1.071	1.209	1.259	1.391
M_1:	Zn-EDTA at1.00 kg ha^{-1} (S)	1.455	1.754	1.582	2.146
M_2:	Zn-EDTA at0.5 kg ha^{-1} (F)	1.372	1.744	1.549	1.820
M_3:	Fe-EDTA at1.00 kg ha^{-1} (S)	1.535	1.690	1.710	2.661
M_4:	Fe-EDTA at0.5 kg ha^{-1} (F)	1.813	2.212	2.523	3.185
M_5:	Zn-EDTA at1.00 kg ha^{-1} (S) + Fe-EDTA at 1.00kg ha^{-1} (S)	1.482	1.699	1.945	2.330
M_6:	Zn-EDTA at0.5 kg ha^{-1} (F) fb Fe-EDTA at 0.5 kg ha^{-1} (F)	1.563	1.949	2.183	2.824
M_7:	Zn-EDTA at1.00 kg ha^{-1} (S) fb Fe-EDTA at 0.5 kg ha^{-1} (F)	1.573	1.870	2.455	2.952
M_8:	Fe-EDTA at1.00 kg ha^{-1}(S) fb Zn-EDTA at 0.5 kg ha^{-1} (F)	1.367	1.597	2.358	2.569
M at same level of V F		0.01	0.04		
V F at same or different level of M		0.02	0.05		

Fig.1 Effect of Zn, Fe and FYM on grain yield and straw yield of rice

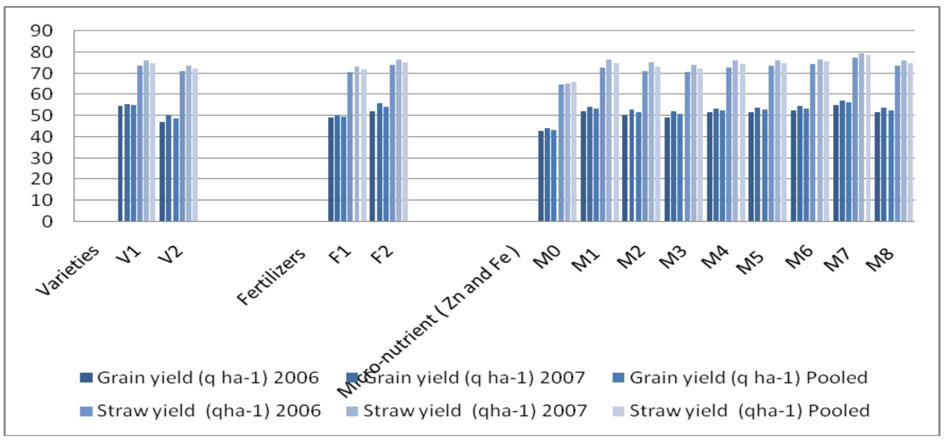


Fig.2 Interaction effect between variety and micronutrient (Zn and Fe) on zinc content (ppm) by grain of rice during 2006 and 2007

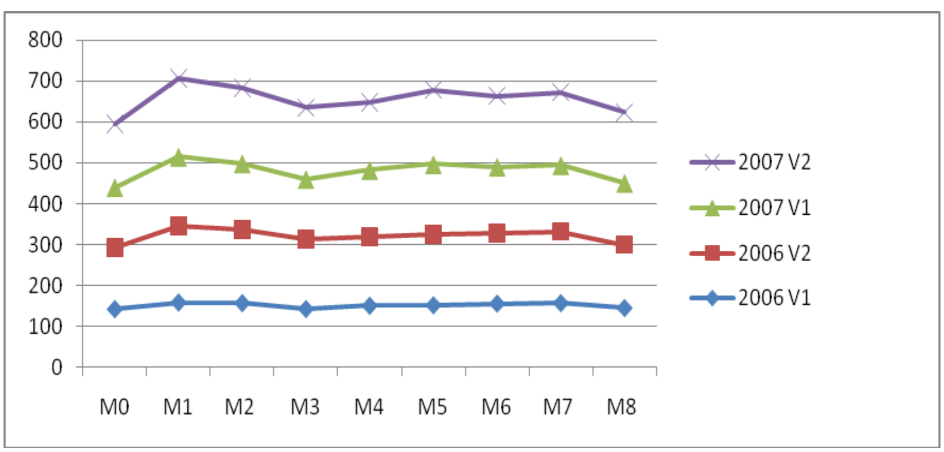


Fig.3 Interaction effect between fertilizer and micronutrient on zinc content of rice grain (ppm) 2007

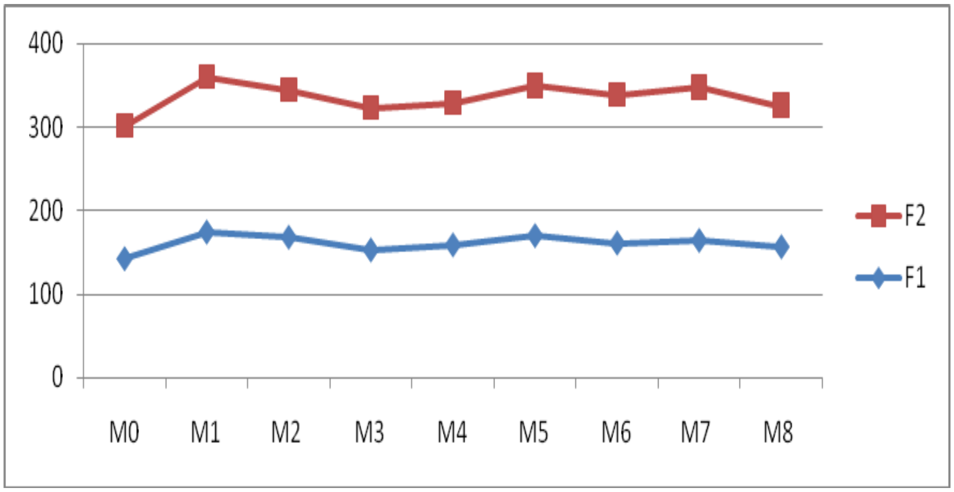


Fig.4 Interaction between variety, fertilizer and micronutrient (Zn and Fe) on Zn content (ppm) by rice grain during 2006

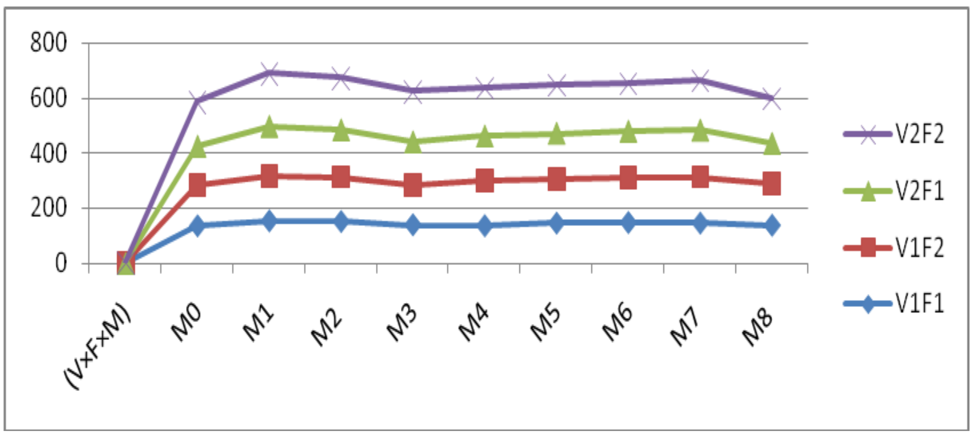


Fig.5 Interaction effect between variety and micronutrient on Fe content (ppm) in grain of rice during 2006 and 2007

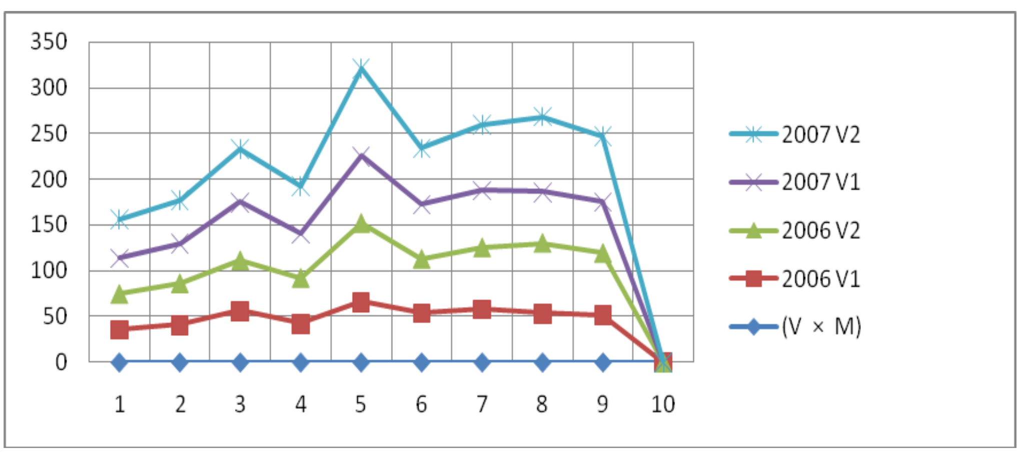


Fig.6 Interaction effect between fertilizers and micronutrient (Zn and Fe) on Fe content (ppm) by rice grain during 2006 and 2007

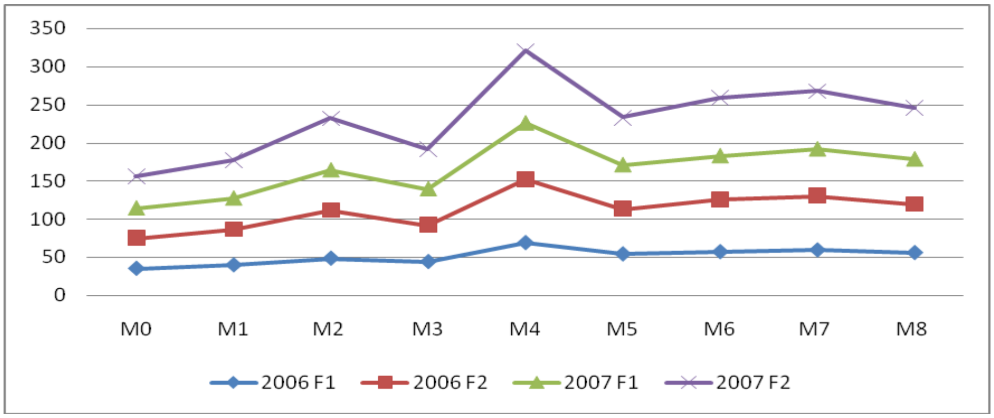


Fig.7 Interaction effect between variety, fertilizers and micronutrient (Zn and Fe) on Fe content (ppm) by rice grain during 2006

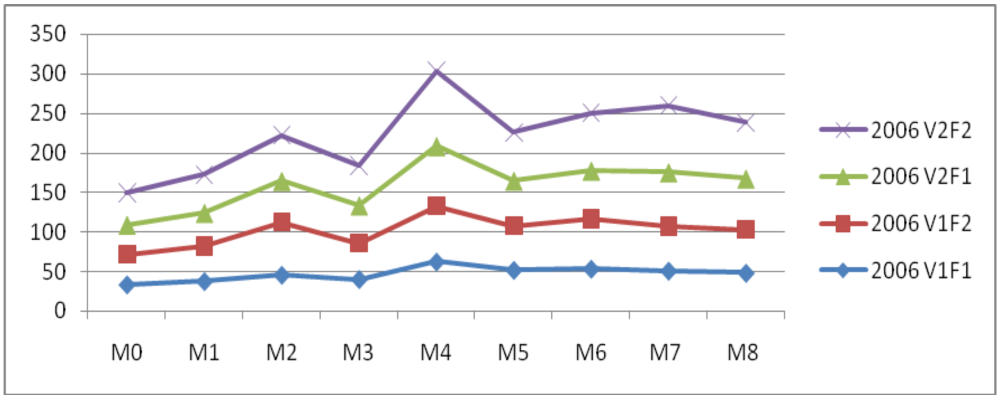


Fig.8 Interaction effect between variety, fertilizers and micronutrient (Zn and Fe) on Fe content (ppm) by rice grain during 2007

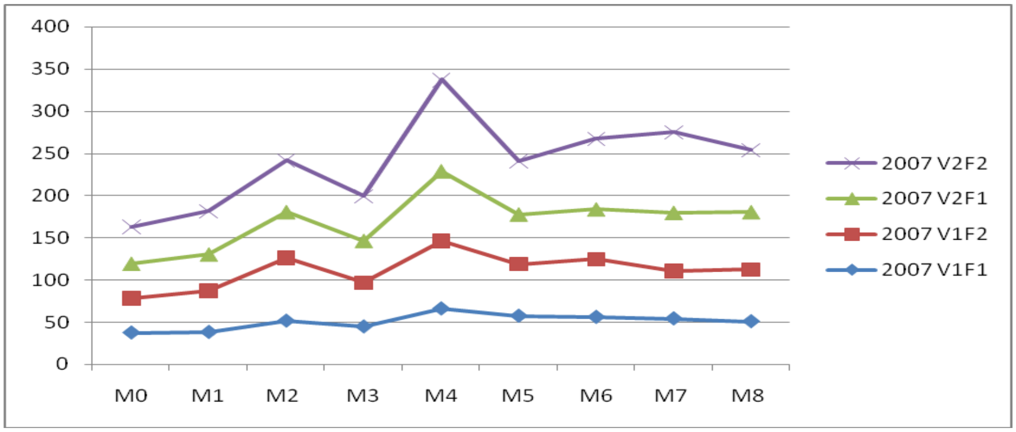


Fig.9 Interaction effect between variety, fertilizers and micronutrient (Zn and Fe) on total Fe uptake (kgha^{-1}) by rice during 2006.

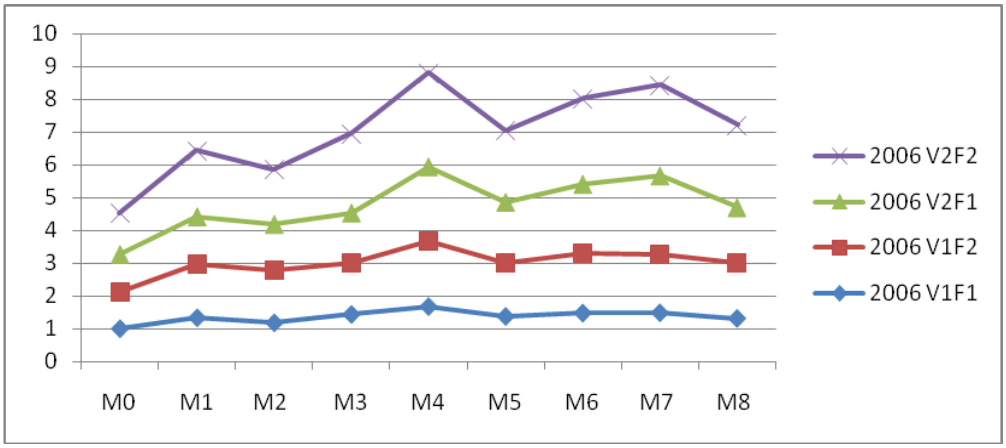
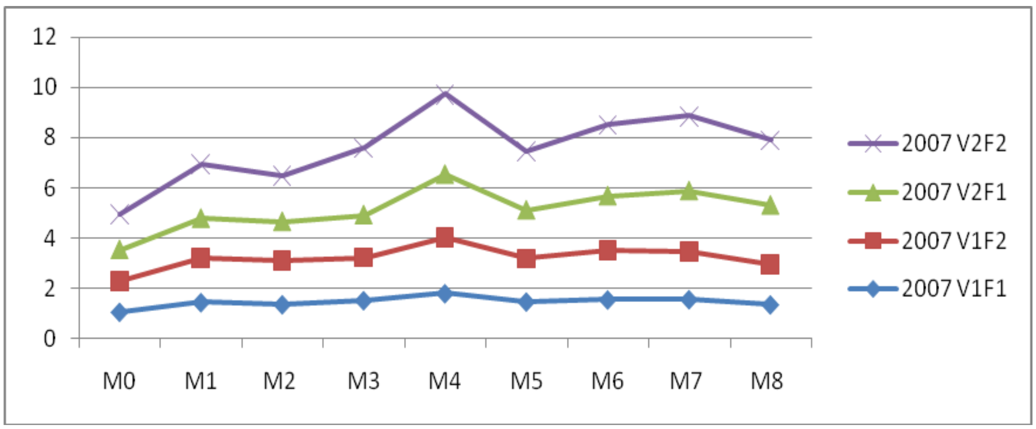


Fig.10 Interaction effect between variety, fertilizers and micronutrient (Zn and Fe) on total Fe uptake (kg ha^{-1}) by rice during 2007.



The combination of V_2 (HUBR 2-1) with Zn-EDTA at 1.00 kg ha^{-1} through soil application recorded highest zinc content in grains than the other combinations but remained at par with Zn as foliar application through Zn-EDTA at 0.5 kg ha^{-1} during both the years of experimentation. This might be due to the efficiency of variety to absorb and store more zinc upon application reported by Tondon (1981).

On the combined application of fertilizer and micronutrient (Zn) had significant interaction in rice grain (Table 1b). Under interaction between fertilizer and micronutrient, Zn content was recorded significantly increased due to F_2 x M_1, but remained at par with F_2 x M_7 (F2 -75% RFD through inorganics + 25% N through FYM) with soil application of Zn-EDTA at 1.00 kg ha^{-1} followed by application of Fe as foliar through Fe-EDTA at 0.5 kg ha^{-1} (M_7) during first year. Most probable reason for this interaction is to be appeared that efficiency of variety to absorb and store more fertilizer nutrient and zinc upon application reported by Nataraja *et al*., (2005).

Significant effect was recorded in interaction between variety, fertilizer and micronutrient on Zn content (VxFxM) in rice grain (Table

1c). Zn content under this interaction significantly increased in V_2 x F_2 x M_1 (V_2-HUBR 2-1, F_2-75% RFD through inorganics + 25% N through FYM, M_1- Zn as soil application through Zn-EDTA at 1.00 kg ha^{-1}) closely followed by V_2 x F_2 x M_2 (M_2-Zn as foliar application through Zn-EDTA at 0.5 kg ha^{-1}) during first year. It might be due to effective absorption of Zn by the variety (Yassen *et al*., 2010).

On Fe content and uptake

Interaction of variety and micronutrient (Fe) showed significant increase in Fe content (VxM) and its total uptake in rice grains during both the years. Higher Fe content and its total uptake in rice grains over control was recorded with HUBR 2-1(V_2) when Fe was applied in the form of foliar spray (Fe-EDTA at 0.5 kg ha^{-1}) in two splits, one at 15 DAT and another at 50 % panicle initiation stages (M_4).This might be due to the efficiency of variety to absorb and accumulate higher Fe upon application (Table 2.1a) was reported by Tondon (1981).

Interaction effect of fertilizers (F_2) and micronutrient (Fe) recorded significant on iron content (FxM) and its total uptake in rice grains during both the years (Table 2.1b). Higher Fe content and its total uptake in rice grains was recorded due to foliar spray of Fe-EDTA at 0.5 kg ha^{-1} in two splits, *i.e.* at 15 DAT and at 50 % panicle initiation stages (M_4). Other combinations remained almost at par. Similar findings were reported by Singh *et al.*, (2002), and Nataraja *et al.*, (2005).

The interaction effect of variety, fertilizers and micronutrient on Fe content in grain (V×F×M) and its total uptake was found significant during both years (Table 2.1c, d, and Table 2a,b). Higher Fe content and its total uptake in rice grains over control was recorded when Fe was applied foliarly through Fe-EDTA at 0.5 kg ha^{-1}. Similarly significantly higher Fe content and total uptake in rice grain was recorded due to application of 75 % RFD through inorganics +25 % N through FYM in combination with Fe as foliar application at 0.5 kg ha^{-1} than rest of the other treatment combinations during both the years of experimentation. Similar findings were reported by Singh *et al.*, (2002) and Yassen *et al*., (2010).

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