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Studies on improvement in fertilizer use efficiency of iron fertilizers in Vertisol

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Abstract
A pot culture experiment entitled "Studies on improvement in fertilizer use efficiency of iron fertilizers in Vertisol" was conducted during *kharif* 2015 at Department of Soil Science and Agricultural Chemistry, VNMKV, Parbhani. The objective of experiment was to evaluate the fertilizer use efficiency of iron fertilizers with combinations of organic and inorganic nutrient sources in Vertisol and response of Soybean to different iron fertilizer combinations. The experiment was conducted with eight treatments viz., T_1 - control, T_2 - only RDF, T_3 - $FeSO_4$ foliar 3 sprays @ 0.5%, T_4 - $FeSO_4$ @20kg ha^{-1}+ Vermicompost @40kg ha^{-1}, T_5 -Fe-EDTA (Soil application @2.5 kg ha^{-1}), T_6 - $FeSO_4$ @20kg ha^{-1}+ DAP @40kg ha^{-1}, T_7 - $FeSO_4$ @20kg ha^{-1}+ 10:26:26 @40kg ha^{-1} and T_8- $FeSO_4$ @20kg ha^{-1} + Urea @40kg ha^{-1}. The experiment was laid out in complete randomized design with three replications. The results emerged out indicated that the significant increase in organic carbon (0.73 %), grain yield (14.27 gm/pot), number of nodules per plant (14.33 and 16.60 at 40, 80 DAS, respectively), number of pods per plant (16.32), DTPA extractable soil micronutrients (Fe, Zn, Cu and Mn) and iron fractions (Exchangeable iron, Dilute acid soluble iron, Water soluble iron and Reducible iron) were found in treatment T_8 ($FeSO_4$ @20kg ha^{-1}+ Urea @40kg ha^{-1}) followed by treatment T_7 ($FeSO_4$ @20kg ha^{-1} + 10:26:26 @40kgha^{-1}) which was found to be at par with each other. Plant micronutrients concentration (Fe, Zn, Cu and Mn) were found to be higher with treatment T_3 - $FeSO_4$ foliar 3 sprays @ 0.5% and Significantly highest fertilizer use efficiency of iron fertilizers (19.92 %) was found in treatment T_5 -Fe-EDTA (Soil application @2.5 kg ha^{-1}).

Keywords: Iron fertilizer, Vertisol, FUE, Iron fractions

Introduction
Low dietary diversity and inadequate daily intake are the main reasons for the widespread occurrence of Fe deficiency in human populations, especially among children and women living in developing world. Impairments of cognitive function, immune system and work capacity and increases in infant and maternal mortality represent major health complications associated with Fe deficiency (Hunt 2005; Carter *et al*. 2010) [11, 4]. Iron is an essential micronutrient for almost all living organisms because of it plays critical role in metabolic processes such as DNA synthesis, respiration, and photosynthesis. Further, many metabolic pathways are activated by iron, and it is a prosthetic group constituent of many enzymes. Iron deficiency has increased from 30% in the 1960s to 40% in the 1990s among the world population (Welch and Graham, 2002) [24]. An imbalance between the solubility of iron in soil and the demand for iron by the plant are the primary causes of iron chlorosis. Iron plays a significant role in various physiological and biochemical pathways in plants. It serves as a component of many vital enzymes such as cytochromes of the electron transport chain, and it is thus required for a wide range of biological functions. In plants, iron is involved in the synthesis of chlorophyll, and it is essential for the maintenance of chloroplast structure and function. Iron is involved in N fixation, electron transfer and respiratory enzyme systems as a part of cytochrome and hemoglobin. Flooding and compaction reduce soil aeration and oxygen level, which decrease or increase Fe availability depending on soil condition. Iron deficiencies usually occur early in the growth season when soils tend to be wetland cool and root growth and microbial activity are limited. As soils warm, microbial activity and root growth increase, allowing plants to absorb more Fe (Rout and Sahoo, 2015) [23]. Iron is primarily absorbed by plants, and it solubilizes Fe^{3+} and then reduces it to Fe^{2+} for absorption or transport into the root. The ability of iron to donate and accept electrons means that if iron is free within the cell, it can catalyze the conversion of hydrogen peroxide into free radicals. Free radicals can cause damage to a wide variety of cellular structures, and they can ultimately kill the cell (Crichton *et al*., 2002) [7].

Material and Methods

A pot culture experiment was conducted in *Kharif* season of 2015 at Department of Soil Science and Agricultural Chemistry, College of Agriculture, VNMKV, Parbhani. The experimental soil is characterized by deep black color (Malewar, 1976) [17] dominated by montmorillonite clay with high coefficient of expansion and shrinkage in summer which leads to deep cracking. This pot culture experiment was laid out by using completely randomized design (CRD) with three replications and eight treatments. The experimental soil is of pH 8.14, EC 0.32 dS m^{-1}, Organic Carbon 0.44%, $CaCO_3$ 5.12%, Fe (3.55mg kg^{-1}), Mn (4.14 mg kg^{-1}), Zn 0.28(mg kg^{-1}) and Cu (1.32 mg kg^{-1}). Iron fractions viz., Exchangeable iron (1.11 mg kg^{-1}), Dilute acid soluble iron (2.10 mg kg^{-1}), Water soluble iron (0.13 mg kg^{-1}) and Reducible iron (1.25 mg kg^{-1}). The treatments T_1 - control, T_2 - only RDF, T_3 - $FeSO_4$ foliar 3 sprays @ 0.5%, T_4 - $FeSO_4$ @20kg ha^{-1}+ Vermicompost @40kg ha^{-1}, T_5 -Fe-EDTA (Soil application @2.5 kg ha^{-1}), T_6 - $FeSO_4$ @20kg ha^{-1}+ DAP @40kg ha^{-1}, T_7 - $FeSO_4$ @20kg ha^{-1}+ 10:26:26 @40kg ha^{-1} and T_8- $FeSO_4$ @20kg ha^{-1} + Urea @40kg ha^{-1}. The soybean was sown by dibbling method with five to six seeds per pot. Nutrients, N, P, K and S @ 30:60:30:20 kg ha^{-1} were applied through urea (46%), Diammonium phosphate (18 %), Muriate of potash (60%), Elemental Sulpher (20%) and $FeSO_4$ @20kg/ha, Fe-EDTA @2.5 kg ha^{-1} and Vermicompost @40kg ha^{-1} as per treatment. Observations on the crop characteristics indicating growth of the crop i.e. plant height at the interval of 30, 60 and 90 DAS, number of branches per plant, pod per plant and nodules per plant were recorded. The soil samples were collected at the time of harvest and analyzed for soil pH, EC, organic carbon, calcium carbonate, DTPA extractable micronutrients (Fe, Zn, Mn, Cu), iron fractions (Exchangeable iron, Dilute acid soluble iron, Water soluble iron and Reducible iron) and fertilizer use efficiency of iron fertilizers were calculated by the formula proposed by Rehman and Farukh (2011) [22].

$$\text{FUE (\%)} = \frac{\text{Yield of fertilized pot (Kg)} - \text{Yield of unfertilized pot (Kg)}}{\text{Amount of fertilizer applied (Kg)}}$$

Result and Discussion

Growth attributing characters

The pooled data on growth attributing characters viz., plant height, number of branches per plant, number of pods per plant and number of nodules per plant were significantly influenced by different iron fertilizer combination (Table 1 and 2). the maximum plant height (28.66, 33.29, 34.66 and 37.30 cm at 30, 60, 90 and at harvest, respectively), number of branches per plant (4.33), number of pods per plant (16.32) and number of nodules per plant (14.33 and 16.60 at 40, 80 DAS, respectively) was recorded in treatment T_8- $FeSO_4$ @20kg/ha +Urea @40kg ha^{-1} which was at par with treatment T_7- $FeSO_4$ @20kg/ha + 10:26:26 @40kg ha^{-1}. The increase in plant height, number of branches per plant, number of pods per plant and number of nodules per plant of soybean with soil application of $FeSO_4$ may be due to the greater role of Fe in chlorophyll synthesis and other metabolic activities of the plant thereby increased vegetative growth of plant. Similar results were in conformity with Rajamani and Shanmugasundaram (2014) [20] in black gram. Abdelmajid and Chedly (2003) [1] explained that in nodules, iron is necessary for leghemoglobin biosynthesis as it regulates oxygen contents within cells. Singh *et a*l. (1995) reported that using $FeSO_4$ and iron citrate increased pod formation. Bhatt *et al*. (2004) [16] in their experiment on the effect of micronutrients on growth and performance of Tomatoes found that applying $FeSO_4$ (100 ppm) through leaf led to the maximum number of branches per plant, leaf number, leaf area, wet plant weight, and dry stem weight. Bhat and Jandial (1996) [2] also reported that application of $FeSO_4$ @ 5 kg ha^{-1} increased the plant height, number of shoots per plant, no. of leaves and yield of Potato.

Table 1: Effect of application of iron fertilizer combinations on number of nodules per plant of Soybean

Treatments	Nodules $plant^{-1}$		Pods $plant^{-1}$	Branches $plant^{-1}$
	40	80		
T_1- Control	10.41	12.46	13.15	3.11
T_2- Only RDF	11.09	13.70	13.21	3.20
T_3- RDF + $FeSO_4$ foliar 0.5% (50 gm 10 lit water).	12.44	14.50	15.22	3.58
T_4- RDF + $FeSO_4$ @20kg/ha+ Vermicompost @40kg ha^{-1}	12.56	14.66	15.68	3.66
T_5- RDF + Fe-EDTA (Soil application @2.5 kg ha^{-1})	13.19	15.11	15.43	3.73
T_6- RDF + $FeSO_4$ @20kg/ha + DAP @40kg ha^{-1}	11.15	13.81	14.27	3.20
T_7- RDF + $FeSO_4$ @20kg/ha + 10:26:26 @40kg ha^{-1}	13.56	15.39	15.88	4.12
T_8- RDF + $FeSO_4$ @20kg/ha + Urea @40kg ha^{-1}	14.33	16.60	16.32	4.33
SE(m)	11.29	0.74	0.42	0.28
CD (0.01)	0.81	2.23	1.27	0.86

Table 2: Effect of application of iron fertilizer combinations on plant height of Soybean

Treatments	Plant height (cm)			
	30	60	90	At Harvest
T_1- Control	22.29	29.31	31.89	33.28
T_2- Only RDF	23.22	29.81	31.56	33.48
T_3- RDF + $FeSO_4$ foliar 0.5% (50 gm 10 lit water)	26.60	31.33	33.44	35.66
T_4- RDF + $FeSO_4$ @20kg/ha + Vermicompost @40kg ha^{-1}	26.55	31.20	33.56	34.51
T_5- RDF + Fe-EDTA (Soil application @2.5 kg ha^{-1})	26.68	30.98	33.11	35.19
T_6- RDF + $FeSO_4$ @20kg/ha+ DAP @40kg ha^{-1}	25.21	30.11	32.18	33.60
T_7- RDF + $FeSO_4$ @20kg/ha + 10:26:26 @40kg ha^{-1}	27.66	32.31	34.55	36.55
T_8- RDF + $FeSO_4$ @20kg/ha + Urea @40kg ha^{-1}	28.66	33.29	34.66	37.30
SE(m)	0.82	0.97	0.67	1.07
CD (0.01)	2.46	2.93	2.02	3.21

Plant Micronutrient content in soybean

The plant micronutrients Zn, Fe, Cu, and Mn status after harvest of soybean as influenced by various treatments is presented in Table 3. The plant Fe, Zn, Cu, and Mn in soil were significantly increased (312, 36.54, 23.33 and 38.60 µg g^{-1}, respectively) in treatment T_3- RDF + $FeSO_4$ foliar 0.5% (50 gm 10 lit water) which was at par with treatment T_8- RDF + $FeSO_4$ @20kg/ha + Urea @40kg ha^{-1}. This may be due to application of foliar $FeSO_4$ increasing the effect of photosynthesis and demand for the increase of essential element, causes to enhancing both absorption and transportation of elements. The similar results were also reported by Hamid and Yases (2012) and Aciksoz *et al.* (2011) [9, 3] in durum wheat in clay loam texture soil.

Table 3: Effect of application of iron fertilizer combinations on plant micronutrient content (µg g^{-1} dry matter) of Soybean

Treatments	Plant micronutrient (µg g^{-1})			
	Fe	Zn	Cu	Mn
T_1- Control	214	31.38	17.55	32.48
T_2- Only RDF	254	32.44	18.44	33.32
T_3- RDF + $FeSO_4$ foliar 0.5% (50 gm 10 lit water).	312	36.54	23.33	38.60
T_4- RDF + $FeSO_4$ @20kg/ha + Vermicompost @40kg ha^{-1}	288	34.45	20.41	36.98
T_5- RDF + Fe-EDTA (Soil application @2.5 kg ha^{-1})	292	34.69	20.98	36.48
T_6- RDF + $FeSO_4$ @20kg/ha+ DAP @40kg ha^{-1}	285	32.09	18.51	35.04
T_7- RDF + $FeSO_4$ @20kg/ha + 10:26:26 @40kg ha^{-1}	286	34.11	20.18	36.11
T_8- RDF + $FeSO_4$ @20kg/ha + Urea @40kg ha^{-1}	298	35.88	22.58	37.51
SE(m)	9.19	0.90	1.14	1.09
CD (0.01)	27.53	2.7	3.42	3.29

Table 4: Effect of application of iron fertilizer combinations on physico- chemical properties of soil after harvest of Soybean

Treatments	pH	EC (dSm^{-1})	Organic carbon (%)	$CaCO_3$ (%)
T_1- Control	7.78	0.35	0.55	4.98
T_2- Only RDF	7.86	0.33	0.60	4.64
T_3- $FeSO_4$ foliar 0.5% (50 gm 10 lit water	7.82	0.33	0.68	4.57
T_4- $FeSO_4$ @20kg/ha + Vermicompost @40kg ha^{-1}	7.86	0.31	0.69	4.73
T_5- Fe-EDTA (Soil application @2.5 kg ha^{-1})	7.81	0.30	0.70	4.43
T_6- $FeSO_4$ @20kg/ha + DAP @40kg ha^{-1}	7.87	0.32	0.65	4.95
T_7- $FeSO_4$ @20kg/ha +10:26:26 @40kg ha^{-1}	7.97	0.32	0.72	4.61
T_8- $FeSO_4$ @20kg/ha + Urea @40kg ha^{-1}	7.94	0.34	0.73	4.73
SE(m)	0.091	0.015	0.018	0.263
CD (0.01)	NS	NS	0.056	NS
Initial value	8.14	0.32	0.44	5.12

Physico- chemical properties of soil after harvest of Soybean

The range of soil pH at harvest stage of soybean in different treatments was varied from 7.78 to 7.97 and the electrical conductivity of soil varied from 0.30 to 0.35 dSm^{-1} (Table 4). The calcium carbonate content was varied from 4.43 to 4.98 per cent. The soil pH, EC and calcium carbonate value did not influence significantly due to application of different iron fertilizer combinations. The significantly highest soil organic carbon content at harvest stage (0.73 per) cent was observed under treatment T_8- $FeSO_4$ @20kg/ha +Urea @40kg ha^{-1} which was at par with T_7- $FeSO_4$ @20kg/ha + 10:26:26 @40kg ha^{-1} and lowest organic carbon (0.55 per cent) was recorded in treatment T_1 (control).

DTPA extractable micronutrient status after harvest

The DTPA extractable micronutrients Zn, Fe, Cu, and Mn status after harvest of soybean as influenced by various treatments is presented in Table 5. The DTPA-Fe, Zn, Cu, and Mn in soil were significantly increased (5.98, 0.45, 1.63 and 4.11 mg kg^{-1}, respectively) in treatment T_8- $FeSO_4$ @20kg/ha +Urea @40kg ha^{-1} which was at par with treatment T_7- $FeSO_4$ @20kg/ha + 10:26:26 @40kg ha^{-1}. Increase in DTPA-extractable Zn, Fe, Cu and Mn content with $FeSO_4$ soil application might be due to formation of different stable complexes with organic ligands. This has decreased their susceptibility for adsorption or fixation or precipitation reaction in soil, which has helped in keeping micronutrient elements soluble and consequently more available to plants for longer period. Mimmo *et al*., (2014) [19] reported that an enhanced release of inorganic (such as protons) and organic (organic acids, carbohydrates, amino acids, phytosiderophores, siderophores, phenolics and enzymes) compounds to increase the solubility of poorly available Fe pools, Kamble *et al.* (2014) [12] in turmeric on Vertisol in Maharashtra and Durgude *et.al* (2013) [8] also reported that application of RDF + $FeSO_4$ @20kg/ha increase the Fe content in soil in onion growth on Entisol.

Table 5: Effect of application of iron fertilizer combinations on DTPA extractable soil micronutrients after harvest of Soybean

Treatments	DTPA-Soil micronutrients (mg kg^{-1})			
	Fe	Zn	Cu	Mn
T_1- Control	3.88	0.33	1.40	3.38
T_2- Only RDF	4.69	0.36	1.42	3.47
T_3- RDF + $FeSO_4$ (foliar) 0.5% (50 gm 10 lit water).	5.33	0.41	1.48	3.75
T_4- RDF + $FeSO_4$ @20kg/ha + Vermicompost @40kg ha^{-1}	5.69	0.39	1.51	3.98
T_5- RDF + Fe-EDTA (Soil application @2.5 kg ha^{-1})	5.77	0.40	1.55	3.81
T_6- RDF + $FeSO_4$ @20kg/ha+ DAP @40kg ha^{-1}	4.81	0.37	1.43	3.51
T_7- RDF + $FeSO_4$ @20kg/ha + 10:26:26 @40kg ha^{-1}	5.83	0.43	1.59	4.09

T_8- RDF + $FeSO_4$ @20kg/ha +Urea @40kg ha^{-1}	5.98	0.45	1.63	4.11
SE(m)	0.30	0.022	0.041	0.17
CD (0.01)	0.90	0.067	0.12	0.51
Initial value	3.55	0.28	1.32	4.14

Soybean yield and fertilizer use efficiency of iron fertilizers

Data presented in Table 6 indicate that, the influence of iron fertilizer combinations on yield of soybean and fertilizer use efficiency were significantly influenced due to variation in fertilizer combinations. The significantly highest grain yield (14.27gm pot^{-1}) was recorded in treatment T_8- RDF + $FeSO_4$ @20kg/ha + Urea @40kg $ha^{-1}$and the significantly highest fertilizer use efficiency (19.92%) was recorded in treatment T_5- Fe-EDTA (Soil application @2.5 kg ha^{-1}). Increase in fertilizer use efficiency with the application of Fe-EDTA might be due to the organic compounds are able to stabilize the metal ions and increase solubility and availability of elements to the plant. Similar resultswere close conformity with chibba *et al.* (2007) [6] who reported that the foliar and soil application of Fe significantly increased yield of Fenugreek. Kumbhar and Deshmukh (1993) [15] also reported the response of Tomato cv. Rupali to soil application of $FeSO_4$ @ 80 kg ha^{-1} for increasing the yield of tomato.

Table 6: Effect of application of iron fertilizers on yield and fertilizer use efficiency of iron fertilizers

Treatments	Yield (gm/pot)	FUE (%)
T_1- Control	11.32	----
T_2- Only RDF	11.39	----
T_3- RDF + $FeSO_4$ foliar 0.5% (50 gm 10 lit water).	13.98	2.48
T_4- RDF+ $FeSO_4$ @20kg/ha + Vermicompost @40kg ha^{-1}	13.88	2.39
T_5- RDF+ Fe-EDTA(Soil application @2.5 kg ha^{-1})	13.91	19.92
T_6- RDF+ $FeSO_4$ @20kg/ha + DAP @40kg ha^{-1}	12.88	1.45
T_7- RDF+ $FeSO_4$ @20kg/ha + 10:26:26 @40kg ha^{-1}	14.11	2.60
T_8- RDF+ $FeSO_4$ @20kg/ha +Urea @40kg ha^{-1}	14.27	2.75
SE(m)	0.491	0.03
CD (0.01)	1.436	0.09

Iron fractions (mg kg^{-1}) in soil after harvest of soybean

Data presented reported in Table 7 indicated that, the influence of iron fertilizer combinations on Iron fractions (Exchangeable iron, dilute acid soluble iron, Water soluble iron and Reducible iron) were significantly influenced due to variation in fertilizer combinations. Iron fractions (Exchangeable iron, dilute acid soluble iron, Water soluble iron and Reducible iron) in soil were significantly increased (1.98, 3.68, 0.92 and 2.87 mg kg^{-1}, respectively) in treatment T_8- $FeSO_4$ @20kg/ha +Urea @40kg ha^{-1} which was at par with treatment T_7- $FeSO_4$ @20kg/ha + 10:26:26 @40kg ha^{-1}.

Table 7: Effect of application of iron fertilizer combinations on iron fractions after harvest of Soybean

Treatments	Iron fractions (mg kg^{-1})			
	Exchangeable Fe	Water soluble Fe	Dilute acid soluble Fe	Reducible Fe
T_1- Control	1.10	0.11	2.13	1.36
T_2- Only RDF	1.22	0.19	2.24	1.46
T_3- RDF + $FeSO_4$ foliar 0.5% (50 gm 10 lit water).	1.43	0.36	2.89	1.98
T_4- RDF + $FeSO_4$ @20kg/ha + Vermicompost @40kg ha^{-1}	1.88	0.73	3.11	2.45
T_5- RDF + Fe-EDTA (Soil application @2.5 kg ha^{-1})	1.90	0.65	3.25	2.58
T_6- RDF + $FeSO_4$ @20kg/ha + DAP @40kg ha^{-1}	1.65	0.54	2.95	2.10
T_7- RDF + $FeSO_4$ @20kg/ha+ 10:26:26 @40kg ha^{-1}	1.93	0.84	3.45	2.66
T_8- RDF + $FeSO_4$ @20kg/ha + Urea @40kg ha^{-1}	1.98	0.92	3.68	2.87
SE(m)	0.076	0.027	0.028	0.057
CD (0.01)	0.222	0.079	0.084	0.167
Initial value	1.11	0.13	2.10	1.25

Conclusions

From the above study it can be concluded that combinations of iron fertilizers with organic and inorganic sources enhanced the growth parameters viz., plant height, number of branches per plant, pod per plant and nodules per plant, grain yield, increased iron fractions (exchangeable Fe, water soluble Fe, dilute acid soluble Fe and reducible Fe and DTPA-extractable soil micronutrients (Fe, Zn, Cu and Mn). $FeSO_4$ @ 20kg ha^{-1} + Urea @ 40kg ha^{-1} found best for all studied parameters than application of $FeSO_4$ foliar spray 0.5% (50 gm 10 lit water). The highest grain yield and Fe, Zn, Cu and Mn content in plant increased significantly with application of three $FeSO_4$ foliar sprays 0.5% (50 gm. in 10 lit water) at different growth stages. Highest fertilizer use efficiency was obtained with application of Fe-EDTA (Soil application @2.5 kg ha^{-1}).

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