STUDIES ON IMPROVEMENT IN FERTILIZER USE EFFICIENCY OF IRON FERTLIZERS IN VERTISOL

SUBMITTED BY

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DISSERTATION

Submitted to the Vasantrao Naik Marathwada Krishi Vidhyapeeth, Parbhani in partial fulfilment of the requirement for the Degree of

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CANDIDATE'S DECLARATION

I hereby declare that this dissertation or part there of

has not been previously submitted by me for

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or university

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This is to certify that **Mr. SANTOSH PARASRAM KALE** has satisfactorily prosecuted his course of research for a period of not less than two semesters and that the dissertation entitled **"STUDIES ON IMPROVEMENT IN FERTILIZER USE EFFICIENCY OF IRON FERTILIZERS IN VERTISOL"** submitted by him is a result of original research work and is of sufficiently high standard to warrant its presentation to the examination. I also certify that dissertation or part thereof has not been previously submitted by him for a degree of any university.

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CERTIFICATE - II

This is to certify that the dissertation entitled **STUDIES ON IMPROVEMENT IN FERTILIZER USE EFFICIENCY OF IRON FERTILIZER IN VERTISOL** submitted by **Mr. SANTOSH PARASRAM KALE** to the Vasantrao Naik Marathwada Krishi Vidhyapeeth, Parbhani in partial fulfillment of the requirement for the degree of **MASTER OF SCIENCE (Agriculture)** in the subject of **SOIL SCIENCE AND AGRICULTURAL CHEMISTRY** has been approved by the Student's Advisory Committee after viva-voce examination in collaboration with the external examiner.

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ABBREVIATIONS

%	:	Per cent
/	:	Per
@	:	at the rate
^{0}C	:	Degree Celsius
B	:	Boron
Cu	:	Copper
Fe^{++}	:	Ferrous
Mn	:	Manganese
Mo	:	Molybdanum
Zn	:	Zinc
et. al	:	and others
Fig.	:	Figure
FYM	:	Farm Yard Manure
ha	:	hectare
K	:	Potassium
kg ha^{-1}	:	Kilo gram per hectare
mg kg^{-1}	:	milli gram per killo
N	:	Nitrogen
No.	:	Number
NS	:	Non Significant
P	:	Phosphorus
SD	:	Standard Deviation
t	:	Tonnes
viz.	:	Namely
µg g^{-1}	:	micro gram per gram

ABSTRACT

"STUDIES ON IMPROVEMENT IN FERTILIZER USE EFFICIENCY OF IRON FERTILIZR IN VERTISOL"

By

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of

Master of Science (Agriculture)

In

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2016

Research Guide	:	Dr. H.K. Kausadikar (Associate Professor)
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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, Vasantrao Naik Marathwada Krishi Vidyapeeth, 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 pH, EC and $CaCO_3$ showed non-significant variation, while there was significant increase in organic carbon, plant height, number of branches per plant, number of nodules per plant and number of pods per plant. Iron fractions (Exchangeable iron, Dilute acid soluble iron, Water soluble iron and Reducible iron), DTPA extractable soil micronutrients and plant micronutrients concentration (Fe, Zn, Cu and Mn) were found to be higher with 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 were found to be at par with each other.

Kale S. P.	**Dr. H. K. Kausadikar**	**Dr. V. D. Patil**
(Student)	**(Research Guide)**	**(Head, SSAC)**

CHAPTER I

INTRODUCTION

Plants are at the beginning of the food chain. Therefore, improving the uptake of minerals from the soil and enhancing their transfer to and bioavailability in the edible parts of the plant will provide benefits to animal and human nutrition

Soybean (*Glycine_max* L.) is a species of Fabaceae native to East Asia. The plant is classed as an oilseed rather than a pulse. It is an annual plant that has been used in China for 5,000 years to primarily add nitrogen into the soil as part of crop rotation. Fat-free Soybean meal is a primary, low-cost, source of protein for animal feeds and most prepackaged meals, vegetable oil is another valuable product of processing the soybean crop. Recent research has shown that a small amount of nutrients, particularly Zn, Fe and Mn applied by foliar spraying increases significantly the yield of crops (Rogers and Guerinot 2007). Soybean is an important source of inexpensive and high quality content of protein and oil. With an average protein content of 40% and oil content of 20%, Soybean has the highest protein content of all food crops and is second only to groundnut in terms of oil content among food legumes. Compared to other protein-rich foods such as meat, fish and eggs, soybean is by far the cheapest. Ca content of Soybean ranged from 268.75 to 293.0, Cu from 1.2 to 1.37, Fe from 9.04 to 13.32, Mg from 261.0 to 296.0, Mn from 3.38 to 4.94, K from 1500 to 1935, Na from 11.9 to 15.11 and Zn from 3.75 to 4.02 mg 100 g^{-1}.

Soybean can be grown in variety of soil condition. Highly fertile and healthy soil with good drainage condition is preferred. It can tolerate mild salinity but acidity is deadly harmful to crop. The availability of micronutrients is influenced by their distribution within the soil profile and other site characteristic (Singh *et al.*, 2004). Micronutrients occur in different forms associated with inorganic and organic components of soil. The relative contribution of the different forms towards the plant available pool varies proportionately and defines the inherent nutrient supplying capacity of soils. Iron deficient plants accumulate unwanted heavy metals, such as cadmium (Samaranayake *et al.*, 2012). Deficiencies of N, P, Fe, B and S may cause soybean yield losses up to 10 %, 29-45 %, 22-90 %, 100 % and 16-30 %, respectively, depending on soil fertility, climate and plant factors.

Soybean, which is a hardy crop, has the ability to grow well even in marginal soils. It is grown on a wide range of soils varying in texture and soil fertility. It has been known for 160 years that iron is essential for plant growth. Its deficiency occurs especially, but not only, in calcareous soils and it limits crop production in large parts (>30%) of the arable land. Iron is one of the most common elements in the Earth's crust and it is fourth on the list of abundance after oxygen, silicon and aluminum. It plays an important role in the biosphere. In plants it is necessary for the formation of chlorophyll, while in animals it acts in transferring oxygen from air or water to animal tissue.

Iron (Fe) is a cofactor for approximately 140 enzymes that catalyze unique biochemical reactions. Deficiency or low activity of iron in the plant affects chlorophyll production in sufficient quantities and the leaves are pale green. The fact that the total Fe content in soils usually far exceeds plant requirements for Fe, its bioavailability in the soil is often severely limited chlorosis because of unavailability of Fe in soils (high pH) is a major agricultural problem that results in diminished crop yields in an estimated 30% of calcareous soils worldwide (Mori 1999). In surface environments iron is very quickly oxidized and changed from the ferrous to the ferric state in minerals. The susceptibility of iron to surface oxidation is one of the major characteristics of its geochemical cycle. Ferric oxide may oxidize organic matter and at the same time become reduced to the ferrous state, but again it could be reoxidized by oxygen from the atmosphere. So iron acts as a catalyst of carbon cycling in nature and their cycles are closely bound to the oxygen cycle (Schmidt 1993).

The general rules governing the behavior of Fe are the redox potential (i.e., oxidizing or reducing conditions) and pH. Neutral pH conditions promote the precipitation of poorly ordered Fe minerals (ferrihydrite), whereas reducing and acid conditions promote the mobilization of Fe minerals. Goethite and hematite are characterized by high stability (lower solubility) in the most habitual Eh–pH soil condition (Gross and Levant 2003). Iron chlorosis, occurs in soils with high soil pH. The classic symptom is chlorosis (yellowing) between the veins of young leaves. A side effect of iron deficiency can be N deficiency, since iron is necessary for nodule formation and function. If iron is deficient, N fixation rates may be reduced. Ferrous iron is more soluble and bioavailable to plants than ferric iron. Iron occurs predominantly as Fe^{3+}oxides in soils (Borgarrd and Shefrad 1988). Goethite is the predominant mineral form. The divalent state (or ferrous state) can be oxidized to the trivalent state (or ferric state), where it may form oxide or hydroxide precipitates, and become unavailable to plants as a micronutrient.

Iron is a commonly occurring metallic element, comprising 4.6% of the igneous rocks and 4.4% of sedimentary rock. The typical range of iron concentrations in soils is from 0.2% to 55% (20,000 to 550,000 mg kg^{-1}). Native iron concentrations are region-specific, and can vary significantly even within localized areas due to soil types and presence of other sources. Sandy soils have the lowest overall iron content, and clayey soils have the highest iron content (Marschner and Romheld 1994). which then reacts with pyrite to generate soluble ferrous iron. Iron deficiencies can also result from an excess of manganese and possibly copper (Snowden and Wheeler 1993). Manganese and copper are oxidizing agents that convert ferrous iron to the more insoluble ferric form. Iron deficiencies caused by manganese toxicity occur in acidic soils that otherwise would supply adequate iron for plant growth. Roots are thickened with large accumulations of inorganically-bound phosphate. Iron is essential for the synthesis of chlorophyll, the green color of plants which functions in photosynthesis but it is not part of the chlorophyll molecule.

Iron is involved in N fixation, photosynthesis, and electron transfer, respiratory enzyme systems as a part of cytochrome and hemoglobin and in other enzyme systems. Flooding and compaction reduce soil aeration and oxygen level. This can 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. In alkaline or calcareous soils rapid microbial activity may produce enough carbon dioxide to react with water to form bicarbonate ions, which when absorbed by plants immobilize Fe within plants resulting in Fe deficiency. Broadcast applications of Fe sources are seldom successful because of the reactivity of Fe in soil rendering it unavailable and are not recommended. Iron chelates applied in a band with other fertilizer materials at planting time have given yield increase of soybean. Not all chelates remain stable over a wide range of soil pH. Fe EDDHA maintains Fe in a soluble form from pH 4.0 to 9.0. Iron DTPA is selective for Fe up to pH 6.3.

Ferrous sulfate, ferrous ammonium sulfate, and chelates are suitable sources for foliar applications. The foliage should be wet thoroughly and if recommended by manufacturer a surfactant may be needed. Foliar applications of Fe to Fe deficient soybean should be made when the first trifoliate leaf is fully emerged and no later than two emerged trifoliate because the plant is permanently injured at later stages of growth and will seldom respond to foliar treatments. Foliar applications of ferrous sulfate to successful because there is limited contact with the soil (Lindsay and Schwab, 1982). The transport of iron within the plant is also affected by the pH of the conducting tissue. Romheld and Marschner (1991) reported that the iron which accumulated in parts of the plant with high pH was not available for plant processes. On the other hand, tissues with low pH did not show any accumulation. The manganese: iron ratio was closely related to the appearance of chlorosis in soybean plant Chlorosis appeared when the ratio was either too high (manganese toxicity) or too low (manganese deficiency i.e. Fe toxicity). Soil iron available to plants is affected markedly by reactions with soil. The characteristic symptoms of iron deficiency are commonly referred to as "lime-induced chlorosis", because iron deficiency commonly occurs on calcareous soils (Brown *et al.*, 1991). Many investigations on the iron nutrition of plants indicated that one or more of calcium bicarbonate, carbonate and pH were major factors causing the onset of deficiency or a reduction in iron status. However, these factors are often not truly independent. It is therefore difficult to infer that an iron deficiency was primarily caused by one factor.

Hence, it is aimed to conduct studies in improvement of iron fertilizer use efficiency in soybean for optimum crop production and balanced fertilization.

The objectives of the study are as below:

1. To evaluate the fertilizer use efficiency of iron fertilizers with organic and inorganic combination in Vertisol.
2. To evaluate the response of soybean for different iron fertilizer combinations.

CHAPTER II

REVIEW OF LITERATURE

A research project entitled “**Studies on improvement in fertilizer use efficiency of iron fertilizer in Vertisol**” was carried out on various aspects. Present investigations related to this topic in recent past are briefly reviewed under following heads.

2.1 Status of iron in soil.

2.1.1 Total iron

2.1.2 Available iron

2.1.3 Exchangeable iron

2.1.4 Reducible iron

2.1.5 Dilute acid soluble iron

2.1.6 Water soluble iron

2.2 Iron fertilizer use efficiency and factors affecting it.

2.3 Fertilizer use efficiency of iron in fertilizers combinations.

2.4 Effect of application of iron fertilizer combinations on soil micronutrient availability and plant content.

2.5 Effect of application of iron fertilizer combinations on growth and yield of crops.

2. 6 Factor affecting the availability of iron in soil.

2.6.1 Soil reaction

2.6.2 Soil moisture

2.6.3 Lime content in the soil

2.6.4 Organic matter

2.7 Response of soybean for different iron fertilizer combination.

2.1 Status of iron in soil

2.1.1 Total iron

Patil and Sonar (1994) analyzed twenty surface soil samples (0-15 cm) in well-shrink soils of Maharashtra and reported total Fe contents ranging from 8.0 to 14.4 per cent with mean value of 10.27 per cent and indicated that the soils from Solapur district contained the highest amount of total Fe.

Malewar (1995) collected fifty-four surface soil samples representing different cropping systems and reported that the potential reserve of total iron content was relatively higher in fruit growing Vertisols and Inceptisoils.

Dangarwala and Patel (1996) analyzed the medium and shallow black soils of Gujrat and reported that the total Fe content in these soils ranged from 0.8 to 11.3 percent.

Nipunge and Pharande (1996) revealed that total Fe content was relatively higher at the surface layer than in subsurface layer of Inceptisols of Maharashtra. These Inceptisols also found to be wide range of content of total Fe (6.4 to 14.40).

Yelwikar *et al*. (1997) analyzed the soils of Beed district of Marathwada and reported that total iron content in deep black soils ranged between 4.12 and 8.16 per cent with a mean value 5.23 per cent.

Khan and Khuman(1997) collected soil samples from five major soil series from the flood-plains of Bangladesh and reported that total Fe contents of 3.3 to 6.2 per cent.

Ismail (1993) studied some soil series of Marathwada region of Maharashtra state and found the DTPA extractable Fe content in the range of 0.34 to 25.14 mg Kg^{-1}.

Yadav *et al.* (2000) studied nutrient management in sugarcane based cropping system during 2000-2001 and stated that an average crop of sugarcane with 100 t ha^{-1} cane yield removed 3.4 Kg Fe ha^{-1}.

2.1.2 Available Iron

Sing and Hans raj (1996) collected 200 and 45 surface soil samples representing cotton-wheat growing areas of sirsa and hissar districts of Haryana and found that available Fe content showed a wide variation of 1.3 to 41.70 mg kg^{-1} with mean value 7.8 mg Kg^{-1}.

Saha and Tirke (1996) collected surface (0-15cm) soil samples from 63 freash water fish ponds located under red, laterite, alluvial soils of Orissa representing the districts of bolangir, Ganjan, Mayurbhanj and puri and reported that the available Fe contents of the soils showed a wide variation and ranged from 11.0 to 94.0 mg Ka^{-1}.

Chattopadhyay and Shrama (1996) collected soil samples from 9 representative soil profiles from three district physiographic units of the vindhyan scarpland areas of Rajsthan viz. hills and hill ridges, sediment and plateau and found that DTPA-extractable Fe content was ranging from 5.0 to 24.9, 4.1 to 7.2 and 1.5 to 6.8 mg Kg^{-1}, respectively.

Ismail *et al.* (1995) analyzed 333 representative surface soil samples from cultivators fields of Maharashtra and reported that DTPA-extractable Fe content ranged from 0.78 to 10.40 mg Kg^{-1} indicating relatively higher content of Fe in light textured soils and also reported that DTPA-Fe was noted in shallow black soil (61per cent) and lowest was observed in light textured soils (12per cent).

More and Kausadikar (2003) reported that 24.54 per cent soil samples in Maharashtra as deficient in DTPA-Fe. They also noted that the soils in marathwada were more prone to its deficiency (35 per cent) and deficient soil samples were highest in Nanded (27per cent) and lowest in Aurangabad and Jalna district.

2.1.3 Exchangeable iron

Rai and Shuman (1978) analyzed deep black soils samples and reported that exchangeable iron ranged from 0.6 to 8.8 ppm.

Dhage and Pawar (1985) reported that exchangeable iron ranged from 0.8 to 3.4 ppm with a mean value of 2.7 ppm in central farm soils of Mahatma Phule Krishi Vidyapeeth, Rahuri.

Yerriswamy *et al*. (1996) analyzed the soil sample from Vertisols of Karnataka and reported that exchangeable iron ranged from 2.2 to 5.4 mg kg^{-1} and it increased with depth in all the soil series.

Yelvikar *et al*. (1996) studied exchangeable iron in deep black soils collected from Bhir district and reported that it varied from 1.25 to 4.06 mg kg^{-1} with an average value 1.92 mg kg^{-1}.

2.1.4 Reducible iron

Choudhari and Pande (1979) observed the reducible iron in surface and subsurface soils of Rajasthan, which ranged from traces to 185 ppm.

Yelvikar *et al*. (1996) reported that reducible iron content in deep, medium and shallow black soils which ranged from 1.10 to 3.31 mg kg^{-1} with a mean value 1.79 mg kg^{-1}, 0.92 to 3.84 mg $kg^{-1}$with a mean value 1.60 mg kg^{-1} and 0.43 to 5.79 mg kg^{-1} with a mean value 1.44 mg kg^{-1}, respectively.

2.1.5 Dilute acid soluble iron

Sharma and Yadav (1984) observed that 0.1 N HCL soluble iron in arid soils of Rajasthan, ranged from 0.88 to 3.13 per cent with mean value of 1.31 per cent.

Kulkarni *et al*. (1991) used different extractants for iron, in Vertisols of Malapuabha project and reported that 0.1 N HCl extractable from content ranged from 3.5 to 6.4 ppm.

2.1.6 Water soluble iron

Mitra and Mandal (1983) studied that the water soluble iron in alluvial soils of west Bengal and reported that all the soils under dry soil conditions found to contain almost nil amount of Ferrous iron in water soluble form.

Singh *et al.* (1990) determined various forms of iron in alluvial, basinal, undifferentiated and dunal plain soils of Haryana and showed that water soluble iron ranged from 1.0 to 2.6 ppm with an average 1.8 ppm.

Yelvikar *et al*.(1996) reported that water soluble iron ranged from 0.80 to 1.29, 0.48 to 1.0, 0.23 to 3.70 mg kg^{-1} with a mean value 0.91, 0.63, 0.89 mg kg^{-1} in deep, medium and shallow black soils, respectively.

2.2 Iron fertilizer use efficiency and factors affecting it

Hajime (1979) revealed that role of ferrous iron in the development of paddy soil profile, an attempt was made to clarify the characteristics of ferrous iron forms in relation to genetic soil types and to identify the changes in ferrous iron forms during the oxidation-reduction process in paddy soils.

Reed *et al*. (1988) reported that ability of leaves to absorb nutrients contained in Fe-chelates depends on the molecular mass of a complex, the uptake of nutrients from a complex of high molecular mass is more difficult. The addition of urea to the application solutions significantly decreased leaf carotenoid content, but had no effect on chlorophyll a + b content in French bean.

Kortessa and Vassilios (2003) revealed that effects of $FeCl_3$, Fe-EDDHA and Fe-EDTA as iron sources at 5 and 6 ppm, as well as their combined effect with the auxins, IBA and a-NAA on rooting capacity and total peroxidase activity of three Citrus rootstocks (*Swingle_Citrumelo, C. taiwanica, and C. aurantium*) in vitro.

Felipe *et al*. (2003) revealed that the Iron chelates analogous to ethylenediamino-di(o-hydroxyphenyl) acetic acid (EDDHA), EDDH4A and EDDH5A are the fertilizers chosen to treat iron chlorosis of crops grown on calcareous soils. The result shows that all of the chelates tested were sufficiently stable in most soil and nutrient solution conditions.

Singh *et al.* (2004) studied the efficiency of different iron sources including polyolefin resin coated slow release Fe fertilizer (PRCCFe) and the results showed that the application of iron 75per cent through pyrite + 25per cent polyolefin resin coated slow release Fe fertilizer produced the highest grain yield of wheat.

Ibrahim and Kharaman (2004) reported that the leaf Fe concentration of strawberry increased continuously with repeated foliar Fe application from both sources. Regarding leaf Fe concentrations, it was seen that the effect of $FeSO_4$. 7 H_2O on leaf Fe concentrations was higher than that of Fe-EDTA.

Morikawa and Saigusa (2004) conducted an experiment to find an efficient method for ameliorating Fe deficiency in two rice cultivars (cv. *Tsukinohikari_and_cv._Sasanishiki*) grown in a calcareous soil (pH 9.2, $CaC0_3$ 384 g kg^{-I}), which was poor in organic matter and available Fe.

Alvarez and Sonia (2004) reported that the effectiveness of commercial EDDHA/Fe^{3+} and EDDHMA/Fe^{3+} fertilizers to correct iron chlorosis in three different crops (sunflower, peach and pear) was more due to increase in Fe concentration, chlorophyll content.

Goos and Brian (2004) studied the response of soybean to several inorganic and organic Fe sources applied alone or coated with organic polymers and the results showed that the increase in leaf chlorophyll content and dry matter productions with FeEDDHA or polymer coated mixture of ferrous sulfate, ammonium sulfate, citric acid.

Zhengqian (2006) studied the influence of three types of decomposing fresh organic materials [pig manure (PM), Astagalus sinicus (AS), and Alternanthera philoxeroides (AP)] on dissolution of Fe_2O_3 and also the use of a loamy calcareous soil as an alternative source of iron (Fe) and reported that the maximum level of solution Fe resulting from the decomposition of three organic materials were 20, 612 and 348 mg l^{-1} for PM, AS and AP, respectively.

Wang and Cai (2006) conducted an experiment by using Slag alone or acidified slag was added to two Fe-deficient calcareous soils at different rates. Results showed that moderate rates (10 and 20g kg^{-1}) of slag or acidified slag substantially increased corn dry matter yield and Fe uptake.

Tsipouridis *et al.* (2006) reported that Fe-EDDHA and $FeSO_4.7H_2O$ + organic matter, applied as soil drench, significantly increased the chlorophyll concentration in leaves of Katerina plant even up to 120 days after application.

Chandra *et al* (2009) reported that the slow-release iron fertilizer in the form of goethite [FeO(OH)]–H_3 PO_4 and [FeO(OH)]–MgO–H_3 PO_4 , The compound is water insoluble, and is based on a polymeric phosphate structure. A significant increase in the yield of wheat and uptake of iron was observed at a dosage of 2 kg ha^{-1} Fe as the slow-release fertilizer.

Patel *et al.* (2009) revealed that the combined applications of inorganic and organic sources as well as micronutrients were found effective in overall growth, yield and quality of okra as that of inorganic fertilizers. The result showed that earlier fifty per cent flowering and the maximum plant height were noted under the treatment of 100 per cent RDF + $FeSO_4$ at 50 kg ha^{-1}.

Piotr and Koota (2009) reported that effect of four chelates, differing in percentage of Fe content and the kind of Fe bonding ligand: Fe 8 Forte (EDTA+

HEEDTA), Fe 9 Premium (DTPA), Fe 13 Top (EDTA), on the state of iron nutrition of F_1 cultivar greenhouse tomato grown traditionally in peat substrate.

Sarfaraz and Ahemad (2010) reported that the leaf chlorophyll was increased significantly by adding Fe to the peach trees. Also tree received 5ppm NAA×60ppm Fe significantly gave the highest leaf chlorophyll (a) content. The interactions of NAA× Fe showed a significant increase in chlorophyll.

Gohari and Seyyed (2010) reported that the effects of iron fertilizers on yield and yield components of peanut (*Arachis hypogaea* L.). The results showed that maximum pod and seed yield values of 2916 and 1828kg ha^{-1}, respectively were recorded for the 4.5g l^{-1} iron fertilizer treatment.

Edward and Michaek (2011) reported that effectiveness of foliar fertilization of French bean with 3 inorganic iron salts [$FeSO_4 \cdot 7H_2O$, $FeCl_3 \cdot 6H_2O$, $Fe(NO_3)_3 \cdot 9H_2O$] and 2 organic iron salts [Fe-Citrate, Fe-EDTA] applied with and without the addition of 0.5per cent $CO(NH_2)_2$. Result showed that the application of inorganic iron salts and Fe-Citrate were significantly increased in the number of nodules formed on the bean roots and their weight in French bean.

Jahangir *et al.* (2012) studied the effect of microcapsules coated with ethylene vinyl acetate (EVA) polymer by dip coating method and concluded that the combination of matrix type formulation and the coating with EVA polymer caused a significant decrease in the release rate of iron.

Raziyeh and Shahram (2013) conducted an experiment with soil and foliar application of different iron fertilizer i.e. $FeSO_4$, Fe-EDDHA, Fe-EDTA and nano iron fertilizer in spathyphyllum illusion. The result indicated that the nano iron fertilizer is superior to other sources.

Hamideh and Jamshid (2013) reported that Fe fertilization increased antioxidant enzymes activities and chlorophylls contents, yield, yield components and the grain quality of wheat, however, application of nano iron oxide was more effective than other sources and rates of other iron fertilizers.

Fahad *et al.* (2014) reported that effect of $FeSO_4$ on growth, flower yield and quality of gladiolus cv. Traderhorn. Application of the $FeSO_4$ significantly increased plant height, leaf chlorophyll content, flower stalk length, flower fresh weight, spike length, florets per spike, florets, fresh weight and diameter flower, fresh weight of corms. Leaf number and days to spike emergence were only influenced by a combined application of all the three micronutrients.

Prasad *et al.* (2014) studied the effect of organic and inorganic sources of nutrients on yield and economics of black gram. The result indicated that application of 100 per cent RDF + Fe (N:P:K- 20:30:15 kg ha^{-1} + $FeSO_4$ 5 kg ha^{-1}) were recorded significantly highest plant height (34.18 cm), dry matter (10.31 g $plant^{-1}$), leaf area index (2.216), number of pods (32.38 $plant^{-1}$), number of seeds (6.88 pod^{-1}), seed yield (870 kg ha^{-1}), straw yield (1843 kg ha^{-1}), biological yield (2713 kg ha^{-1}), harvest index (32.10per cent), gross return (50975), net return (34930 ha^{-1}) and B-C ratio (3.18).

Davarpanah *et al.* (2014) reported that the foliar application of Fe-EDDHA and its effect on yield and some quantitative and qualitative characteristics of pomegranate. Results show that 2000 mg l^{-1} of foliar iron concentration have statistically differences with control on Yield, Fruit Number, Fruit size, Total soluble solids (TSS).

Zahra and Hassan (2014) conducted an experiment with four concentrations of iron chelate (10, 50, 100 and 250 ppm) and four concentrations of nano-iron chelate (10, 50, 100 and 250 ppm). Result showed that the Chlorophyll a and total chlorophyll (a + b) in nano-iron chelate treatment was lower compared with Fe-EDDHA treatments in green gram.

Mohammad *et al*. (2014) revealed that the Nano-Fe Foliar application at tillering + stem elongation and at tillering had 9.17per cent and 5.19per cent more grain yield, respectively, compared to foliar application of Fe at stem elongation. Increasing Nano-Fe concentration, increased wheat yield and yield components. In this study, spraying with concentrations of 4per cent produced maximum grain yield, with no significant differences found between 4 and 6per cent concentrations. Foliar application of Fe at 2per cent, 4per cent and 6per cent produced an increase of 12per cent, 22.09per cent and 19.07per cent grain yield.

Saeideh and Khalesi (2015) reported that effect of nano iron chelate and Fe-EDDHA chelate on saffron. Treatments included iron fertilizer at two levels of application of nano iron chelate fertilizer and iron chelate fertilizer with base of EDDHA and the second agent was amount of fertilizer at three levels of 0, 5 and 10 kg ha^{-1}. The results showed that nano-based iron fertilizer is more effective than micro and 5 kg ha^{-1} application of this fertilizer is superior to 10 kg ha^{-1}.

Baligar *et al*. (2015) reported that effects of five iron sources iron sulfate heptahydrate, ferric ethylenediamine ferric diethylenetriamin epentaacetic acid, ($FeSO_4.7H_2O$, FeEDDHA, FeDTPA, FeEDTA,) at 10 mg Fe kg^{-1} on growth, photosynthesis, content of photosynthetic pigments and starch and macro- and micronutrient nutrition of cacao. The various iron sources had significant effects on shoot and root dry biomass accumulation, leaf chlorophyll a and b content, carotenoid levels, SPAD index.

Hadi *et al*. (2015) reported that iron and zinc fertilizers increased the tubers weight and the tubers number weight ratio ($P < 0.01$). Also, results showed that the effects of Fe and Zn fertilizers application in irrigation water was more significant ($P < 0.01$) than by spray application. In addition, application of Fe and Zn fertilizers resulted in higher concentrations of these ions in the harvested tubers improving their nutritional values.

Kamble *et al*. (2015) reported that the soil application of 20 kg $FeSO_4$ ha^{-1} or four sprays of 1per cent $FeSO_4$ along with RDF to turmeric can be recommended for getting the highest yield, monetary benefits and maintaining soil fertility.

2.3 Fertilizer use efficiency of iron in fertilizers combinations

Yadav and Patel (2002) conducted an experiments comprising four level of $FeSO_4$ (0, 2, 4, 6 kg Fe ha^{-1}). Result indicated that the seed and stover yield of mungbean increased with 4 kg Fe ha^{-1}.

Pervaiz and Hussain (2003) reported that application of $FeSO_4$ 5 kg ha^{-1} gave an increase of 14per cent in wheat grain.

Kumawat and Rathore (2006) reported that foliar application of 0.5per cent $FeSO_4$ + 0.1per cent citric acid at both branching and flowering responded more than those that received treatment at either branching or flowering For best results, it is suggested to use 25.0 kg $FeSO_4$ ha^{-1} in a basal application along with 40 kg S ha^{-1}, as plants require most of their S and Fe at the early growth stages.

Caliskan and Ozkaya (2007) that the application of starter and top dressed N in combination with two split FeEDTA fertilization (0,200,400 g ha^{-1}) can be beneficial to improve early growth and final yield of inoculated soybean in Mediterranean-type soils.

Amanda (2009) revealed that foliar and seed applied Fe fertilizers can reduce the incidence of Fe chlorosis under irrigated soybean production. The seed-applied chelated Fe fertilizer increased yields by approximately 60per cent for both tolerant and susceptible varieties.

Abbas and Khan (2009) reported that the application of $FeSO_4$ showed a significant response to wheat at lower rate. High rates of Fe reduced the growth and yield contributing parameters of crop. The best results were obtained when applied Fe 12 Kg ha^{-1} with recommended NPK.

Mazahrynya *et al.* (2010) showed that adding iron nano oxide in soil increased iron concentration, this increase in concentration in a real shoots was observed in 5 kg treatment and 10 kg ha^{-1} treatment showed a significant increase yield as compared to control.

Yadav *et al.* (2011) recorded that the application of iron and zinc enriched with organics (FYM and Vermicompost) with two levels of recommended dose of nitrogen and phosphorus (RDNP), increased both grain as well as biomass yield of the wheat by 2.3 to 6.6per cent as compared to direct and by 5.6 to 10.3per cent as compared to no application of the micronutrients..

Seher and Atilla (2011) reported role of soil and foliar-applied Fe fertilizers in improving shoot and grain Fe concentration in durum wheat (*Triticum durum*).The results showed that the grain Fe concentration increased due to foliar Fe fertilization when Fe fertilizers were sprayed together with 1per cent urea.

Yuan *et al.* (2012) reported the effect of Fe foliar application on rice plants and found that Fe concentration in plants was improved by 14.5per cent. They also found an improvement in grain yield, protein content and total amino acid content in rice.

Amuamuha *et al.* (2012) studied the effect of different concentrations of iron nanoparticles (1, 2 and 3 g l^{-1}) on marigold in three growth stages of stem elongation, flowering and after harvest, and reported that the highest flower yield and essential oil percentage were achieved when 1 g l^{-1} iron nano particles was applied at stem elongation stage.

Hosinkhani *et al.* (2013) conducted an experiment to evaluate the effect of Fe foliar application at stem elongation and 50per cent flowering stage of wheat and reported that the biologic yield was the highest when the foliar application was conducted at the stem elongation stage.

Sunil and Shankaralingappa (2014) reported that the application of RDF + FYM + $FeSO_4$ recorded significantly higher growth, yield parameters and yield as compared to RDF + FYM + IWM practices in rice.

Zhang and Dong (2014) reported that sodium nitroprusside (SNP) was used to supply Nitric oxide for hydroponic peanut plants. After 18 days, the peanut seedlings growing without iron exhibited significant leaf interveinal chlorosis, and this iron-deficiency induced symptom was completely prevented by Nitric oxide.

Hamdi *et al*. (2014) reported that the effects of foliar Fe-sulfate fertilization in Fe-deficient, chlorotic leaves were minor outside the leaf surface treated, indicating that Fe mobility within the leaf is a major constraint for full fertilizer effectiveness in crops where Fe-deficiency is established and leaf chlorosis occurs.

Meral *et al*. (2015) reported that the application of Fe-EDTA (10^{-4} M) increased the plant growth, photosynthesis rate and leaf area index of mandarin.

Chopde and Maske (2015) studied the effect of foliar application of $FeSO_4$ (0.5per cent, 0.5per cent, 0.6per cent) and results revealed that the foliar application of 0.4per cent iron recorded maximum vegetative growth and yield of gladiolus.

2.4 Effect of application of iron fertilizer combinations on soil micronutrient availability and plant content

Ghasemi *et al.* (2002) reported that application of Fe-EDDHA significantly increased soybean shoot Fe concentration and uptake but decreased shoot Mn concentration by 91per cent.Transportation of Fe and Mn from roots to shoots affected by antagonistic effects of these elements and thus it differ from the uptake by roots from the soil.

Erdal *et al*. (2003) concluded that foliar application of $FeSO_4$ in strawberry cultivars had negative impact on leaf Mn and especially Ca concentration and the mechanism of this response.

Erdal *et al.* (2004) studied on the effect of foliar Fe applications ($FeSO_4.7H_2O$ and Fe-EDTA) at different growth stages on Fe and some nutrient concentrations in strawberry. The results showed that the leaf Fe concentration of strawberry increased continuously with repeated foliar Fe application from both sources. Although the leaf Fe and Zn concentrations increased with foliar Fe applications, leaf P, K and Mg concentrations did not significantly affect, but leaf Ca and Mn concentrations were negatively affected by foliar Fe applications.

Soheil and Ghorban (2011) reported that iron fertilizer had significant effects on the other elements concentration in grain and root. The fertilizer treatment increased the micronutrients concentrated higher in roots compared to shoots.

Irmak *et al*. (2012) studied the Soil and foliar Fe application affected the copper content of peanut. There were negative correlations between Fe application and Cu contents of leaf and grain samples collected in two years. Increasing Fe application decreased the Cu content of leaf and grain.

2.5 Effect of application of iron fertilizer combinations on growth and yield of crops

Hussain and Khan (1989) reported that foliar application of Fe in the form of ferrous ammonium citrate at 0.1 per cent at 30, 60 and 75 DAT resulted in significant improvement in the plant height of chilli.

Al-Kanh and Abdulla (2009) studied the effects of amounts of inorganic (FeSO4.7H2O) and chelated (Fe-EDTA) iron fertilizers. The results showed that the grain yield of corn increased with increasing the amount of $FeSO_4.7H_2O$ and Fe-EDTA applied.

Seilsepour and Nadim (2007) stated that effect of Fe is significant on quantitative and quality parameters of winter wheat. Results showed that foliar application of Fe increased grain yield and protein content.

Abu-Dahi and Khan (2009) reported that interaction between 120 kg K ha^{-1} soil and foliar application with concentration of 100 ppm Fe improved chlorophyll content. The foliar application with the combination of 100 ppm Fe gave highest plant height and flag leaf area.

Safyan (2012) reported that foliar application of $FeSO_4$ (3 ppm) increased on corn grain yield 30per cent as compared to control. Also total content of grain's carbohydrates, starch, Indole acetic acid and protein was increased by foliar application $FeSO_4$.

Rawashden and Sala (2014) reported influence of foliar application of Fe-chelate on growth and physiological parameters of wheat at various growth stage. Results showed that foliar application of Fe significantly increased and improved the plant height, number of plants per square meter, flag leaf area and flag leaf chlorophyll content as compared to without Fe application.

Armin and Haderssin (2014) found that foliar application of Nano-Fe fertilizer had a significant effect on tillers number, seeds per spike, grain yield, biological yield and thousand grains weight of wheat.

Razaeiy and Shoman (2014) investigated the effect of iron nano chelated fertilizers foliar application on three wheat cultivars. Results showed that effect of iron nano chelate foliar application, wheat cultivars and interaction of them had significant effects on spike number, grain per spike, 1000 grain weight, biological yield and harvest index compared to control.

Durgude and Kadam (2014) investigated the effect of soil and foliar application of iron on nutrient uptake and iron availability in soil and yield of bulb onion. Result showed that the highest onion bulb yield (28.11 Mg ha^{-1}) was obtained under the treatment soil application of $FeSO_4$ @ 20 kg ha^{-1} on Entisol.

Saravaiyahad *et al*. (2014) reported that the significantly maximum plant height (131.73 cm), number of branches plant^{-1} (5.81), fresh weight of plants (25.65 t ha^{-1}), dry matter yield of plants (7670.03 kg ha^{-1}), maximum days to last picking (166.68), number of fruits plant^{-1} (34.26), fruit length (5.52 cm), fruit diameter (4.64 cm), fruit volume (67.53 cm^3), single fruit weight (49.20 g), fruit weight plant^{-1} of tomato were obtained with the foliar treatment of Fe fertilizers.

Bakhtiari *et al*. (2015) reported the response of wheat growth, yield and quality to iron nanoparticles spraying. Among the Fe concentrations, the highest values of spike weight (666.96 g), 1000 grain weight (37.96 g), biologic yield (8895.0 kg/ha), grain yield (3776.5) and protein content (16.44per cent) were obtained in 0.04per cent Fe concentration and the lowest values were obtained in the control treatment.

Davarpanah and Akabri (2014) reported the foliar application of Fe-EDDHA and its effect on yield and some quantitative and qualitative characteristics of Iranian pomegranate. Results showed that 2000 mg l^{-1} of foliar iron concentration have statistically differences with controls on Yield, Fruit Number, Fruit size, Total soluble solids (TSS).

Rezapour and Torhan (2015) carried out a trial on corn to study the effect of foliar application of nano-iron oxide on grain yield production and seed set of corn and observed foliar application of nano Fe_3O_4 fertilizer significantly increased phytase activity and iron concentrations in corn seed.

2. 6 Factor affecting the availability of iron in soil

2.6.1 Soil reaction

Thompson and Troeh (1973) reported that solubility of ferric and ferrous iron are much higher at low pH than at high pH. Iron compounds, including

$Fe(OH)_3$ and $Fe(OH)_2$, have low solubility and can be precipitated at high pH because OH^- ions become more abundant when the pH rises. One of the hazards of over liming a soil is the precipitation of previously mobile iron and the resulting lime-induced chlorosis.

Gotoh and Patrick (1974) revealed that redox potential and soil pH increases, the availability of iron in soil solution to plants decreases. The critical redox potential for Fe^{+2} reductions is between +300 mV and +100 mV at pH 6 and 7, and -100 mV at pH 8.

Lindsay and Nowell (1978) revealed that the Solubility of Fe is highly pH dependent and the activities of Fe^{+3} and Fe^{+2} decrease by 1000-fold and 100-fold respectively, for each unit increase in pH. Under alkaline conditions Fe^{+2} is oxidized to Fe^{3+},which is relatively unavailable to plants and precipitates as Ferric oxide (Fe^{+2}), whose solubility is extremely low 10^{-38} M.

Zeaid and Siader (2012) revealed that the mobility of iron in aqueous systems is dependent on the redox potential and pH of the environment. Under reducing conditions, ferrous iron predominates and is generally relatively soluble up to near pH 8.

2.6.2 Soil moisture

Ponnamperuma (1972) reported that the oxidation potential Increases with increasing aeration and thus increased oxidation potential leads to conversion of Fe^{2+} to Fe^{3+} and thus decreases its availability.

Chaney (1984) concluded that the high soil moisture has a strong effect on Fe chlorosis through its effect on plant metabolism. Also, excess irrigation or prolonged wet periods result in Fe chlorosis particularly in dicot with Strategy I type, as a result of building up of HCO_3 in calcareous soils.

Zaharieva and Romheld (1991) concluded that the relationship between H/OH ion release and Fe nutrition of groundnut plants is complex under soil conditions and depends on soil parameters including $CaCO_3$ contents and that even by enhanced H^+ release Fe nutrition could be impaired if soils $CaCO_3$ is too high.

2.6.3 Lime content in the soil

Sutaria and Patel (1987) concluded that the concentration and uptake of Fe by pea plants was reduced with increased lime. High free lime content significantly decreased the pod and haulm yields of groundnut due Fe chlorosis. The critical levels of total $CaCO_3$ in soil was 20 -25per cent and 10per cent for free $CaCO_3$ (active lime).

Lopez and Jimenez (1985) concluded that Chlorosis is often a useful indicator of iron content or its activity in avocado leaves. Increased chlorosis was related to decreased leaf Fe, chlorophyll, and catalase activity of young leaves when avocado seedlings were grown in increasing levels of $CaCO_3$ in soil (5 to 30per cent).

Bloom and Inskeep (1988) revealed the High HCO_3 concentrations decrease the availability of Fe in calcareous soils.

Hashemimajd and Golchin (2009) concluded that in calcareous soils the application of mineral iron fertilizer was not usually fully effective in curing iron deficiency as compared to organic chelates.

Farida and Khan (2013) reported that the soil salinity is one of the major limiting factors of soybean production in semiarid regions, and chloride salinity has a more depressive effect on yield than sulphate salinity. The goal of nutrient management is to maximize soybean productivity while minimizing environmental consequences.

2.6.4 Organic matter

Bodek *et al.* (1988) concluded that distribution of extractable iron in soil depends on the presence of organic matter. Iron forms metal chelates with organic matter. Soil humic acid strongly adsorbs or complexes with iron at pH > 3.

Wallace and Lunt (1991) revealed that heavy manuring in alkaline soils reduces the availability of Fe as it is strongiy adsorbed on the surface of organic matter, but on decomposing it is slowly supplied to the plant.

Mandal and Verman (2013) revealed that the presence of organic matter in the soil promotes the availability of iron. The contribution of organic matter to micronutrient iron binding is highest when the predominant clay mineral is kaolinte.

2.7 Response of soybean for different iron fertilizer combination

Goos and Johnson (2000) studied the foliar application of FeEDTA and FeEDDHA on seed yield of soybean. Result showed that the significant increase in seed yield of soybean with FeEDTA treatment but seed treatment with FeEDDHA did not.

Kumawat *et al*. (2009) reported that soil applied $FeSO_4$ (25.0 kg ha^{-1}) significantly improved accumulation of dry matter, grain and biological yields of soybean by 66.6 and 41.9 per cent respectively, over control.

Roghayyeh and Mohammad (2010) revealed that effect of nano-iron oxide on soybean yield and quality. Results showed that nano-iron oxide at the concentration of 0.75 g l^{-1} was increased leaf + pod dry weight and pod dry weight. The highest grain yield was observed with using 0.5 g l^{-1} nano-iron oxide that showed 48per cent increase in grain yield in comparison with control.

Moosavi and Ronaghi (2011) reported the effect of soil and foliar applications of Fe and Mn on yield and Fe-Mn status of soybean plant. Results showed that soil or foliar application of Fe or Mn did not influence soybean root or shoot dry matter yield (SDMY). Both soil and foliar applications of Fe significant increased shoot Fe concentration and uptake.

Pooladvand *et al.* (2012) reported that application of $FeSO_4$ increased seed production, nodule formation and the number of pods and leaves in soybean. However, higher concentrations of $FeSO_4$ reduced nodules and leaf numbers. It was also observed that antioxidant enzymes activity in roots and shoots gradually increased with an increase in $FeSO_4$ concentration.

Vahid *et al.* (2010) reported the effects of iron on the yield of soybean. It was found that iron application at 50 kg ha^{-1} resulted in highest number of pods (37.37) and pods weight per plant (23.81 g) while, the lowest number of pods per plant (33.61) and pods weight per plant (21.93 g) were recorded when no iron was applied.

Trivedi *et al.* (2011) reported the effect of iron application on growth and yield of soybean. Two levels of iron (15 and 20 mg kg^{-1} soil) and was applied as split dose application on soybean var PK-327 individually and in combination. Positive effect of iron application was observed on different investigated parameters *viz*., shoot height, root length, number of leaves $plant^{-1}$, chlorophyll content, leaf nitrogen content, number of pods $plant^{-1}$, length of pods, growth analyses parameters, 100 seed weight and seed protein content.

Ronaghi (2011) studied the influence of foliar and soil applications of iron and manganese on soybean dry matter, yield and iron-manganese relationship in a calcareous soil. Results showed that both soil and foliar applications of Fe significantly increased shoot Fe concentration and uptake. However, foliar application was more effective. Foliar spray of 1 per cent $FeSO_4$ improved plant Fe content and had no effect on (SDMY) shoot dry matter yield or on shoot Mn concentration.

Faisal *et al.* (2013) reported response of soybean to iron. Results indicated that iron applied at the rate of 400 g ha^{-1} had a significant effect on shoot length; shoot dry weight, number of nodules $plant^{-1}$, nodules fresh weight and thousand seed weight. of 400 g ha^{-1}.

CHAPTER – III

MATERIAL AND METHODS

The details of the material used and methods adopted during the course of investigation entitled “studies on improvement in fertilizer use efficiency of iron fertilizer in Vertisol.” are presented below under different heads and subheads.

3.1 Materials

3.1.1 Location and climate

A pot culture experiment was conducted in *Kharif* season of 2015 at Department of Soil Science and Agricultural Chemistry, College of Agriculture, VNMKV, Parbhani.

Geographically, Parbhani district is situated within the Godavari drainage basin in the central part of India between 76^{o}46’ East longitude and 19^{0}16’ North latitude having elevation of 408.46 m above the mean sea level. The main rivers flowing in the district are Godavari, Purna and Dudhana. The Parbhani district falls under semi-arid tropical climate and assured rainfall zone.

The average annual precipitation of Parbhani is 830mm mostly concentrated during the monsoon month of July and August. The annual maximum temperature ranges from 29.5^{o} C to 41.1^{o}C and minimum from 21.1^{o}C to 24.5^{o}C in the month of May and December, respectively. The mean minimum and maximum relative humidity varies between 25 to 63 per cent and 85 to 96 per cent, respectively.

3.1.2 Soil and their mineralogy

The major soils of the Parbhani district are derived from “Deccan trap” rock (basalt) which is rich in iron, lime and magnesium. On the basis of morphology, soil depth and texture, soil belongs to Parbhani series

(*Typic Haplusterts*) as classified by Malewar (1977). The mineralogical studies as carried the Parbhani series constitute bulk of iron, along with augite, epidote, chlorite, hornblende, tourmaline, pyrite, pyroxenes, feldspar, quartz and muscovite. The soils are invariably dominant in Montmorilonite followed by moderate amount of Kaolinite and traces of Illite.

3.1.3 Experimental site

A pot culture experiment was conducted at Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vasantrao Naik Marathwada Krishi Vidhyapeeth, Parbhani. The experimental soils is characterized by deep black color (Malewar, 1976) dominated by montmorilonite clay with high coefficient of expansion and shrinkage in summer which leads to deep cracking.

Table no. 1. Weekly weather data for the year 2015 at Parbhani

Week	Period	Rainfall (mm)	R.D.	Temperature ^{o}C		Humidity (%)	
				Max.	Min.	AM	PM
28	09-15 July	0.0	0.0	36.2	25.8	69	37
29	16-22 July	0.6	0.0	35.8	24.8	76	45
30	23-29 July	8.0	1.0	34.0	24.0	75	47
31	30-05 Aug	19.8	1.0	33.0	23.1	80	59
32	06-12 Aug	28.8	4.0	29.9	23.0	87	68
33	13-19 Aug	23.4	2.0	31.3	23.0	85	57
34	20-26 Aug	11.2	1.0	32.9	23.0	81	49
35	27-02 Sept	0.0	0.0	32.2	23.3	79	50
36	03-09 Sep	88.1	4.0	32.9	22.2	87	60
37	10-16 Sep	38.4	4.0	31.8	22.7	90	63
38	17-23 Sep	57.4	1.0	31.4	22.0	81	59
39	24-30 Sep	0.0	0.0	33.5	20.9	74	44
40	01-07 Oct.	1.8	0.0	34.3	20.9	75	44
41	08-14 Oct.	0.0	0.0	35.1	19.4	73	32
42	15-21 Oct.	0.0	0.0	35.7	18.3	70	29
43	22-28 Oct.	0.0	0.0	35.1	19.5	70	31
44	29-04 Nov.	0.0	0.0	33.0	18.9	75	36
45	05-11 Nov.	0.0	0.0	34.0	16.9	68	25
46	12-18 Nov.	0.0	0.0	33.6	14.3	75	23
47	19-25 Nov.	0.0	0.0	32.1	18.4	78	36

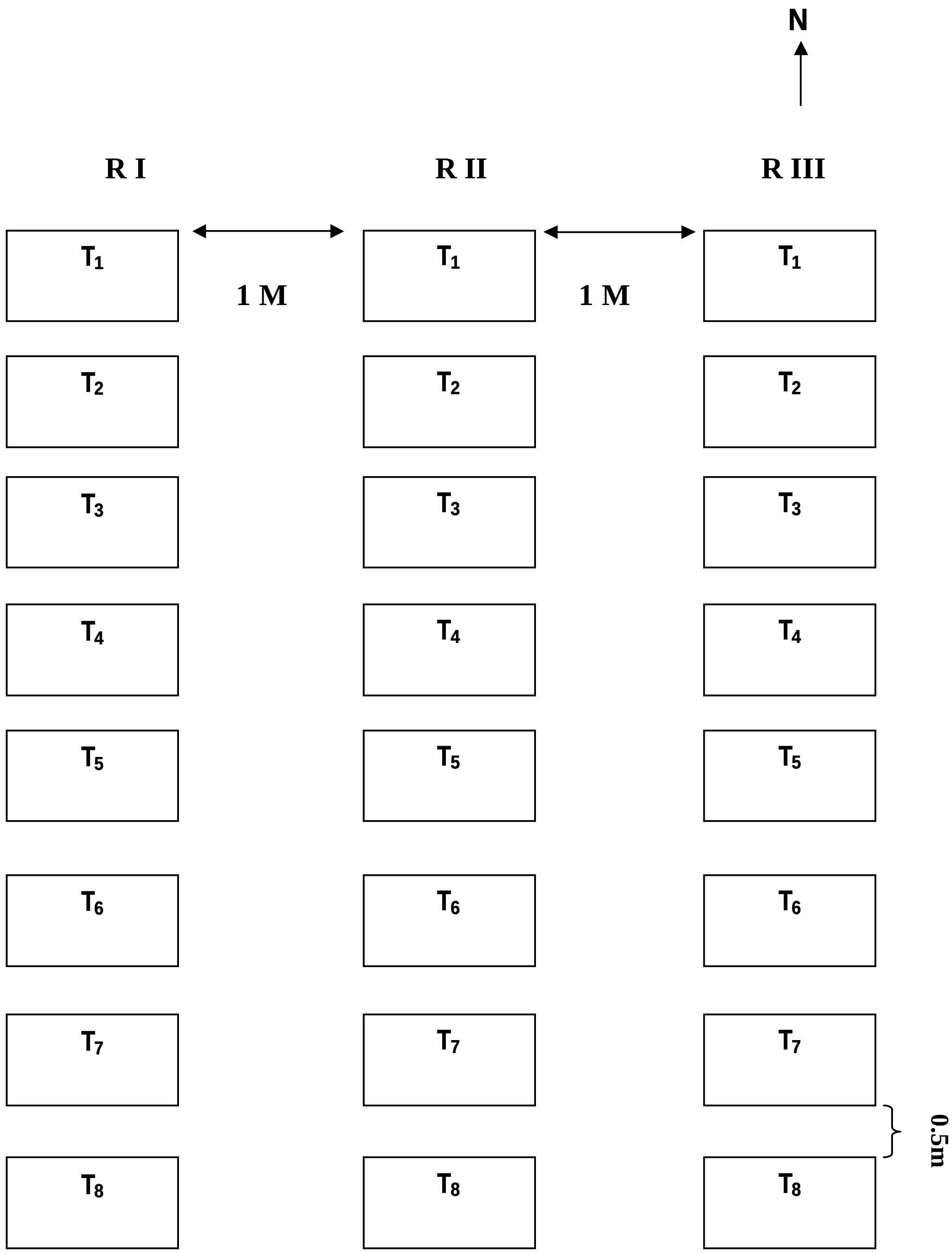

Fig 1: PLAN OF LAYOUT

Table 2. Physico-chemical properties of experimental soil taken for pot culture experiment.

Sr. No.	Particular	Composition
A.	**Mechanical composition**	
1.	Course sand (%)	6.02
2.	Fine sand (%)	12.65
3.	Silt (%)	25.75
4.	Clay (%)	55.58
5.	Textural class	Clayey
B.	**Chemical composition**	
1.	Soil pH	8.14
2.	Electrical conductivity (dSm^{-1})	0.32
3.	Organic carbon (%)	0.44
4.	Free calcium carbonate (%)	5.12
9.	DTPA extractable Fe (mg kg^{-1})	3.55
10.	DTPA extractable Mn (mg kg^{-1})	4.14
11.	DTPA extractable Zn (mg kg^{-1})	0.28
12.	DTPA extractable Cu (mg kg^{-1})	1.32
13.	Exchangeable Fe (mg kg^{-1})	1.11
14.	Water soluble Fe (mg kg^{-1})	0.13
15.	Dilute acid soluble Fe (mg kg^{-1})	2.10
16.	Reducible Fe (mg kg^{-1})	1.25

3.2 Experimental details

This pot culture experiment was laid out by using completely randomized design (CRD) with three replications and eight treatments.

3.2.1 Experimental details

1. Season : Kharif: 2015-16
2. Crop : Soybean
3. Variety : MAUS-71
4. Pot capacity : 12 kg
5. Design of experiment plot : CRD
6. Replications : 3
7. Treatments : 8
8. Method of Sowing : Dibbling

Table 3. Details of treatments.

Sr. No.	Treatment
T_1	Absolute control
T_2	RDF only
T_3	RDF + $FeSO_4$ (foliar) 3 sprays 0.5% (50 gm in 10 lit water).
T_4	RDF + $FeSO_4$ @20kg ha^{-1} + Vermicompost @40kg ha^{-1}
T_5	RDF + Fe-EDTA (Soil application @2.5 kg ha^{-1})
T_6	RDF + $FeSO_4$ @20kg ha^{-1} + DAP @40kg ha^{-1}
T_7	RDF + $FeSO_4$ @20kg ha^{-1} + 10:26:26 @40kg ha^{-1}
T_8	RDF + $FeSO_4$ @20kg ha^{-1} +Urea @40kg ha^{-1}

Where, RDF = 30:60:30:20 Kg NPKS per ha^{-1}

All fertilizers were given at the time of sowing.

3.3 Sowing and fertilizers application

The Soybean was sown by dibbling method with five to six seed per pot. N, P, K and S @ 30:60:30:20 kg ha^{-1} were applied through urea (46%), Diammonium phosphate (18 %), Murate of potash (60%), Elemental Sulpher (20%), $FeSO_4$ @20kg/ha, Fe-EDTA @2.5 kg ha^{-1} and Vermicompost @40kg ha^{-1} as per treatment.

3.4 Soil analysis

3.4.1 Collection and preparation of soil samples

Soil samples were collected from each pot at harvest stage of soybean. The collected soil samples were thoroughly mixed and brought to the laboratory, air dried, ground with wooden mortar and pestle and sieved through 2 mm sieve, for analyzing pH, EC, Organic carbon, Calcium carbonate, DTPA extractable soil micronutrients and iron fractions (Exchangeable Fe, Water soluble Fe, Dilute acid soluble Fe and Reducible Fe). The sieved samples were stored in polythene bags with proper labeling for subsequent analysis. All the precaution were followed in the estimation of particularly A.R. grade chemicals, uncontaminated glassware's and use of double distilled water as suggested by Jackson (1973).The initial soil sample was collected and analysed for their physical and chemical properties are presented in Table 2.

3.5 Chemical properties

3.5.1 Soil pH

It was determined in 1:2.5 soil water suspensions using digital pH meter (Jackson, 1973).

3.5.2 Electrical conductivity

It was estimated in 1:2.5 soil water suspension using conductivity bridge (Jackson, 1973).

3.5.3 Organic carbon

It was assessed by Walkely and Black's rapid titration method as described by Piper (1966).

3.5.4 Free Calcium carbonate

The free calcium carbonate was determined by rapid titration method as outlined by Jackson (1973).

3.5.5 DTPA extractable micronutrients viz., Fe, Mn, Zn and Cu

It was extracted with DTPA and determined by using AAS (Lindsay and Norvell, 1978).

3.5.6 Iron fractions (Jackson, 1973)

3.5.6.1 Exchangeable Fe

1. Transfer 25 gm of soil in 500 ml conical flask.
2. Add 250 ml of 1 N NH4OAC (neutral)
3. The suspension is shaken vigorously for 20-30 sec. and filter through filter paper
4. The filtrate containing exchangeable Fe is freed of NH_4OAC by evaporation on electric hot plate
5. The last traces of organic matter are removed by add 10 ml of Aauq regia (triacid mixture of nitric acid, sulphuric acid and perchloric acid in the proportion of 10:1:4.
6. Add 2 ml of 10% hydroxyl amine hydrochloride and 1 ml of 1.5% orthophenthroline solution.
7. This solution is made up to volume with distilled water
8. Read in spectrophotometer with light of 490 µu.

3.5.6.2 Dilute acid soluble Fe (Jackson, 1973)

1. Take 25 gm of soil in 500 ml conical flask
2. Add 250 ml of 1 N NH_4OAC (pH 3)
3. The suspension is shaken vigorously for 20-30 sec. and filter through filter paper
4. The filtrate containing exchangeable Fe is freed of NH_4OAC by evaporation on electric hot plate
5. The last traces of organic matter are removed by add 10 ml of Aauq regia (10:1:4)
6. Add 2 ml of 10% hydroxyl amine hydrochloride and 1 ml of 1.5% orthophenthroline solution.
7. This solution is made up to volume with distilled water
8. Read in spectrophotometer with light of 490 µu.

3.5.6.3 Water soluble (Jackson, 1973)

1. Take 25 gm of soil in 500 ml conical flask
2. Add 250 ml distilled water
3. The suspension is shaken by a mechanical shaker for 30 min
4. Mixture is filter through whatman no. 5 filter paper
5. Filtrate is evaporated to dryness the organic matter is destroyed
6. Add 2 ml of 10% hydroxyl amine hydrochloride and 1 ml of 1.5% orthophenthroline solution.
7. This solution is made up to volume with distilled water
8. Read in spectrophotometer with light of 490 µu.

3.5.6.4 Reducible Fe (Jackson, 1973)

1. Take 10 gm soil in 250 ml conical flask
2. Add 1 N NH_4OAC (pH 3)
3. Shake on 30 min on mechanical shaker
4. Filter through what no. 5 filter paper
5. Add 20 ml concentrate HCl to filtrate
6. The filtrate is evaporated to dryness on hot plate
7. Add 2 ml of 10% hydroxyl amine hydrochloride and 1 ml of 1.5% orthophenthroline solution.
8. This solution is made up to volume with distilled water
9. Read in spectrophotometer with light of 490 µu.

3.6 Plant analysis

3.6.1 Collection and preparation of plant samples

The treatment wise plant samples of soybean were collected. The plants were cleaned by rubbing with cloth followed by rinsing with detergent followed by 0.02 N. HCl followed by distilled water. After cleaning the plant, they were air dried and oven drying and grinded in an electrically operated stainless steel blades grinder up to maximum fineness. The grind samples were stored in polythene bags with proper labeling for chemical analysis.

3.7.2 Digestion

1 g of fine powdered plant sample was taken in 100 ml conical flask and 5 ml concentrated nitric acid added to it and kept for overnight. On the next day, 10 ml of diacid mixture (HNO_3 and $HClO_4$ in 9:4) was added and digested on hot plate as described by Piper (1966). After digestion, known

volume was prepared with glass distilled water and filtered used for the estimation of, Fe, Zn, Cu and Mn.

3.8 Total micronutrients (Cu, Fe, Mn and Zn)

It was determined by using plant digestion obtained from digestion of HNO_3 and $HCLO_4$ and measurements were taken on an Atomic Absorption spectrophotometer as described by Lindsay and Norvell (1978).

3.9 Biometric observations

Observations on the crop characteristics indicating growth of the crop i.e. plant height at interval of 30, 60 and 90 DAS, number of branches per plant, pod per plant and nodules per plant were recoreded.

3.9.1 Height of plant

The plants height was measured from the base of plant i.e. from ground level to the base of last fully opened leaf at the apex. Observations on plant height at 30, 60, 90 DAS and at harvest of crop was recorded.

3.9.2 Number of branches per plant

Total number of branches per plant were counted and recorded**.**

3.9.3 Pods per Plant

Soybean plants were selected for each observation from each pot. After removing the root and counts the number of pods per plant.

3.9.4 Number of nodules per plant

The uprooted plants were washed and bold nodules per plant were separated and counted and expressed on average basis.

3.10 Grain yield

The crop was harvested net pot wise and grain yield was obtained and expressed on gm pot^{-1}.

3.11 Fertilizer use efficiency of iron fertilizer

Fertilizer use efficiency was calculated as the increase in yield of the harvested portion of the crop per unit area of fertilizer applied (Rehman and Farukh 2011)

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

3.12 Statistical analysis and interpretation of data

The data emerged out from the field experiment were analyzed by analysis of variance and degree of freedom were partitioned into different variance due to replication and treatment combinations. The standard errors (SE) for the treatment were calculated based on error variance when ever, the results were, and critical differences (CD) were calculated for comparison of treatment means at 1 per cent level of significance. Results were statistically analyzed as per the methods given by Panse and Sukhatme (1985).

CHAPTER- IV

RESULTS AND DISCUSSION

The present investigation entitled "Studies on improvement in fertilizer use efficiency of iron fertilizer in Vertisol", was carried out at Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani during the year 2015-2016. There were eight treatments and three replications. The experiment was fitted in completely randomized design (CRD) and conducted during *Kharif* 2015. The result of present investigation are presented, interprited and discussed in this chapter under following appropriate heads and subheads.

4.1. Effect of application of iron fertilizer combinations on physico-chemical properties of soil after harvest of Soybean.

4.1.1 Soil pH

4.1.2 Soil EC

4.1.3 Organic carbon content (%)

4.1.4 Calcium carbonate (%)

4.2. Effect of application of iron fertilizer combinations on Soybean

4.2.1 Plant height of Soybean

4.2.2 Number of nodules per plant of Soybean

4.2.3 Pod per plant

4.2.4 Number of branches per plant

4.3 Effect of application of iron fertilizer combinations on DTPA-micronutrients in soil after harvest of soybean

4.3.1 DTPA-Fe

4.3.2 DTPA-Zn

4.3.3 DTPA-Cu

4.3.4 DTPA-Mn

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

4.4.1 Plant Fe

4.4.2 Plant Zn

4.4.3 Plant Cu

4.4.4 Plant Mn

4.5 Effect of application of iron fertilizer combinations on iron fractions in soil after harvest of Soybean

4.5.1 Exchangeable Fe

4.5.2 Water soluble Fe

4.5.3 Dilute acid soluble Fe

4.5.4 Reducible Fe

4.6 Effect of application of iron fertilizers on yield and fertilizer use efficiency of iron fertilizers of Soybean

4.6.1 Yield of soybean

4.6.2 Fertilizer use efficiency

4.1 Effect of application of iron fertilizer combinations on pH, EC, Organic carbon, $CaCO_3$ of soil at harvest stage of Soybean.

4.1.1 Soil pH

The data pertaining to soil pH is reported in Table 3. The initial soil pH value was 8.14. The range of soil pH at harvest stage of soybean in different treatments was varied from 7.78 to 7.97. The soil pH value did not influence significantly due to application of different iron fertilizer combinations.

4.1.2 Electrical conductivity

The data on electrical conductivity of soil at harvest stage of soybean is reported in Table 3. The initial value of electrical conductivity of soil was 0.32 dSm^{-1} and it was observed that, the electrical conductivity of soil varied from 0.30 to 0.35 dSm^{-1}. The value of electrical conductivity in soil did not influence significantly due to application of iron fertilizer combinations.

4.1.3 Organic carbon

The data on organic carbon content in soil after harvest of soybean is furnished in Table 3. The initial value of organic carbon in soil was 0.44 per cent, the organic carbon content in soil varied from 0.55 to 0.73 per cent. The significantly highest organic carbon content at harvest stage (0.73 per) cent was observed in soil 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).

4.1.4 Calcium carbonate

The data on calcium carbonate content in soil after harvest of soybean is presented in Table 3. The initial value of calcium carbonate was 5.12 %, the calcium carbonate content was varied from 4.43 to 4.98 per cent. The value of calcium carbonate in soil did not influence significantly due to application of iron fertilizer combinations.

Table 3. 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

4.2.1 Effect of application of iron fertilizer combinations on plant height (cm) of soybean

The plant height of soybean was significantly influenced due to application iron fertilizer combinations (Table 4 and Fig. 2.) The data indicated that, the maximum plant height (28.66, 33.29, 34.66 and 37.30 cm at 30, 60, 90 and at harvest, 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} and minimum plant height was noticed in treatment (T_1) control (19.55 cm). The positive effect of iron on soybean growth may be due to optimal $FeSO_4$ concentration would have been sufficient to satisfy the basic requirements for cell division and differentiation indicating that $FeSO_4$ is one of the factor controlling the induction and growth of shoots.

Chopde and Maske (2015) reported that the iron applied with proper concentration acts as an important catalyst in the enzymatic reaction of metabolism. This ultimately would have helped in larger biosynthesis of photoassymilates, thereby enhanced vegetative growth of plant. The results were also in conformity with the findings of Samira *et al.* (2015) in tomato. The lowest plant height was recorded under treatment (T_1) control. This might be due to low soil available macro and micronutrients status and ultimately less uptake of nutrient. Similar observations were recorded by Rajamani and Shanmuga sundaram (2014).

Table 4. 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

4.2.2. Effect of application of iron fertilizer combinations on number of nodules per plant of soybean

Data reported in Table 5 and Fig.3 indicated that, the influence of iron fertilizer combinations on number of nodules per plant of soybean was significantly influenced due to variation in combination of treatments and it was ranged from 10.41 to 14.33 at 40 DAS and 12.46 to 16.60 nodule $plant^{-1}$ at 80 DAS. Highest nodules per plant (14.33 and 16.60 at 40, 80 DAS, respectively) were recorded in treatment T_8- $FeSO_4$ @20kg/ha +Urea @40kg ha^{-1} and it was at par with treatment T_7- $FeSO_4$ @20kg/ha + 10:26:26 @40kg ha^{-1}. The lowest nodules were observed in control (T_1) and only RDF treatments. The increased number of nodule of soybean with soil application of $FeSO_4$ may be due to the iron is necessary for leghaemoglobin biosynthesis. Similar results were close in conformity with Somayeh and Ghorbanil (2013) in soybean.

Table 5. Effect of application of iron fertilizer combinations on number of nodules per plant of Soybean

Treatments	Nodules plant^{-1}	
	40	**80**
T_1- Control	10.41	12.46
T_2- Only RDF	11.09	13.70
T_3- RDF + $FeSO_4$ foliar 0.5% (50 gm 10 lit water).	12.44	14.50
T_4- RDF + $FeSO_4$ @20kg/ha+ Vermicompost @40kg ha^{-1}	12.56	14.66
T_5- RDF + Fe-EDTA (Soil application @2.5 kg ha^{-1})	13.19	15.11
T_6- RDF + $FeSO_4$ @20kg/ha + DAP @40kg ha^{-1}	11.15	13.81
T_7- RDF + $FeSO_4$ @20kg/ha + 10:26:26 @40kg ha^{-1}	13.56	15.39
T_8- RDF + $FeSO_4$ @20kg/ha + Urea @40kg ha^{-1}	14.33	16.60
SE(m)	11.29	0.74
CD (0.01)	0.81	2.23

4.2.3 Effect of application of iron fertilizer combinations on number of branches per plant of soybean

Data reported in Table 6 indicated that, the influence of iron fertilizer combinations on number of branches per plant of soybean was significant due to variation in fertilizer combinations and it was ranged from 3.11 to 4.33 branches plant^{-1}. Highest branches per plant (4.33) were recorded in treatment. The lowest number of branches per plant was observed in control (T_1) and only RDF treatments. The increase in number of branches per plant of soybean with soil application of $FeSO_4$ may be due to the greater role of iron in chlorophyll synthesis and other metabolic activities of the plant thereby increased vegetative growth of plant. Similar results were in conformity with Rajamani and Shanmuga sundaram (2014) in black gram and Kamble and Kadam (2014) in turmeric on Vertisol in Maharashtra.

4.2.4 Effect of application of iron fertilizer combinations on number of pods per plant of soybean

Data reported in Table 6 indicated that, the influence of iron fertilizer combinations on number of pods per plant of soybean was significantly influenced due to variation in combination of treatments and it was ranged from 13.15 to 16.32 pods plant^{-1} and highest pods per plant (16.32) were recorded in treatment T_8- $FeSO_4$ @20kg/ha +Urea @40kg ha^{-1} and it was at par with treatment T_7- $FeSO_4$ @20kg/ha+ 10:26:26 @40kg ha^{-1}. The lowest number of pod per plant was observed in control (T_1) and only RDF treatments. The increase in number of pods per plant of soybean with soil application of $FeSO_4$ may be due to the greater role of iron 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) in black gram and Kamble *et al*. (2014) in turmeric on Vertisol in Maharashtra.

Table 6. Effect of application of iron fertilizer combinations on growth parameters viz. pod per plant and number of branches per plant of Soybean

Treatments	**Pods plant^{-1}**	**Branches plant^{-1}**
T_1- Control	13.15	3.11
T_2- Only RDF	13.21	3.20
T_3- RDF + $FeSO_4$ foliar 0.5% (50 gm 10 lit water).	15.22	3.58
T_4- RDF + $FeSO_4$ @20kg/ha + Vermicompost @40kg ha^{-1}	15.68	3.66
T_5- RDF + Fe-EDTA (Soil application @2.5 kg ha^{-1})	15.43	3.73
T_6- RDF + $FeSO_4$ @20kg/ha + DAP @40kg ha^{-1}	14.27	3.20
T_7- RDF + $FeSO_4$ @20kg/ha + 10:26:26 @40kg ha^{-1}	15.88	4.12
T_8- RDF + $FeSO_4$ @20kg/ha + Urea @40kg ha^{-1}	16.32	4.33
SE(m)	0.42	0.28
CD (0.01)	1.27	0.86

4.3 Effect of application of iron fertilizer combinations on DTPA extractable micronutrients in soil at harvest stage of soybean

4.3.1 DTPA - Fe (mg kg^{-1})

The DTPA-Fe status in soil is presented in Table 7. The DTPA Fe content in soil was varied from 3.88 to 5.98 mg kg^{-1} after harvest stage of soybean. The treatment T_8- $FeSO_4$ @20kg/ha +Urea @40kg ha^{-1}showed significantly higher DTPA-Fe content (5.98 mg kg^{-1}) which was at par with treatment T_7- $FeSO_4$ @20kg ha^{-1} + 10:26:26 @40kg ha^{-1}, followed by T_3- $FeSO_4$ (foliar) 0.5% and T_4- $FeSO_4$ @20kg/ha + vermicompost @40kg ha^{-1} and T_5- Fe-EDTA (Soil application @2.5 kg ha^{-1}) which are at par with each other and lowest Fe content was observed in treatment T_1 (control). This may be due to high Nitrogen nutrition increases activity and abundance of Fe transportation in root cell membranes which positively affect roots and shoots transport of Fe. The variation in DTPA-extractable Fe 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. Similar results are also reported by Bahar and Atilla (2011) in wheat and Yadav *et al.* (2011) in wheat on sandy loam soil in Gujarat and Durgude and Kadam (2014) in onion on Entisols in Maharashtra.

4.3.2 DTPA Zn (mg kg^{-1})

The DTPA-Zn status in soil is presented in Table 7. The DTPA Zn content in soil was varied from 0.33 to 0.45 mg kg^{-1} after harvest stage of soybean. The treatment T_8- $FeSO_4$ @20kg/ha +Urea @40kg ha^{-1}showed significantly higher DTPA-Zn content (0.45 mg kg^{-1}) which was at par with treatment T_7- $FeSO_4$ @20kg ha^{-1} + 10:26:26 @40kg ha^{-1}, followed by T_3- $FeSO_4$ (foliar) 0.5% and T_4- $FeSO_4$ @20kg/ha + Vermicompost @40kg ha^{-1} and

T_5- Fe-EDTA (Soil application @2.5 kg ha^{-1}) which are at par with each other and lowest Zn content was observed in treatment T_1 (control). This might be due to improved plant nitrogen status may have also a significant impact on biosynthesis and release of PS from roots by increasing the amount of nitrogenous substances and activity of enzymes contributing to PS biosynthesis, such as nicotinamine and NA-synthease. Similar results are also reported by Mori and Nishizawa (1987). Bahar and Atilla (2011) also reported that enhancement in Fe and Zn concentration in wheat may be due to the synergistic effect of nitrogen on plant growth.

4.3.3 DTPA -Cu (mg kg^{-1})

The DTPA- Cu status in soil is presented in Table 7. The DTPA- Cu content was varied from 1.40 to 1.63 mg kg^{-1} after harvest stage of soybean. The treatment T_8- $FeSO_4$ @20kg/ha +Urea @40kg ha^{-1} showed significantly higher DTPA- copper content (1.63 mg kg^{-1}) which was at par with treatment T_7- $FeSO_4$ @20kg/ha + 10:26:26 @40kg ha^{-1}, followed by T_3- $FeSO_4$ (foliar) 0.5% and T_4- $FeSO_4$ @20kg/ha + vermicompost @40kg ha^{-1} and T_5- Fe-EDTA (Soil application @2.5 kg ha^{-1}) which are at par with each other and the lowest Cu content was observed in treatment T_1 (control). This may be due to increasing Nitrogen supply in the form of nitrate stimulates root uptake and shoot transport of cationic nutrients in order to balance excess anionic charges from uptake and assimilation of nitrate (Kirkby and Knight 1997). Similar results were also reported by Bahar and Atilla (2011) in wheat.

4.3.4 DTPA Mn (mg kg^{-1}).

The available Mn status in soil is presented in Table 7. The available Mn content in soil was varied from 3.38 to 4.11 mg kg^{-1} after harvest stage of soybean. The treatment T_8-$FeSO_4$ @20kg/ha +Urea @40kg ha^{-1} showed significantly higher available Mn content (4.11 mg kg^{-1}) which was at par with treatment T_7- $FeSO_4$ @20kg ha^{-1} + 10:26:26 @40kg ha^{-1}, followed by T_3- $FeSO_4$ (foliar) 0.5% and T_4- $FeSO_4$ @20kg/ha + vermicompost @40kg ha^{-1}

and T_5- Fe-EDTA (Soil application @2.5 kg ha^{-1}) which was at par with each other and lowest Mn content was observed in treatment T_1 (control) and T_2 (only RDF). This 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. Similar results are also reported by Kamble *et al*. (2014) in turmeric on Vertisol in Maharashtra and Bahar and Atilla (2011) in wheat.

Table 7. 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

4.4 Effect of application of iron fertilizer combinations on plant micronutrient content in soybean

4.4.1 Fe concentration in soybean plant

From examination of the data given in Table 8, the Fe content in plant varied from (214 to 312 µg g^{-1}). The significantly highest Fe content was recorded at harvest stage in treatment T_3- $FeSO_4$ (foliar) 0.5% in plant (312 μg.g^{-1}) which was at par with treatment T_8-$FeSO_4$ @20kg/ha +Urea @40kg ha^{-1}and T_5- Fe-EDTA (Soil application @2.5 kg ha^{-1}) over control treatment. 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 Bahar and Atilla (2011) in durum wheat in clay loam texture soil.

4.4.2 Zn concentration in soybean plant

An evaluation of the data given in Table 8, these was increase in concentration of Zn in soybean plant with foliar application of Fe. The Zn content in plant varied from 31.38 to 36.54 μg g^{-}1. The significantly highest Zn content was recorded (36.54 μg g^{-1}) in treatment T_3- $FeSO_4$ (foliar) 0.5% which was at par with the treatment T_8- $FeSO_4$ @20kg/ha +Urea @40kg ha^{-1} and T_5-Fe-EDTA (Soil application @2.5 kg ha^{-1}) over control treatment. 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 enhanced both absorption and transportation of elements. Similar findings were also reported by Raziyeh and Shahram (2013) in Spathyphylum illusion plant and Merhaut and Hamid (2012) in wheat and Bahar and Atilla (2011) in wheat.

4.4.3 Cu concentration in soybean plant

An evaluation of the data given in Table 8, the Cu content at harvest stage of soybean varied from 17.55 to 23.33 μg g^{-1}. The significantly highest Cu content in plant (23.33 μg g^{-1}) was recorded in treatment T_3- $FeSO_4$ (foliar) 0.5% which was at par with treatment T_8 - $FeSO_4$ @20kg/ha + Urea @40kg ha^{-1} and T_5 - Fe-EDTA (Soil application @2.5 kg ha^{-1}) over control treatment. The minimum concentration of Cu (21.17 μg g^{-1}) was reported in treatment T_1 (control). This may be due to application of foliar $FeSO_4$ increasing the effect of photosynthesis and demand for the increase of essential element, auses to enhanced both absorption and transportation of elements.

Similar findings were also reported by Hamid and Yases (2012) in Capsicum annum and Joseph and Yeser (2012) in marigold.

4.4.4 Mn concentration in soybean plant

An evaluation of the data given in Table 8, showed that there was the significant increase in concentration of Mn in soybean plant with foliar application of $FeSO_4$. The plant Mn content varied from 32.48 to 38.60 µg g^1. The maximum Mn content was recorded at harvest stage in treatment T_3-$FeSO_4$ (foliar) 0.5% in plant (38.60µgg^{-1}) which was at par with treatment T_8-$FeSO_4$ @20kg/ha +Urea @40kg ha^{-1} and T_5- Fe-EDTA (Soil application @2.5 kg ha^{-1}) and significantly superior over control treatment. 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 enhanced both absorption and transportation of elements. The similar results also reported by Asch and Joseph (1999) and Al-Yahya and Khan (1995).

Table 8. 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

4.5. Effect of application of iron fertilizer combinations on Iron fractions (mg kg^{-1}) in soil at harvest stage of soybean

4.5.1 Effect of application of iron fertilizer combinations on exchangeable Fe (mg kg^{-1}) in soil at harvest stage of soybean

It is observed from Table 9 that the exchangeable Fe content at harvest stage of soybean varied from 1.10 to 1.98 mg kg^{-1}. The highest exchangeable Fe content in soil (1.98 mg kg^{-1}) 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^{-1} + 10:26:26 @40kg ha^{-1} and significantly superior over control treatment. The minimum concentration of exchangeable Fe (1.10 mg kg^{-1}) was reported in treatment T_1 (control). The higher content of Fe in Vertisol might be due to ferromagnesium minerals of the parent material from which the Vertisol have developed. The values are comparable with the values reported for soils of Marathwada. (Jadhav and Rathod 1978).

4.5.2 Effect of application of iron fertilizer combinations on water soluble Fe (mg kg^{-1}) in soil at harvest stage of soybean

It is observed from Table 9, the water soluble Fe content at harvest stage of soybean varied from 0.11 to 0.92 mg kg^{-1}. The highest water soluble Fe content in soil (0.92 mg kg^{-1}) 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^{-1} + 10:26:26 @40kg ha^{-1}significantly superior over control treatment. The minimum concentration of water soluble Fe (0.11 mg kg^{-1}) was reported in treatment T_1 (control). The higher content of Fe in Vertisol might be due to ferromagnesium minerals of the parent material from which the Vertisol have developed. The values are comparable with the values reported for soils of Marathwada (Jadhav and Rathod 1978), Yelvikar *et al.* (1997).

4.5.3 Effect of application of iron fertilizer combinations on dilute acid soluble Fe (mg kg^{-1}) in soil at harvest stage of soybean.

It is observed from Table 9, the dilute acid soluble Fe content at harvest stage of soybean varied from 2.13 to 3.68 mg kg^{-1}. The highest dilute acid soluble Fe content in soil (3.68 mg kg^{-1}) 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^{-1} + 10:26:26 @40kg ha^{-1}significantly superior over control treatment. The minimum concentration of dilute acid soluble Fe (2.13 mg kg^{1}) was reported in treatment T_1 (control). The higher content of acid soluble Fe in Vertisol might be due to fine texture of soil and high organic carbon content. These findings are accordance with those obtained by Malewar and Randhawa (1978).

4.5.4 Effect of application of iron fertilizer combinations on reducible Fe (mg kg^{-1}) in soil at harvest stage of soybean.

It is observed from Table 9 that the dilute reducible Fe content at harvest stage of soybean varied from 1.36 to 2.87 mg kg^{-1}. The highest reducible Fe content in soil (2.87 mg kg^{-1}) 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^{-1} + 10:26:26 @40kg ha^{-1}significantly superior over control and only RDF treatments. The minimum concentration of reducible Fe (1.36 mg kg^{-1}) was reported in treatment T_1 (control). The higher content of reducible Fe in Vertisol might be due to fine texture of soil and high organic carbon content. These findings are in accordance with those obtained by Malewar and Randhawa (1978).

Table 9. 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

4.6.1 Effect of application of iron fertilizer combinations on soybean yield and fertilizer use efficiency of iron fertilizers

Data reported in Table 10 indicated that, the influence of iron fertilizer combinations on yield of soybean was significantly influenced due to variation in fertilizer combinations and it was ranged from 11.32 to 14.27 gm pot^{-1} and highest grain yield (14.27gm pot^{-1}) was recorded in treatment T_8-$FeSO_4$ @20kg/ha +Urea @40kg $ha^{1}$and it was at par with treatment T_7- $FeSO_4$ @20kg/ha + 10:26:26 @40kg ha^{-1}. The lowest grain yield (11.32gm pot^{-1}) was observed in control (T_1) treatments. This might be due to improving plant nitrogen status may have also a significant impact on biosynthesis and release of PS from roots by increasing the amount of nitrogenous substances and activity of enzymes contributing to PS biosynthesis, such as nicotinamine and NA-synthease. Similar results are also reported by Mori and Nishizawa (1987). Results were also in conformity with the finding of Chibba and Ninada (2007) in fenugreek, Bahar and Atilla (2011) in durum wheat and Sharma and Yadav (2015) in black gram.

4.6.2 Effect of application of iron fertilizer combinations on Fertilizer use efficiency of iron fertilizers

It is observed from Table 10 that the fertilizer use efficiency of iron fertilizers applied to soybean varied from 1.45 to 19.92 %. The significantly highest fertilizer use efficiency (19.92%) was recorded in treatment T_5- Fe-EDTA (Soil application @2.5 kg ha^{-1}). The minimum fertilizer use efficiency (1.45%) was reported in treatment, T_6 (RDF+ $FeSO_4$ @20kg/ha + DAP @40kg ha^{-1}). Where T_8 and T_7 are found at par and also T_3 and T_4 were at par with each other. The highest may be due to organic source carrying material and lowest due to antagonistic effect of Fe and phosphorus present in DAP.

Table 10. 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-EDT(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

Chapter V

SUMMARY AND CONCLUSIONS

5.1 Summary

A pot culture experiment entitled "Studies on improvement in fertilizer use efficiency of iron fertilizer in Vertisol." was conducted during the Kharif 2015 at Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani.

The experiment was designed in completely randomized design with three replications to study effect of iron fertilizers combinations on nutrient availability and fertilizer use efficiency of iron fertilizers to Soybean crop. The treatments compressed of $FeSO_4$ (foliar) 0.5%, $FeSO_4$ @20kg/ha + vermicompost @40kg ha^{-1}, Fe-EDTA (Soil application @2.5 kg ha^{-1}), $FeSO_4$ @20kg/ha + DAP @40kg ha^{-1}, $FeSO_4$ @20kg/ha + 10:26:26 @40kg ha^{-1}, $FeSO_4$ @20kg/ha +Urea @40kg ha^{-1} and applied at the time of sowing. The recommended dose was applied through SSP, DAP, MOP and elemental Sulphur at the time of sowing.

The soybean seed was dibbled in the pot during sowing and thinning was done 15 DAS. The plant and soil sample were collected dried in hot air oven, grind and kept in polythne bag with proper labeling. The soil sample were analyzed for DTPA-micronutrients (Fe, Zn, Cu, Mn), iron fractions and pH, EC, Organic carbon, calcium carbonate. Plant samples were analyzed for plant micronutrients (Fe, Zn, Cu, Mn), height of plant (30, 60, 90 and harvest stage), number of nodules per plant, branches per plant, pod per plant and yield of soybean crop. The results presented, interpreted and discussed in previous chapter are summarized as below.

1. Soil pH, EC, and $CaCO_3$ content of soil at various stages of crop growth were not influenced due to application of different iron fertilizer combinations were statically non –significant.
2. The organic carbon content of soil significantly influenced with application of the iron fertilizer combinations. The treatment T_8-$FeSO_4$ @20kg/ha +Urea @40kg ha^{-1} showed maximum increase in soil organic carbon content at harvest stages of soybean crop.
3. Soybean growth parameter viz., The plant height, number of branches per plant, number of nodules per plant and number of pods per plant growth parameter of soybean were significantly influenced at harvest stage of crop due to application of different iron fertilizer combinations. Maximum plant height, number of leaves per plant, number of nodules per plant and number of pods per plant were recorded with the application of T_8- $FeSO_4$ @20kg/ha +Urea @40kg ha^{-1}. followed by T_7- $FeSO_4$ @20kg/ha + 10:26:26 @40kg ha^{-1}.
4. DTPA-Fe content of soil at harvest stage of soybean was significantly influenced due to application of iron fertilizer combinations. The highest content of DTPA-Fe (5.98 mg kg^{-1}) was recorded at harvest stage with the use of T_8 - ($FeSO_4$ @20kg/ha +Urea @40kg ha^{-1}).
5. The treatment T_8-$FeSO_4$ @20kg/ha +Urea @40kg ha^{-1}showed significantly higher DTPA- Zn content (0.45 mg kg^{-1}) which was at par with treatment T_7- $FeSO_4$ @20kg ha^{-1} + 10:26:26 @40kg ha^{-1} and lowest Zn content was observed in treatment T_1 (control) and T_2 (only RDF).
6. The treatment T_8-$FeSO_4$ @20kg/ha +Urea @40kg ha^{-1} showed significantly higher DTPA - copper content (1.63 mg kg^{-1}) in soil followed by treatment T_7- $FeSO_4$ @20kg/ha + 10:26:26 @40kg ha^{-1} and the lowest Cu content was observed in treatment T_1 (control).

7. The treatment T_8- $FeSO_4$ @20kg/ha +Urea @40kg ha^{-1}showed significantly higher DTPA- Mn content (4.11 mg kg^{-1}) which was at par with treatment T_7- $FeSO_4$ @20kg ha^{-1} + 10:26:26 @40kg ha^{-1}.

8. The Fe content in plant varied from (214 to 312 µg g^{-1}). The significantly highest Fe content was recorded at harvest stage in treatment T_3- $FeSO_4$ (foliar) 0.5% in plant (312 µg g^{-1}). The above values were at par with treatment T_8- $FeSO_4$ @20kg/ha +Urea @40kg $ha^{-1}$and T_5- Fe-EDTA (Soil application @2.5 kg ha^{-1}) and significantly superior over control and only RDF treatments.

9. The Zn content in plant varied from (31.38 to 36.54 µg g^{-}1). The maximum Zn content was recorded (36.54 µg g^{-1}) treatment T_3- $FeSO_4$ (foliar) 0.5%. The above values were at par with treatment T_8- $FeSO_4$ @20kg/ha +Urea @40kg ha^{-1} and T_5- Fe-EDTA (Soil application @2.5 kg ha^{-1}) and significantly superior over rest of the treatments.

10. The Cu content at harvest stage of soybean varied from 17.55 to 23.33 (µg g^{-1}). The highest Cu content in plant (23.33 µg g^{-1}) was recorded in treatment T_3- $FeSO_4$ (foliar) 0.5% which was at par with treatment T_8- $FeSO_4$ @20kg/ha +Urea @40kg ha^{-1} and significantly superior over control and only RDF treatments. The minimum concentration of Cu (17.55 µg g^{-1}) was reported in treatment T_1 (control).

11. The plant Mn content varied from (32.48 to 38.60 µg g^{-1}). The maximum Mn content in plant was recorded at harvest stage in treatment T_3- $FeSO_4$ (foliar) 0.5% in plant (38.60 µg g^{-1}) which was at par with treatment T_8- $FeSO_4$ @20kg/ha +Urea @40kg ha^{-1} and T_5- Fe-EDTA (Soil application @2.5 kg ha^{-1}) significantly superior over control .

12. The influence of iron fertilizer combinations on yield of soybean was significantly influenced due to variation in combination of treatments and it was ranged from 11.32 to 14.27 gm pot^{-1} and highest grain yield (14.27gm pot^{-1}) was recorded in treatment T_8- $FeSO_4$ @20kg/ha +Urea @40kg ha^{-1} and it was at par with T_7- $FeSO_4$ @20kg ha^{-1} + 10:26:26 @40kg ha^{-1}. The lowest grain yield (11.32gm pot^{-1}) was observed in control (T_1) treatments.

13. In case of iron fractions, the exchangeable Fe content at harvest stage of soybean varied from 1.10 to 1.98 mg kg^{-1}. The highest exchangeable Fe content in soil (1.98 mg kg^{-1}) 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^{-1} + 10:26:26 @40kg ha^{-1} and significantly superior over control treatment.

14. The water soluble Fe content at harvest stage of soybean varied from 0.11 to 0.92 mg kg^{-1}. The highest water soluble Fe content in soil (0.92 mg kg^{-1}) 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^{-1} + 10:26:26 @40kg ha^{-1} and significantly superior over control.

15. The dilute acid soluble Fe content at harvest stage of soybean varied from 2.13 to 3.68 mg kg^{-1}. The highest dilute acid soluble Fe content in soil (3.68 mg kg^{-1}) 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^{-1} + 10:26:26 @40kg ha^{-1} and significantly superior over control.

16. The reducible Fe content at harvest stage of soybean varied from 1.36 to 2.87 mg kg^{-1}. The highest reducible Fe content in soil (2.87 mg kg^{-1}) 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^{-1} + 10:26:26 @40kg ha^{-1} and significantly superior over control.

CONCLUSIONS:

From the results summarized as above following conclusions can be are drawn.

- Plant height, number of nodules per plant, no. of branches per plant and number of pod per plant were increased significantly with the application iron fertilizer combinations.
- The Fe, Zn, Cu and Mn content in plant increase significantly increased due to the application of $FeSO_4$ foliar spray 0.5% followed by T_5- Fe-EDTA (Soil application @2.5 kg ha^{-1}) over control.
- DTPA-micronutrients (Fe, Zn, Cu and Mn) in soil increased significantly due to the application of T_8- $FeSO_4$ @20kg/ha +Urea @40kg ha^{-1} followed by T_7- $FeSO_4$ @20kg ha^{-1} + 10:26:26 @40kg ha^{-1} which was at par with each other.
- Application of $FeSO_4$ @20kg/ha +Urea @40kg ha^{-1} increased the grain yield (14.27 gm) of soybean over control and rest of the other fertilizer combinations.
- Application of $FeSO_4$ @20kg/ha +Urea @40kg ha^{-1} increased the concentration of iron fractions (Exchangeable Fe, Water soluble Fe, Dilute acid soluble Fe and Reducible Fe) in soil after harvest of soybean. Which was followed by $FeSO_4$ @20kg ha^{-1} + 10:26:26 @40kg ha^{-1} and $FeSO_4$ @20kg ha^{-1} + 10:26:26 @40kg ha^{-1}.
- The highest Fertilizer use efficiency (19.92) was found in T_5 Fe-EDTA (Soil application @2.5 kg ha^{-1}) followed by $FeSO_4$ @20kg ha^{-1} + 10:26:26 @40kg ha^{-1} (2.75) in $FeSO_4$ @20kg ha^{-1} + 10:26:26 @40kg ha^{-1}.

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