EFFICACY OF SOME IRON CHELATES IN CORRECTION OF CHLOROSIS OF MAIZE AND SORGHUM

A Thesis submitted to the
MAHATMA PHULE KRISHI VIDYAPEETH
(AGRICULTURAL UNIVERSITY)
RAHURI, Dist. Ahmednagar
(Maharashtra State)

in partial fulfilment of the requirements for the degree
of
Master of Science (Agriculture)
in
Agricultural Chemistry

By
Gorakhanath Ramkrishna Shelke
B. Sc. (Agri.) First Class

DEPARTMENT OF AGRICULTURAL CHEMISTRY AND SOIL SCIENCE
Post-Graduate School, Rahuri

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August, 1977

Approved by the Advisory Committee :

1. Chairman and Research guide.	S.Y. Daftardar
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CERTIFICATE

This is to certify that the thesis entitled "Efficacy of some iron chelates in correction of chlorosis of maize and sorghum", submitted to the Faculty of Agriculture, Post-Graduate School, Mahatma Phule Krishi Vidyapeeth, Rahuri, in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE (AGRICULTURE) in AGRICULTURAL CHEMISTRY, embodies the results of a piece of <u>bona fide</u> research carried out by Shri G.R. Shelke, under my guidance and supervision and that no part of the thesis has been submitted for any other degree or publication.

Rahuri,
4th August, 1977.

S.Y. Daftardar

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It is my proud privilege to place on record my sincere and grateful thanks to the members of the Advisory Committee, Dr. G.M. Kende, Head, Department of Agricultural Chemistry and Soil Science, Rahuri and Dr. [illegible] Kapat, Sorghum Breeder, Mahatma Phule Krishi Vidyapeeth, Rahuri.

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Last but never the least, I must admit that words fail me in properly expressing my feelings and gratitude towards my revered parents for encouraging me throughout my educational life.

Rahuri,
Dt. [illegible] August, 1977.

(C.L. [illegible]helke)

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Chapter-1

INTRODUCTION

Iron chlorosis is potentially a problem on most calcareous soils. Possibly a third of the world's land is calcareous at the surface horizon. The severity of the limitation of iron is shown by the reports of failure of crops like sorghum, sugarcane, grapes etc. on the calcareous soils of Maharashtra. Any factor that decreases availability of iron in a soil or competes in the absorption process contributes to iron chlorosis.

Iron deficiency is perhaps the most difficult of all mineral deficiencies to correct. Inorganic forms of iron do not usually correct iron chlorosis unless enormous quantities of iron are applied locally around a tree or shrub. Plant deficiencies of iron usually have been corrected by adding relatively expensive chelates of iron to high value cash-crops. Iron chelates have been effective agents for supplying iron to plants, but high costs preclude their extensive use particularly for grain crops like sorghum. Iron uptake is found to be genetically controlled in some crops like soybean, maize etc. and the solution to the problem lies in selection of plants that can extract iron from the root environment. Use of iron chelates appears as a stopgap measure rather than a permanent solution. Literature shows the utility of some iron chelates like Fe EDTA (iron salt of ethylenediamine tetraacetic acid and FeEDDHA (iron salt of ethylenediamine di (O-hydroxyphenylacetic acid)) for correcting iron deficiencies in crops especially on calcareous soils. But these chelates are not so far manufacture in India and hence are required to be imported. The cost of such imported iron chelates is usually beyond the reach of an average Indian farmer. Our farmers are, therefore, left with no other alternative except to use inorganic salt of iron viz. ferrous sulphate for correction of iron deficiencies of their crops.

In an attempt to study and evaluate cheap and effective source/s of iron for correction of iron-chlorosis, sand culture experiments on maize (*Zea mays*) variety Deccan Double Hybrid and Sorghum (*Sorghum bicolor* (L.) Moench) variety 2077 A were conducted in the laboratory of Agricultural Chemistry and Soil Science Department of Mahatma Phule Krishi Vidyapeeth, Rahuri in 1976-77. The objective of the experiments was to assess the effectiveness of a locally synthesized iron chelate viz. iron humate and three commercially available iron chelates viz. iron oxalate, iron citrate and iron tartarate by comparing them with FeEDTA and $FeSO_4$. For this purpose, effects of these iron sources on the dry matter and iron and chlorophyll contents of maize and sorghum plants grown in sand culture were studied.

Chapter-2

REVIEW OF LITERATURE

2.1 Chlorosis of plants that can be cured by supplying iron to chlorotic plants and hence referred to as "Iron Chlorosis" is not only the oldest known deficiency disease of plants (Gris, 1843, 1844), but is also the most widespread mineral nutritional disorder in the world, especially on the calcareous soils which cover more than one-third area of the world (Brown, 1956; 1961; Wallace and Lunt, 1960). The disorder has been reported from different agroclimatic soil regions of India (Agarwala and Mehrotra, 1963; Kanwar and Randhawa, 1974).

2.2 Factors conducive to iron chlorosis

Iron is abundantly present in the lithosphere, 0.07 % - 4.2 % or more (Jackson, 1964), lack of iron in rooting medium is rarely a cause of iron deficiency (Wallace and Hewitt, 1946). Since iron chlorosis results in serious economic losses to agricultural and horticultural crops the problem has been investigated from various angles, and different facets of the disorders have been discussed by several workers (Thorne, et al. 1950; Brown 1956, 1960, 1961; Brown, et al. 1959; Wallace and Lunt, 1960; Wallace, 1962, 1971; Hewitt, 1963; Little, 1971). The principal factors conducive to iron chlorosis are as under :

1. High $CaCO_3$ in soil
2. High bicarbonate in soil, or irrigation water
3. High levels of heavy metals-Mn, Cu, Zn, etc.
4. Unbalanced cation ratios.

The role of a few factors conducive to iron chlorosis is detailed below on the basis of available literature.

2.2.1 Bicarbonate :

Impetus to HCO_3 investigation was provided by Harley and Linder (1946) who reported that irrigation relatively high in bicarbonates induced chlorosis in apples and pears. In a soil solution the concentration of bicarbonate ion is related to aeration and under given conditions, increases with increasing CO_2 pressure. Reuther and Crawford (1947) and McGeorge (1951) have considered poor soil aeration and poor drainage as factors contributing to lime-induced chlorosis. Poor soil aeration results in decreased partial pressure of oxygen and increased pressure of carbondioxide, thus increasing the concentration of the bicarbonate ion in the soil solution.

Porter and Thorne (1955) were able to demonstrate chlorosis in beans at high bicarbonate levels regardless of the pH of the solution. On the contrary, Brown (1960) did not observe any chlorosis in PI soybeans with addition of 10 me/l of $NaHCO_3$ to the solution culture in the absence of Fe or P. He suggested that the effect of bicarbonate on the development of Fe chlorosis appears to be one which is indirect rather than direct.

2.2.2 Calcium :

Certain plants absorb less Fe and develop Fe chlorosis when comparatively high concentration of calcium is present in the growth medium (McGeorge[(b)], 1949; Thorne et al. 1950 and Vosburgh et al. 1948). High concentrations of calcium in the soil have been thought to be a major causative factor of Fe-Chlorosis (Brown, 1956 and Wallace & Hunt, 1960), but effect of this is difficult to separate from the effect of soil pH on iron availability. Iron was internally inactivated in plants (Brown, et al. 1955) principally from the combined effect of phosphorus and calcium, resulting in the formation of a complex insoluble salt. Calcium must be present in much higher concentration in substrate to interfere with Fe uptake and transport to any great degree. Lingle, et al. (1963) concluded from their experiments that calcium concentration had to exceed 5×10^{-3} M before the concentration of Fe in the exudate was lower than the control.

Calcium may not be a factor in all cases of iron chlorosis because decreased leaf calcium is a characteristic in most cases of iron chlorosis. Synergism between iron and calcium has not been studied to any great extent. The effect of excess calcium in a soil is generally associated with high pH and consequent unavailability of iron (Schock, 1955).

2.2.3 Manganese :

The importance of the ratio of iron to manganese in plant tissues has been pointed out by several workers and data have suggested that a ratio of 1.5 to 2.5 is required for normal growth (Shive, 1941). Twyman (1946) has reported that manganese deficiency symptoms on oats were identical to those of iron toxicity and iron chlorosis has been produced by increasing the manganese levels. Somers and Shive (1942) in a classic paper clearly demonstrated that the manganese/iron ratio was of importance in determining whether soybean plants showed symptoms of chlorosis or appeared healthy, chlorosis appearing when the ratio was either too high (Manganese toxicity) or too low (Manganese deficiency). They further stated that the iron content of plant was higher at a low than at high manganese level in growth media indicating that iron and manganese show reciprocal relationship in absorption. Chapman and Brown (1942) and McCargue (1945) suggested that excess manganese hinders the translocation of iron by rendering iron in the plant into an insoluble form. All these trends suggest interaction between iron and manganese in the development of toxicity or deficiency. However, Tanaka and Navasero (1966) in their experiment on rice could not suggest Fe/Mn ratio as a factor on which development of iron deficiency symptom depends.

Thus iron chlorosis is an outcome of soil factors that reduce its availability to plants or is caused by poor efficiency of the plant for absorption, translocation or utilization of iron. Depending upon the soil factors, iron chlorosis may be qualified as carbonate-induced, bicarbonate-induced, lime-induced, phosphate-induced or heavy metal (Mn, Cu, Zn, Mo, V, Co, N, etc.)-induced

2.3 Diagnosis of iron chlorosis :

a) Iron in tissue and rooting medium :

Evaluation of availability of iron to plants has been quite problematic as neither analysis of "available" iron content of soils (Thorne, 1941; Thorne and Wallace, 1944; Olsen and Carlson, 1949; Gallego and Laborda, 1958; Agarwala and Mehrotra, 1963), nor the tissue content of iron in plants provide any reliable index of iron availability (Mehrotra et al., 1976).

b) Concentration of other nutrient elements :

Iron deficiency, whether true or induced, results in marked changes in the concentration of other nutrient elements and suggestions have been made to use tissue concentration of certain elements (other than iron) as an index of availability of iron to plants. Iron chlorosis is almost always associated with increase of potassium, nitrogen, copper, molybdenum and boron. In most cases the chlorotic leaves also contain higher concentration of zinc, sodium, phosphorus and sulphur than normal green leaves (Mehrotra, et al. 1976).

c) Nutrient ratios :

Several workers have suggested the use of certain nutrient ratios for identifying iron chlorosis. Dekock and his associates (1960) suggest that high K/Ca and P/Fe ratios in plant tissues are suggestive of iron deficiency. Somers and Shive (1942) and O'Sullivan (1969) identified a high Mn/Fe ratio as characteristic of iron chlorosis irrespective of its cause. Mehrotra et al. (1976) suggest that iron deficient plants are always associated with high Cu/Fe ratio and generally a high Zn/Fe ratio may be used as an index of iron deficiency. Gangwar and Mann (1972) observed that zinc application to rice field markedly decreased iron and manganese concentration in plant. Yates and Kruetsch (1973) observed Fe deficiency in two varieties of corn when nutrient solution was supplied with more P (> 22 ppm). But similar results were not observed under field condition when higher rates of P were applied (50-400 kg/ha). Wallace et al. (1976) in their study of comparison of the effects of high levels of DTPA (iron salt of diethylene triamine pentaacetic acid) and EDDHA on micronutrient uptake in Bush-beans observed that both agents resulted in large increases on Fe in shoots. Leaf/stem ratio were increased by DTPA for Co and Ni and to a lesser extent for Fe and Zn indicating some transport through the plants as the metal chelates. Twyman (1946) has reported that manganese deficiency symptoms on oats were identical to those of iron toxicity and iron chlorosis has been produced by increasing the manganese levels.

d) Organic acids :

Plants exhibiting iron chlorosis are reported to show a disturbance in organic acid metabolism which is generally associated with increase in the concentration of citric acid (McGeorge[a], 1949; Iljin, 1951; Rhoades, et al. 1959; Dekock and Morrison, 1958). Dekock and Morrison (1956, 1958) have suggested a high tricarboxylic to dicarboxylic acid ratio in the chlorotic leaves as suggestive of iron deficiency.

e) Nitrogen metabolism :

Several workers have observed that the chlorotic tissue undergoes a major disturbance in nitrogen metabolism, the disorder being generally associated with increased accumulation of amino-acids in the plants showing iron chlorosis (Mehrotra, et 1976).

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Hodgson (1967) has suggested that complexing agents can increase the availability of micronutrients to plants by increasing their mass-flow to roots through the soil. Schnitzer (1969) suggested that fulvic-acid has positive effects on root initiation, which appears to be related to its metal complexing ability. Many workers (Beckwith, 1959; Russell, 1961) found that humic-acid can hold metallic ions in particular iron, in solution. Martin and Reeve (1958) are of the opinion that bond between the metal ion and the humate anion involves complex formation.

2.5 Chelates :

Chelation of metal ions occurring in the vicinity of plant roots plays an important role in supplying nutrients to plants. Were it not for this important phenomenon, most soils would be devoid of plant growth because iron and, in some cases, zinc, copper, and manganese are too insoluble in soils to maintain adequate levels of soluble nutrients.

The primary role of chelating agent is to make the iron water soluble and more accessible to plant root. Wallace (1956) has listed the characteristics that an acceptable chelate must have :

1. The metal (Fe, Zn, Mn or Cu) in the chelate ring must not be easily replaced by other metals.
2. The metal chelate must be stable against hydrolysis.
3. The chelating agent must not be decomposed by soil microorganisms.
4. The metal chelate must be water soluble.
5. The chelate must not be easily fixed in soil.
6. The metal must be available to the plant either at root surface or somewhere in the plant.
7. The chelating agent must be nontoxic to plants in the amounts needed.
8. The metal chelate must be in a form easily applied to soil or to plants.
9. The metal chelate must be inexpensive.

2.6 Stability of metal chelates :

The word chelate comes from the Greek signifying claw and refers to the ring configuration when a metal ion combines with two or more electron donors. There are a large number of chelating agents but the electron donors which bind to the metals are limited to nitrogen, oxygen and sulfur (Stewart and Leonard, 1954). After a chelate is formed, the metal ceases to have its ionic chemical properties. Naturally occurring chelates are citric, tartaric, oxalic and amino acids Some very selective chelates are chlorophyll, a magnesium chelate, and the cytochromes which are very stable iron complexes.

The chelation reaction proceeds according to the law of mass action (Stewart and Leonard, 1954):

Metal ion + chelating agent $\rightleftharpoons$ metal chelate.

$$K = \frac{(\text{Metal chelate})}{(\text{Free metal ion}) \times (\text{chelating agent})}$$

K is the equilibrium constant of the reaction and defines the molar ratio of the metal which occurs in the chelate to the metal in the ionized state. Where K is very large, the metal ion concentration is very small. The K value is commonly referred to as the stability constant of the chelate and will vary depending on the metal, chelating agent, and other factors. Stability constants are usually expressed as the logarithm of the K value, the higher the log K value the more stable is the complex and the lesser the tendency for the complex to yield metal ions.

The properties of chelates vary with pH, for example, above pH 6, the OH^- ion will compete with EDTA for Fe^{+++} until, at about pH 8, EDTA ceases to be a very effective chelate for this metal. Iron chelated in the soil by the above chelates becomes a part of negatively charged anion which makes it less susceptible to conversion to an unavailable form and diminishes the tendency of the iron to be precipitated as an insoluble hydrated iron oxide. The absorption of chelated iron by the plant appears to be governed by those factors which control anion absorption. Iron chelates which exhibit the least tendency to bind hydroxyl ions and have the greatest stability, as measured by the stability constant, are the ones which show the least tendency to dissociate in rooting media (Wall et al. 1957).

Stability diagrams provide a convenient means for representing and interpreting metal chelate equilibria. With the aid of these diagrams, the major consequences of many interdependent equilibria may be visualised and understood quickly.

2.6.1 Stability of individual chelates :

EDTA :

The stability diagram for EDTA is presented in Fig. 1a where mole fraction of EDTA associated with each cation is plotted on a log scale. The plotted values cover the range from 10^{-3} to 10^{0} which is, of course, the range from 0.001 to 1.

EDTA chelates Fe^{3+} almost exclusively below pH 6.3. Competition from Ca^{2+} becomes increasingly important above pH 6 and Ca-chelates predominate above approximately pH 6.8 (Norvell, 1972). These conclusions are in excellent agreement with studies of reactions of EDTA in soils (Hill-Cottingham and Lloyd-Jones, 1957; Lindsay et al. 1967; Norvell and Lindsay, 1969; Wallace et al. 1955).

Mg^{2+} is also a weak competitor for EDTA and Mg-EDTA chelates should not be important in soils unless Ca^{2+} concentrations are severely depressed. The protonated species of EDTA are of much lower stability, and they do not appear within the range of mole fractions plotted (Norvell, 1972).

CITRATE :

The stability diagram for citrate in soil solution is dominated by Al-, Ca-, and Mg- chelates (Fig. 1b). Al-CIT dominates from pH 4 to 6.7 and seriously limits CIT as an effective chelating agent for Fe^{3+}, even under acid soil conditions. Ca-CIT dominates from pH 6.7 to 7.9, but Al-and Mg-species are also important. As Ca^{2+} solubility decreases above pH 7.5, Mg-CIT increases rapidly in importance until it dominates above pH 7.9. The generally low stability of CIT chelates is reflected by the presence of relatively large mole fractions of free ligand. At high pH, the free CIT ligand may be the dominant species in soil solutions (Norvell, 1972).

OXALATE

The stability diagram for OA is presented in Fig. 1c. This diagram is generally similar to the diagram for CIT except that FeOA chelates are not sufficiently stable to appear in the diagram, and the mole fraction of the free ligand rises to relatively high levels even in acid soil solution. OA forms many multi-ligand complexes, and its stability diagram is thus influenced by the total ligand concentration. Fig. 1c is inappropriate for total OA concentrations that differ widely from 10^{-4} M. This is particularly true for very high concentrations (Norvell, 1972).

2.6.2 Summary of Fe-chelate stability :

In a summary stability diagram (Fig. 1d), the ratio of the concentration of chelated-Fe to the concentration of total chelating agent is plotted on a linear scale for several chelates to emphasise the more effective chelates for Fe^{3+}. Both the individual and relative stabilities of the Fe-chelates vary as a function of pH in soil solution. The main limitation to chelation of Fe^{3+} by OA, CIT, NTA (Nitrilotriacetic acid), EGTA (ethylene glycolbisamino ethylether tetraacetate) and HEDTA (Hydroxy ethylethylene diamine triacetic acid) arises from the competition of Al^{3+} and Ca^{2+} with Fe^{3+} for these chelating ligands. Competition

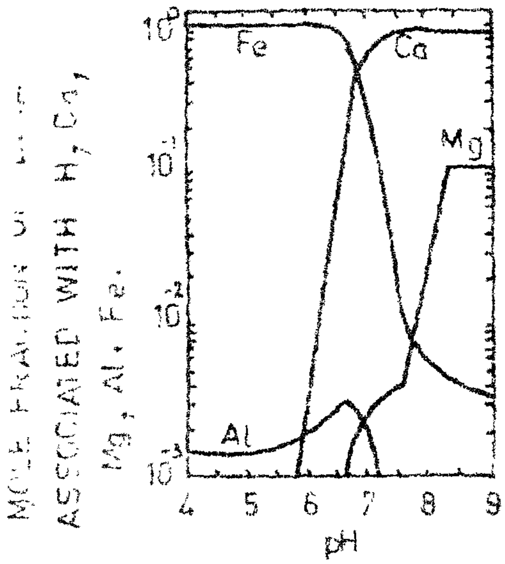

FIG 1A: STABILITY DIAGRAM FOR EDTA IN EQUILIBRIUM WITH H^+, Ca, Mg^{2+}, Al^{3+} AND Fe^{3+} IN SOIL SOLUTION.

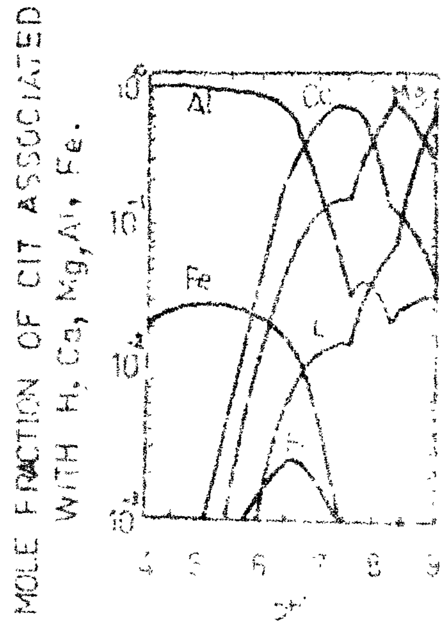

FIG 1B: STABILITY DIAGRAM FOR CIT [illegible] EQUILIBRIUM WITH H^+, Ca^{2+}, Mg^{2+} Al^{3+} AND Fe^{3+} [illegible]

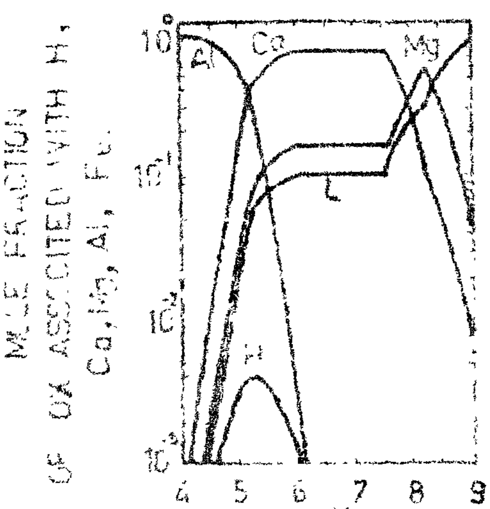

FIG 1C: STABILITY DIAGRAM FOR OX IN EQUILIBRIUM WITH H^+, Ca^{2+}, Mg^{2+}, Al^{3+} AND Fe^{3+} IN SOIL SOLUTION.

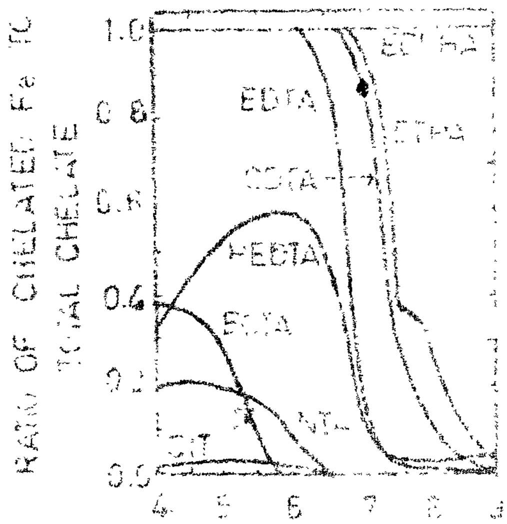

FIG 1D: COMPARISON OF [illegible] STABILITIES IN SOIL SOLUTION. EQUILIBRIUM BETWEEN H^+, Ca Mg^{2+} Al^{3+} AND Fe^{3+} AND [illegible] M CONCENTRATIONS OF EACH CHELATING AGENT [illegible] ASSUME from Ca^{2+} alone significantly limits chelation of Fe^{3+} by EDTA, CDTA (Cyclohexane diamine tetraacetic acid) and DTPA (Diethylene triamine pentaacetic acid) but this does not become important until pH rises above 6 to 7. Among the chelating agents considered, EDDHA is unique because chelation of Fe^{3+} is not seriously limited by competition from H^{+}, Ca^{2+}, Mg^{2+}, or Al^{3+} in the pH range from 4 to 9 (Norvell, 1972).

2.7 Role of chelates near plant root :

The effectiveness of metal chelates as metal carriers in soils depends on the rate of their disappearance from the soil solution, which is related to their stability. Stability diagrams of synthetic metal-chelates in soil solutions under equilibrium conditions (Lindsay and Norvell, 1969; Norvell, 1972) together with experimental data on the disappearance of these compounds from the soil solution (Norvell, 1972; Wallace, 1963; Wallace and Lunt, 1956) provide an adequate basis for understanding their behaviour in soil-water system. Differences among the various iron chelates are of concern principally because of their relative stabilities at high pH values. Thus, FeEDTA is useful in soils that are slightly acid, but in soils above pH 7.0, other iron chelates become increasingly effective in the order Fe HEEDTA (iron salt of hydroxyethyl ethylene diamine triacetate), FeDTPA, and

FeEDDHA. For use in calcareous soils, FeEDDHA is probably to be recommended (Wallihan, et al. 1975).

The greatest benefit from chelates in increasing nutrient availability in soils is believed to be due to their effect on diffusion and mass flow of nutrients in the immediate vicinity of plant roots Elgawhary et al. (1970) demonstrated that chelating agents can increase the diffusion of nutrients by using a stimulated root technique. They showed that chelating agents played an important role in overcoming the rate-limiting steps of solution and diffusion which are largely responsible for the movement of micronutrient cations in soils. Hodgson et al. (1967) showed that 2×10^{-3} citrate acting as chelating agent increased the transport of Zn through agar jel from a $ZnCO_3$ source by 100-fold. The results compare favourably with a theoretical treatment of the solubility and diffussional process involved. O'Connor et al. (1971) showed that addition of FeEDDHA increased the self diffussion of Fe in soils; they also showed that the uptake of Fe by sorghum roots was directly related to total soluble Fe in solution. The evidence is rapidly accumulating that chelating agents provide a means of solubilizing micronutrient cations and that the increased concentration levels provide greater diffusion gradients for the transport of Fe in soils.

The question of whether chelated metal enters the root intact or whether the complex dissociates at the root surface is often asked. Wallace[a] (1963) and Hill-Cottingham and Lloyd-Jones (1965) concluded that both mechanisms are operative. Recently Chaney et al. (1972) proposed that reduction of Fe^{3+} at the root surface is important in making chelated Fe available for absorption.

2.8 Fate of chelates applied to soil

Lahav, and Hochberg (1975 attributed the disappearance of Zn and iron from soil solution after their addition as soluble metal-chelates due to adsorption and fixation. The fixation of iron applied as FeEDTA was found to be a first order reaction. They also observed that FeEDDHA was neither absorbed nor was its iron fixed by the soil to any significant extent.

The effectiveness of chelates may be altered differentially by variation in soil texture. Some metal chelates are fixed irreversibly on the clay in soil while others are not fixed (Wallace and Lunt, 1956).

A few workers have noted deficiency symptoms or decreases in uptake of certain divalent metals when Fe was supplied in chelated form. DeKock and Mitchell (1957) found that divalent metals were absorbed less readily in chelated than in ionic form. Guinn and Joham (1963) observed the effect of FeEDTA and FeHEEDTA in decreasing the uptake of divalent metals such as copper and zinc, may be at least partly due to some of the divalent metals becoming chelated.

2.9 Foliar application :

Iron chelate solutions have also been used as foliar sprays, as have some complexes formulated by adding iron to natural plant products. The principal advantage of these materials over ferrous sulfate lies in a reduced toxicity to plants, thereby making possible the use of higher concentrations. In some cases, concentrations as high as five pounds per hundred gallons have been used satisfactorily, although FeEDTA, FeDTPA and FeHEEDTA are often toxic at this concentration. The value of such sprays depends primarily on the species of plant. For instance, they have been quite successful on eucalyptus and acacia trees, but are of questionable value on citrus and avocado trees (Wallihan, 1975

Singh and Singh (1966) found that application of chelated form of iron Fe-EDTA at the rate of 9 kg/ha in the soil supplemented by the foliar spraying of equivalent amount of citrate or tartarate forms of iron in three sprayings made 80 per cent rice seedlings survive till transplanting as against complete mortality in check plots.

Chapter-3

MATERIAL, METHODS AND EXPERIMENTAL

3.1 Materials :

3.1.1 Sand :

White quartz sand (less than 2 mm) was used after giving repeated washings with 4 per cent hydrochloric acid, 2 per cent NaOH and distilled water until free of chlorides.

3.1.2 Soil :

Noncalcareous black soil (0-20 cm 2 mm, vertisol from Agricultural College Farm (F-Block), Pune-5 was used and its pertinent properties are given in Table 1.

3.1.3 Calcium carbonate :

Naturally occurring calcium carbonate nodules were collected from village Sada, Dist. Ahmednagar, ground, sieved through 2 mm sieve and used for the purpose. It contained 73 % $CaCO_3$ equivalent.

3.1.4 Seeds :

a) Sorghum (Sorghum bicolor (L) Moench :

A male sterile parent (2077 A) of C.S.H.-5 supplied

Table 1. Soil physico-chemical properties of the soil used.

Location :- I Block, College of Agriculture Farm, Pune-5.	
Properties	
Physical properties	
Sand (%)	21.1
Silt (%)	29.4
Clay (%)	49.50
Textural class	Clay
Chemical properties	
pH (H_2O) 1:1	7.4
EC (1:1) mmho/cm at 25°C	0.51
Total nitrogen (%)	0.072
Organic carbon (%)	1.05
$CaCO_3$ equivalent %	0.35
CEC (me/100 g)	49.50
Total iron (ppm)	3200
Available iron (ppm)	1.5

by Sorghum Breeder, Mahatma Phule Krishi Vidyapeeth, Rahuri was used.

b) Maize (*Zea mays*) :

Deccan Double Hybrid variety of maize supplied by the Director of Farms, Mahatma Phule Krishi Vidyapeeth, Rahuri was used.

3.1.5 Iron sources :

The iron sources used in the experiments were ethylenediamine tetraacetic acid-ferric monosodium salt (FeEDTA), Ferrous Sulphate ($FeSO_4$ $7H_2O$) Ferric citrate, ferric tartarate, Ferrous oxalate and iron humate. The details of these compounds are given in Table 2.

3.1.6 F.Y.M. :

Well decomposed FYM (< 2 mm) was used.

3.1.7 Soil culture pots :

Plastic buckets (diameter-27 cm, height-29 cm) of 13-litre capacity were used for pot culture experiment using medium black soil.

3.1.8 Sand culture pots :

Synthetic polythene cylindrical pots of 11-cm diameter and 18-cm height having 1-cm drainage hole at the lowest end of the side were used for the sand culture experiment.

Table 2. The details of iron sources used.

Iron source	Obtained from	Form	Iron content %	Cost of the compound
Ethylenediamine tetraacetic acid-ferric monosodium salt	BDH Chemicals Ltd., Poole England	Powder	11.1	Rs.180/100 g
Ferric citrate	Riedel-Deben Ag Steelze-Hannover	Grannular	1[illegible].0	Rs.96/500 g
Ferric tarterate	Amrut Industrial Products, Bombay	Crystallie	15.0	Rs.40/50 g
Ferrous oxalate	New Modern Chemical Corporation, Bombay	Powder	7.6	Rs.15/500 g
Ferrous sulphate (Analar)	British Drug House Pvt. Ltd., Bombay.	Crystalline	20.5	Rs.15/500 g
Iron humate	Prepared in Laboratory from FYM and iron chloride (Details given in section 3.2.2)	Colloidal suspension in water	20.0	-

3.2 Methods :

3.2.1 Soil analysis :

The soil was analysed by standard methods of analysis as given in Table 3.

Table 3 : Methods used for soil analysis.

Characteristic	Method adopted	Reference
1. Particle size distribution	Bouyoucos hydrometer	Bouyoucos (1962
2. Calcium carbonate equivalent	Pressure calcimeter	Skinner and Halstead (1958)
3. Organic carbon	Walkley Black	Jackson (1958)
4. Total nitrogen	Kjeldahl method	Bremner (1965)
5. CEC and exchangeable cation	Ammonium acetate and sodium acetate	Jackson (1958) Chapman (1965)
6. Soil pH	Potentiometric	Jackson (1958)
7. Electrical conductivity	Conductometric	Jackson (1958)
8. Total iron	Orthophenanthroline	Jackson (1958)
9. Available iron	Olsen and Carlson	Jackson (1958)

3.2.2 Preparation of iron humate :

Iron humate was prepared in the laboratory. Fifty gram of Farm Yard Manure was shaken with 500 ml of 0.5 N NaOH solution in 1-litre plastic bottle for 24 hours. Following centrifugation at 2000 rpm for 10 minutes, the supernatant was decanted and adjusted to pH 2.5 and allowed to stand overnight. The precipitate (humic acid) was separated by centrifugation. To this material 10 per cent ferric chloride was added and shaken in 1-litre plastic bottle for 8 hours. Following the centrifugation at 2000 rpm for 10 minutes the supernatant was transferred to dialysis bags and dialysed exhaustively against distilled water until free of chlorides. Iron humate thus prepared was removed from the bag, made to a volume of 250 ml and Fe content was determined by orthophenanthroline method.

3.2.3 Plant analysis :

a) Preparation of plant sample :

The harvested plants were washed with distilled water, the excess water was blotted with a filter paper. Fresh weights of plant tops as well as plant roots were recorded. The chlorophyll content of the fresh youngest leaf of the plant was determined. The plant material was dried in a forced air oven at 70°C and the dry matter was recorded. The dried samples were ground using a procelain mortar and pestle.

The plant samples were analysed by using standard methods of analysis as given in Table 4.

Table 4. Methods of plant analysis.

Parameter	Method used	Reference
Chlorophyll	Acetone extraction	Arnon, D.A. (1949)
Iron	Orthophenanthroline	Jackson (1958)
Manganese	Potassium metaperiodate	Jackson (1958)

The fresh plants were extracted with acetone and the extract read on Spectronic-20 at 645 and 663 m μ for chlorophyll while the powdered dry plant samples were digested using HNO_3 + $HClO_4$ (5:2) and the extract was used for determination of Fe and Mn (Piper, 1942).

3.2.5 Statistical analysis :

The data on fresh and dry weights of maize plant tops, concentration and uptake of Fe and Mn of plant tops and chlorophyll content of fresh youngest leaf of maize were statistically analysed by analysis of variance method for Completely Randomised Design of the experiment (Cochran and Cox, 1957).

3.3 Experimental :

3.3.1 Solubility of iron sources in modified Hoagland solution

In order to study the solubility of the five chelates in the nutrient solution used for growing maize seedlings

(modified Hoagland solution) an experiment was conducted. The five iron chelates and $FeSO_4$ as an inorganic source for comparison were added to the modified Hoagland solution so as to reach concentration of one millimole of iron per liter of the nutrient solution. Separate portions of the nutrient solution-iron source mixtures were adjusted at the pH values of 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, 7.5, 8.0 and 8.5 by using dilute HCl or NaOH solutions, shaken for two hours on a to and fro shaker and stored in glass bottles for a period of 72 hours. In some of the stored solutions, reddish precipitates were observed. After 72 hours of storage, the supernatant solutions were filtered through Whatman No.42 filter paper and the iron in the filtrates was determined by orthophenanthroline method.

3.3.2 Sand culture experiments

For knowing the efficacy of different iron compounds as a source of Fe to plants three sand culture experiments were carried out. Two experiments with maize as a test crop were carried out from 25th February, 1977 to 17th April, 1977 and 14th April, 1977 to 4th June, 1977 respectively. The experiment with sorghum as the test crop was carried out from 25th February, 1977 to 17th April, 1977.

The cylindrical polythene pots used for the experiments were thoroughly washed with HCl and distilled water. One kg of white quartz sand washed with acid, alkali and distilled water was filled per pot. It stood to a height of 16 cm leaving a 2-cm space at the top of the plot. The drainage hole of the pot was stoppered with a rubber stopper and was used for draining the nutrient solution as well as washings given from time to time during the experiment. The drainage hole was covered from inside with a wad of glass wool to prevent the loss of sand. To each pot 100 ml of distilled water was added to moisten the sand before seeding. By means of a clean glass rod, holes were made in the sand up to a depth of 4 cm for sowing seeds (treated with 96 % alcohol for about 8 hours to prevent subsequent fungal growth.). Six seeds of maize and eight seeds of sorghum were sown per pot and were loosely covered with sand. After germination, a uniform number of five seedlings of maize and six seedlings of sorghum was maintained per pot. The seedlings were watered with distilled water (about 100 ml at three days interval) up to 11 days after sowing. From 12th day onwards 100 ml of modified Hoagland nutrient solution (Johnson et al. 1957) adjusted at pH 5 to 5.1 was added per pot after an interval of 72 hours. The composition of Hoagland nutrient solution used is given in Table 5. The nutrient solution used contained all nutrients except iron. Three such additions of nutrient solution were made. Each time, the nutrient solution in the pot was leached out by removing the stopper and the sand in the pots was washed with distilled water by giving repeated washings before fresh nutrient solution was added.

Table 5. Composition of modified Hoagland solution used.*

Compounds	Volume of stock solution per litre of final solution (ml)	Elements	Final conc. of element (ppm)
KNO_3	6	N	224
$Ca(NO_3)_2\ 4H_2O$	4	K	235
$NH_4\ H_2PO_4$	2	Ca	160
$MgSO_4\ 7H_2O$	1	P	62
		S	32
		Mg	24
KCl	1	Cl	1.77
H_3BO_3	1	B	0.27
$MnSO_4\ H_2O$	1	Mn	0.11
$ZnSO_4\ 7H_2O$	1	Zn	0.131
$CuSO_4\ 5H_2O$	1	Cu	0.032
H_2MoO_4 (85 % MoO_3)	1	Mo	0.05

* Johnson et al. (1957).

Deficiency symptoms of iron such as yellowing of newly thrown leaf started appearing when the plants were three weeks old. Actual treatments of different iron sources were applied from the 21st day onwards as below. The nutrient solution with the iron source was added as per treatment. The washing of sand and addition of nutrient solution was repeated after every seventy two hours. The nutrient solution with iron was thus applied nine times during the 51-days life of the crop. There were seven treatments (Table 6).

Table 6. Details of treatments.

Code		Details
1. Control	...	Modified Hoagland solution (without Fe).
2. $FeSO_4$	...	Modified Hoagland solution (without Fe) + 2.24 ppm Fe from $FeSO_4$.
3. FeEDTA	...	Modified Hoagland solution (without Fe) + 2.24 ppm Fe from FeEDTA.
4. FeOX	...	Modified Hoagland solution (without Fe) + 2.24 ppm Fe from ferrous oxalate.
5. FeCIT	...	Modified Hoagland solution (without Fe) + 2.24 ppm Fe from ferric citrate.
6. Fe-TART	...	Modified Hoagland solution (without Fe)+2.24 ppm Fe from ferric tartarate.
7. FeHUM	...	Modified Hoagland solution (without Fe) + 2.24 ppm Fe from ferric humate.

Each treatment was replicated three times in the case of maize and two times in the case of sorghum. Iron humate was tried for the experiment on maize crop conducted from 19th April, 1977 to 8th ~~May~~ June, 1977. At 51-days of age, plants were harvested.

3.3.2 Pot culture experiment

The noncalcareous medium black soil and calcium carbonate were mixed thoroughly to bring $CaCO_3$ content to 21 per cent by weight. Ten-kg portion of this mixture was placed in each of the seven plastic buckets. Nitrogen in the form of urea, phosphorus in the form of superphosphate and potassium in the form of muriate of potash was added and mixed in top 10-cm layer of soil in each pot to supply N, P and K at the rate of 100, 50, 50 kg/ha. Six-maize seeds were sown per pot to a depth of 4-cm and pots were watered. After germination a uniform number of four plants was maintained in each pot. The pots were watered from time to time as per requirement. The pots were so placed as to receive sunshine only in the morning hours. After about 40-days iron deficiency symptoms such as yellowing of newly thrown leaf started appearing. From 45-days of plant age iron spray was given with the following iron compounds as a source of iron, FeEDTA, $FeSO_4$, FeOX, FeCIT, FeTART and FeHUM. The iron concentration of the spray solution used was 0.5 per cent. Eight sprays were given after every 72 hours. Three days after last spraying the plant tops were harvested and its chlorophyll, Fe and Mn concentration were determined as given in section 3.2.3.

Chapter-4

RESULTS AND DISCUSSION

The results of the five experiments carried out are reported and discussed below in the following sequence :

Experiment 1	:	pH versus solubility of five different chelates used.
Experiment 2	:	Sand culture experiment to study the efficacy of chelates on maize. (25th February, 1977 to 17th April, 1977).
Experiment 3	:	Sand culture experiment to study the efficacy of chelates on maize (14th April, 1977 to 4th June, 1977).
Experiment 4	:	Sand culture experiment to study the efficacy of chelates on sorghum (25th February, 1977 to 17th April, 1977).
Experiment 5	:	Foliar spray trial of chelates on maize grown in calcareous soil (24th March, 1977 to 4th June, 1977).

4.1 Experiment 1 : pH versus solubility of chelates in modified Hoagland solution.

The data on the solubility of the different iron sources at different pH values from 4.5 to 8.5 in modified Hoagland solution are reported in Table 7 and Figure 2. The standard inorganic source viz. $FeSO_4$ lost its solubility with rise in pH from 4.5 to 6.5 and then remained more or less insoluble up to pH 8.5. Among the chelates, FeEDTA was the most soluble source of iron at different pH levels. However, solubility of FeEDTA also gradually decreased with increasing pH from 54.0 ppm at pH 4.5 to 24.5 ppm at pH 8.5. FeCIT recorded the highest soluble iron concentration of 17.6 ppm at pH 6.0, but the solubility decreased fast at pH 6.5 (5 ppm) and then went on decreasing gradually with further rise in pH. The concentration of soluble iron from FeHUM source remained almost steady in a narrow range of 1.6 to 3.6 ppm. The soluble iron from FeOX showed peak solubility of 4.4 ppm at pH of 6.5. The FeTART showed the lowest soluble Fe values of 1.5 and 0.4 ppm at the two extremes of the pH range (4.5 and 8.5 respectively) with a peak of 5.8 ppm at pH 6.0.

It may be mentioned that the term "soluble" iron here includes, ionic, complexed, chelated as well as ion pairs of iron in solution. The EDTA shows a relatively high specificity for Fe^{3+}, and in general, forms metal chelates of high stability (Norvell, 1972). EDTA chelates Fe^{3+} almost exclusively below

Table 7 : Influence of pH on soluble iron measured from different iron sources in modified Hoagland solution.

pH of modified Hoagland solution at the start	Measured soluble iron in modified Hoagland solution (ppm)					
	Iron source					
	FeEDTA	FeCIT	FeOX	FeTART	FeHUM	$FeCO_4$
4.5	55.0	12.5	2.0	1.5	2.4	5.5
5.0	49.5	9.2	2.0	1.5	2.8	4.8
5.5	46.5	11.4	2.4	0.7	2.5	2.2
6.0	46.5	17.6	3.6	5.8	3.6	1.3
6.5	42.0	5.0	4.4	1.4	2.8	0.8
7.0	42.0	4.6	3.0	1.0	2.0	0.8
7.5	36.5	4.2	2.8	0.9	1.6	0.6
8.0	34.5	3.0	2.5	0.6	2.5	0.6
8.5	24.5	2.8	2.0	0.4	3.2	0.6

Fe added through each iron source : 56 ppm (1 millimole/lit.)

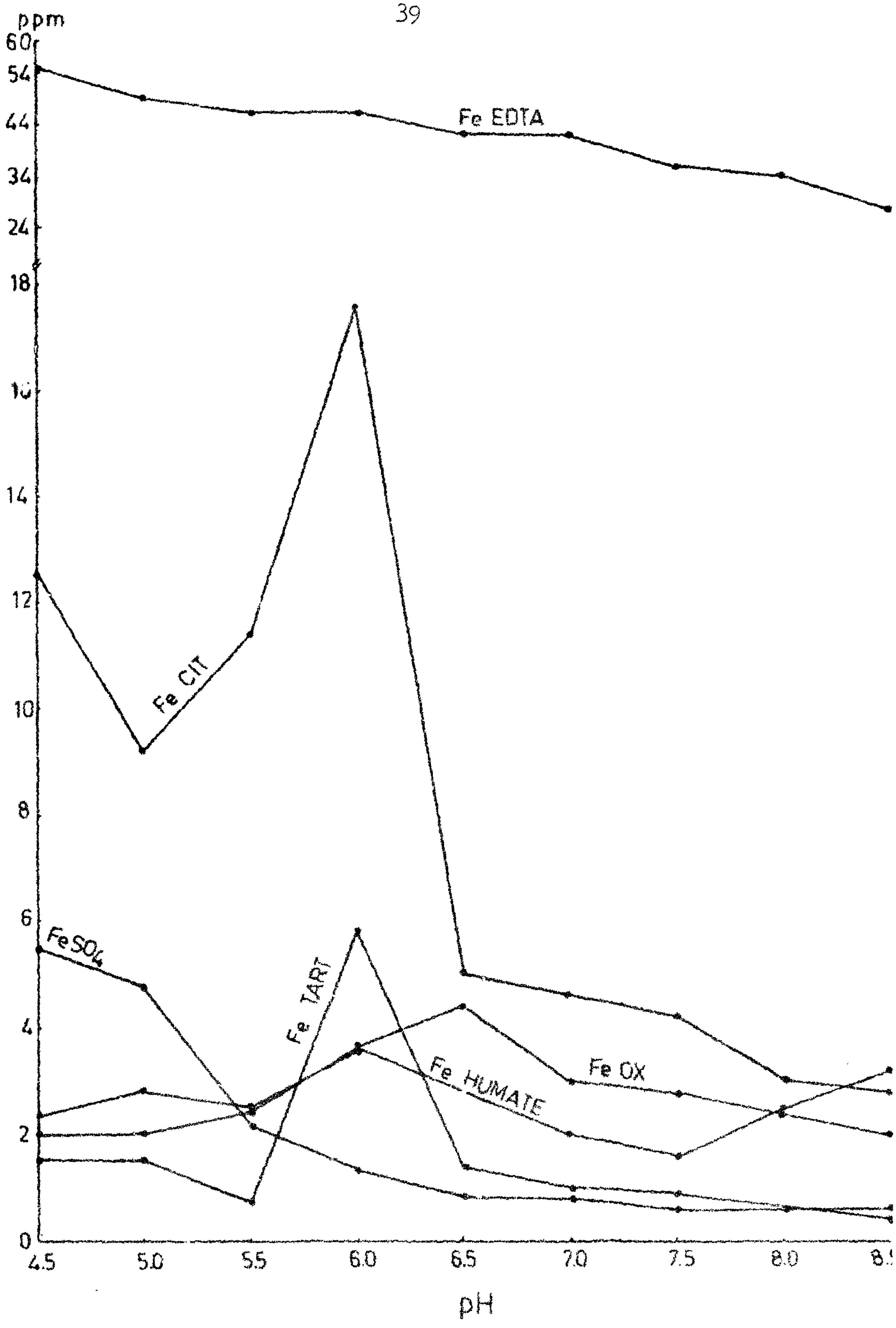

FIG. 2 : INFLUENCE OF pH ON SOLUBLE IRON FROM DIFFERENT IRON SOURCES IN MODIFIED HOAGLAND SOLUTION

pH 6.3 (Norvell, 1972). The data in the present experiment show the high solubility of iron which may be due to high stability of FeEDTA in nutrient solution from pH 4.5 (55.00 ppm Fe) to pH 7.5 (42.00 ppm Fe). The data also show that FeEDTA could maintain iron in solution, though to a smaller extent, even in the alkaline pH range. Haertl and Martell (1956) and Lindsay et al. (1967) have stated that FeEDTA has stability range from pH 3.0 to 8.0. Except FeEDTA all other sources have shown poor solubility not only in alkaline range but also in acidic range. FeCIT appeared to be better among the remaining iron sources with some solubility (about 10 ppm Fe) between a pH range of 4.5 to 6.0. FeOX, FeTART and FeHUM appeared to be almost on par in respect of soluble iron in nutrient solution up to a pH of 6.0 to 6.5. The values of soluble iron recorded for FeOX, FeTART and FeHUM were very low at the different pH values. These results are in agreement with the findings of Norvell (1972) in respect of FeCIT and FeOX. The present experiment showed that FeTART and FeHUM were not much different from the FeCIT and FeOX in respect of their solubility. Norvell (1972) has opined that FeOX is not sufficiently stable. A peculiar feature in the present experiment is the almost uniform, though low, soluble iron values for FeHUM in the acidic as well as alkaline pH range. Thus the FeHUM solubility did not appear to be very much influenced by the pH of nutrient solution.

4.2 Experiments 2 and 3 : Sand culture experiments to stud efficacy of chelates on maize

4.2.1 The yield of plant tops and roots

The data on fresh weight and dry weight in plant tops and roots are reported in Tables 8 and 9 for experiments 2 and 3 respectively. The data are graphically presented in Fig. 3 for the experiment 3. The data of plant tops were statisticall processed. But the data of plant roots could not be processed statistically mainly because of the small weights of the plant roots

The data indicate that addition of iron sources to nutrient solution significantly increased the fresh as well as dry weights of plant tops over control. Addition of different iron sources to the nutrient solution resulted in production of plant tops (dry weight) in the following decreasing order.

FeEDTA > FeHUM > FeTART > FeCIT > FeOX > $FeSO_4$ > Control.

The fresh weights of the plant tops followed a similar order as above. FeHUM was used only in the experiment 3 and not in the experiment 2. The weight of plant tops produced by application of FeHUM was more than that produced by any other source except FeEDTA.

The differences in weights of plant tops can be attributed to the effect of different iron sources on plant

Table 8 : Effect of different iron sources on fresh weight and dry weight of plant tops and roots of maize grown in sand culture for 51 days (experiment 2).

Iron source	Weight of plant tops		Weight of roots	
	Fresh	Dry	Fresh	Dry
	mg/plant			
Control	1014.3 a	210.3 a	109.8	46.1
$FeSO_4$	1431.6 b	238.9 b	182.4	64.8
FeEDTA	2391.6 f	454.6 f	336.0	110.0
FeCA	1544.8 c	284.1 c	173.7	65.5
FeCIT	1733.3 d	311.9 d	200.4	79.7
FeTART	1905.7 e	354.8 e	218.6	78.3
L.S.D.	50.29	9.48		
C.D.	109.58	20.65		

Means followed by the same letter in a column are not significantly different at 5 per cent level of probability

Table 9 : Effect of different iron sources on fresh weight and dry weight of tops and roots of maize grown in sand culture for 51 days (experiment 3) .

Iron source	Weight of plant tops		Weight of roots	
	Fresh	Dry	Fresh	Dry
	g/plant			
Control	1037.00 a	197.1 a	122.9	49
$FeSO_4$	1311.00 b	236.0 b	190.8	72
FeEDTA	2410.00 e	482.0 g	347.2	120
FeCA	1439.67 c	287.9 c	174.6	68
FeCIT	1467.67 c	323.0 d	201.8	81
FeTANT	1927.00 d	385.4 e	213.9	77
FeHUM	3074.67 f	457.2 f	257.1	91
S.E.D.	48.04	9.62		
L.S.D.	103.04	20.62		

Means followed by the same letter in a column are not significantly different at 5 per cent level of probability.

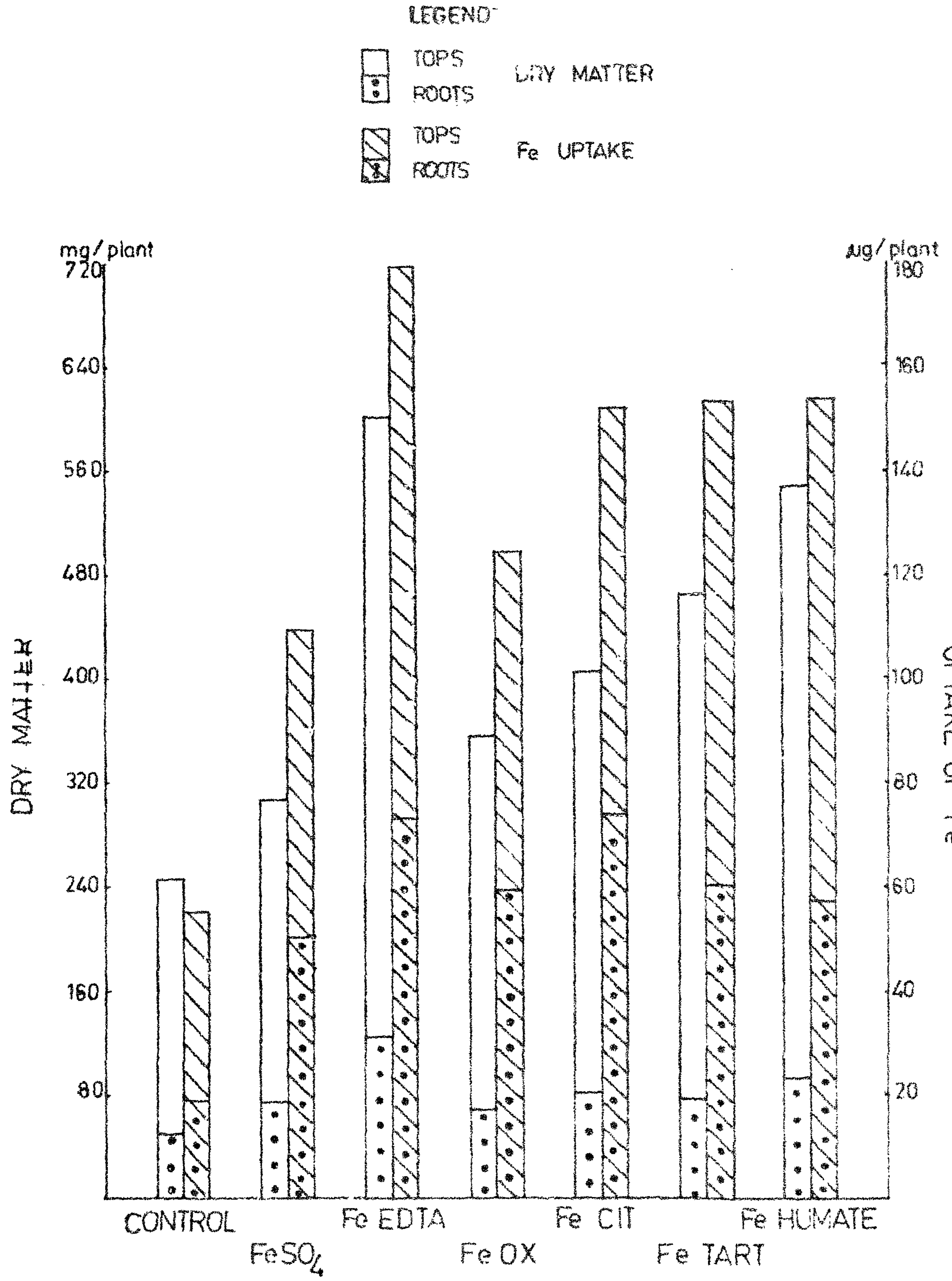

FIG. 3 . INFLUENCE OF DIFFERENT IRON SOURCES ON DRY MATTER AND IRON UPTAKE OF PLANT TOPS AND ROOTS OF MAIZE GROWN IN

growth. Thus, FeEDTA could be considered as the best of the iron sources used in the present investigation. The more important fact is the highly significant effect of FeHUM on plant weight. The effect of FeEDTA on dry matter could have been due to higher uptake of Fe by the chlorotic plants (Table 10). But the almost comparable effect of the FeHUM could have been due to (a) its role in supplying iron to plants (Table 10) and (b) the possible direct effects which occur when humic substances are taken up by plant roots (Schnitzer and Khan, 1972). Kononova (1966) has reported that small concentrations of humic substances (i.e. up to 60 ppm) enhanced root development and plant growth. Dixit and Kishore (1967) have also reported stimulating effects on humic substances on nutrient uptake and growth rate of plants. All other chelates were significantly superior to the inorganic source viz. $FeSO_4$ in their effect on plant growth.

The content of iron in plant tops is reported in Table 10 and graphically presented in Fig. 3. These data also indicate that the contents of iron in plants tops followed the same order (except in the case of FeHUM and FeTANE which were on par), as that of dry matter of plant tops. Wallace(b)(1963) has also reported that chlorotic plants preferentially take up iron from a chelated source. The dry yields generally corresponded to the iron which was

Table 10 : Influence of different iron sources on uptake of iron and manganese through plant tops and roots of maize grown in sand culture for 51 days.

Iron source	UPTAKE (ug/plant							
	Experiment 2				Experiment 3			
	Fe		Mn		Fe		Mn	
	Tops	Roots	Tops	Roots	Tops	Roots	Tops	Roots
Control	40.63 a	16.79	10.15 a	0.46	36.94 a	18.87	8.83 a	0.5
$FeSO_4$	64.23 b	43.42	17.18 b	0.78	59.93 b	49.82	16.26 b	1.2
FeEDTA	97.17 e	66.22	38.75 e	1.87	106.30 f	73.20	39.08 e	2.4
FeCA	66.66 b	56.20	19.71 b	0.85	65.68 c	59.30	20.17 b	1.0
FeCIT	73.34 c	69.34	25.41 c	0.88	77.94 d	73.71	25.19 c	0.9
FeTART	87.73 d	59.35	31.67 d	1.25	93.01 e	60.06	31.99 d	1.6
FeHUM	-	-	-	-	97.45 e	57.33	34.79 d	2.1
S.E.D.	4.30		1.76		2.38		1.94	
C.D.	9.36		3.83		5.11		4.15	

Means followed by the same letter in a column are not significantly different at 5 per cent level of probability.

Table 11 : Influence of different iron sources on chlorophyll in the youngest leaf, Fe, Mn and Fe/Mn ratio in plant tops and roots of maize grown in sand culture for 51 days (experiment 2).

Iron source	Fe(ppm)		Chlorophyll in the youngest leaf of plant (mg/100 g of fresh weight)	Mn(ppm)		Fe/Mn	
	Tops	Roots		Tops	Roots	Tops	Roots
Control	193.33 a	365	36.58 a	48.00 a	10	4.02 d	36.5
$FeSO_4$	268.67 d	670	39.61 a	72.00 b	12	3.73 cd	55.83
FeEDTA	213.33 ab	602	80.70 c	85.33 c	17	2.50 a	35.41
FeOX	234.67 bc	858	46.59 a	69.33 b	13	3.38 bcd	66.00
FeCIT	248.00 bcd	870	62.44 b	81.33 bc	11	3.05 abc	79.09
FeTART	247.33 bc	758	65.13 b	89.33 c	16	2.77 ab	47.38
S.E.D.	10.21		5.57	5.86		0.33	
C.D.	22.25		12.13	12.77		0.72	

Means followed by the same letter in a column are not significantly different at 5 per cent level of probability.

Table 12 : Influence of different iron sources on chlorophyll in the youngest leaf, Fe, Mn and Fe/Mn ratio in plant tops and roots of maize grown in sand culture for 51 days (experiment 3).

Iron source	Fe(ppm)		Chlorophyll in the youngest leaf of plant (mg/100 g of fresh weight)	Mn (ppm)		Fe/Mn	
	Tops	Roots		Tops	Roots	Tops	Roots
Control	185.33 a	385	16.39 a	45 a	12	4.12 d	32.08
$FeSO_4$	294.00 e	692	40.03 b	69 b	17	3.68 c	40.71
FeEDTA	220.00 bc	610	72.84 d	81 d	20	2.72 a	30.50
FeOX	228.00 c	872	41.53 b	70 bc	15	3.26 b	58.13
FeCIT	241.33 d	910	52.40 c	78 cd	12	3.09 ab	75.83
FeTART	241.33 d	780	53.64 c	83 d	22	2.91 a	35.45
FeHUM	213.33 b	630	63.59 cd	76 bcd	24	2.81 a	26.25
S.E.D.	4.73		4.98	4.18		0.19	
C.D.	10.14		10.68	8.95		0.41	

Means followed by the same letter in a column are not significantly different at 5 per cent level of probability.

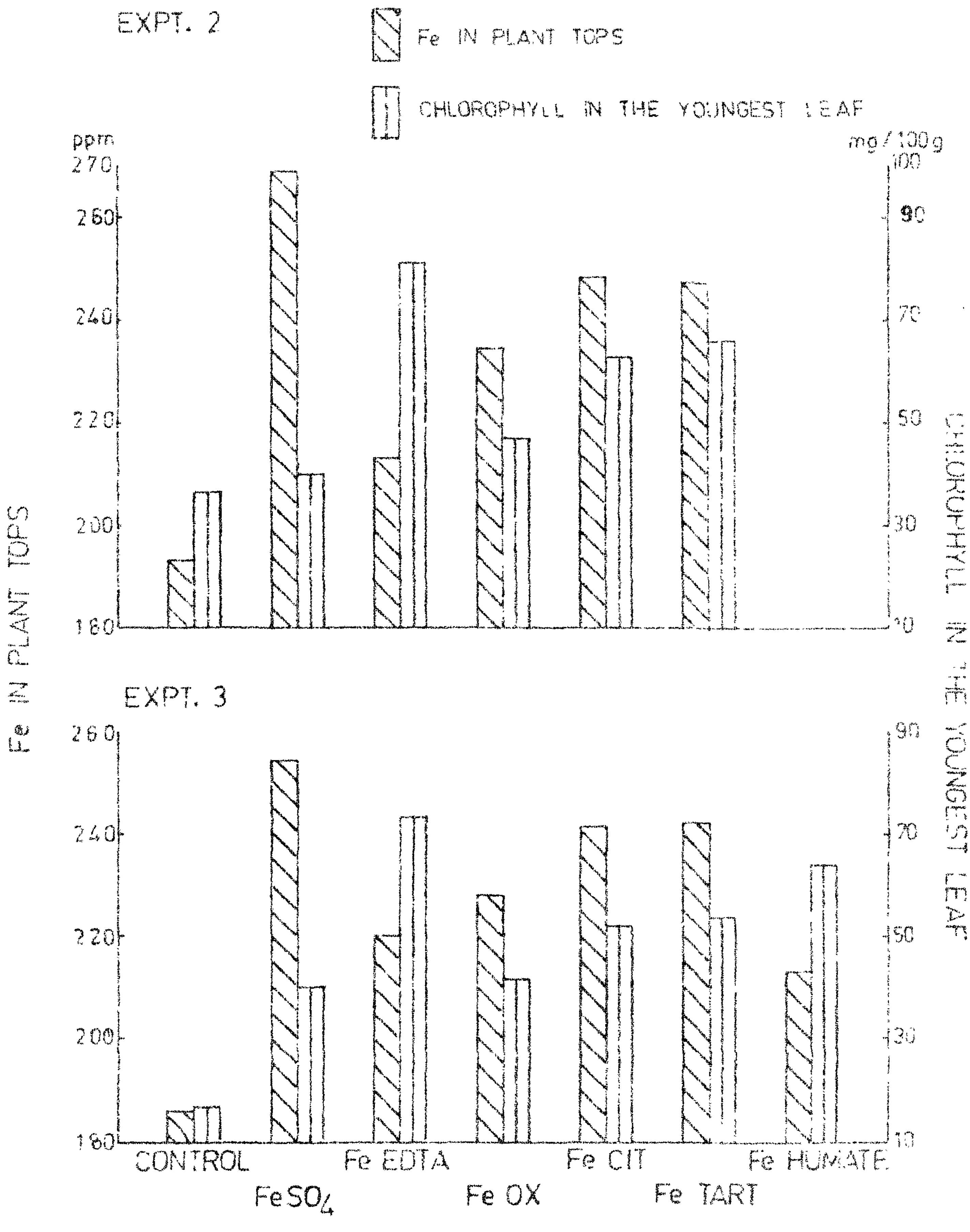

FIG 4 : INFLUENCE OF DIFFERENT IRON SOURCES ON IRON CONCENTRATION IN PLANT TOPS AND CHLOROPHYLL sources was absorbed and translocated to the plant tops. The highest iron concentration was recorded in the plant tops fed with $FeSO_4$. The significantly less quantity of plant tops produced due to $FeSO_4$ application (Tables 8 and 9) may be responsible for the apparently concentrating effect on the iron content. In the Experiment 2 the remaining treatments were on par in respect of iron concentration in maize plants tops. However, in the experiment 3, following was the decreasing order of iron concentrations based on statistically significant differences

$FeSO_4$ > FeCIT = FeTART > FeOX ≈ FeEDTA ≈ FeHUM > Control.

By and large, it appears from the decreasing orders of dry weights (section 4.2.1) and iron concentration noted above that iron concentration was inversely proportional to the dry weights of plant tops. This can be attributed to the dilution effect.

The iron concentrations in roots (though not subjected to statistical analysis) indicate the following decreasing order in experiment 2 as well as in experiment 3.

FeCIT > FeOX > FeTART > $FeSO_4$ > FeHUM > FeEDTA > Control.

4.2.3 Chlorophyll concentration in the youngest leaf of maize plants :

The data on total chlorophyll concentration in the youngest leaf of maize plants as influenced by the different iron sources are reported in Tables 11 and 12 for the experiments 2 and 3 respectively and graphically presented in Fig. 4.

The data indicate that the total chlorophyll concentration in leaves was maximum in FeEDTA treatment and was on par with FeHUM treatment. The second category of chlorophyll values was that of FeCIT and FeTART. These were on par with each other but were significantly less than the FeEDTA values. The third category of chlorophyll values in the decreasing order consisted of those due to FeOX and $FeSO_4$ which were on par with each other in both the experiments. In the experiment 2, chlorophyll values for FeOX and $FeSO_4$ were on par with that of the control while in the experiment 3 chlorophyll values for FeOX and $FeSO_4$ were significantly more than that for the control.

4.2.4 Comparison of iron and chlorophyll concentrations :

The concentrations of iron in plant tops and chlorophyll in the youngest leaf of maize plants in the experiments 2 and 3 are graphically presented in Fig. 4. It may be seen that the plants fed with $FeSO_4$ on one hand and the plants fed with FeEDTA and FeHUM on the other indicate contrasting trends. Thus, though the iron concentration in plant tops fed with $FeSO_4$ was high, the chlorophyll concentration of the youngest leaf was low while the opposite was the case with FeEDTA and

FeHUM sources. FeCIT, FeTART and FeOX indicated intermediate trend. Llorente et al. (1976) have shown that the soluble iron rather than the total iron in leaf is important for chlorophyll production. They have shown that the chlorophyll concentration and peroxidase activity were directly related to the soluble iron concentration in leaf. It is possible that a major part of Fe taken up from $FeSO_4$ source could have remained in insoluble state while the chelates viz. FeEDTA and FeHUM might have helped the iron in leaf to remain in soluble state thereby resulting in increased chlorophyll content due to the latter sources. The intermediate trend depicted by FeCIT and FeTART indicate that these chelates could help the plants to maintain iron in soluble form only to a limited extent, which was superior to $FeSO_4$ but inferior to FeEDTA and FeHUM.

4.2.5 Manganese concentration and Fe/Mn ratio in maize plants :

Data on the manganese concentration in maize plant tops and roots as influenced by application of different iron sources are reported in Table 12 for the experiment 3. Iron addition to nutrient solution resulted in increase in the manganese concentration in plant tops. The manganese concentration in plant tops due to $FeSO_4$ application was on par with that due to FeOX, and FeHUM. However, the Mn concentration due to FeHUM was also on par with that due to FeCIT, FeEDTA and FeTART. The Mn concentration in maize roots also showed comparatively higher values due to application of FeHUM, FeTART and FeEDTA.

Data on Fe/Mn ratio in maize plant tops and roots are also reported in Table 12. The data indicate that Fe/Mn ratio of less than 3 was obtained in plant tops in three treatments viz. FeEDTA, FeTART and FeHUM. The treatments FeOX (3.26) and FeCIT (3.09) were found to be on par with each other in respect of Fe/Mn ratio in plant tops. $FeSO_4$ addition to nutrient solution resulted in highest Fe/Mn ratio of 3.68 in plant tops. Shive (1941) has given 1.5 to 2.5 as the optimum Fe/Mn ratio for normal growth of rice plant. Although similar values for maize are not available, it appeared that the ratio was maintained below 3 by FeEDTA, FeTART and FeHUM indicating their superiority over FeOX and FeCIT which, in turn, were found superior to $FeSO_4$ in maintaining a good balance between Fe and Mn concentrations in maize plant tops.

The very high values of Fe/Mn ratio in maize roots indicate that Mn was translocated to plant tops from roots much better than iron. Further, the comparatively lower Fe/Mn ratios for roots for the treatments FeEDTA, FeTART and FeHUM probably show that these sources helped more iron translocation to plant tops than the other sources.

The data on Mn concentration and Fe/Mn ratio in maize tops and roots for the experiment 2 (reported in Table 11) lead us to similar conclusions as detailed above.

4.2.6 Uptake studies :

The data on uptake of Fe and Mn by maize plants are reported in Table 10 for the experiments 2 and 3 and in Fig. 3 for the experiment 3

Uptake of iron by maize :

It is observed that addition of iron sources to nutrient solution has resulted in significantly higher uptake of iron in maize plant tops. The data indicate the following decreasing trend in the experiment 3.

FeEDTA > FeHUM ≈ FeTART > FeCIT > FeOX > $FeSO_4$ > Control.

The data of the experiment 2 indicate similar trend except that the Fe uptake due to FeOX was on par with that of $FeSO_4$.

The data on Fe uptake by maize roots could not be statistically analysed. However, the data indicate the following decreasing trends.

Experiment 2 :

FeCIT > FeEDTA > FeTART > FeOX > $FeSO_4$ > Control.

Experiment 3 :

FeCIT > FeEDTA > FeTART > FeOX > FeHUM > $FeSO_4$ > Control.

The data indicate that Fe added through FeEDTA was absorbed by roots and translocated to plant tops to the highest extent. The high stability of FeEDTA is well documented in literature (Hill-Cottingham and Lloyd-Jones, 1957, Lindsay et al, 1967; Norvell and Lindsay, 1969; Wallace et al. 1955), and the experiment 1 also showed high solubility of FeEDTA (Table 7). Thus the source of highest stability viz. FeEDTA was absorbed to the highest extent indicating the direct relationship between the stability of an iron source and its absorption. O'Connor et al.(1971) showed that the uptake of iron by sorghum roots was directly related to the total soluble iron in solution. Lindsay et al. (1967) have shown that chelate stability diagrams are useful in predicting plant response to the iron chelates. Halvorson (1971) has also shown the usefulness of stability diagrams to predict and interpret plant nutrient responses in nutrient solution experiments. He further showed that FeEDTA was the best source at pH 5.3 and 7.5 among the four sources he tried viz. FeEGTA, FeEDTA, FeDTPA and FeEDDHA. The findings of the present investigation confirm the superiority of FeEDTA as a source of iron to maize among the chelates used.

The highest chlorophyll concentration in the youngest leaf of plants fed with FeEDTA (Table 11 and 12 for the experiments 2 and 3) also supports the above observation because it shows that the iron from FeEDTA was translocated to the plant tops. Further, the iron supplied through FeEDTA probably increased soluble iron content in plant leaf and hence resulted in production of the highest chlorophyll concentration. The question of whether chelated metals enter the roots intact or whether the complex dissociates at root surface has been reviewed by Wallace[a] (1963) and more recently by Hill-Cottingham and Lloyd-Jones (1965). They have concluded that both the mechanisms are operative and differential uptake of chelating agent and metal varied on factors such as plant species, kind of chelating agent, pH etc. FeEDTA can, therefore, be called as the best iron source among the different sources tried in this investigation because it was absorbed in roots and also translocated to the tops to the highest extent.

The data on the ratio of the Fe uptake of shoots : Fe uptake by roots as influenced by different iron sources are reported in Table 13. The fact that iron fed through FeHUM was comparatively less in plant roots but more in plant tops indicated that humate could translocate comparatively more iron from roots to plant tops. Dekock (1955) has also stated that humic acids promote the translocation of iron to leaves and so prevent chlorosis. The data reported in Table 13 in respect of FeCIT indicate that probably there were maximum difficulties in translocation of iron supplied as iron citrate in plants as compared to the other chelates. This could also be the reason for the lower performance of FeCIT particularly in comparison with FeTAHT. The uptake of iron in plant tops from FeOX compared to that from $FeSO_4$ was slightly more in the experiment 3 while in the experiment 2 they were on par. The

Table 13 : Influence of different iron sources on the ratio of the uptake of Fe in plant tops/uptake of Fe in roots of maize plants grown in sand culture for 51 days.

Iron sources	Uptake of Fe (plant tops / Uptake of Fe (roots	
	Experiment 2	Experiment 3
Control	2.42	1.94
$FeSO_4$	1.48	1.20
FeEDTA	1.47	1.45
FeOX	1.19	1.11
FeCIT	1.05	1.06
FeTART	1.48	1.55
FeHUM	*	1.70

* Not determined.

translocation of iron provided through the two sources, therefore, appeared to be almost similar. Considering the poor stability of iron oxalate in solution (Norvell, 1972) the poor translocation of iron from FeOX in plants can be very well expected. Thus, FeOX does not seem to afford any great advantage in translocation of iron in plants over ionic source viz. $FeSO_4$. In respect of root uptake also, FeOX was only slightly better than $FeSO_4$. It, therefore, appears that FeOX as an iron source for maize plants is either comparable to or not far superior to $FeSO_4$.

The data in Table 13 also indicate that performance of FeTART was almost equal to that of FeEDTA in respect of translocation of Fe from roots to tops. It can thus, be concluded that, among the different commercial chelates tried, FeTART occupied No. 2 position, next in importance only to FeEDTA which was the best chelate tried.

A comparison of the Fe uptake data of the control and $FeSO_4$ sources indicates that, in absence of any chelate, even $FeSO_4$ would be able to supply iron to maize plants. Further, the Fe from $FeSO_4$ appeared to have been translocated to the plant tops only to a limited extent. The limited translocation of ionic iron in plants is well known.

4.2.7 Uptake of manganese by maize plants :

The data on uptake of manganese by maize plants in the experiments 2 and 3 are reported in Table 10. The uptake of manganese by maize plant tops increased significantly due to application of iron sources. The following decreasing order of manganese uptake by plants tops based on statistical significance was observed in the experiment 3.

FeEDTA > FeHUM ≈ FeTART > FeCIT > FeOX > $FeSO_4$ > Control.

Similar trend was also observed in the experiment 2. The valu for uptake of manganese by maize roots were very low. The data for root uptake of manganese are not statistically analysed. However, the data generally indicate similar trend as in plant tops, particularly in respect of the experiment 2.

4.4 Experiment 4 : Sand culture experiment to study the efficacy of Fe chelates on sorghum.

The influence of different iron sources on the fresh an dry weights of plant tops and roots, iron and manganese concen tration and uptake and chlorophyll concentration in the younge leaf of sorghum plants was also studied in a sand culture experiment. The experiment consisted of two replications and the average values are reported below. The data are not subjected to statistical analysis.

4.4.1 The yield of plant tops and roots :

The fresh and dry weights of plant tops and roots of sorghum of 51 days age as influenced by different iron sources are reported in Table 14 and Fig. 5. The data indicate the following decreasing trend :

FeEDTA > FeTART > FeCIT > FeOX > $FeSO_4$ > Control.

Table 14 : Effect of different iron sources on fresh weight and dry weight of tops and roots of sorghum grown in sand culture for 51 days.

Iron source	Weight of plant tops		Weight of plant roots	
	Fresh	Dry	Fresh	Dry
	mg/plant			
Control	105.25	50.12	78.94	30.21
$FeSO_4$	135.75	63.14	91.66	35.21
FeEDTA	195.28	91.25	165.24	61.20
FeOX	157.50	75.00	104.70	39.80
FeCIT	182.86	83.12	118.80	45.70
FeTART	186.65	87.22	135.20	51.00

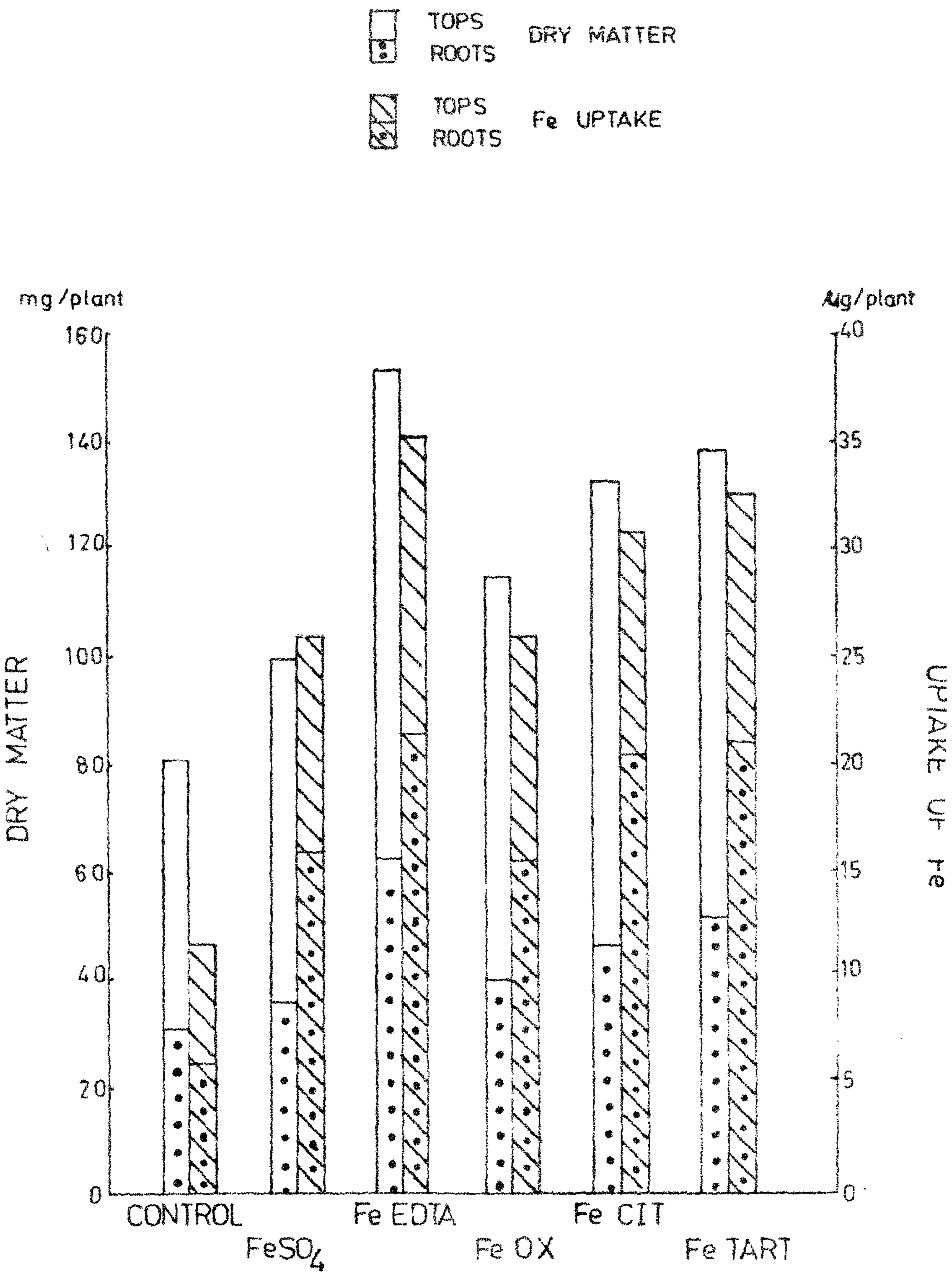

FIG. 5 : INFLUENCE OF DIFFERENT IRON SOURCES ON DRY MATTER AND IRON UPTAKE OF PLANT TOPS AND ROOTS OF SORGHUM GROWN

A comparison of the data on sorghum with similar data of maize yield produced in 51 days in experiment 2 (Table 8 or 9) indicate that the yield of plant tops of sorghum was about 10 times less than that of maize plant tops. The dry weights of sorghum plant tops were about 4 times less than those of maize plant tops. The sorghum also produced fresh and dry weights of plant roots which were about one half in weight as compared with those of maize. However, although the weights of sorghum were comparatively less, the trend of the effect of the different iron sources on weights of plant tops and roots was similar to that of maize reported in the experiment 2 Thus, the yield data of sorghum confirmed the findings regarding the effect of iron sources reported under the experiment 2 on maize.

4.4.2 Iron concentration in sorghum

The data on iron concentration in plant tops and roots of sorghum as affected by different iron sources are reported in Table 15 and graphically presented in Fig. 6. The data indicate the following decreasing order of iron concentration

Plant tops : $FeSO_4$ > FeTART > FeEDTA > FeCIT > FeOX > control

Plant roots : $FeSO_4$ > FeCIT > FeTART > FeOX > FeEDTA > contr

As pointed out under maize (section 4.2.2) the reason for this trend may be the concentration or dilution effect due

Table 15 : Influence of different iron sources on chlorophyll in the youngest leaf, Fe, Mn and Fe/Mn ratio in plant tops and roots of sorghum grown in sand culture for 51 days.

Iron source	Fe (ppm)		Chlorophyll in youngest leaf of plant (mg/100 g of fresh weight	Mn (ppm)		Fe/Mn	
	Tops	Roots		Tops	Roots	Tops	Root
Control	122	233.33	97.28	36	10.67	3.39	21.87
$FeSO_4$	154	466.67	111.33	48	12.00	3.21	38.89
FeEDTA	144	366.67	133.51	52	9.33	2.78	39.30
FeOA	138	400.00	114.72	44	16.00	3.14	25.00
FeCIT	142	450.00	117.01	52	17.33	2.73	25.97
FeTART	150	426.67	126.36	56	10.67	2.68	39.99

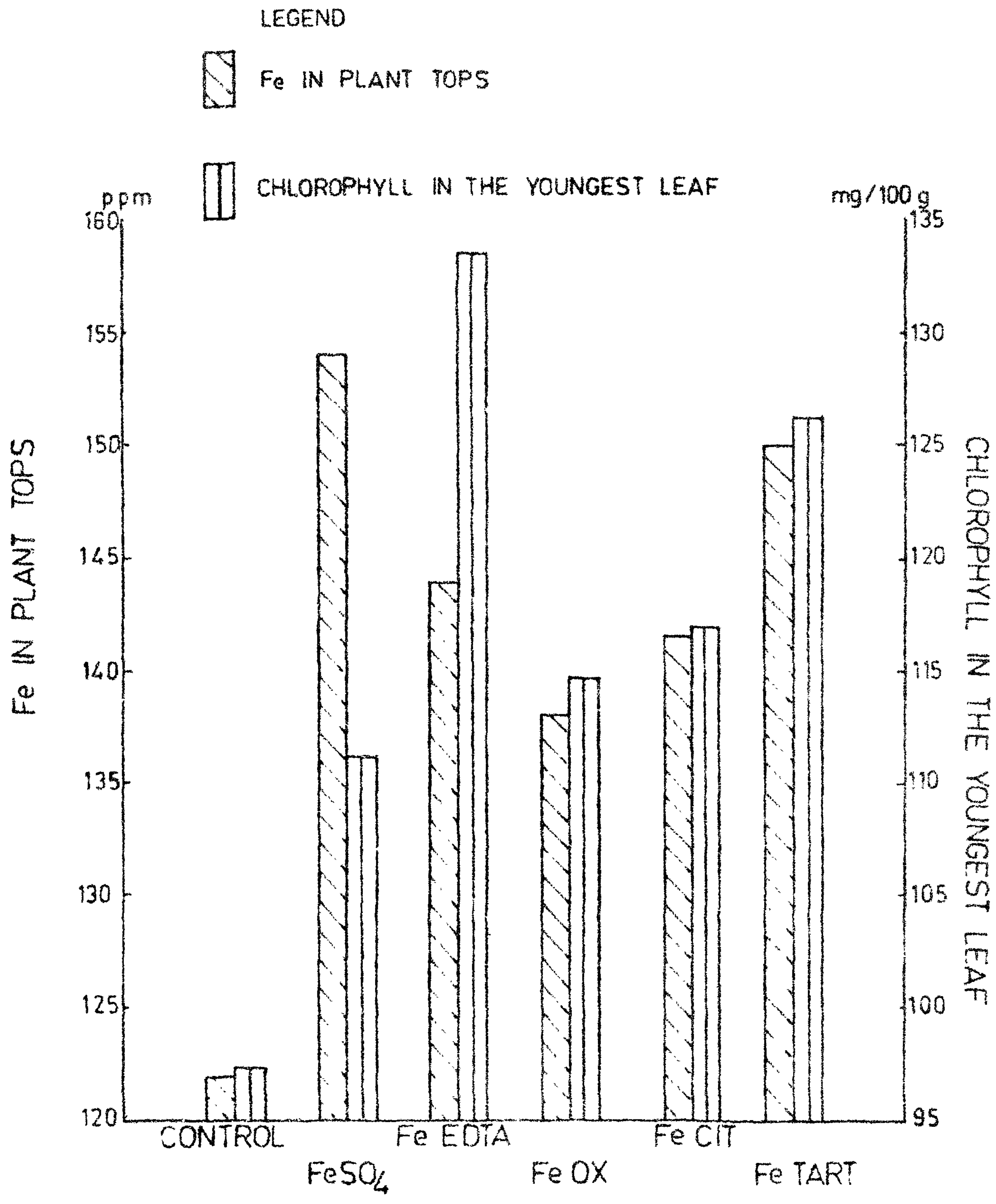

FIG. 6: INFLUENCE OF DIFFERENT IRON SOURCES ON IRON CONCENTRATION IN PLANT TOPS AND CHLOROPHYLL IN THE YOUNGEST LEAF OF SORGHUM GROWN IN SAND CULTURE FOR 51 DAYS.

to comparatively decreased or increased dry matter production respectively. The actual values of iron concentration were of lower order in sorghum.

4.4.3 Chlorophyll concentration in the youngest leaf of sorghum :

The data on chlorophyll concentration in the youngest leaf of sorghum are reported in Table 15 and graphically presented in Fig. 6. The decreasing order of chlorophyll concentration given below also generally agrees with the decreasing order observed in maize.

FeEDTA > FeTART > FeCIT > FeOX > $FeSO_4$ > Control.

The above order is an indirect indication of the effectiveness of the different iron sources in correcting the iron-chlorosis of sorghum. The same order of effectiveness of the different chelates was observed in the case of maize. The soluble iron concentration in leaf was directly related to chlorophyll concentration of leaves (Llorente et al. 1976). Thus, although $FeSO_4$ application showed higher total iron concentration in sorghum plant tops (section 4.4.2) the soluble iron content in the youngest leaf might have been low as a result of which probably very low leaf chlorophyll concentration were recorded.

4.4.4 Manganese concentration and Fe/Mn ratio in sorghum plants

The data on manganese concentration in plant tops and roots (Table 15) indicate the following trends -

Plant tops : FeTART > FeEDTA = FeCIT > $FeSO_4$ > FeOX > Control

Plant roots : FeCIT > FeOX > $FeSO_4$ > FeTART = Control.> FeEDTA

The Fe/Mn ratio of plant tops of sorghum was less than 3 only in the case of FeEDTA, FeCIT and FeTART. A Fe/Mn ratio between 1.5 to 2.5 is considered ideal for normal plant growth (Shive, 1941). Thus, the three chelate sources viz., FeEDTA FeCIT and FeTART could be considered as better chelates as the have produced Fe/Mn values nearer the ideal values. So also, it may be noted that there was very little difference in the Fe/Mn ratios of FeOX and $FeSO_4$ indicating the near-equality of the two sources of iron.

4.4.5 Uptake of iron and manganese by sorghum plant :

The data on uptake of iron by sorghum (Table 16 and Fig. 5) indicate the following decreasing order

Plant tops : FeEDTA > FeTART > FeCIT > FeOX > $FeSO_4$ > control.

Plant roots : FeEDTA > FeTART > FeCIT > $FeSO_4$ > FeOX > Control.

These trends are almost similar to those reported for maize in the experiment 2 and confirm the findings of the maize experiment regarding the order of effectiveness of different sources of iron.

Table 16 : Influence of different iron sources on uptake of iron and manganese through plant tops and roots of sorghum grown in sand culture for 51 days.

Iron source	UPTAKE (µg/plant)			
	Fe		Mn	
	Tops	Roots	Tops	Roots
Control	6.11	7.05	1.80	0.32
$FeSO_4$	9.72	16.39	3.03	0.42
FeEDTA	13.14	22.44	4.75	0.57
FeCA	10.35	15.92	3.30	0.64
FeCIT	10.80	20.57	4.32	0.79
FeTAKT	13.08	21.76	4.03	0.54

The data on uptake of manganese by sorghum plants (Table 16) indicate the following decreasing order -

Plant tops : FeTART > FeEDTA > FeCIT > FeOX > $FeSO_4$ > Control.

Plant roots : FeCIT > FeOX > FeEDTA > FeTART > $FeSO_4$ > Control.

The data generally indicated the superiority of FeEDTA and FeTART in the absorption and translocation of manganese to plant tops of sorghum.

Experiment 5 : Foliar spray trial of chelates on maize grown in calcareous soil

The influence of different iron sources applied as eight foliar sprays on the production of yield, iron concentration of maize plant tops and chlorophyll in the youngest leaf of maize plants grown in a calcareous soil (21 % lime), was studied in experiment 5. The experiment consisted only of a single replication and the data could not be subjected to statistical analysis. The experiment may, therefore, be considered as a feeler trial.

4.5.1 The yield of plant tops :

The fresh and dry weights of plant tops of maize of 72 days age as influenced by foliar application of different iron sources are reported in Table 17. The data indicate the following decreasing order :

FeEDTA > FeHUM > FeTART > FeCIT > FeOX > $FeSO_4$ > Control.

Table 17 : Effect of foliar application of different iron sources on fresh weight and dry weight of plant tops of maize grown in calcareous soil for 72 days.

Iron source	Weight of plant tops (mg/plant)	
	Fresh	Dry
Control	5130	1200
$FeSO_4$	7470	1330
FeEDTA	11650	2900
FeOX	7630	1460
FeCIT	7700	1970
FeTART	10230	1800
FeHQ	9570	2160

comparison of the data of maize grown in calcareous soil with the data of maize grown in sand culture experiment 3 (Table 9 indicate that yields of dry plant tops were about 4 to 5 times more than those in the experiment 3. This may be due to longer growth period of 72 days in the experiment 5 as compared to 51 days of growth period in the experiment 3. However, the trend of different iron sources used as sprays on yield of plant tops was similar to that of the experiment 3. Thus, the yield data confirm the findings regarding the effect of iron sources reported under the experiment 3 and also suggest the utility of the iron sources for foliar application to correct iron chlorosis.

4.5.2 Effect of foliar application of iron sources on iron and chlorophyll concentration of maize leaves :

The data reported in Table 18 indicate that the iron in the plant tops and chlorophyll in the youngest leaf were in the following decreasing order

Fe in the plant tops	: FeTART > FeCIT > FeOA = FeEDTA > FeHUM = $FeSO_4$ > Control.
Chlorophyll in the youngest leaf	FeEDTA > FeTART > FeHUM > FeCIT > FeOA $FeSO_4$ > Control.

If chlorophyll content is taken as the criterion of chlorosis correcting ability of the different iron sources,

Table 18 : Influence of foliar application of different iron sources on chlorophyll in the youngest leaf and Fe in plant tops of maize grown in calcareous soil for 72 days.

Iron source	Fe in plant tops (ppm)	Chlorophyll in the youngest leaf of plant (mg/100 g of fresh weight
Control	200	45.02
$FeSO_4$	210	80.15
FeEDTA	220	134.60
FeOA	220	88.82
FeCIT	230	96.62
FeTART	240	120.54
FeHUM	210	107.00

Table 19 : Influence of foliar application of different iron sources on iron content in plant tops of maize grown in calcareous soil for 72 days.

Iron source	Iron content (ug/plant)
Control	240.00
$FeSO_4$	279.30
FeEDTA	638.00
FeOA	321.20
FeCIT	361.10
FeTART	451.20
FeHUM	453.60

the decreasing order for chlorophyll indicates the probable decreasing order of effectiveness of different iron sources in correcting chlorosis of maize.

4.5.3 Iron content in plant tops :

The data on iron content of maize plant tops (Table 19 indicate the following decreasing order :

FeEDTA > FeHUM > FeTART > FeCIT > FeOX > $FeSO_4$ > Control.

This decreasing trend is almost similar to the trend in the experiment 3 (Table 9) except that the values for uptake are nearly 5 to 6 times higher than those of the experiment 3. This may be due to the higher yield of maize tops and also the probable root absorption of iron from the soil (in addition to foliar absorption) in the experiment 5. The experiment 5 has indicated good scope for using some of the chelates like FeEDTA, FeHUM and FeTART for spray application because their sprays resulted in substantial iron contents in maize plants. The aforesaid chelates showed a definite advantage over the inorganic source viz. $FeSO_4$ which is commonly used for correction of iron chlorosis particularly by the cultivators in Maharashtra.

Chapter-5

SUMMARY AND CONCLUSION

Sand-culture experiments were carried out in the laboratory of Agricultural Chemistry and Soil Science Department, Mahatma Phule Krishi Vidyapeeth, Rahuri, to study the effectiveness of five different chelates as a source of iron to correct chlorosis in plants using maize (Zea mays) variety Deccan-Double-Hybrid and sorghum (Sorghum bicolor (L) Moench) variety 2077 A as the test crops. The plants were grown for a period of 51 days by feeding them with modified Hoagland solution (pH 5.0 ± 0.2 and the effect of four commercially available chelates viz. ethylenediamine tetra-acetic acid-ferric monosodium salt, ferric tartarate, ferric citrate, and ferrous oxalate and one chelate prepared in the laboratory viz. iron humate on dry matter yield, iron, chlorophyll and manganese content was studied. Ferrous sulphate was used as a standard inorganic source for comparison. Separate nutrient solutions were prepared by adding different iron sources to modified

Hoagland solution so as to obtain a uniform total iron concentration of 2.24 ppm in respect of each source. Since the availability of the chelates depends on their remaining in solution, the solubility of each iron source in the modific Hoagland solution in the pH range of 4.5 to 8.5 was studied.

The important findings of the investigation are summarised below :

1. Solubility of iron sources : Among the different chelates used, FeEDTA showed the highest solubility in modific Hoagland solution at different pH levels. Fe-Citrate ranked second in this respect while all other chelates were almost on par with each other. Fe-humate maintained a low and almost uniform solubility irrespective of the pH variation from 4.5 to 8.5.

2. Dry matter yield : Addition of FeEDTA to nutrient solution resulted in production of the highest dry matter yield of maize and sorghum. Among the remaining chelates, Fe-humate and Fe-tartarate ranked second and third in this respect.

3. Iron uptake : Both the crops viz. maize and sorghum showed uptake of iron in the following decreasing order :

FeEDTA > FeHUATE > FeTARTARATE > FeCITRATE > FeOXALATE > FeC

4. Chlorophyll : Addition of Fe humate to nutrient sol resulted in a chlorophyll concentration in the younges of maize and sorghum plants which was on par with the

Hoagland solution so as to obtain a uniform total iron concentration of 2.24 ppm in respect of each source. Since the availability of the chelates depends on their remaining in solution, the solubility of each iron source in the modified Hoagland solution in the pH range of 4.5 to 8.5 was studied.

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3. Iron uptake : Both the crops viz. maize and sorghum showed uptake of iron in the following decreasing order :

FeEDTA > FeHUATE > FeTARTARATE > FeCITRATE > FeOXALATE > $FeSO_4$ > Con

4. Chlorophyll : Addition of Fe humate to nutrient solution resulted in a chlorophyll concentration in the youngest leaf of maize and sorghum plants which was on par with the highest

concentrations produced due to FeEDTA addition. Fe tartarate, Fe citrate, Fe oxalate and $FeSO_4$ followed the Fe humate, in that order, in respect of leaf chlorophyll concentration.

5. Manganese uptake : The uptake of manganese by maize and sorghum was almost in the same order as that of the iron uptake

6. Fe/Mn ratio : Addition of only three chelates viz. FeEDTA Fe humate and Fe tartarate helped to approach the ideal range o Fe/Mn concentration in maize and sorghum plant tops.

7. A feeler trial conducted to compare different iron sources for their effectiveness for foliar application on maize gave the same trend as noted under Fe uptake or chlorophyll concentration obtained by root feeding experiment.

From the above results, it may be concluded that the iron humate compared well with the imported and costly FeEDTA as an effective iron source for correcting iron chlorosis of maize and sorghum. Among the commercially available chelates tried, iron tartarate was better than iron citrate and iron oxalate. Iron oxalate was not much better than the inorganic source viz. ferrous sulphate in its chlorosis-correcting effect on maize and sorghum.

Chapter Opener Page

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