

**IRON MANAGEMENT PRACTICES FOR
GROUNDNUT-MAIZE CROPPING SEQUENCE
IN CALCAREOUS VERTISOL**

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**IRON MANAGEMENT PRACTICES FOR
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IN CALCAREOUS VERTISOL**

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By

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CERTIFICATE

This is to certify that the thesis entitled "IRON MANAGEMENT PRACTICES FOR GROUNDNUT-MAIZE CROPPING SEQUENCE IN CALCAREOUS VERTISOL" submitted by Mr. FARID ABDEL AZIZ EL-SAYED HELLAL for the degree of DOCTOR OF PHILOSOPHY in SOIL SCIENCE AND AGRICULTURAL CHEMISTRY to the University of Agricultural Sciences, Dharwad, is a record of research work carried out by him during the period of his study in this University, under my guidance and supervision, and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

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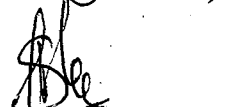
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Affectionately Dedicated To

My

Father, Late Mother,

Wife and Children

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INTRODUCTION

I. INTRODUCTION

Calcareous soils are widely spread in arid and semi arid regions. It has been estimated that these soils comprise over one-third of the world's land surface area. This includes most of western and mid-western United States and semi-arid or arid regions of the Central Europe, Africa, Asia and South America.

In India, the calcareous soils constitute about 228.8 million hectare and covers 69.4 per cent of the total geographical area of the country and spread over 38 out of 60 agro-ecological sub-regions, which indicate that calcareous soils are present not only in arid and semi-arid climatic regions, but also in humid and per humid regions, where soils were developed on a strongly calcareous parent material or in young geomorphic surface (Pal *et al.*, 2000).

Iron is the fourth most abundant element in the earth's crust after oxygen, silicon and aluminum, where its concentration is 4.7 per cent (by weight). The iron content expressed as percentage of Fe_2O_3 makes up one to six per cent of many soils, which is comparable to seven per cent in earth's crust and one to seven per cent of various rocks (Mengel and Kirkby, 1982).

A characteristic problem associated with crops grown in calcareous soils is the condition called iron chlorosis. The Fe deficiency and whose most characteristic symptom is interveinal chlorosis. When a plant that lacks certain metabolic abilities to grow in calcareous soil, it develops symptoms of iron chlorosis, because Fe is not found in available form, which can be corrected with the application of iron in available forms to plants. Calcareous soil does not lack Fe, but availability is limited.

In India, iron deficiency seems to be one-fourth as extensive as that of Zn, amongst the micronutrients. In Karnataka state, the results reported by the research institutions and the State Department of Agriculture, indicate that 39 per cent of soil samples are found to be deficient in iron (Sakal and Singh, 2001).

Fractionation of soil iron by sequential extraction is useful for determining chemical forms of iron in soils. Such information is valuable in predicting bio-availability, leaching rates and transformation between chemical forms of iron. The information on the contribution of each fraction to the total iron contents and their relationship with soil properties is meagre especially in calcareous soil.

In plant, iron plays a role in the synthesis of chlorophyll, carbohydrate production, cell respiration, chemical reduction of nitrate and sulphate and in N assimilation. Iron deficiency symptoms appear on younger leaves indicating yellowish interveinal areas of leaves commonly referred to as iron chlorosis. In case of severe deficiency, leaves become almost pale-white due to loss of chlorophyll. In cereals, alternate yellow and green stripes along the length of the leaf blade may be observed. At later stage, complete leaf fall occur and shoots may die also.

Iron chlorosis is widespread in different crops grown on calcareous soils, particularly in groundnut and is the function of high concentration of Ca and Mg carbonate and bicarbonate, excess of phosphorus, deficiency of potassium, high pH, heavy metal toxicity which affect the sorption and utilization of iron by plants (Mengel, 1994).

Out of the important oilseed crops grown in India, groundnut contributes nearly 60 per cent to the total edible oil production. Area and production of groundnut in the world is 7.74 million hectare and 6.73 million tonnes, respectively. In India, groundnut is grown over an area of 7.1 million hectares, with the production of 6.1 million tonnes and productivity of 859 kg ha⁻¹ (Anon., 2000). The total demand for groundnut is about 14 million tonnes while; the production is only 9.2 million tonnes with a gap of 4.8 million tonnes. It is estimated that a reduction in pod yield of 13 to 15 per cent occurs when groundnut crop is affected with iron chlorosis.

Groundnut production in *kharif* was severely affected and it was only 3.56 million tonnes while the targeted production was 6.9 million tonnes. In *rabi*, there was a slight improvement in the performance of the crop. The total groundnut production for the year was 5.11 million tonnes, while the target was to achieve a production of 9.2 million tonnes (Venkataramani, 2004).

Maize is believed to be a native of South America. It was introduced in India by the Portuguese during the 17th century. Maize is one of the most important cereals in the world. In India, maize has become the third important food grain after wheat and rice. In terms of area, 6.6 million hectares and production 12.1 million tonnes (Anon., 2003 a), it ranks next to rice, wheat, jowar and bajra. It has overtaken sorghum and pearl-millet in importance. The demand for maize is going up in India with the increase in demand for poultry and animal feed. Karnataka stands first in the country with respect to production

(14.73 % to national pool) followed by Bihar and Andhra Pradesh (Anon., 2003 b). The *kharif* maize production rose to 9.17 million tonnes (with the target of 10.50 million tonnes), and the *rabi* maize was edging 1.94 million tonnes, which was pretty close to the target of 2 million tonnes (Venkataramani, 2004).

In Karnataka, maize occupies an area of 6.9 lakh hectares with the production of 21.4 lakh tonnes and the average productivity is about 3.4 tonnes ha⁻¹ (Anon., 2003 a). Important maize growing districts in Karnataka are Belgaum, Bangalore, Dharwad, Kolar, Mysore, Tumkur, and Bijapur. It is grown under irrigated conditions, mainly in the commands of Malaprabha, Ghataprabha and Tungabhadra projects of North Karnataka. The soils under these irrigation projects belong to Vertisols.

Since, fertilizers do have residual and cumulative effects, their application for one crop will also have some effect on the next crop grown in a sequential multiple cropping system. The residual effect of fertilizer applied to the preceding crop might help to regulate the demand of nutrients for the succeeding crop.

Groundnut followed by maize is a promising cropping system with respect to net return and nutrient utilization in Karnataka, Tamil Nadu, Andhra Pradesh and calcareous soils of Bihar.

Keeping these points in view, the present investigation was initiated to study the iron management in groundnut-maize cropping sequence in calcareous Vertisol, with the following objectives.

- 1) To know the distribution pattern of iron fractions content of soil and their relationship with soil properties,
- 2) To study the effect of application of ferrous sulphate on the periodical changes of iron fractions content of soil in Vertisol at different levels of free calcium carbonate,
- 3) To investigate the direct effect of iron management practices on nutrient uptake, growth, yield, quality and biochemical parameters of groundnut crop and
- 4) To find out the residual effect of iron management practices on nutrient uptake, growth, yield, quality and biochemical parameters of succeeding maize crop

REVIEW OF LITERATURE

II. REVIEW OF LITERATURE

Calcareous soils are wide spread over the world particularly in arid and semi-arid regions. Fuller (1963) had defined calcareous soils as those containing any excess of calcium carbonate from trace up to more than 50 per cent. Hillal *et al.* (1973) stated that the level at which some agricultural problems such as micronutrients deficiencies and phosphate fixation appear could be the margin at which the soil could be considered calcareous. They stated that this level at 8 to 10 per cent CaCO_3 content depending on the size distribution and its accumulation. Anter *et al.* (1973) found that an abrupt decrease in the uptake of iron and P^{32} in soil with 8 per cent CaCO_3 . They considered this level as the margin at which the soil could be considered calcareous. Lime induced iron chlorosis, is a common problem in arid and semiarid regions, where calcareous soils are dominant.

The Fe content of green plant tissues is low in comparison with the macronutrient and generally in the order of about 100 ppm in the dry matter. In cereal grains, tubers and root crops, it is often considerably low. Total soil iron is thus always in excess of crop requirement. According to Lindsay (1974) most agriculture crops require less than 0.5 ppm available iron in soil (in the plough layer) while, the total Fe level is about 2 per cent or 20,000 ppm. Any problem of iron deficiency is due to iron unavailability. Iron is absorbed by plant roots as Fe^{2+} , Fe^{3+} and organically complexed Fe chelate. The Fe^{2+} is more stable and available for incorporation into bio-molecular structures. Total iron content of the plant is not a true indicator of the iron status of the plant but Fe^{2+} gives good picture about iron status (Katyal and Sharma, 1980).

Literature on iron management on groundnut-maize cropping sequence in calcareous Vertisol is presented under the following heads:

2.1 Iron in soil.

2.2 Iron in plant nutrition.

2.3 Effect of iron on growth and growth parameters.

2.4 Effect of iron on yield and yield components.

- 2.5 Effect of iron on quality parameters.
- 2.6 Effect of iron on biochemical parameters
- 2.7 Effect of iron on nutrient uptake by plants
- 2.8 Mechanisms of iron uptake by plants and
- 2.9 Factors influencing iron availability.

2.1 IRON IN SOILS

2.1.1 Total iron in soils

Mengel and Kirkby (1982) reported that iron makes up about 5 per cent by weight of the earth's crust and is invariably present in all soils. The major part of soil Fe usually occurs in the crystal lattices of many minerals. The primary minerals in which Fe is present include the ferromagnesium silicates such as olivine, augite, hornblende and biotite. These minerals along with biotite micas constitute the major Fe source in igneous rocks. Primary iron oxides which occur in many soils include haematite (Fe_2O_3), ilmenite (FeTiO_3), and magnetite (Fe_3O_4). In sedimentary rocks, iron oxides and siderite (FeCO_3) are usually the most common primary iron forms. Iron may also be present in secondary mineral lattices in soils and it is an essential element in a large group of clay minerals. As weathering proceeds, iron originally present in the easily weatherable ferromagnesium primary minerals appears in illitic clay minerals. The high stability of primary iron oxides means that during oxidative weathering, Fe oxides accumulate as hydrous oxides in the clay fraction. Thus, in soils, at an advanced stage of oxidative weathering as in the case of lateritic soils, these oxides together with Al-oxides and kaolinite predominate in the profile.

Kanwar and Randhwa (1974) reported that the total iron content in some Indian soils was in the range of 0.46 to 27.3 per cent.

Holah (1977) showed that the total iron content in soils of Egypt ranged from 1.09 to 8.3 per cent. El-Falaky (1981) reported that the average values of total iron content in alluvial, sandy and calcareous soils were 5.77, 1.26 and 1.17 per cent, respectively.

Kumar *et al.* (1981) studied the total iron content in soils of Kumaon and Garhwal Himalayas which ranged from 3.20 to 9.50 per cent, 2.25 to 4.15 per cent and 2.0 to 4.05 per cent in Bageshwar, Garur and Ranichauri soils, respectively. The total iron content was higher in subsurface horizons than in surface layers, which was due to illuviation of iron from surface to subsurface layers.

Verma and Tripathi (1982) estimated that the total iron in deficient region of Himachal Pradesh soils varied from 1.4 to 6.4 per cent under rice crop. Jones (1982) showed that the values of total iron in soils ranged between 200 ppm and 10 per cent.

Dubey *et al.* (1983) estimated iron content in salt affected black soils of western Madhya Pradesh. The total iron in the soils was fairly high which could be attributed to the presence of iron bearing minerals. The content generally decreased with the depth of the profile.

According to Mured and Fischer (1988) the total Fe content in soils ranged from less than 1 to greater than 20 per cent with an average value of 3.2 per cent.

In the eastern desert of Egypt, Rabie *et al.* (1989) showed that total iron content of different soils ranged from 1716 to 41077 ppm with lowest value in sandy soils. The high averages were observed in the soils containing low calcium carbonate.

2.1.2 Available iron in soils

The deficiency of iron is quite common in calcareous soils because of its low availability. Under conditions of satisfactory aeration, iron is found in most soils, principally as precipitates of oxides and phosphate. The occurrence of iron oxides, magnetite, goethite, hematite, limonite and lepidocrite has been recorded in soils (Brown, 1960). The availability of these oxides in soils is determined by the changes in pH, oxidation reduction potential and the presence of soluble complexing agents. Available iron in Indian soils varies from 0.09 to 225 ppm (Kanwar and Randhwa, 1974).

The availability of iron in soils is a function of a number of properties; including texture, CaCO_3 content, organic matter and the amount of Fe in the solid form, which is in equilibrium with those in the soil solution. A very small proportion of soil total Fe is available for higher plants. The concentrations of ionic Fe^{3+} and Fe^{2+} are extremely low

(10^{-10} M or lower) in the aerated media maintained in the physiological pH range (Lindsay, 1974). He separated 77 Colorado soils into deficiency and non-deficiency categories and indicated that no response to iron fertilizer was obtained when DTPA extractable iron exceeded 4.5 ppm.

Babarai and Patel (1980) found an increase in the availability of iron at 10 ppm of iron, to soils. The effect was more pronounced as the incubation period was increased up to 42 days.

Cottenie *et al.* (1982) demonstrated that the critical level of DTPA extractable soil iron more than 4.5 ppm Fe is considered adequate.

Welp *et al.* (1983) found that in soils with high organic matter (>2% carbon) and especially under alkaline conditions, the concentration of organic Fe-chelates can reach values up to 10^{-4} to 10^{-3} M. However, in well-aerated soil inorganic matter, Fe concentration in the soil solution ranged from 10^{-8} to 10^{-7} M and thus is lower than the required amount for adequate plant growth.

Bienfait (1988) showed that the lower most abundant forms of ionic iron, ferric and ferrous, were only slightly soluble in a stable form in aerated soil solution. In flooded soils, where O_2 availability was low, ferrous ions can attain high levels. The ferrous ion was easily taken up by roots, and when ferrous levels are high, toxicity can occur.

Rajkumar *et al.* (1990) studied the depth-wise distribution of four available micronutrients in soil series of Bundelkhand region of Madhya Pradesh and reported that available Fe and Mn increased with depth.

Prasad and Sakal (1991) studied the available iron in calcareous soils extracted by different extractants (DTPA- $CaCl_2$, DTPA- NH_4HCO_3 , EDTA- $(NH_4)_2CO_3$ and EDTA-Ammonium acetate) and reported that, significant negative correlation with pH, free $CaCO_3$ and active $CaCO_3$, whereas positively with organic carbon. Clay content showed a tendency of positive correlation with extractable and total iron.

Sakal and Singh (2001) observed an overall deficiency of iron in Indian soils. In Karnataka about 39 per cent soils are deficient in iron.

2.1.3 Critical limit of iron deficiency in soils

Several methods have been employed in order to assess the availability of iron in soils. Olsen and Carlson (1950) used 1N NH_4OAc (pH 4.8) to estimate available iron. They found that at Fe levels between 0.01 and 0.3 ppm chlorosis was moderate to severe, between 0.3 and 2.2 ppm Fe chlorosis was slight to moderate and plants grown on soil testing between 2.0 and 32.0 ppm Fe were not chlorotic. Also, Hegazy (1980) concluded that the NH_4OAc (pH 4.8) solution was the most reliable iron test and the critical level was 2.1 ppm.

Lindsay and Norvell (1978) used a mixture of 0.005 M DTPA, 0.01 M CaCl_2 and 0.1 M triethanolamine adjusted to pH 7.3 for the simultaneous extraction of available Fe and other micronutrients. The critical level of Fe for corn was 4.5 ppm (<2.5 deficient, 2.4 - 4.5 marginal and > 4.5 adequate). Cottenie *et al.* (1982) demonstrated that the critical level of DTPA extractable iron in soil was < 2.5 ppm. El-Gala *et al.* (1986) suggested that Fe critical levels in different Egyptian soil types, alluvial, calcareous and sandy soils were 5.6, 3.4 and 3.8 ppm, respectively.

Campillo and Torrent (1992) chose chickpea and sunflower as test crops and grew in a growth chamber on 25 calcareous soils from arid Alusia representing Xeroflurents, Xeroorthants, Xerochrepts, Haploxeralfs, Radoxeralfs, Chromoxerents and Pelloxerents. They found mean chlorophyll contents of the plants were most strongly and negatively correlated with soil calcium carbonate equivalent and native lime and positively correlated with acid ammonium oxalate extractable Fe, DTPA extractable Fe. The Fe form most closely related to Fe chlorosis was acid NH_4 -oxalate extractable Fe, the critical level separating soils with high and low probabilities of responding to Fe fertilizer was 0.63 g kg^{-1} of soil.

2.1.4 Iron fractions in soils

The solid phase plays an important role in determining the solubility of micronutrients in soils. The nutrients in soil solution are usually in equilibrium with the solid phase. Thus the solid phase tends to buffer the concentration of soluble nutrients in soils and iron is not an exception to this principle.

Several attempts have been made to fractionate the nutrients present in different forms in order to have a better understanding of their chemistry and availability in soils. Viets and Jr (1962) postulated that micronutrient cations existed in five distinct pools in the soils which apply to iron also, water soluble, exchangeable fraction, complexed or chelate extractable fractions, iron held in secondary clay minerals and in metal oxides by occlusion, iron held within the primary minerals.

According to Viets and Jr (1962), water soluble, exchangeable, and chelated iron are in reversible equilibrium with each other and the iron in these pools are readily available to plants.

Tessier *et al.* (1979) sequentially extracted the soil iron into exchangeable, bound to carbonate, bound to iron and manganese oxides, bound to organic matter, and residual iron fractions by using MgCl_2 (pH 7.0), $\text{NaOAc} / \text{HOAc}$ (pH 5.0), $\text{NH}_2\text{OH-HCl}$ in 25 per cent HOAc (pH 2), $\text{H}_2\text{O}_2 / \text{HNO}_3$ (pH 2.0) and HF , and HClO_4 reagents respectively. Reports revealed that residual iron was dominant fraction, which was present in primary and secondary minerals followed by Fe, and Mn oxide bound iron.

Lindau and Hossner (1982) sequentially extracted sediment samples iron into exchangeable + water soluble, easily reducible, organic + sulfide, moderately reducible and residual iron by using 1 N MgCl_2 , 0.1 M $\text{NH}_2\text{OH-HCl}$ in 0.01 M HNO_3 , 3 per cent H_2O_2 , $\text{Na}_3\text{O}_6\text{H}_5\text{O}_7$ H_2O - $\text{Na}_2\text{S}_2\text{O}_4$ and an HNO_3 - H_2SO_4 - HF acid mixture extractants respectively. Exchangeable + water soluble iron concentrations were low and residual and reducible iron were the dominant fractions.

Fractionation of soil iron in the profile samples was made by successive extractions with MgCl_2 , oxalate, citrate-dithionate bicarbonate (CDB) and NaOCl . After the oxalate, CDB and NaOCl extractions removed iron associated with amorphous Fe oxides, crystalline Fe oxides and organic matter respectively. Residual iron was then determined by the difference between total (HNO_3 - HClO_4 extractable) and sum of the above metal fractions. The amounts of exchangeable iron was below the detection limit as was the fraction of iron associated with organic matter (Kuo *et al.*, 1983).

Metals held on soil surface by covalent type bonding termed 'specifically adsorbed' or 'inner sphere' complexed metals (Sposito, 1984). These types of specifically adsorbed

metals can be differentiated into two fractions. One such was Pb-extractable metal, which displaces only those metal ions bound covalently to oxidic or organic functional groups (Ramamoorthy and Rust, 1978). The second one was acidic reagent ($\text{CH}_3\text{-COOH}$), which was capable of dissolving some poorly crystalline hydroxy-carbonate metal phase of these metals (Miller, 1981). Organic matter and hydrous oxides of iron and Mn were the major surface responsible for metal retention (Jenne, 1977).

A modified method of sequential extraction procedure for soil iron was proposed by Shuman (1985). He extracted soil iron into exchangeable, organic, Mn oxides, amorphous iron oxides and crystalline iron oxides by extracting with 1 M $\text{Mg}(\text{NO}_3)_2$ (pH 7.0), 0.7 M NaOCl (pH 8.5), 0.1 M $\text{NH}_2\text{OH-HCl}$ (pH 2.0), 0.2 M $(\text{NH}_4)_2\text{C}_2\text{O}_4 \cdot \text{H}_2\text{O}$ –0.2 M $\text{H}_2\text{C}_2\text{O}_4$ (pH 3.0) and 0.2 M $(\text{NH}_4)_2\text{C}_2\text{O}_4 \cdot \text{H}_2\text{O}$ –0.2 M $\text{H}_2\text{C}_2\text{O}_4$ (pH 3.0)–0.1 M ascorbic acid respectively and reported that soil iron was predominantly in the crystalline Fe oxide fraction, and exchangeable fraction was very low.

Miller *et al.* (1986) formulated modified sequential extraction procedure for extracting soil metals (Mn, Fe and Cu). They extracted soil iron into water soluble, exchangeable, Pb-displaceable, acid soluble, Mn oxide occluded, organically bound, amorphous Fe oxide occluded, crystalline Fe oxide occluded, and residual iron using double distilled water, 0.5 M $\text{Ca}(\text{NO}_3)_2$, 0.05 M $(\text{Pb}(\text{NO}_3)_2 + 0.1 \text{ M } \text{Ca}(\text{NO}_3)_2)$, 0.44 M $\text{CH}_3\text{COOH} + 0.1 \text{ M } \text{Ca}(\text{NO}_3)_2$, 0.01 M $\text{NH}_2\text{OH.HCl} + 0.1 \text{ M } \text{HNO}_3$, 0.1 M $\text{K}_4\text{P}_2\text{O}_7$, 0.175 M $(\text{NH}_4)_2\text{C}_2\text{O}_4 + 0.1 \text{ M } \text{H}_2\text{C}_2\text{O}_4$ oxalate reagent under ultraviolet irradiation and hydrofluoric acid reagents respectively. They concluded that residual and crystalline Fe oxide occluded iron were the dominant fractions. They further reported that water soluble and the exchangeable iron fractions were the least among the different fractions.

Studies conducted by Singh *et al.* (1988) on the content of different fractions of iron in calcareous soils revealed that carbonate bound iron ranged from 4.1 to 70.5 ppm with an average of 19.4 ppm. The organically bound was in the range of 0.2 to 1.3 with an average of 0.7 ppm, manganese oxide bound iron ranged between 2.12 and 6.9 ppm, amorphous iron ranged between 900 and 7000 ppm, crystalline iron oxide ranged between 5100 and 71500 ppm and residual iron varied between 8.8 and 21.2 ppm

2.1.5 Distribution of iron fractions in soils

The distribution of iron in soils is a function of the oxidation potential of the soil environment. In soil, divalent form of Fe is less strongly held by soil surface than other micronutrients like Cu, Zn but the property of being oxidized to higher valence states, which can form very insoluble oxides and phosphates renders these elements much less available to process of leaching. Distribution of iron in soil is mainly depends upon organic matter content, clay content, oxidation-reduction state and drainage condition.

Mahendra Singh and Dahiya (1975) studied the effect of added CaCO_3 and iron on the transformation of iron in a light textured soil in laboratory, and reported that, the exchangeable, available and reducible iron decreased with increasing CaCO_3 addition. Increase in time of incubation also caused significant decrease in all forms of iron irrespective of CaCO_3 addition. Addition of soluble iron salt resulted immediate increase in all forms of iron, which also decreased with incubation time.

Patel *et al.* (1982) conducted an incubation study on calcareous clay soil of Junagadh, Gujarat to study the effect of lime (0, 5 %) and sulphur (0, 50 ppm) on available iron under soil moisture regime of 50 per cent field capacity, field capacity and saturation at different incubation periods. The results revealed that available iron in soil increased with the passage of time up to 28 days and thereafter it decreased. Application of lime depressed Fe content, whereas that of sulphur favorably affected its content in soil. Among the moisture regimes, saturation increased available iron ten fold over its initial value. First and second order interactions were significant, adverse effect of lime was found to be mitigated by sulphur application.

To study the distribution of different forms of iron in soils of Uttar Pradesh, Misra and Pande (1975) collected soils from different agroclimatic regions of Uttar Pradesh. None of the soil was found to be deficient in available iron as soils were analysed for exchangeable, reducible, available, complexed, organic, dil. HCl soluble and free iron forms. The order followed by the different forms of Fe in respect of its extractability was: free Fe > 0.1N HCl soluble Fe > organic Fe > complexed Fe > reducible Fe > available Fe > exchangeable Fe. The correlation with Fe was found positive to organic carbon and negative to pH and CaCO_3 content.

Dubey *et al.* (1983) estimated iron content in salt affected black soils of Western Madhya Pradesh. The total iron in soils was fairly high which could be attributed to the presence of iron bearing minerals. The content generally decreased with the depth of the profile.

Sharma and Yadav (1986) studied the distribution of different forms of iron in soil profiles. Clay content is an important factor governing the status of total iron. The content of reducible and available forms of iron was generally more in the soils layer close to ground water table.

Jha and Sharma (1989) found that the calcareous soils were alkaline (32.2 – 48.5 % CaCO_3) in nature, surface enrichment of micronutrients was noted. Reducing condition in low lands mobilized Fe and to some extent Mn, leading to their enrichment in lower heavy layers by subterranean movement.

Yerriswamy *et al.* (1995) studied the forms of Fe and their distribution in five typical Vertisol series of Karnataka. Fractionation revealed that water soluble, Mn-oxide occluded and organically bound iron decreased, whereas exchangeable, acid soluble, Pb-displaceable, amorphous iron-oxide occluded and residual Fe increased with depth. The percentage contribution of different fractions to the total iron was in following order. Residual iron > amorphous Fe-oxide occluded iron > organically bound iron > Mn-oxide occluded iron > Pb-displaceable iron > exchangeable iron > acid soluble iron > water soluble iron. The amount of iron in labile pools was very low and this could be the reason for the frequent appearance of iron chlorosis in calcareous Vertisol of Karnataka.

Two Usterts picked out from middle and lower Narmada valley, namely Karanpur (Typic Chromusterts) and Keshvi (Typic Pellusterts) were evaluated for their physico-chemical properties and forms of iron. Study of different forms of iron by Thakur *et al.* (1995) revealed water soluble, exchangeable and available forms of iron content decreased with depth, it was probably due to precipitation of soluble iron at lower depth by adsorption on clays and uncharged oxides. Positive significant correlations were observed between different forms of iron. The water soluble iron was seen significantly correlated with silt and clay in both the soils. However, total and available iron were positively correlated with CaCO_3 , silt, clay, semectite in both the Usterts.

To find the cause for iron deficiency in the Vertisols (Typic Chromustets) in Maharashtra, Yelvikar *et al.* (1996) have analysed several soil samples and found significant influence of pH, CaCO₃, organic carbon and clay to different fractions of iron. The fractions of iron tested were DTPA-extractable Fe, exchangeable, reducible, dilute acid soluble and water soluble iron.

The distribution of various forms (exchangeable, organically bound, associated with Mn oxide, amorphous and associated with crystalline Fe oxide forms) of Fe, Mn, Al and P in the surface horizons and the distribution of these elements in different depths in six soil series in Florida representing Spodosols, Alfisols and Entisols. Variation in concentration of total Fe with depth of soil was significantly correlated with clay content. Greater than 60 per cent of total Fe was present in the amorphous form in soils with pH < 6.5, while more than 80 per cent of total iron was present in the crystalline form in soils with pH > 6.5. The distribution of total and oxalate-extractable P was significantly related to the content of amorphous Al and Fe and crystalline Fe oxides in the soils. (Zhang *et al.*, 1997)

2.2 IRON IN PLANT NUTRITION

2.2.1 Ferrous and total iron

Chaney *et al.* (1972) reported that reduction of Fe³⁺ (ferric ion) to Fe²⁺ (ferrous ion) is found to be obligatory, before it can be absorbed by the plants. The deficiency of iron was attributed to non-availability of iron in soil rather than total iron in the soil (Decock, 1978).

Krishnamurthy and Raj (1975) reported that application of organic matter to calcareous soils under waterlogged conditions increased the ferrous iron content of soils. The formation of ferrous iron in waterlogged soils was attributed to the reducing compounds and carbon dioxide produced in the course of anaerobic decomposition or fermentation of added organic matter. Such substances dissolve insoluble ferric iron compounds in soils and reduce them to ferrous form. They also reported that anaerobic conditions reflect and increase in the activity of the ferrous iron and at the same time there was decrease in pH.

Katyal and Sharma (1980) identified higher amount of total iron in chlorotic leaves of paddy in comparison to green leaves. In order to overcome the elusive behavior of iron

they analyzed for active iron Fe^{2+} or dilute acid extractable iron using 1-10 Orthophenanthroline and reported that chlorotic plants contain less of Fe^{2+} than green plants.

Basanna (1982) reported that Fe^{2+} was generally greater in green leaves (lower leaves) than chlorotic (upper) leaves. The total iron content was generally more in chlorotic (top) leaves than in green (lower) leaves of groundnut in medium black soil at Agricultural College farm, Dharwad.

Chandrshekar Reddy and Krishnamurthy (1985) conducted a field experiment in sandy loam soil at Agricultural College farm, Rajendranagar, Hyderabad in *Kharif* 1980 and summer 1981 season. They studied Fe distribution in different parts of plant and reported that the concentration of Fe in the groundnut parts was in the order: stem > root > petiole > leaf let > shell > kernal.

Rao *et al.* (1987) reported that the measurement of iron contents of chlorotic and normal leaves of field-grown groundnut (*Arachis hypogaea* L.) in calcareous soil, Chittoor, Andra Pradesh showed that total iron was unsatisfactory as the measure of the iron status of the plant tissue. Iron status was better assessed by ferrous iron content estimation of fresh leaf by extraction with o-phenanthroline. Ferrous iron content was increased with leaf age. Chlorotic buds or the first fully opened leaf always contained less than 6 mg extractable Fe /g fresh tissue.

Basappa (1990) studied the iron uptake efficiency in groundnut genotypes at Agricultural College, Dharwad. The result indicated that both soil and foliar application of iron increased the total iron content in plants which was more at harvest stage of the crop than at flower initiation stage.

Field experiment was carried out by Rashid and Din (1992) to investigate the cause for chlorosis in some varieties of chickpea grown on calcareous soils of Pothwar region of Pakistan. The results indicated that total Fe content of leaf-tissue was not related with chlorosis, but Orthophenanthroline extractable ferrous (Fe^{2+}) content of fresh leaves was more related to the severity of chlorosis.

Kullkarni *et al.* (1994) conducted a pot culture experiment in Dharwad, Karnataka to know the productivity of groundnut (*Arachis hypogaeae* L.) varieties. Soil samples were

collected from the farmer's field. They reported that the chlorophyll and active iron (Fe^{2+}) concentration of leaves was less in iron inefficient genotypes when compared to efficient types in calcareous soil.

Since, total iron content is a misleading index of Fe nutritional status of plant. Determination of physiologically active (ferrous iron) Fe^{2+} fraction was suggested by Katyal and Sharma (1980). Rashid *et al.* (1997) conducted a survey work in two districts, Chakwal and Attock of the rainfed Potohar Plateau of Pakistan on groundnut crop. They reported that Fe^{2+} concentration in plants decreased with increasing severity of chlorosis and thus proved effective techniques for determining the intensity of Fe chlorosis. Green plants contained 40.1 to 67.3 mg Fe^{2+} kg^{-1} , mildly chlorotic 32.1 to 40.0 mg Fe^{2+} kg^{-1} , moderately chlorotic 28.0 to 32.00 mg Fe^{2+} kg^{-1} and severely chlorotic < 28.00 mg Fe^{2+} kg^{-1} . The minimum Fe^{2+} requirement in green plants was estimated to be 40.0 mg kg^{-1} on dry weight basis.

Maya *et al.* (1999 a) conducted a pot culture experiment in Parabhani, Maharashtra, to know the effect of different levels of CaCO_3 (5 to 20%) on the chlorophyll and ferrous iron content using groundnut as a test crop. Results indicated that ferrous iron content decreased significantly with the increase in CaCO_3 levels.

Chandrshaker (2002) studied the effect of CaCO_3 on ferrous iron in stem, younger and older leaves of groundnut at 60 and 70 day after sowing. Results indicated that ferrous iron concentration decreased significantly and negatively in stem, younger and older leaves with increase CaCO_3 in soil. It was observed that increase in CaCO_3 levels in soil increased the HCO_3^- concentration in root medium leading to increase pH of plant system, neutralize the proton pumped out of the crystal and decrease the ferric reductase activity in the plasma membrane.

2.2.2 Critical limits of iron deficiency in plant

In plant leaves, Bergmann (1992) stated that the critical deficiency concentration (CDC) of iron ranged from 30 to 50 ppm on dry weight basis. The CDC was presumably considerably higher in fast growing meristematic and expanding tissues.

Marschner (1991) declared that the critical concentrations of Fe in leaves are usually in the range between 50 and 150 mg. kg^{-1} dry weight.

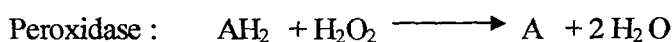
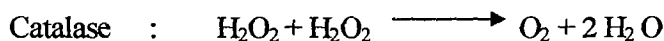
2.2.3 Role of iron in crops

Iron as a transition element is characterized by easy change of its oxidation state (Fe^{3+} and Fe^{2+}). The most well known function of iron is in enzyme systems. There are two major groups of Fe- containing proteins: heme proteins and Fe- S proteins.

[I] Heme proteins

Here iron plays a somewhat similar role of Mg in the porphyrin structure of chlorophyll. These heme enzyme systems include catalase, peroxidase, cytochrome oxidase as well as the various cytochromes.

Catalase and peroxides catalyze the following reactions:



Although highly important in metabolism, the haem pigments constitute only about 0.1 per cent of the total iron in plant leaves.

[II] Fe-S protein

The most well known Fe-S protein is ferredoxin. Other Fe-S proteins have functions in metabolic processes, such as photosynthesis, SO_4 and SO_3 reduction, respiration, the tricarboxylic acid cycle, and N_2 fixation. In addition to its functions in heme and Fe-S proteins, Fe-activates a number of enzymes including aminoleavulinic acid synthetase, co-protophyrinogen oxidase, and plays a role in the synthesis of ribonucleic acid.

Ferredoxin (non-heme $\text{Fe}_2\text{-S}_2$ protein) decreases in leaves of Fe-deficient plants similarly to chlorophyll. Because of various functions of ferredoxin (e.g. reduction of NADP^+ , NO_2 and SO_4 , and assimilation of NH_3), several metabolic disturbances are, therefore, to be expected as a result of Fe-deficiency.

The role of iron in photosynthesis is universal. An "active iron" which is localized in chloroplasts is closely connected to chlorophyll protein complex in the biosynthesis of chlorophyll, that is in condensation of succinyl CO-A (from citrate cycle) and glycine (from amino acid metabolism) resulting in the formation of amino-laevulinic acid, in

reaction of oxidative decarboxylation of co-protoporphyrinogen to protoporphyrin, and in joining phytol to protochlorophyll (Amberger, 1974).

2.3 EFFECT OF IRON ON GROWTH AND GROWTH PARAMETERS

Verma and Bajai (1964) noticed chlorosis of young leaves, reduction in leaf size and highly stunted plants growth in groundnut due to iron deficiency.

Westfall *et al.* (1971) reported that iron sulphate, alone or in combination with $ZnSO_4$ was the most effective in correcting rice seedling chlorosis grown on calcareous soil

Patil (1975) conducted a field experiment on an Vertisol at Dharwad, Karnataka and reported that the foliar application of ferrous sulphate (0.5%) at 30, 60 and 75 days after sowing, significantly increased the plant height, number of branches per plant, dry matter production of groundnut at harvest stage.

Chandrashekar Reddy (1976) conducted a field experiment on a black soil at Dharwad, found that spraying of 0.5 per cent ferrous sulphate significantly increased the dry matter production of groundnut.

Channal (1978) reported that foliar application of 0.5 per cent ferric chloride, significantly increased the plant height, dry matter accumulation, number of green leaves of sunflower in black clay soil of Agricultural College farm, Dharwad.

Francis and Rajagopal (1978) observed that application of $FeSO_4$ and complexed Fe to black calcareous and red soils of Coimbatore, increased the growth and grain yield of sorghum hybrid CSH-5.

Singh and Chaudhari (1997) showed that application of iron 20 kg ha^{-1} and 10 kg of S in calcareous soil of Junagadh, India reduced the chlorosis in groundnut leaves and increased the dry matter, root nodules, biomass, pod, shoot and oil yield. It increased the pod yield by 8.6 to 9.8 per cent and oil yield by 8.8 to 15 per cent.

Sarkar *et al.* (1998) conducted a field experiment in calcareous soil of West Bengal to know the effect of micronutrients on groundnut yield and yield attributes. They reported

that micronutrients spray had the greater effect on increasing biomass production, leaf area index, crop growth rate and yield attributes, resulting in 41 per cent greater pod yield than control.

2.4 EFFECT OF IRON ON YIELD AND YIELD COMPONENTS

2.4.1 Soil application

Mathers (1970) found that application of 250 ppm or more iron with 250 ppm or more H_2SO_4 to sandy loam soil, near Muleshone, Texas increased yield of grain sorghum. Residual effects were observed due to heavy application of $FeSO_4$ and H_2SO_4 on the third crop also.

According to Hartzook *et al.* (1971), application of iron increased the yield of groundnut and deficiency of iron led to iron chlorosis, resulting in reduction in yield of groundnut from 50 to 38 per cent.

Belavanaki (1979) noticed a significant increase in the grain yield and 1000-grain weight of sorghum due to soil application of 10 kg ferrous sulphate per ha.

Savithri and Sree Ramulu (1980) studied the effect of continuous application of Zn, Cu and Fe to maize-groundnut-sorghum cropping sequence on yield and availability of major and micronutrients in a red loamy soil of Coimbatore. Marginal increase in yield of maize grain due to Cu application, substantial increase in both kernel and haulm of groundnut for the individual application of all the three micronutrients and also for Zn and Fe in the third sorghum crop were observed.

Sakal *et al.* (1982) studied the direct effect of iron carriers and compost on yield and Fe uptake by rice and their residual effect on winter maize and reported that the residual effect of $FeSO_4$ alone on maize yield was not so distinct while that of pyrite alone was about four times greater which may be due to acidulating action of pyrite and the residual response was magnified when these Fe carriers were applied in conjunction with organic manure.

Acid forming materials like pyrites as a source of Fe and S has been used to increase availability of nutrients and to improve soil properties by reducing the pH and creating favorable conditions for the growth of rice. Sedimentary iron pyrite was

considered as a multipurpose soil amendment, an acidifier, plant nutrient mobilizer and a co-fertilizer to supply sulphur and iron to plants in soils deficient in these nutrients (Tiwari *et al.*, 1984).

Singh *et al.* (1984) reported that application of FeSO_4 at the rate of 0, 5, 10, 20 and 40 kg per ha, increased the grain yield and iron content of lentil crop grown in calcareous soil of Bihar.

Sharma and Lal (1992) reported that among the individual micronutrient treatments in loamy sand soil of Rajasthan, the highest grain and straw yield of wheat were obtained due to the application of FeSO_4 at the rate of 50 kg per hectare. Grain yield of wheat increased by 22.7 per cent due to application of 50 kg FeSO_4 per hectare over control.

Prasad and Rajkumar (1992) recorded the significant increase in dry matter yields and iron uptake by rice in calcareous soil of Bihar due to the application of iron in the form of FeSO_4 as well as Fe-chelates.

Based on survey work conducted in Chittor district of Andhra Pradesh, Rao *et al.* (1993) reported that yield decreased in chlorotic fields compared to non chlorotic fields and found a significant positive correlation ($r = 0.93^{**}$) between ferrous iron and pod yield of groundnut.

Potdar (1994) reported that iron chlorosis could result in yield reductions of about 32 per cent pods, 18 per cent fodder and 25 per cent of total dry matter of groundnut in calcareous soil of Maharashtra.

To quantify groundnut (*Arachis hypogaea* L.) yield loss due to Fe chlorosis, diagnostic on-farm trials were carried out at two village sites prone to Fe-chlorosis in Maharashtra. Soils at the experimental sites were alkaline ($\text{pH} > 8$) and rich in lime (16% CaCO_3). Severe chlorotic symptoms occurred as early as in the seedlings stage at both sites and iron chlorosis caused reduction in pod, fodder and total dry matter production (Potdar *et al.*, 1995).

Shashidhar *et al.* (1995) stated that the use of organic manure and inorganic fertilizer not only increased the sorghum yield due to synergetic effect between organic

and inorganic form of nutrients and formation of stable organic complexes by chelating but also improved the physical and biological properties of soil of Agricultural College, Dharwad.

Singh *et al.* (1995) conducted an experiment on a calcareous black soil of Bihar and raised groundnut (GAUG-1, GG-2 and J-11) varieties with normal and excess irrigation and ferrous sulphate and iron chelate were applied. The chlorophyll content increased with application of ferrous sulphate with normal irrigation. The reduction in pod yield of groundnut was due to chlorosis to extent of 15.9 to 32.3 per cent. Pod yield of groundnut increased due to iron chelate application and uptake of N, P, K and S increased with application of ferrous sulphate.

Tupatkar and Sonar (1995) studied the effect of pyrite on yield of rice and release of Fe, P, and S in calcareous soil of Rahuri, Maharashtra. They concluded that, increasing rates of iron pyrite increased number of tillers, dry matter accumulation, grain and straw yield of rice. Also, gradually increased DTPA-Fe in soil at all the growth stages of rice. This may be due to release of native iron from soil as a result of acidulation effect of pyrite (pH decreased from 8.5 to 8.0) as well as iron released by oxidation of iron pyrite.

Srinivas and Srinivas Raju (1998) observed that when maize was grown in sequence with different crops (groundnut, sunflower, sesame, Indian mustard, greengram, pigeonpea) highest maize-equivalent yield (140.5 q ha^{-1}), net return (Rs 38,538) and B: C ratio were found in maize-groundnut sequence.

Sarkar (2000) conducted a pot culture experiment (imposing three moisture and five CaCO_3 levels) at Dharwad to know the uptake of iron and groundnut pod yield. The results indicated that, yield decreased with increase in CaCO_3 and moisture level.

2.4.2 Foliar application

Subbarao (1978) reported that the critical limit for the iron chlorosis was influenced by high soil pH, CaCO_3 and Mn / Fe ratio. It was observed that the total iron content of soil did not regulate the availability of iron and iron chlorosis in sugarcane was mainly due to the presence of calcium carbonate in soil, which adversely affected the availability of Fe. The iron level in sugarcane leaves was not an indicator of iron deficiency because in such cases the iron was physiologically inactive. This can be reversed by foliar spray of FeSO_4

(Naik and Joshi, 1979). Patil *et al.* (1979) found that foliar application of 0.5 per cent and FeSO_4 at 30, 60 and 75 DAS produced the highest pod yield.

Chen and Barak (1982) stated that a major problem with foliar application is the poor translocation of applied iron within the plants. The main disadvantages of foliar sprays are possible deleterious effects on plant foliage and the need for repeated application under same conditions

Foliar application was much more efficient in controlling Fe chlorosis, especially in terms of amounts needed (Leavey and Horesh, 1984 and Mortvedt, 1986). Foliar application should be made in the early morning or late afternoon and on cool, cloudy days for maximum effectiveness. Iron absorption occurs mainly through the stomata, as demonstrated by spraying FeSO_4 solution on the upper or lower surfaces of orange leaves. Foliar sprays should be applied during the active growth season.

Nagasundaram *et al.* (1986) assessed the comparative efficiency of FYM addition and soil and foliar application of FeSO_4 to sorghum in ameliorating chlorosis and increasing yield. Foliar application of FeSO_4 was found effective in increasing iron uptake by plants. Soil application of FeSO_4 (37.5 kg ha^{-1}) in combination with foliar spray of two per cent FeSO_4 to sorghum was more effective in increasing the yield particularly in calcareous soil.

Mortvedt (1986) reported that because most fertilizers are applied directly to soil, many iron sources have been applied alone or with NPK fertilizers. Soil applications of inorganic iron sources are usually not effective unless high rates are applied because these iron sources are rapidly converted to forms, which are not available to plants. Ferrous-Fe is rapidly oxidized to the ferric form in well-aerated soil. Therefore, broadcast applications of these inorganic sources to iron deficient calcareous soils generally, are not as effective as band applications because soil-fertilizers contact is more limited with band application.

Ramaswami (1992) found that the application of one per cent FeSO_4 as foliar spray along with 0.1 per cent citric acid had better influence on the yield of sugarcane throughout and the quality parameters. Iron availability was enhanced when pyrite was applied up to 300 kg per hectare along with Mussoorie rockphosphate as source of phosphorus or FYM at 10 t ha^{-1} .

Singh and Dayal (1992) conducted a field experiment on iron deficient calcareous soil, using groundnut as a test crop to know the effect of foliar application of iron salts on pod yield. They reported that 13-19, 12-18 and 11-18 per cent increase in yield was recorded by spraying iron sulphate, iron citrate and Fe-EDTA, respectively over control.

Singh *et al.* (1993) reported that the foliar application of ferrous sulphate (0.5%) and multi micronutrients caused the regreening of chlorotic leaves, increased chlorophyll content, pod and haulm yield of groundnut in calcareous soil, Junagadh, India.

Patel *et al.* (1993) reported that foliar application of one per cent FeSO_4 with 0.1 per cent citric acid and two per cent ferric citrate significantly increased pod and haulm yield of groundnut by about two folds by significantly increasing chlorophyll and active iron content of leaves about three to four folds over control.

Rashid *et al.* (1997) conducted a field experiment on calcareous (typic hapludalfs) soil to know the effect of foliar-spray of iron salts on pod yield of two groundnut varieties. Results indicated that spraying of sequestrene (Na-Fe-EDDHA) registered increase in pod yield to the tune of 42 per cent in *cv.* BARD-92 and 27 per cent in *cv.* BARD-699 over control.

Uday Kumar (2002) concluded that application of FeSO_4 either through soil or foliar spray on highly calcareous soil (25 % CaCO_3) resulted in significantly higher growth, yield and uptake of nutrients by different groundnut varieties but foliar application of FeSO_4 was better than soil application in increasing growth and yield parameters and decreasing chlorosis.

2.5 EFFECT OF IRON ON QUALITY PARAMETERS

2.5.1 Protein

Patil (1975) observed increase in oil and crude protein content in groundnut kernels due to iron application. Burn and Huffman (1975) reported that iron deficient plants are low in protein.

Channal (1978) obtained increase oil and crude protein content of sunflower seeds by the foliar application of 0.5 per cent iron and zinc in black clay soil of Agricultural College farm, Dharwad.

Patil *et al.* (1979) reported that soil application of 10 kg FeSO₄ per ha increased in crude protein content of wheat in black clay soil of Agricultural College farm, Dharwad. Torry (1980) noticed that leaf soluble protein content decreased due to iron stress. Nagaraj and Kullkarni (1987) observed increase in protein content of groundnut due to 0.1 per cent iron application through foliage.

A field experiment was conducted by Maya *et al.* (1999 b) to study the effect of iron application (0, 4 and 8 kg Fe ha⁻¹) on groundnut in Vertisol at Parabhani. They reported that the protein content increased significantly from 12.37 to 17.0 per cent due to the application of 8 kg Fe per ha in the form of ferrous sulphate.

2.5.2 Oil Content

Patil *et al.* (1979) reported that soil (10 kg FeSO₄ ha⁻¹) and foliar (0.5 % FeSO₄) application of iron significantly increased the protein and oil content, shelling percentage and pod yield of groundnut in black clay soil of Agricultural College farm, Dharwad.

Poleshi (1984) reported that application of 20 kg FeSO₄ with 30 kg ZnSO₄ per hectare to groundnut in black soil of Tungabhadra Project area resulted in significant increase in oil content over control (RDF only).

Krishnappa *et al.* (1994) conducted a field experiment on an clay soil at V.C. farm, Mandya and reported that application of NPK + Fe gave significant higher oil content of cv. Dh – 8 and TG-17 groundnut varieties over control (NPK only).

Singh and Chaudhari (1997) noticed that application of 10 kg Fe and 2 kg Zn and 4 kg Mn per hectare significantly increased the oil yields by 20.1, 13.9 and 12.2 per cent, respectively over control in groundnut cv. JL-24 and J-11.

2.5.3 Starch content

Muthuswamy and Chiranjivi Rao (1981) reported that with increasing nitrogen fertilization protein content increased and starch content decreased in tapioca tuber. This might be due to the diversion of carbohydrates for the synthesis of protein and non-protein nitrogenous compounds resulting in decreasing the polymerization of glucose to starch.

Jambunathan *et al.* (1992) analyzed newly released groundnut cultivars for their chemical composition and protein content. Result indicated that protein content was

significantly increased in post rainy season. While starch and sugar, biological value significantly higher in rain season. The iron efficient groundnut varieties were higher in oil and sugar and lower in starch content.

2.5.4 Acid value, iodine number and saponification value

The iodine number indicates the number of unsaturated bonds and indirectly helps in knowing the unsaturated fatty acids. Whereas, saponification value is related to molecular weight of fatty acids. Saponification value will be on higher side if there are higher numbers of shorter chain fatty acids and its value will be on lower side in case there are larger numbers of longer chain fatty acids.

The fatty acid composition in runner types of groundnut was observed to range between 50.55 and 57.49 per cent of oleic acid, 30.33 and 33.37 per cent of linoleic acid, 8.54 and 10.77 per cent of palmitic acid, 2.03 and 3.14 per cent of stearic acid and 2.23 and 4.31 per cent of other fatty acids (Sekhon *et al.*, 1980).

Many workers have reported that the iodine value in groundnut oil varies from 82.0 and 106.0 (Badami *et al.*, 1978 and Shivamurthy, 1979). Knowles and Mutwakil (1963) observed that lower iodine value reflects lower content of linoleic acid and higher oleic acid content. Ford and Zimmerman (1964) observed positive association between iodine value and 100-pod and seed weight of groundnut crop.

According to Badami *et al.*, (1978), and Shivamurthy (1979) both the saponification value and percentage of unsaponified matter in bunch type varieties of groundnut varied between 185.0 and 195.0 and 0.3 and 1.4, respectively.

Uday Kumar (2002) studied on the performance of groundnut cultivars as influenced by FeSO_4 application on a calcareous soil at Amminabhavi. The result showed non-significant relationship between iron application and quality parameters of groundnut particularly, saponification, iodine number, acid value and oil content.

The results of field experiment conducted on Vertisols of Agricultural College farm, Dharwad indicated that, the combination of $30 \text{ kg S ha}^{-1} + \text{Fe} + \text{Zn}$ foliar spray gave significantly higher oil and protein content of safflower over control (RDF only).

Whereas, the combination of these treatments recorded lower saponification, iodine number, acid value and oil content as compared to control (Ravi, 2004).

2.6 BIOCHEMICAL PARAMETERS

2.6.1 Chlorophyll

Although iron is not an integral part of chlorophyll molecule, it is essential for its synthesis, normally 60-80 per cent of iron content of leaves is found in chloroplast. Iron chlorosis refers to the yellowing of plants due to lack of chlorophyll. The severity of chlorosis depends on the extent of iron deficiency in the plant.

Katyal and Sharma (1980) showed that iron though indispensable for the biosynthesis of chlorophyll, its total content in plants was associated with occurrence of chlorosis.

Romheld and Marschner (1990) found that Fe-deficient plants were characterized by lower concentration of chlorophyll and iron in their shoot.

Singh *et al.* (1993) studied the spray schedule of micronutrients to overcome chlorosis in groundnut on a calcareous soil and reported that, iron application under chlorotic condition brought about 24-80 per cent increase in leaf chlorophyll content during active growth stage.

Singh *et al.* (1995) reported that application of iron sulphate, iron chelate and sulphur fertilizer to groundnut on calcareous soil of Junagadh significantly increased the chlorophyll content, pod yield and dry matter production and nutrient uptake by groundnut crop. The pod yield reduction due to chlorosis was 15.9 to 32.3 per cent.

2.6.2 Organic Acids

The accumulation of various organic compounds, especially organic acids, in roots and shoots, as well as their presence in limited amounts in nutrient solutions of plants growing under iron stress condition has been postulated to account for species differences in iron use efficiency, pH changes, chelation of iron, and transport in the xylem. Iljin (1951) found a higher concentration of amino acids and organic acids in chlorotic leaves of grape plants than in normal leaves.

Decock and Morrison (1958) found larger amounts of free amino acids and organic acids associated with chlorotic tissue. Su and Miller (1961) induced iron chlorosis in soybean by inadequate iron, high bicarbonate ion, high phosphorus, and high manganese levels. Significant increase in citric acid and malic acid were found in chlorotic leaves, regardless of how chlorosis was induced. Leaves of the Fe-efficient HA cultivar contained 19 and 108 milliequivalent citric acid per gram fresh weight in normal and bicarbonate-induced chlorotic leaves, respectively. Organic acids, especially citric acid, increased in higher amounts in leaves of iron-stressed Fe-efficient soybean cultivars than in Fe-inefficient cultivars sensitive to Fe chlorosis.

Tiffen (1972) reported that the major form of iron in the exudates was Fe-citrate and this probably the form translocated in plant.

Bienfait (1988) favored a probable increase in transport of isocitric acid to the cytoplasm and an increase in its oxidation by isocitric dehydrogenase. However, no increase of this enzyme activity could be detected in iron-stressed bean roots.

Pich and Scholl (1992) suggested that citrate accumulation in organs of mutant plants grown under iron deficiency is caused by inhibition of aconitase activity due to lack of available iron. A change in aconitase activity despite of citrate accumulation in bean roots under iron deficiency. High amount of organic acids (malate and citrate) could be the sources of extra hydrogen ion released by roots.

Bergmann (1992) reported that the iron uptake and translocation is enhanced by an increase in the concentrations of organic acids, particularly, citric acid in root and xylem. Bienfait and Scheffers (1992) reported that the iron in xylem is translocated as citrate complex.

2.7 EFFECT OF IRON ON NUTRIENT UPTAKE BY PLANTS

2.7.1 Macronutrients

Bansal and Singh (1975) recorded significant increase in S, N uptake and chlorophyll content in cowpea leaves when 0.1 per cent spray of FeSO_4 was followed.

Belavanaki (1979) also noticed significant increase in nitrogen content of sorghum leaves when $10 \text{ kg FeSO}_4 \text{ ha}^{-1}$ was applied to the soil.

Dahiya and Mahendra Singh (1976) observed that addition of Fe decreased the concentration of phosphorus in pea plants. Mahendra Singh and Dahiya (1976) noticed that concentration of calcium in pea plants decreased with the application of iron.

Pareek *et al.* (1978) showed applied Fe had no effect on P content in maize plants. Aiyer (1984) reported an inverse relationship between iron and potassium content in plants.

2.7.2 Micronutrients

Djendo (1972) noticed that iron content in the roots and stem of sunflower generally increased with increased rates of iron application.

Mikesell *et al.* (1973) reported that the addition of iron fertilizers significantly increased the concentration of iron in shoots of sorghum plants and decreased the Zn, Mn and P concentration. This was attributed to the antagonistic relationship of these elements with iron.

Mahendra Singh and Dahiya (1976) reported that addition of 10 ppm of iron as FeSO_4 at 45 days and 5 ppm at 15 days increased the dry matter yield of oat. They also indicated that iron concentration and uptake decreased with increase in added calcium carbonate and increased with application of iron at both the stages of crop growth. Application of iron and calcium carbonate decreased the concentration and uptake of phosphorus significantly at both the stages of crop growth.

Prasad (1981) reported that addition of Zn and Fe fertilizers to soil individually increased their individual concentrations to values higher than their critical levels, but antagonistic effect of one on the other was also conspicuous. The effect of organic manure was noted to raise Zn and Fe contents of plants from deficiency to sufficiency levels, which appeared to be responsible for the improvement in dry matter yield of maize. Thus, natural complexing agent such as organic manure was found to be important in increasing the availability of Zn and Fe to plants even under moderate to acute deficiency conditions.

Dahiya and Singh (1982) studied the effect of calcium carbonate and iron on dry matter yield and nutrient uptake by oat plants. They reported that dry matter yield and iron uptake increased with increased levels of iron application. Decrease in uptake of iron was

observed in presence of added calcium carbonate and was attributed to conversion of soluble iron into insoluble ferric hydroxide or ferric oxide. They also reported that concentration of phosphorus and manganese decreased significantly with added iron. This was probably due to antagonism between iron and phosphorus and between iron and manganese.

Singh and Steenborg (1975) noticed that zinc concentration and uptake in barley was found to increase with increased iron levels.

Pareek *et al.* (1978) reported increased iron content in maize plant with 7.5 ppm Fe application. But further increase in Fe rates showed no effect.

Sanchez Raya *et al.* (1974) reported that supply of iron influenced the amount of manganese absorbed by the plants. When it was low, increased manganese uptake and translocation occurred. However, with excessive iron supply manganese uptake diminished under conditions of very low iron availability.

Mahindra Singh and Yadav (1980) noticed that concentration of copper, zinc and manganese decreased in sorghum with the added iron up to 20 ppm, but the uptake of these nutrients was highest with 5 ppm added iron and then declined. According to them iron showed an antagonistic relationship with copper, zinc and manganese.

Sakal *et al.* (1990) reported that in old alluvial calcareous soils of Bihar, available Zn, Cu, Fe and Mn were significantly and negatively correlated with pH. Equation analysis indicated that the availability of Zn and Cu was dominantly correlated by organic carbon whereas, Fe and Mn by pH, organic carbon and available phosphorus content of these soils.

Saha *et al.* (1990) while studying on the distribution of available Fe, Mn, Zn and Cu and B in rice growing soils of Orissa, reported that the clay content had significant positive correlation with available Mn, Cu and B but negative correlation with Fe, and pH had negative correlation with DTPA extractable micronutrients.

A field experiment was conducted by Kalyan Singh *et al.* (1992) to study the effect of iron carriers and compost application on rice yield and their residual effect on succeeding wheat crop in an Entisol at Varanasi and reported that the application of 25 kg

ferrous sulphate per ha significantly increased uptake of iron in grain and straw over other treatments.

Jagtap and Mohite (1994) studied the influence of level of moisture, organic matter, CaCO_3 and particle size of saline sodic calcareous soil on release of sulphur and iron from pyrite. During incubation release of Fe and S were increased up to 30 and 40 days, respectively and thereafter decreased gradually. The release of available S, Fe and soil pH decreased with addition of organic matter (20 t ha^{-1}) and the application of finer (>100 mesh) particles of pyrite during incubation. The soil pH decreased initially in pyrites treated soil up to 7 days and thereafter increased slightly.

Biradar (1996) conducted a field experiment on a clay soil at Dharwad (Karnataka) to study on the effect of iron and manganese application on groundnut and noticed that increased levels of application of iron and manganese increased iron and manganese content in plant tissues. The highest Fe content was recorded due to foliar spray of 0.5 per cent FeSO_4 .

2.8 MECHANISMS OF IRON UPTAKE BY PLANTS

The ability of a plant to absorb and translocate micronutrients is regulated by adaptive process that responds to elements deficiency stress. Plant are classified as “ions deficient” if they respond to these ions deficiency by inducing biochemical reaction.

Genotypical differences in susceptibility to iron chlorosis are well known, both in natural vegetation and crop plants. Brown and Jolley (1986) stated that plant genotypes differ in their ability to take up Fe from a growth medium. Fe-efficient plant adapts more to Fe-stress than Fe-inefficient plant. Several products or biochemical reactions are affected when a Fe-efficient plant responds or adapts to Fe-stress. Among these products are:

- 1- Hydrogen ions are excreted from the roots.
- 2- Reducing compounds are excreted from the roots of some plants.
- 3- The rate of reductions (Fe^{3+} to Fe^{2+}) increase at the root surface.
- 4- Organic acids (particularly citrate) increase in the root sap.
- 5-The plant remains tolerant of relatively high P in the growth medium.

Marschner *et al.* (1989) reported that higher plants could mobilize iron in the rhizosphere by non-specific and specific (adaptive) mechanisms. Non-specific mechanisms are, for example, rhizosphere acidification related to high cation-anion uptake ratios, or citric acid excretion. The specific mechanisms are root responses to Fe-deficiency and can be classified into two different strategies. They stated that in the plant kingdom at least two different strategies exist in the Fe-deficiency induced root responses, which lead to enhancement of both iron mobilization in the rhizosphere and uptake rate of iron.

Marschner and Romheld (1995) concluded that, strategy I: exists in dicotyledenous and monocotyledenous, species, with the exception of the gramineous species (grasses). This strategy is characterized by three compounds; First; an increase in the activity of a plasma membrane-bound reductase "turbo". Second; enhanced rates of ferric reductions by protons and corresponding splitting of ferric chelates at the plasma membrane. Often, the net rate of H^+ extrusion, i.e. acidification of the rhizosphere, is also increased. This acidification facilitates iron uptake by both enhancement of the reductase activity and solubilization of Fe in the rhizosphere. And third; an additional mobilization of sparingly soluble iron in the rhizosphere may occur by release of reducing and /or chelating substances (e.g. phenolics) from the Fe-deficient root in response to the acidification.

Strategy II has been found only in gramineous species. This strategy is characterized by two main compounds mainly: First; Fe-deficiency induced enhancement of release of phytosiderophores (non-protein amino acids) which mobilize sparingly soluble inorganic Fe^{+3} compound by complexation of Fe^{+3} and formation of Fe-phytosiderophores (Fe^{+3} PS) is only slightly depressed by high substrate pH and is positively correlated to genotypical differences between species in their resistance of "lime chlorosis". Second; a highly efficient uptake system for Fe^{+3} PS, which is further activated under Fe-deficiency. The principal differences between strategy I and II have important ecological implications and also require systematic consideration in the development of screening methods for higher resistance to "lime chlorosis". (Marschner and Romheld, 1995).

2.9 FACTORS INFLUENCING IRON AVAILABILITY

Lime induced iron chlorosis is a common problem when crops are grown on calcareous soils. Iron chlorosis may be due to absolute Fe deficiency in the soil. Such cases may occur on degraded sandy soils, but are not frequent. Iron chlorosis on calcareous is not caused by absolute Fe deficiency. In most cases it even result as a consequences of two low availability of Fe in the soil, but is rather a physiological disorder (Mengel and Kirkby, 1996).

Calcareous soils are characterized by high carbonate content, high pH and high bicarbonate concentration in the soil. So, the pH of the plant system grown on these soils will increase resulting in lesser reduction of Fe^{+3} by Fe-reductase located in plasma membrane, which is pH dependant (Mengel, 1994).

Morris *et al.* (1990) classified the factors influencing iron availability into five heads were; soil factors, plant factors, nutritional factors, microbial factors and environmental factors

2.9.1 Soil factors

2.9.1.1 Bicarbonate (HCO_3)

Pot experiment and field trails were conducted by Boxma (1972) to determine the direct cause for lime-induced chlorosis in Netherlands. Results indicated that, high bicarbonate in the soil was the main cause for lime induced iron chlorosis. There was a significant correlation between lime induced chlorosis and bicarbonate content of the soil in the spring under field conditions.

Mengel *et al.* (1984) conducted a pot culture experiment using grape crop on a calcareous and on a non-calcareous soil with low and high water saturation. Soil saturation increased pH and HCO_3 ions in both soils, but this level was much higher in calcareous soil. Soil and plants were also analyzed for Fe and P after three weeks of growing period. They confirmed that HCO_3 was the primary cause for iron chlorosis but not phosphorus.

Pot culture experiment was conducted by Inskeep and Bloom (1986) with five calcareous soils from Western Minnesota to determine the effect of soil moisture on Fe chlorosis in soybean (*Glycine max* L.). Total chlorophyll contents of Anoka soybean

decreased as soil moisture, soil $p\text{CO}_2$ and soil solution HCO_3 increased. The same response was not observed in all calcareous soils. Calcareous soil with lower amount of clay sized CaCO_3 , lower soil solution Mg or P may be additional stress factors associated with HCO_3 induced chlorosis.

Mengel (1994) conducted a laboratory experiment and reported that iron chlorosis can commonly occur in plants grown on calcareous soils. Such soils may contain high HCO_3 concentrations in their soil solution. These soils were characterized by a high soil pH and they rather tend to accumulate nitrate than ammonium because of high pH. Hence, in these soils plant roots may be exposed to high nitrate and high bicarbonate concentration.

Watanbe and Matsumoto (1994) studied effect of monosilicate, phosphate and carbonate on iron ferrihydrite as a mineral of Fe used to study dissolution rate by the phytosiderophore mugenic acid (MA) suspended in NaCl (aqueous, pH 4–9) containing orthophosphate, monosilicate and carbonate at a range of concentrations. The results showed inhibited Fe absorption by MA in presence of anions. Monosilicate inhibited > 80 per cent at > pH 8. The inhibition of iron dissolution by monosilicate decreased significantly with decreasing pH. In case of phosphate, it inhibited dissolution of Fe at low concentration and on all the tested pH values.

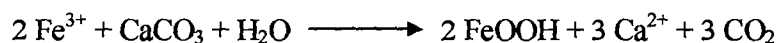
2.9.1.2 CaCO_3

The problem of iron chlorosis due to high calcareousness of soil in groundnut was first reported in Texas by Young (1967). Irrigated groundnut grown on calcareous soils with pH between 7.2 and 8.5 showed severe signs of lime induced iron chlorosis. Under such conditions, the supply of available iron was greatly reduced by precipitation and fixation reactions in the soils (Hartzook, 1975).

A significant negative correlation was noticed between available iron and CaCO_3 by Singh and Patiram (1975). It was probably due to precipitation and absorption of iron in the presence of CaCO_3 .

Chen *et al.* (1982) reported the incidence of Fe-deficiency in soybean (*Glycine max* L.) grown in calcareous soil. Joshi *et al.* (1983) also observed negative dominating influence of CaCO_3 on DTPA extractable iron in coarse and medium textured arid soils.

Leoppert and Clarke (1984) reported that reaction between iron salts and calcite was stoichiometric. They further reported that the calcite serves as a proton sink during the immobilization reaction.



They observed that ferrous salts favoured the formation of lepidocrite and / or goethite. Whereas ferric salts favoured poorly crystallined, ferrihydrate and rate of dissolution of iron oxides decreased in the following order: Ferrihydrate > Lepidocrocite > Magnetite > Haematite > Goethite.

Dhage *et al.* (1985) noticed a significant negative correlation ($r = - 0.617^{**}$) between calcium carbonate and DTPA extractable iron in soils of Rahuri.

Singh *et al.* (1988) found significant negative correlation ($r = - 0.340^*$) between available iron and CaCO_3 content of in calcareous soils of Haryana.

Papastylianou (1989) reported various degree of chlorosis based on survey conducted in groundnut (*Arachis hypogaea* L.) fields. In the area concerned, plant appearance was classified according to a 'chlorotic index' and corresponding soil samples were taken and analyzed for free CaCO_3 , pH, $\text{NO}_3\text{-N}$, DTPA extractable Fe and active lime. Results from regression analysis showed that CaCO_3 , active lime and $\text{NO}_3\text{-N}$ were positively correlated while DTPA extractable Fe was negatively correlated with degree of chlorosis. Further he reported that plants appeared to be chlorotic when DTPA-Fe was below 2.5 mg per kg.

Total Fe in Indian soils varied from less than 1.3 per cent to more than 8 per cent with an average value of 3.3 per cent as mentioned by Katyal and Sharma (1991). But, iron chlorosis often occurs in calcareous soil. This lime-induced chlorosis is not a consequence of too low availability of Fe in the soil, but is rather a physiological disorder influenced by CaCO_3 . Despite physiological disorder some specific cultivar may not face iron chlorosis. So, it can be expressed that there are other factors, which were related to iron chlorosis.

Sarkar (2000) studied the availability of iron to groundnut in calcareous soils imposing three moisture and five CaCO_3 levels in Dharwad. The result indicated that, at

the harvest content and uptake of iron in plant increased but yield decreased with increase in CaCO_3 and moisture level.

2.9.1.3 Soil moisture

Grasso *et al.* (1973) observed reduced conditions of declining pH values because of most favorable conditions for dissolution of Fe^{2+} near the soil surface. However, the concentration of Fe^{2+} was the lowest near the surface because of their leaching from surface and the shorter time of contact between soil solution and soil particles. The concentration of Fe^{2+} was higher in deeper horizons of the soil profile.

Srinivasarao *et al.* (1993) reported that iron chlorosis in groundnut is common in calcareous soils. They observed chlorosis particularly in excess irrigated fields. There was a strong significant correlation ($r = 0.96^{**}$) observed between soil moisture and bicarbonates. The high bicarbonate concentration enhanced the availability of phosphorus and decreased the availability of ferrous iron. Due to this iron induced chlorosis and reduced yield were observed.

Sarkar (2000) conducted studies on the effect of different levels of calcium carbonate and moisture levels on the water soluble and DTPA extractable iron in calcareous soils of Dharwad and reported increase in water soluble and DTPA extractable iron with increase in moisture percentage. Highest concentration of water soluble and DTPA extractable iron was recorded at 150 per cent field capacity.

2.9.1.4 Soil reaction

Arora and Sekhon (1981) reported a significant negative relationship ($r = -0.68^*$) between DTPA extractable iron and pH of soils. According to Lindsay and Schwab (1982) each unit increase in pH, decrease the solubility of iron as much as 1000 times

Clemens *et al.* (1989) investigated soil conditions leading to chlorosis symptoms on plants for a number of arid and semi arid soil types using groundnut an indicator plant. The occurrence of chlorosis was described as a function of CaCO_3 , Fe supply and pH.

Rajkumar *et al.* (1990) studied the depth wise distribution of four available micronutrients in soil series of Bundelkhanda region of Madhya Pradesh and reported that

available Fe and Mn increased with depth and pH was found to be dominant factor controlling the availability of Fe and Mn in these soils.

Khorsandi (1994) studied the effect of sulphuric acid on the availability of Fe and P in two calcareous soils and concluded that the change in soil pH was the key to the increased nutrient availability and subsequent crop yield.

To find out the causes for iron deficiency in the Vertisol (Typic chromousterts) in Maharashtra, Yelvikar *et al.* (1996) analyzed several soil samples and found significant influence of pH, CaCO₃, organic carbon and clay to different fractions of iron.

2.9.1.5 Organic matter

Rai *et al.* (1970) reported that, the available Fe content in most of the soils depends upon organic matter content. A significant positive correlation between available iron and organic carbon was observed in the deep black soil of Madhya Pradesh.

According to Wada and Higshi (1976) reported that addition of fresh organic matter to the Andisols increased the water soluble iron in soil solution while solubility level reached a minimum in the pH range between 7.4 and 8.5.

Saha *et al.* (1982) obtained significant and positive correlation ($r = 0.413^*$) between available iron and organic carbon content in jute growing areas of Assam and West Bengal. Similar results were obtained by Sakal *et al.* (1985) and Yelvikar *et al.* (1996).

Loeppert and Hallmark (1985) stated that iron chlorosis in plants is commonly associated with calcareous soils however soil factors other than carbonates may also influence the plants ability to obtain adequate Fe for growth. Further, reported that, although total CaCO₃ content was important in influencing iron availability, the quantity, mineralogy and crystallinity of the Fe oxide assumed a dominant role, clay and organic matter contents were positively correlated with plant available Fe.

Saha *et al.* (1990) noticed the positive significant correlation between available Fe and organic matter content in soils of Assam, West Bengal and Rajasthan.

Katyal and Sharma (1991) also observed positive relationship of DTPA-Fe with content of organic matter in soil in different zones of India.

2.9.1.6 Clay content

Choudhari *et al.* (1979) observed a significant positive correlation ($r = 0.56^*$) between total iron and clay content in major soils of Rajasthan.

Raut *et al.* (1998) conducted a survey work in groundnut growing areas of Jayakwadi command area of Maharashtra. They analyzed one hundred surface soil samples for iron status differed in soil characteristics and worked out correlation coefficients and found that significant negative correlation between total Fe and available iron with pH, CaCO_3 and sand. Whereas, organic carbon, clay and available N had significant positive correlation.

2.9.2 Plant factors: varietal differences

Information on the inheritance of efficiency/inefficiency of iron absorption in groundnut (*Arachis hypogaea* L.) was derived from visual scores of iron deficiency symptoms in materials from 14 crosses at 60 days after sowing. Five iron inefficient (TMV-2, Dh-3-30, JL-24, KRG-1 and S-204) and 3 efficient (GG-2, Dh-8 and Tatu) genotypes and their F₁ progeny were grown in calcareous soil during summer 1989 at Dharwad, parents and F₂ progeny were grown during *kharif* 1990. F₁ hybrids from all the crosses were inefficient, indicating that absorption efficiency was dominant and inefficiency was recessive. F₂ progeny from crosses involving GG-2 and Dh-8 segregated 21 efficient: 43 inefficient plants, indicating the involvement of genes, designated as I-Faa and I-Fbb (Gowda *et al.*, 1993).

To evaluate iron absorption efficiency of groundnut (*Arachis hypogaea* L.) cultivars. Kulkarni *et al.* (1994) conducted a pot experiment. They observed for visual chlorosis, Fe^{2+} and chlorophyll content. Based on these parameters they also reported that Tatu, GG-2 and Dh-8 were iron efficient plants among eight cultivars selected for screening.

2.9.3 Nutritional factors

Supplying ammonium sulphate and urea granules in the presence of nitrification inhibitor (nitrapyrin) reduced Fe chlorosis in groundnut grown on very high calcareous soil (98 % CaCO_3) in Israel (Kafkafi and Ganmore Neumann, 1985). Ammonium nutrition resulted in higher cation uptake than anion uptake, and protons (H^+) were released from

the roots. This proton excretion reduced the pH in rhizosphere thus increasing Fe availability and correcting Fe chlorosis. In practice, band placement of ammonium sulphate with nitrapyrin is less expensive than application of Fe chelates in soils where iron chlorosis is usually observed.

Dahiya and Mahendra Singh (1976) studied the effect of salinity, alkalinity and iron application on the iron availability in soil and the result indicated that addition of Fe decreased the concentration of phosphorus in pea plants.

Mullner (1979) reported that even at high values of available P in calcareous soil phosphate induced iron chlorosis was noticed in vine cultivation.

Rao *et al.* (1993) observed lime induced iron chlorosis in groundnut and studied the plant nutrient content and soil factors on samples collected at different stages of the crop and yield in chlorotic and non-chlorotic plots. They found significant negative correlation between phosphorus content and ferrous iron in calcareous soils of Andhra Pradesh.

Barak and Chen (1984) found that K fertilization at rates of 135 to 405 mg K per kg soil ameliorated iron chlorosis in groundnut grown in an extremely calcareous soil (63 % CaCO₃). These results were attributed to the cation-anion balance of ion uptake. The plant takes up more cations than anions, there is an flux of H⁺ to correct this imbalance, the rhizosphere is acidified and consequently iron is more available to roots.

In a greenhouse experiment conducted on calcareous soil of Egypt, maize *cv.* Giza 2 was given 0, 50, 100 or 150 mg K and/or 0, 20 or 40 mg Fe kg⁻¹ soil. Iron status, K and chlorophyll content in the leaves were determined. Application of K₂SO₄ at the rates of 100 and 150 mg K kg⁻¹ soil increased Fe²⁺, total Fe and chlorophyll content in maize leaves. Maize plant growth was optimum with the application of 100 mg K plus 20 mg Fe kg⁻¹ soil application (Aly *et al.* 1999).

Iyenger (1968) reported that the iron content of coffee leaves increased in general with increase in the level of iron in the medium but such increase was not always been linear or proportional. The iron content being lower in chlorotic leaves than in the green leaves when high manganese concentration was present in the medium.

Venkata Subramanyam and Mehta (1975) studied the availability of iron as influenced by different levels of Zn, Fe and moisture in calcareous soil at Anand, Gujarat. They found antagonistic effect of Zn towards Fe availability. The highest available Fe was present under flooding, the least under field capacity and intermediate under saturated condition.

Along with soil samples, chlorotic and healthy groundnut plant samples were collected from different village in Saurashtra region of Gujarat. They reported that interveinal chlorosis was not due to Fe, S, Zn or Mn deficiency in the soil and it was suggested that chlorosis was caused by an imbalance of nutrients leading to inactivation of P, Ca, Mg, Fe, Zn and Cu particularly in younger plant parts (Patel *et al.*, 1995).

2.9.4 Microbial factors

Pseudomonas putida strain isolated from groundnut (*Arachis hypogaea* L.) roots excreted yellow-green fluorescent siderophores (pigments) when grown under Fe-deficient condition. In a growth chamber experiment Fe from unpurified Fe-siderophores produced by *Pseudomonas putida* was used on highly calcareous soil at the rate of 11 mg kg⁻¹ and 19 mg kg⁻¹ of soil. Groundnut plants grown on these soils were able to produce 75 and 100 per cent chlorophyll concentration, respectively over control (Jurkevitch *et al.*, 1988).

In a sterilized sand-vermiculite medium supplied with N-free nutrient solution (pH 7.0), inoculation of nodulating groundnut with *Bradyrhizobium* strain NC-43.3 enhanced whole plant dry matter production and O-phenanthroline extractable Fe and N content of the plants. The supply of mineral N at 100 mg N per liters (as NH₄NO₃) through deionized water induced Fe-chlorosis symptoms in nodulating groundnuts grown in Vertisols. The induced iron chlorosis was only partially correlated by inoculation with *Bradyrhizobium* strains NC-92 and NC-43.3 (Sharawat *et al.*, 1990)

2.9.5 Environmental factors

Wei *et al.* (1994) conducted a laboratory experiment to know the influence of soil temperature (7 to 33 °C) on chlorosis expression and mineral nutrition of Fe using Karridale (susceptible) and Kaola (resistant) subclover varieties on low Fe Parria soil (pH

8.2, clayey, hyperthermic, shallow petrocalcic paleustoll). They reported that Karridale was more chlorotic at low and high soil temperature than at intermediate temperature, while the Koala changed only slightly with soil temperature, indicated the cultivars difference to temperature. Further, they reported that shoot Fe concentration of Kaola was higher at intermediate temperature. Whereas, Karridale exhibited less dependance on temperature and results indicated that soil temperature as differential expression of Fe-deficiency chlorosis between subclover cultivars.

MATERIAL AND METHODS

III. MATERIAL AND METHODS

The details regarding the survey and Characterization, incubation study and field experiment conducted and analytical methods employed are presented in this chapter.

3.1 SURVEY AND CHARACTERIZATION

To know the distribution pattern of different fractions of soil iron and their relationship with soil properties.

Survey and characterization study of calcareous soils was carried out with the help of five soil profiles representing major soil types of North Karnataka. The details of soil sites are presented in Table 1. The depth-wise soil samples were collected by the standard procedure at (0-15, 15-30, 30-60, 60-90 and 90-120 cm) and analyzed for pH, EC, OC, CEC, CaCO₃, clay content and iron fractions (water soluble, exchangeable, Pb-displaceable iron, acid soluble, Mn oxide occluded iron, organically bound iron and amorphous iron oxide occluded). Correlation coefficient, were worked out between soil properties and different iron fractions.

3.2 INCUBATION STUDY

An incubation study was conducted in laboratory to know the release pattern of applied iron on its fractions in calcareous soils.

Surface soil samples (0-15 cm) with varying amounts of CaCO₃ were collected (2.51, 7.46, 15.23 and 22.47 % CaCO₃) and graded levels of Fe (0, 50 and 100 kg FeSO₄ ha⁻¹) were applied to these soils. Five hundred grams of soil was taken in plastic containers. The sides and bottom of the containers were covered by polythene covers. The recommended doses of (25: 50: 25) N: P₂O₅: K₂O kg ha⁻¹, 10 t ha⁻¹ FYM and graded levels of ferrous sulphate were added according to the treatments. Moisture was maintained uniformly (50 % of water holding capacity) throughout the experiment by covering the surface of the containers with polythene covers. Soil samples were taken at different intervals (0, 15, 30, 45, 60 and 100 days after incubation) and iron fractions content of soils were estimated using Atomic Absorption Spectrophotometer (Shimadzu, AA 630-11).

Table 1. Details of soils used for survey and characterization study

Sl. No.	Soil sites	Location	Classification (Grate group)
1.	Dharwad	Main Agricultural Research Station, Agriculture College, Dharwad	Haplusterts
2.	Durgadevigudi	Farmer's field, four kms away from Dharwad	Haplusterts
3.	Amminabhavi	Indo American Research Farm, two kms away from Amminabhavi village	Haplusterts
4.	Belavatagi	Water Management Research Center, five kms away from Nargund	Pellusterts
5.	Bijapur	Regional Agricultural Research Station, Agriculture College, Bijapur	Pellusterts

3.3 FIELD EXPERIMENT

A field experiment was conducted on a calcareous Vertisol at farmer's field, Durgadevigudi, near Dharwad city during *kharif* and *rabi* seasons of 2002-03 and 2003-04 to investigate the effect of iron management practices on growth, yield, quality and biochemical parameters and nutrient uptake and iron fraction content of soil of groundnut-maize cropping sequence under irrigated condition. The details of materials used and methodology adopted during the course of investigation are presented in this chapter.

3.3.1 Location of field experiment

The field experiment was conducted on calcareous Vertisol, at farmers field, Durgadevigudi, Dharwad, which is situated at 15° 21' N latitude and 75° 07' E longitudes with an altitude of 678 meters above the mean sea level.

3.3.2 Climatic conditions

The meteorological data were recorded during the period of experimentation and average of past 53 years at Main Agricultural Research Station, Dharwad. The total annual rainfall received during *kharif* and *rabi* 2003 and during *kharif* and *rabi* 2004 were 169.0 mm and 264.1 mm, respectively as against the average rainfall of 763.0 mm for the past 53 years. The mean monthly maximum temperature was 31.3 °C of 2003 and 32.5 °C of 04 while the minimum temperature of the year of 2003 and 2004 was 19.3 °C respectively. The mean relative humidity was 63.8 and 61.7 per cent of the year of 2003 and 04 respectively. The average evaporation of 2003 and 04 was 3.94 mm (Table 2).

3.3.3 Soil characters of experimental site

The soil of the experimental site was calcareous Vertisol. Composite soil sample from 0-30 cm depth was collected from experimental site before sowing and analyzed for physical and chemical characteristics by employing standard methods. The values obtained are presented in results chapter.

3.3.4 Experimental details

Details of field experiment, plan of layout of the experiment, methods of analysis of soil samples, fractionation of soil iron, methods of analysis of plant samples and methods of recording observations of different parameters are presented in Tables (3-7) and Fig.(1).

Table 2. Monthly meteorological data for the year of 2002-04 and average of the past 53 years (1950-2002) of Main Agricultural Research Station, Dharwad

Months	Rain fall (mm)			Mean temperatures (°C)						Mean relative humidity (%)			Mean EP (mm)
	2003	2004	1950-2002	Maximum			Minimum			2003	2004	1950-2002	
				2003	2004	1950-2002	2003	2004	1950-2002				
January	0.0	0.0	0.07	30.3	29.6	29.23	16.2	14.7	13.95	52.0	54.0	66.03	3.7
February	0.0	0.0	0.00	33.9	32.5	34.71	18.0	16.4	15.42	51.00	53.0	52.14	4.8
March	0.7	0.0	0.11	35.2	36.5	37.11	20.2	19.6	19.30	53.0	49.0	56.66	6.4
April	45.4	24.4	45.46	36.5	37.4	37.02	21.1	19.8	21.33	57.0	51.0	74.29	6.4
May	0.0	61.1	80.93	36.6	33.6	30.14	21.7	21.4	20.74	57.0	66.0	69.01	6.3
June	32.3	43.8	111.71	30.2	28.8	28.52	21.4	21.5	21.36	75.0	80.0	78.56	3.2
July	15.3	24.8	151.10	27.2	29.2	27.49	21.3	21.0	20.58	82.0	79.0	84.00	2.5
August	8.6		97.25	27.2		28.24	20.9		20.03	81.00		86.40	2.5
September	16.1		104.01	27.5		28.59	19.9		20.22	79.0		83.25	2.6
October	48.7		135.61	30.8		30.23	19.8		19.46	67.0		78.34	3.1
November	1.9		32.94	30.6		29.60	16.8		15.03	60.0		68.11	3.0
December	0.0		3.78	29.9		30.16	14.3		12.17	51.0		66.42	2.8

Table 3. Details of field experiment

Sl. No.	Particular	Details
1.	Title	Iron management practices for groundnut-maize cropping sequences in calcareous Vertisol
2.	Design	Split plot design
3.	Treatments	<p>Main plot treatments (Methods of iron application):</p> <p>F₀ = Soil application of iron F₁ = Soil plus foliar application of iron</p> <p>Sub plot treatments (Iron levels):</p> <p>S₀ = No iron (control) S₁ = 50 kg FeSO₄ ha⁻¹ S₂ = 100 kg FeSO₄ ha⁻¹ S₃ = 25 kg Pyrite ha⁻¹ S₄ = 50 kg pyrite ha⁻¹</p> <p>Soil application of Fe as FeSO₄ and pyrite was done for groundnut only, whereas one per cent Fe as FeSO₄ foliar application sprayed at 25 and 50 DAS to both crops groundnut and maize.</p>
4.	Replication	Four
5.	Plot size:	
	Gross plot area	4.5 m x 5.6 m
	Net plot area	3.6 m x 4.5 m
6.	Lay out	Fig. 1
7.	Crops:	
	Groundnut	Main crop/ first crop
	Maize	Residual crop/ succeeding crop

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Sl. No.	Particular	Details
8.	Variety: Groundnut Maize	Jl-24 DMH-2
9.	Fertilizers: Groundnut Maize	N; P ₂ O ₅ : K ₂ O kg ha ⁻¹ in the form of Urea, Diammonium phosphate and Murite of potash respectively 25 : 50 : 25 150 : 75 : 40 and 10 t ha ⁻¹ FYM was applied before sowing to groundnut as well as maize.
10.	Seed rate: Groundnut Maize	125 kg kernels ha ⁻¹ 20 kg grains ha ⁻¹
11.	Spacing: Groundnut Maize	10 cm x 30 cm 30 cm x 60 cm
12.	Date of sowing: <u>2002-03</u> Groundnut Maize <u>2003-2004</u> Groundnut Maize	25-12-2002 03-05-2003 16-12-2003 25-04-2004
13.	Date of harvest: <u>2003</u> Groundnut Maize <u>2004</u> Groundnut Maize	15-04-2003 19-08-2003 05-04-2004 07-08-2004

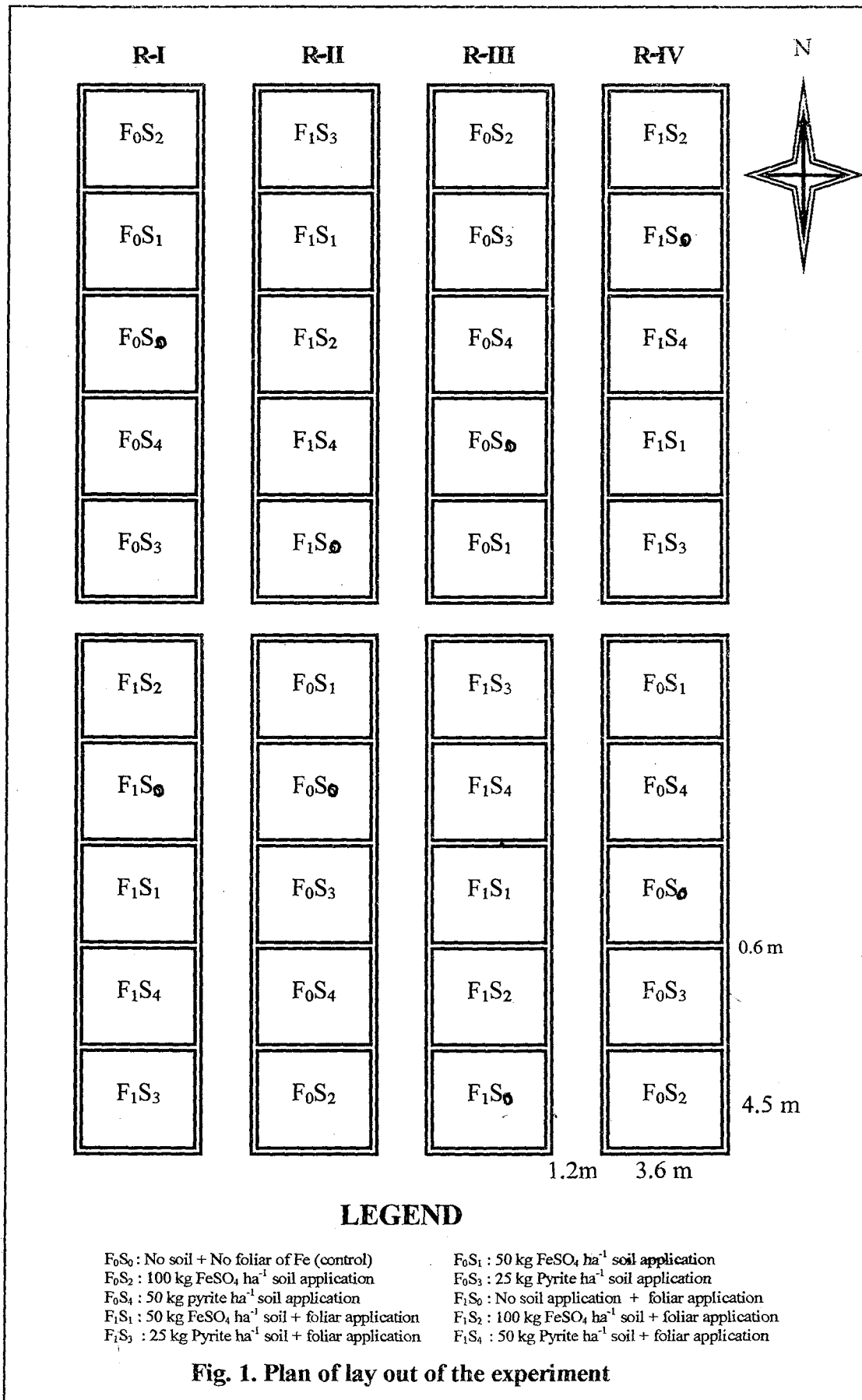


Table 4. Methods of analysis of soil samples

Sl. No.	Particulars	Author (s)	Remarks
I. Physical properties			
1.	Particle size analysis	Piper (1966)	International pipette method
II. Chemical properties			
1.	Soil reaction	Jackson (1967)	pH meter (Systronic 331)
2.	Electrical conductivity	Jackson (1967)	EC meter (Systronic 304)
3.	Organic carbon	Jackson (1973)	Walkely and Black's wet oxidation method
4.	Calcium carbonate	Piper (1966)	Rapid titration method
5.	Cation exchange capacity	Jackson (1973)	Sodium saturation method
6.	Total iron	Hesse (1971)	Atomic absorption spectrophotometer
III. Available nutrients			
1.	Available nitrogen	Subbiah and Asija (1956)	Alkaline permanganate method
2.	Available phosphorous	Jackson (1967)	Ascorbic acid method
3.	Available potassium	Jackson (1967)	Flame photometer
4.	Available Fe, Zn, Mn and Cu	Lindsay and Norvell (1978)	Atomic absorption spectrophotometer
5.	Iron fractions	Miller <i>et al.</i> (1986)	Atomic absorption spectrophotometer

Table 5. Fractionations of soil iron as outlined by Miller *et al.* (1986)

Sl. No.	Iron fraction	Procedure followed
1.	Water soluble iron	Five hundred mg of air dried soil was transferred to a 50 ml polythene centrifuge tube, 20 ml of double distilled water was added, stoppered and shaken for 16 hours. It was centrifuged and supernatant solution was filtered,
2.	Exchangeable iron	To the soil in the centrifuge tube 20 ml of 0.5 M $\text{Ca}(\text{NO}_3)_2$ was added, shaken for 16 hrs, centrifuged and supernatant solution was filtered,
3.	Lead displaceable iron	To the soil in the centrifuge tube 20 ml of 0.5 M $\text{Pb}(\text{NO}_3)_2$ + 0.1 M $\text{Ca}(\text{NO}_3)_2$ was added, shaken for 16 hrs, centrifuged, and supernatant solution was filtered,
4.	Acid soluble iron	To the soil in the centrifuge tube 20 ml 0.44 M CH_3COOH + 0.1 M $\text{Ca}(\text{NO}_3)_2$ was added, shaken for 8 hrs, centrifuged, and supernatant solution was filtered,
5.	Manganese oxide occluded iron	To the soil in the centrifuge tube 20 ml of 0.01 M $\text{NH}_2\text{OH} \cdot \text{HCl}$ + 0.1 M HNO_3 was added, shaken for 30 minutes, centrifuged, and supernatant solution was filtered,
6.	Organically bound iron	To the soil in the centrifuge tube 20 ml of 0.1 M $\text{K}_4\text{P}_2\text{O}_7$ was added, shaken for 24 hrs, centrifuged, and supernatant solution was filtered,
7.	Amorphous iron oxide occluded iron.	To the soil in the centrifuge tube 20 ml of 0.175 M $(\text{NH}_4)_2\text{C}_2\text{O}_4$ + 0.1M $\text{H}_2\text{C}_2\text{O}_7$ (oxalate reagent) was added,, shaken for 4 hrs in dark, centrifuged, and supernatant solution was filtered. Iron fractions in the filtrates were estimated using atomic absorption spectrophotometer (Shimadzu, AA 630-11) and
8.	Residual iron	The residual fraction of soil iron was calculated by deducting the above fractions of soil iron from total iron.

Table 6. Methods of analysis of plant samples

Sl. No.	Particulars	Author (/s)	Remarks
1.	Nitrogen	Jackson (1973)	Micro-kjeldahl's method
2.	Phosphorous	Jackson (1973)	Vando-molybdate yellow colour methods and estimation by Spectrophotometer (Systronics, UV - V 75 model SL - 118)
3.	Potassium	Jackson (1973)	Flame photometer (CL-22D)
4.	Iron, Zinc, Manganese and Copper	Jackson (1973)	Atomic absorption spectrophotometer (Shimadzu, AA 630-11)
5.	Ferrous iron	Katyal and Sharma (1980)	Orthophenanthroline method and estimation by Spectrophotometer (Systronics, UV - V 75 model SL - 118)

Table 7. Methods of recording observations of different parameters

Sl. No.	Parameters	Procedure followed
1.	<p>Growth parameters</p> <p>1.1 Plant height (cm)</p> <p>1.2 Number of green leaves per plant</p> <p>1.3 Total Dry matter production (kg ha⁻¹)</p>	<p>Five plants per plot were randomly selected and observations at three stages (30, 60 DAS and at harvest) were recorded.</p> <p>Plant height of five randomly selected plants was measured from the base of the plant to the base of the fully opened leaf at 30 and 60 DAS and at harvest. The average was recorded as plant height in cm.</p> <p>Total numbers of green leaves produced were counted from the five randomly selected plants and their average was taken as the number of green leaves per plant.</p> <p>Five plants from each treatment were selected randomly at 30, 60 DAS and at harvest stage of crop. The plants were dried in shade for 24 hours and then oven dried at 65 °C to 70 °C till a constant weight obtained and the oven dry weight was recorded and expressed in kg ha⁻¹.</p>
2.	<p>Yield parameters of groundnut</p> <p>2.1 Number of pods per plant</p> <p>2.2 Hundred-kernel weight</p> <p>2.3 Shelling percentage</p>	<p>The randomly selected plants were utilized for recording the observations regarding yield and yield components.</p> <p>The total number of pods produced per plant was counted and recorded.</p> <p>A sample of 100-kernels was taken from the net plot produce of each plot and their weight was recorded.</p> <p>Hundred grams of dry and clean pods were taken. Kernels were separated from the husk and weighed. Then, the shelling percentage was worked out by using the following formula:</p>

Sl. No.	Parameters	Procedure followed
		$\text{Shelling percentage} = \frac{\text{Kernel weight (g)} \times 100}{\text{Total weight of pods (g)}}$ <p>Harvest index is the ratio of economic yield to total biological yield. The harvest index was worked out as indicated below (Donald, 1962).</p> $\text{Harvest index} = \frac{\text{Economic yield (kg ha}^{-1}\text{)}}{\text{Biological yield (kg ha}^{-1}\text{)}}$ <p>At physiological maturity pods obtained from net plot area were cleaned and dried after removing impurities and immature pods. The pods were weighed and yield was expressed in kg ha⁻¹.</p> <p>After removing the pods from the plant, the haulm from each net plot was kept for air drying and the haulm yield was recorded after complete drying, then yield per hectare was worked out and expressed in kg ha⁻¹.</p>
3.	Yield parameters of maize 3.1 Cob length 3.2 Cob diameter 3.3 Cob weight per plant	<p>The length of five randomly selected cobs were measured from the base of the lower most primary rachis to the tip of the cob and average was recorded as cob length in cm.</p> <p>The diameter of five randomly selected cobs were measured and average was recorded as cob diameter in cm.</p> <p>Cob weight was determined as the weight of cobs divided by the number of cobs harvested from the net plot and expressed in g per cob.</p>

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Sl. No.	Parameters	Procedure followed
3.4	Grain number per cob	The number of grains was counted in five randomly selected cobs and the average was recorded as grain number per cob.
3.5	Grain weight per cob	The grains from the sun-dried cobs of five plants were separated and the weight was recorded. The average grain weight per plant was expressed as g per plant.
3.6	Test grain weight	Five cobs from each treatment were randomly selected and shelled. From this, representative samples of 100 maize kernels were picked out and weighed using an electrical balance and expressed in g per 100 kernels.
3.7	Grain yield	At physiological maturity cobs from each net plot were harvested. Cobs were separated, air dried, shelled, cleaned and weighed. Grain yield per ha was worked out and expressed in $q\ ha^{-1}$.
3.8	Stover yield	Stover yield was recorded after complete sun drying the stalks from each net plot and expressed in $q\ ha^{-1}$.
4.	Biochemical Parameters 4.1 Total chlorophyll content ($mg\ g^{-1}\ f. wt.$)	<p>The total chlorophyll content in leaf was determined by dimethyl sulfoxide method (DMSO). Known weight of leaves (100mg) was homogenized with 7 ml of DMSO in the tube. The test tubes was kept in oven at $65^{\circ}C$ about 30 minutes. Leaves residue was removed by decanting the solution and final volume was made to 10 ml by DMSO. The absorbance of the extract was measured at 652 nm in spectrophotometer (Systronics, UV-VIS model SL-154) and a blank was run using DMSO (Shoaf and Lium, 1976).</p> $\text{Total chlorophyll (mg g}^{-1}\text{ f. wt.)} = 27.8 (A_{652}) \times \frac{V}{1000 \times 9 \times f. wt}$ <p>Where, A_{652} = Absorbance of the extract at 652 nm, a = Path length of the cuvette (1 cm)</p>

Sl. No.	Parameters	Procedure followed
	4.2 Organic acids (mg g ⁻¹ dry wt)	<p>b= Volume of the extract (10 ml), f. wt. = Fresh weight of the leaf sample (100 mg)</p> <p>After grinding the plant leaves in a pestle-mortar with the help of water. Filtration was done through muslin cloth and made up to known volume. A suitable aliquot of the filtrate was taken for titration against strong alkali. Organic acid as citric and malic acid were calculated as mg g⁻¹ dry weight. (Sadasivam and Manickam, 1992).</p>
5.	<p>Quality Parameters</p> <p>5.1 Protein content (%)</p> <p>5.2 Oil content (%)</p> <p>5.3 Acid value (mg KOH g⁻¹ oil)</p> <p>5.4 Iodine number (g Iodine 100 g⁻¹ oil)</p> <p>5.5 Saponification value (mg KOH g⁻¹ oil)</p>	<p>The nitrogen content in groundnut kernel was estimated by modified Kjeldahl's method (Jackson, 1967). The protein content was calculated by multiplying the per cent nitrogen with a factor 6.25 (Tai and Young, 1974).</p> <p>The estimation of oil in groundnut kernel was done by Nuclear Magnetic Resonance (NMR) spectrophotometer (Brooker Minispee, P-2C). The oil content was expressed in percentage (A.O.A.C., 1975).</p> <p>The acid value as Oleic acid of an oil was estimated by dissolving the known amount of oil in a neutral solvent and titrating it against the standard KOH solution using phenolphthalein as an indicator (Sadasivam and Manickam, 1992).</p> <p>Iodine number was estimated by titrating the mixture of known amount of oil, Hanus iodine and bromine solutions against the standard sodium thiosulphate using the starch indicator (Sadasivam and Manickam, 1992).</p> <p>To determine the saponification value, a known quantity of oil was refluxed with an excess amount of alcoholic KOH. Then the remaining KOH was estimated by titrating against a standard HCl solution using phenolphthalein as an indicator (Sadasivam and Manickam, 1992).</p>

Sl. No.	Parameters	Procedure followed
5.6	Starch content (%)	The finely powdered dried grains sample was treated with 80 per cent alcohol to remove sugars and then starch was extracted with perchloric acid. In hot acidic medium starch was hydrolysed to glucose and dehydrated to hydroxymethyl furfural. This compound forms a green colored product with anthrone and the intensity of this green colored complex was measured by Spectrophotometer at 630 nm (Sadasivam and Manickam, 1992).
6.	Path analysis	Path analysis carried out using correlation coefficient between yield of groundnut and maize 1/3. soil iron fractions and plant iron fractions to know direct and indirect effects from different iron fractions to groundnut and maize yield (Dewey and Lu, 1957).
7.	Statistical analysis	The data collected during the course of investigation at different crop growth stages were subjected to statistical analysis as described by Gomez and Gomez (1984). The level of significance used in 'F' and 't' tests was P=0.05. Critical differences were calculated wherever 'F' test was significant.
8.	Economic analysis 8.1 Net returns 8.2 Benefit cost ratio	<p>The prices of the inputs that were prevailing at the time of their use were considered for working out the cost of cultivation.</p> <p>Net returns per hectare was calculated by deducting cost of cultivation per hectare from gross income per hectare.</p> <p>Benefit: Cost = $\frac{\text{Gross returns (Rs. ha}^{-1}\text{)}}{\text{Total cost of cultivation (Rs. ha}^{-1}\text{)}}$</p>

EXPERIMENTAL RESULTS

IV. EXPERIMENTAL RESULTS

The results of the investigations are presented in three parts:

- 4.1 Characterization study to know the distribution of iron fractions in different soil sites of north Karnataka as influenced by the physico-chemical properties of soils.
- 4.2 Incubation study to investigate the effect of ferrous sulphate application on the periodical changes of iron fractions content of soils varying of calcium carbonate level and
- 4.3 Field experiment to find out the effect of iron management practices on growth and yield of groundnut and maize cropping sequence on calcareous Vertisol.

4.1 CHARACTERIZATION STUDY

A five soil profiles representing the major calcareous soil areas of north Karnataka were selected and analyzed for some physico-chemical properties of soil viz. particle size analysis, pH, EC, OC, CEC, CaCO₃, total and available iron and iron fractions (water soluble iron, exchangeable iron, acid soluble iron, Pb-displaceable iron, Mn oxide occluded iron, organically bound iron, amorphous iron oxide occluded iron) at 0-15, 15-30, 30-60, 60-90 and 90-120 cm depth. The results of the study are presented in this chapter.

4.1.1 Physico-chemical properties of soils

Results of the particle size distribution and chemical properties of the different soil sites soils included for the characterization study are given in Table 8 and 9.

4.1.1.1 Particle size analysis

The data furnished in Table 8 indicate that the highest coarse sand fraction was noticed in subsurface layer of Amminabhavi (26.7%), followed by subsurface soil of Bijapur (22.6%), Durgadevigudi (18.7%) and Belavatagi (14.4%) and the lowest was in subsurface soils of Dharwad (8.1%).

The fine sand fraction was in the range of 8.1 to 20.4 per cent and the highest was in the surface layer of Amminabhavi (20.4%) and the lowest was in subsurface soils of Bijapur (8.1%).

Table 8. Particle size distribution of selected soil profiles of north Karnataka

Soil profile site	Depth (cm)	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Textural Class
Dharwad (Haplusterts)	0-15	8.1	11.2	18.6	61.8	Clay
	15-30	7.4	13.6	15.1	63.1	„
	30-60	8.5	10.8	14.2	66.2	„
	60-90	9.3	9.6	11.6	68.7	„
	90-120	8.1	9.1	11.1	71.1	„
Belavatagi (Pellusterts)	0-15	9.6	14.1	15.6	60.2	Clay
	15-30	11.6	12.7	14.0	60.9	„
	30-60	13.5	11.1	13.2	61.5	„
	60-90	14.2	10.6	10.1	64.4	„
	90-120	14.4	10.1	8.9	66.1	„
Durgadevigudi (Haplusterts)	0-15	11.7	14.5	18.7	54.8	Clay
	15-30	9.1	14.6	18.1	57.8	„
	30-60	11.4	12.6	16.4	59.1	„
	60-90	13.5	10.1	14.3	60.8	„
	90-120	18.7	9.5	10.3	60.6	„
Bijapur (Pellusterts)	0-15	12.8	16.5	22.6	47.6	Clay
	15-30	13.4	15.2	19.6	51.1	„
	30-60	16.3	13.8	16.1	52.3	„
	60-90	17.5	9.3	15.6	56.7	„
	90-120	22.6	8.1	11.3	57.2	„
Amminabhavi (Haplusterts)	0-15	10.1	20.4	23.4	45.3	Clay
	15-30	15.6	16.5	18.7	47.6	„
	30-60	21.2	14.1	15.4	48.5	„
	60-90	22.5	11.0	14.1	51.6	„
	90-120	26.7	11.6	10.8	50.3	„

Silt was more in surface layer of Amminabhavi (23.4%) and found low in subsurface soils of Belavatagi (8.9%).

The clay content of surface layer of Amminabhavi was the lowest (45.3 %) and the highest was noticed in subsurface soils of Dharwad (71.1%). Fine sand, and silt content decreased, while clay content increased with depth, in all the soil bodies studied.

4.1.1.2 Soil reaction (pH)

The data furnished in Table 9 showed that pH of the soils varied from 7.64 to 8.63 in the surface soils of Dharwad and subsurface soil of Amminabhavi. With increase in depth an increase in pH was noticed in Dharwad and Bijapur. No definite trend was observed in other soil series.

4.1.1.3 Electrical conductivity (dSm^{-1})

The lowest electrical conductivity value was recorded in case of surface layer of Dharwad (0.27 dSm^{-1}) and the highest was in subsurface soils of Amminabhavi (0.59 dSm^{-1}).

4.1.1.4 Organic carbon (%)

The organic carbon content of the soils varied between 0.23 per cent in Amminabhavi soil profile to 0.69 per cent in Belavatagi. With an increase in depth, a decrease in organic carbon content was noticed in all the soil sites that were included for the study.

4.1.1.5 Free calcium carbonate (%)

The highest free calcium carbonate content was noticed in subsurface layers of Amminabhavi (31.90%) and the lowest in surface layer of Dharwad (2.06%).

4.1.1.6 Cation exchange capacity $\{\text{cmol (p}^+) \text{ kg}^{-1}\}$

The maximum cation exchange capacity was noticed in subsurface layers of Dharwad ($64.20 \text{ cmol (p}^+) \text{ kg}^{-1}$) while the lowest was recorded in surface layers of Amminabhavi ($41.90 \text{ cmol (p}^+) \text{ kg}^{-1}$).

Table 9. Chemical properties of selected soil profiles of north Karnataka

Soil profile site	Depth (cm)	pH (1:2.5)	EC (dSm ⁻¹) (1:2.5)	OC (%)	CaCO ₃ (%)	CEC {cmol (p ⁻) kg ⁻¹ }
Dharwad (Haplusterts)	0-15	7.64	0.27	0.61	2.06	51.70
	15-30	7.73	0.29	0.54	2.08	53.30
	30-60	7.85	0.34	0.52	2.12	55.70
	60-90	7.80	0.41	0.41	2.94	60.80
	90-120	7.98	0.28	0.42	2.85	64.20
Belavatagi (Pellusterts)	0-15	8.04	0.30	0.69	7.15	48.60
	15-30	8.13	0.31	0.65	7.13	49.30
	30-60	8.03	0.33	0.60	7.21	55.10
	60-90	7.97	0.43	0.59	6.92	56.40
	90-120	8.07	0.44	0.53	7.24	61.70
Durgadevigudi (Haplusterts)	0-15	8.21	0.34	0.61	11.90	45.90
	15-30	8.20	0.36	0.58	13.00	47.30
	30-60	8.18	0.49	0.51	16.30	48.10
	60-90	8.29	0.42	0.42	20.40	51.40
	90-120	8.40	0.31	0.36	22.40	50.50
Bijapur (Pellusterts)	0-15	8.39	0.25	0.53	19.00	43.50
	15-30	8.40	0.30	0.45	20.80	44.80
	30-60	8.39	0.33	0.44	22.30	46.10
	60-90	8.18	0.29	0.35	24.60	47.90
	90-120	8.49	0.28	0.28	25.70	53.20
Amminabhavi (Haplusterts)	0-15	8.50	0.44	0.40	23.80	41.90
	15-30	8.41	0.48	0.38	24.50	42.60
	30-60	8.42	0.50	0.29	23.10	44.70
	60-90	8.49	0.59	0.40	29.60	49.30
	90-120	8.63	0.25	0.23	31.90	48.60

4.1.2 Distribution of total and available iron in selected soil profiles

The results on distribution of total and available iron in soil profiles are presented in Table 10.

4.1.2.1 Total iron (%)

The highest total iron content was registered in the subsurface layers of Amminabhavi (3.76%) followed by Durgadevigudi (3.71%) and the lowest was in surface layers of Belavatagi (2.71%). With increase in depth, an increase in total iron was observed in all the soil sites.

4.1.2.2 Available iron (DTPA-extractable) (ppm)

The data given in Table 10 showed that DTPA-extractable iron ranged from 2.28 to 4.76 ppm in different soil sites. The highest (4.76 ppm) was recorded in surface layers of Dharwad, followed by Belavatagi (4.69 ppm) and the lowest was recorded in subsurface layers of Amminabhavi (2.28 ppm). No definite trend in the distribution pattern of DTPA-extractable iron was observed in the soils investigated.

4.1.3 Distribution of different iron fractions in soils

Results on fractionation of soil iron and its distribution throughout different soil depths are presented in Table 11.

4.1.3.1 Water soluble iron (ppm)

The results showed that the water soluble iron in soils varied from 0.32 to 1.16 ppm. The lowest value of water soluble iron was observed in subsurface layer of Amminabhavi, and the highest was recorded in surface layer of Dharwad, The decrease in water soluble iron with increase in depth of the soil body was observed in all the soil sites.

4.1.3.2 Exchangeable iron (ppm)

The highest amount of exchangeable iron was noticed in subsurface layer of Dharwad (3.65 ppm) followed by Belavatagi (3.43 ppm) and the lowest value was

Table 10. Distribution of total iron and available iron (DTPA-extractable) in selected soil profiles of north Karnataka

Soil profile site	Depth (cm)	Total-Fe (%)	Available iron (ppm)
Dharwad (Haplusterts)	0-15	2.97	4.76
	15-30	3.06	4.61
	30-60	3.22	4.59
	60-90	3.15	4.66
	90-120	3.40	4.67
Belavatagi (Pellusterts)	0-15	2.71	4.69
	15-30	2.92	4.08
	30-60	3.62	4.11
	60-90	3.69	4.05
	90-120	3.02	4.35
Durgadevigudi (Haplusterts)	0-15	3.16	3.36
	15-30	3.32	3.58
	30-60	3.27	3.57
	60-90	3.38	3.68
	90-120	3.71	3.59
Bijapur (Pellusterts)	0-15	3.21	2.74
	15-30	3.35	2.69
	30-60	3.40	2.77
	60-90	3.31	2.69
	90-120	3.56	2.81
Amminabhavi (Haplusterts)	0-15	3.37	2.37
	15-30	3.48	2.29
	30-60	3.35	2.44
	60-90	3.51	2.28
	90-120	3.76	2.35

observed in surface layer of Amminabhavi (1.82 ppm). The increase in exchangeable iron content was observed with increase in depth in all the soil sites.

4.1.3.3 Pb-displaceable iron (ppm)

The results in Table 11 indicate that lead displaceable iron content increased with increase in depth in all the soil profiles. The highest lead displaceable iron was observed in subsurface layer of Dharwad (64.80 ppm) and the lowest was recorded in surface layer of Amminabhavi (17.40 ppm).

4.1.3.4 Acid soluble iron (ppm)

The acid soluble iron in soils ranged from 0.91 to 3.26 ppm. The highest value of acid soluble iron was recorded in subsurface layer of Dharwad, while the lowest was observed in surface layer of Amminabhavi. The acid soluble iron increased with an increase in depth at all the soil sites.

4.1.3.5 Manganese oxide occluded iron (ppm)

The highest manganese oxide occluded iron content was recorded in surface layer of Dharwad (245.2 ppm) and the lowest value was registered in subsurface layer of Amminabhavi (101.2 ppm). The manganese oxide occluded iron content decreased with increase in depth at all the soil sites that were included for the study.

4.1.3.6 Organically bound iron (ppm)

Organically bound iron content varied between 693.30 and 345.80 ppm in different soil profiles. The highest (693.30 ppm) and the lowest (345.80 ppm) value of organically bound iron was noticed in surface and subsurface soils of Dharwad and Amminabhavi. Organically bound iron decreased with depth in all profiles.

4.1.3.7 Amorphous iron oxide occluded iron (ppm)

The highest amorphous Fe-oxide occluded iron was recorded in subsurface layer of Dharwad (2306.70 ppm), and the lowest was observed in surface layer of Amminabhavi (1317 ppm). This form of iron was found to increase with increase in depth in all the sites.

Table 11. Distribution of iron fractions of selected soil profiles of north Karnataka

Soil profile site	Depth (cm)	Water soluble iron (ppm)	Exchangeable iron (ppm)	Pb-displaceable iron (ppm)	Acid soluble iron (ppm)	Mn oxide occluded iron (ppm)	Organically bound iron (ppm)	Amorphous Fe oxide occluded iron (ppm)	Residual iron (%)
Dharwad (Haplusterts)	0-15	1.16	3.37	56.40	1.69	245.20	693.30	2012.20	2.67
	15-30	1.11	3.40	56.88	2.11	232.50	684.20	2246.30	2.74
	30-60	1.08	3.41	57.12	2.47	240.10	604.20	2284.20	2.90
	60-90	1.06	3.42	58.14	3.42	234.60	549.10	2293.40	2.84
Belavatagi (Pellusterts)	0-15	0.91	3.15	39.54	1.86	218.30	603.60	1921.20	2.43
	15-30	0.90	3.18	40.14	1.93	215.60	592.20	1958.20	2.64
	30-60	0.87	3.24	35.62	1.95	211.70	587.80	1931.10	3.34
	60-90	0.83	3.21	36.10	1.82	217.00	581.10	1921.10	2.76
Durgadevigudi (Haplusterts)	0-15	0.80	3.43	39.31	1.81	230.80	576.70	1968.20	2.74
	15-30	0.84	2.70	25.11	1.68	174.10	487.30	1513.30	2.94
	30-60	0.80	2.77	28.63	1.73	168.30	481.60	1536.30	3.09
	60-90	0.77	2.80	31.72	1.79	163.10	476.20	1571.10	3.05
Bijapur (Pellusterts)	0-15	0.72	2.94	35.11	1.71	156.10	471.00	1529.60	3.16
	15-30	0.71	2.87	37.60	1.74	151.40	463.10	1591.10	3.49
	30-60	0.56	2.14	19.81	1.11	146.20	443.40	1383.40	3.01
	60-90	0.50	2.19	21.63	1.17	138.60	435.20	1394.30	3.15
Amminabhavi (Haplusterts)	0-15	0.49	2.18	26.71	1.23	135.10	427.10	1416.10	3.20
	15-30	0.41	2.26	25.81	1.27	135.70	431.30	1402.20	3.11
	30-60	0.43	2.34	31.10	1.26	122.80	417.40	1431.60	3.36
	60-90	0.47	1.82	17.40	0.91	119.10	406.50	1317.00	3.18
Amminabhavi (Haplusterts)	0-15	0.41	1.85	19.71	0.96	110.30	381.70	1321.10	3.29
	15-30	0.43	2.01	22.42	1.04	113.70	387.10	1342.20	3.16
	30-60	0.38	1.90	20.90	1.01	106.10	363.40	1338.30	3.33
	60-90	0.32	2.03	28.72	1.10	101.20	345.80	1364.10	3.58

4.1.3.8 Residual iron (%)

The results indicated that the residual iron content ranged from 2.43 to 3.58 per cent in different soil profiles. It was highest in subsurface layer of Amminabhavi (3.58%) followed by Durgadevigudi (3.49%). Surface layer of Belavatagi recorded the lowest (2.43%) among the soils studied. This form of iron increased with increase in depth in all the soil profiles that were included for the study.

4.1.3.9 Percentage contribution of soil iron fractions to total iron

Regarding to the percentage contribution of different fractions of soil iron to total iron (Table 12), the contribution of water soluble (0.0034 %), acid soluble (0.0082 %), exchangeable iron (0.0109 %) was minimum in Dharwad profile. Whereas, residual iron contributed more than 90 percent to the total iron followed by amorphous iron oxide occluded (7.052 %), organically bound iron (1.953 %), Mn oxide occluded iron (0.7430 %) and Pb-displaceable iron (0.1857 %). Similar trend was noticed in Belavatagi, durgadvigudi and Bijapur. In Amminabhavi soil profile, the highest percent contribution of iron fraction to total iron was (94.84 %) of residual iron. Whereas, the lowest was registered in water soluble iron (0.0011 %).

4.1.3.10 Correlation study

The data on correlation coefficient between total and DTPA-extractable iron and different iron fractions with soil properties are presented in Table 13 and 14.

The results of the investigation indicated that clay content, soil pH and CaCO_3 significantly positively correlated with total iron. Whereas, organic carbon significantly negatively correlated with total iron.

Highly significant positive correlation was found between DTPA-extractable iron and clay content, organic carbon and cation exchange capacity. However, highly negative correlation was observed between DTPA-extractable iron and soil pH and CaCO_3 .

Clay content and pH and CaCO_3 indicated highly significant negative correlation with water soluble iron. However, clay content, organic carbon and cation exchange capacity indicated highly significant positive correlation with exchangeable iron, Pb-displaceable iron, Mn oxide occluded iron, organically bound iron and amorphous iron

Table 12. Percentage contribution of iron fractions to total iron in different soil profiles

Soil profile site	Water soluble iron	Exchangeable iron	Pb-displaceable iron	Acid soluble iron	Mn oxide occluded iron	Organically bound iron	Amorphous iron oxide occluded iron	Residual iron
Dharwad	0.0034	0.0109	0.1857	0.0082	0.7430	1.953	7.052	90.19
Belavatagi	0.0027	0.0102	0.1196	0.0059	0.6855	1.844	6.081	87.15
Durgadevigudi	0.0023	0.0084	0.0939	0.0051	0.4825	1.412	4.594	93.47
Bijapur	0.0014	0.0066	0.0742	0.0036	0.4026	1.279	4.171	94.07
Amminabhavi	0.0011	0.0001	0.0626	0.0029	0.3154	1.080	3.829	94.84

Table 13. Correlation coefficients between total iron and available iron (DTPA-extractable) Vs soil properties

Soil properties	Total iron	Available iron
Clay	0.451*	0.912**
pH	0.485*	-0.914**
EC	0.069	-0.057
OC	-0.492*	0.595**
CaCO ₃	0.508**	-0.941**
CEC	-0.029	0.740**

* Significant at 5 per cent level

** Significant at 1 per cent level

Table 14. Correlation coefficients between iron fractions Vs soil properties of north Karnataka

Soil properties	Water soluble Iron	Exchangeable Iron	Pb-displaceable iron	Acid soluble iron	Mn oxide occluded iron	Organically bound iron	Amorphous iron oxide occluded iron	Residual iron
Clay	-0.813**	0.950**	0.879**	0.054	0.851**	0.760**	0.890**	0.454*
pH	-0.922**	-0.878**	0.833**	-0.024	-0.935**	-0.931**	-0.891**	0.705**
EC	-0.027	-0.050	-0.186	0.365	0.040	-0.108	-0.079	-0.028
OC	0.671**	0.559**	0.269	0.061	0.697**	0.735**	0.483*	-0.650**
CaCO ₃	-0.958**	-0.919**	0.814**	0.513*	0.977**	-0.935**	0.927**	-0.732**
CEC	-0.607**	0.796**	0.793**	-0.070	0.699**	0.573**	0.805**	-0.271

* Significant at 5 per cent level

** Significant at 1 per cent level

oxide occluded iron. Whereas, the relationship between these iron fractions and soil pH was highly significant and negatively correlated.

The residual iron gave significantly negative correlation with CaCO_3 and organic carbon. Whereas, soil pH and clay content registered highly positive correlation with residual iron.

4.2 INCUBATION STUDY

Incubation study was conducted in the laboratory to study the effect of ferrous sulphate application on the periodical changes of different iron fractions at soils varying in calcium carbonate level.

The data on the effect of ferrous sulphate application to soil varying in calcium carbonate levels on the periodical changes of water soluble iron, acid soluble iron, exchangeable iron, Pb-displaceable iron, Mn oxide occluded iron, organically bound iron and amorphous iron oxide occluded iron at 0, 15, 30, 45, 60 and 100 days after incubation are presented hereunder

4.2.1 Water soluble iron (ppm)

Results of the periodical changes in water soluble iron content of soils due to application of FeSO_4 levels and different CaCO_3 levels in soil at 0, 15, 30, 45, 60 and 100 days after incubation (DAI) are presented in Table 15.

As the period of incubation increased, a gradual increase in water soluble iron content of soils was noticed up to 30 days after incubation and thereafter decreased at 45 days after incubation onwards.

The water soluble iron content of soils differed significantly due to applied iron and varying levels of CaCO_3 in soils.

Increased CaCO_3 levels in soil significantly decreased water soluble iron content of soil at varying period of incubation. Higher levels of CaCO_3 in soil recorded significantly lower water soluble iron content of soils (0.92, 0.96, 1.15, 1.07, 1.03 and 0.94 ppm) and the highest water soluble iron content of soil (1.90, 1.96, 2.12, 2.04, 1.99 and 1.98 ppm) was obtained in soil at lower CaCO_3 levels at all period of incubation, respectively.

Table 15. Effect of CaCO₃ and FeSO₄ levels on water soluble iron (ppm) at different days after incubation

Iron levels	CaCO ₃ levels				Mean
	2.51 (%)	7.46 (%)	15.23 (%)	22.47 (%)	
0 DAI					
No Fe (control)	1.17	1.03	0.87	0.58	0.91
50 kg FeSO ₄ ha ⁻¹	1.71	1.41	1.28	0.87	1.32
100 kg FeSO ₄ ha ⁻¹	2.81	2.19	1.85	1.31	2.04
Mean	1.90	1.54	1.33	0.92	
15 DAI					
No Fe (control)	1.19	1.04	0.87	0.61	0.93
50 kg FeSO ₄ ha ⁻¹	1.76	1.51	1.31	0.89	1.37
100 kg FeSO ₄ ha ⁻¹	2.93	2.24	1.91	1.38	2.12
Mean	1.96	1.60	1.36	0.96	
30 DAI					
No Fe (control)	1.23	1.17	0.98	0.73	1.03
50 kg FeSO ₄ ha ⁻¹	1.99	1.73	1.48	1.08	1.57
100 kg FeSO ₄ ha ⁻¹	3.14	2.51	2.12	1.63	2.35
Mean	2.12	1.80	1.53	1.15	
45 DAI					
No Fe (control)	1.20	1.12	0.95	0.67	0.99
50 kg FeSO ₄ ha ⁻¹	1.93	1.62	1.39	0.99	1.48
100 kg FeSO ₄ ha ⁻¹	2.98	2.36	1.98	1.54	2.22
Mean	2.04	1.70	1.44	1.07	
60 DAI					
No Fe (control)	1.17	1.06	0.92	0.61	0.94
50 kg FeSO ₄ ha ⁻¹	1.89	1.49	1.36	0.98	1.43
100 kg FeSO ₄ ha ⁻¹	2.91	2.29	1.95	1.50	2.16
Mean	1.99	1.61	1.41	1.03	
100 DAI					
No Fe (control)	1.15	0.98	0.85	0.52	0.88
50 kg FeSO ₄ ha ⁻¹	1.85	1.44	1.34	0.91	1.39
100 kg FeSO ₄ ha ⁻¹	2.94	2.26	1.91	1.40	2.13
Mean	1.98	1.56	1.37	0.94	

For comparing Means of	S.Em±	CD	S.Em±	CD	S.Em±	CD	S.Em±	CD	S.Em±	CD	S.Em±	CD
		(0.01)		(0.01)		(0.01)		(0.01)		(0.01)		(0.01)
	0 DAI		15 DAI		30 DAI		45 DAI		60 DAI		100 DAI	
CaCO ₃	0.02	0.12	0.02	0.12	0.03	0.12	0.03	0.12	0.03	0.12	0.02	0.17
FeSO ₄	0.03	0.10	0.03	0.11	0.03	0.11	0.03	0.10	0.02	0.10	0.02	0.11
Interaction	0.05	0.20	0.06	0.20	0.05	0.20	0.05	0.20	0.05	0.20	0.05	0.20

(DAI = Day after incubation and NS = Non-significant)

At 30 days after incubation, application of 100 kg FeSO₄ per ha recorded the highest water soluble iron content of soils (2.35 ppm) and it was significantly superior over 50 kg FeSO₄ per ha (1.48 ppm) and no iron treatment (1.03 ppm).

At 45 days after incubation, the highest water soluble iron content of soils (2.22 ppm) due to application of 100 kg FeSO₄ per ha which differ significantly over other treatments. The lowest water soluble iron content of soils (0.99 ppm) was found in the treatment received no iron (control).

Similar trend of water soluble iron was also found due to iron application in soils at other days after incubation.

The interaction effects between CaCO₃ levels and levels of applied iron in soils were significant at varying days after incubation period.

4.2.2 Exchangeable iron (ppm)

Results of the periodical changes in exchangeable iron content of soils due to FeSO₄ and CaCO₃ levels in soils at 0, 15, 30, 45, 60 and 100 days after incubation are presented in Table 16.

As the period of incubation increased, a gradual increase in exchangeable iron content of soils was noticed up to 30 days after incubation and thereafter decreased at 45 days after incubation onwards.

The exchangeable iron content of soils differed significantly due to applied iron and varying levels of CaCO₃ in soils.

Increased CaCO₃ levels in soil significantly decreased exchangeable iron content of soils at varying period of incubation. Higher levels of CaCO₃ in soil recorded significantly lower exchangeable iron content of soils (3.02, 3.08, 3.21, 3.14, 3.10 and 3.04 ppm) and the highest exchangeable iron content of soils (4.85, 5.01, 5.26, 5.09, 4.99 and 4.93 ppm) was obtained in soil at lower CaCO₃ levels at all period of incubation, respectively.

At 30 days after incubation, application of 100 kg FeSO₄ per ha recorded the highest exchangeable iron content of soils (5.57 ppm) and it was significantly superior over 50 kg FeSO₄ per ha (4.43 ppm) and no iron treatment (2.81 ppm).

Table 16. Effect of CaCO₃ and FeSO₄ levels on exchangeable iron (ppm) at different days after incubation

Iron levels	CaCO ₃ levels				
	2.51 (%)	7.46 (%)	15.23 (%)	22.47 (%)	Mean
0 DAI					
No Fe (control)	3.13	3.04	2.64	2.09	2.73
50 kg FeSO ₄ ha ⁻¹	4.75	4.22	3.86	3.16	3.99
100 kg FeSO ₄ ha ⁻¹	6.67	5.60	4.31	3.81	5.10
Mean	4.85	4.29	3.60	3.02	
15 DAI					
No Fe (control)	3.15	3.11	2.69	2.11	2.77
50 kg FeSO ₄ ha ⁻¹	4.94	4.55	3.93	3.22	4.16
100 kg FeSO ₄ ha ⁻¹	6.94	5.82	4.47	3.90	5.28
Mean	5.01	4.49	3.70	3.08	
30 DAI					
No Fe (control)	3.19	3.14	2.74	2.15	2.81
50 kg FeSO ₄ ha ⁻¹	5.27	4.81	4.16	3.46	4.43
100 kg FeSO ₄ ha ⁻¹	7.33	6.18	4.75	4.01	5.57
Mean	5.26	4.71	3.88	3.21	
45 DAI					
No Fe (control)	3.14	3.08	2.71	2.10	2.76
50 kg FeSO ₄ ha ⁻¹	4.97	4.56	4.11	3.34	4.25
100 kg FeSO ₄ ha ⁻¹	7.17	5.98	4.61	3.97	5.43
Mean	5.09	4.54	3.81	3.14	
60 DAI					
No Fe (control)	3.08	3.03	2.62	2.05	2.70
50 kg FeSO ₄ ha ⁻¹	4.93	4.48	4.03	3.29	4.18
100 kg FeSO ₄ ha ⁻¹	6.98	5.93	4.54	3.96	5.35
Mean	4.99	4.48	3.73	3.10	
100 DAI					
No Fe (control)	3.01	2.96	2.57	2.01	2.64
50 kg FeSO ₄ ha ⁻¹	4.88	4.42	3.94	3.24	4.12
100 kg FeSO ₄ ha ⁻¹	6.91	5.85	4.46	3.88	5.28
Mean	4.93	4.41	3.66	3.04	

For comparing means of	S.Em±	CD	S.Em±	CD	S.Em±	CD	S.Em±	CD	S.Em±	CD	S.Em±	CD
		(0.01)		(0.01)		(0.01)		(0.01)		(0.01)		(0.01)
	0 DAI		15 DAI		30 DAI		45 DAI		60 DAI		100 DAI	
CaCO ₃	0.07	0.26	0.07	0.27	0.10	0.38	0.07	0.29	0.07	0.29	0.07	0.27
FeSO ₄	0.06	0.23	0.06	0.23	0.08	0.33	0.06	0.25	0.06	0.25	0.06	0.23
Interaction	0.11	0.45	0.12	0.46	0.17	0.66	0.13	0.51	0.12	0.50	0.12	0.46

(DAI = Day after incubation and NS = Non-significant)

At 45 days after incubation, the highest exchangeable iron content of soils (5.43 ppm) due to application of 100 kg FeSO₄ per ha which differ significantly over other treatments. The lowest exchangeable iron content of soil (2.76 ppm) was found in the treatment received no iron (control).

Similar trend of exchangeable iron content of soils was also found due to iron application in soils at other days after incubation.

The interaction effects between CaCO₃ levels and levels of applied iron in soils were significant at varying days after incubation period.

4.2.3 Pb-displaceable iron (ppm)

Results of the periodical changes in Pb-displaceable iron content of soils due to application of FeSO₄ levels and CaCO₃ levels in soil at 0, 15, 30, 45, 60 and 100 days of incubation are presented in Table 17.

As the period of incubation increased, a gradual increase in Pb-displaceable iron content of soils was noticed up to 30 days after incubation and thereafter decreased at 45 days after incubation onwards.

The Pb-displaceable iron content of soils differed significantly due to applied iron and varying levels of CaCO₃ in soils.

Increased CaCO₃ levels in soil significantly decreased Pb-displaceable iron content of soils at varying period of incubation. Higher levels of CaCO₃ in soil recorded significantly lower Pb-displaceable iron content of soils (24.3, 25.3, 26.9, 26.2, 25.1 and 24.1 ppm) and the highest Pb-displaceable iron content of soils (56.3, 67.3, 75.2, 66.2, 67.2 and 61.4 ppm) was obtained in soil at lower CaCO₃ levels at all period of incubation, respectively.

At 30 days after incubation, application of 100 kg FeSO₄ per ha recorded the highest Pb-displaceable iron content of soils (55.5 ppm) and it was significantly superior over 50 kg FeSO₄ per ha (51.2 ppm) and no iron treatment (40.2 ppm).

At 45 days after incubation, the highest Pb-displaceable iron content of soils (53.9 ppm) due to application of 100 kg FeSO₄ per ha which differ significantly over other

Table 17. Effect of CaCO₃ and FeSO₄ levels on Pb-displaceable iron (ppm) at different days after incubation

FeSO ₄ levels	CaCO ₃ levels				
	2.51 (%)	7.46 (%)	15.23 (%)	22.47 (%)	Mean
0 DAI					
No Fe (control)	47.7	37.2	30.0	22.3	34.3
50 kg FeSO ₄ ha ⁻¹	58.2	41.9	34.7	23.9	39.7
100 kg FeSO ₄ ha ⁻¹	62.9	47.9	38.9	26.8	44.1
Mean	56.3	42.3	34.5	24.3	
15 DAI					
No Fe (control)	56.9	43.0	31.9	22.5	38.6
50 kg FeSO ₄ ha ⁻¹	68.8	51.2	37.9	25.2	45.8
100 kg FeSO ₄ ha ⁻¹	76.3	56.7	41.9	28.2	50.8
Mean	67.3	50.3	37.2	25.3	
30 DAI					
No Fe (control)	60.5	43.9	33.0	23.3	40.2
50 kg FeSO ₄ ha ⁻¹	79.7	56.1	41.5	27.5	51.2
100 kg FeSO ₄ ha ⁻¹	85.3	61.7	45.2	29.9	55.5
Mean	75.2	53.9	39.9	26.9	
45 DAI					
No Fe (control)	46.9	42.9	31.0	22.2	35.8
50 kg FeSO ₄ ha ⁻¹	70.0	53.5	39.8	26.9	47.6
100 kg FeSO ₄ ha ⁻¹	81.8	59.7	44.6	29.5	53.9
Mean	66.2	52.0	38.5	26.2	
60 DAI					
No Fe (control)	53.7	41.9	29.4	21.4	36.3
50 kg FeSO ₄ ha ⁻¹	69.3	52.5	38.7	25.5	46.5
100 kg FeSO ₄ ha ⁻¹	78.5	58.3	43.2	28.4	52.1
Mean	67.2	50.9	37.1	25.1	
100 DAI					
No Fe (control)	48.2	37.7	28.7	20.8	33.9
50 kg FeSO ₄ ha ⁻¹	66.2	48.6	36.9	24.2	43.9
100 kg FeSO ₄ ha ⁻¹	69.9	53.4	39.8	27.4	47.6
Mean	61.4	46.6	35.1	24.1	

For comparing means of	S.Em±	CD	S.Em±	CD	S.Em±	CD	S.Em±	CD	S.Em±	CD	S.Em±	CD
		(0.01)		(0.01)		(0.01)		(0.01)		(0.01)		(0.01)
	0 DAI		15 DAI		30 DAI		45 DAI		60 DAI		100 DAI	
CaCO ₃	0.5	2.0	0.8	3.2	0.9	3.6	0.8	3.1	0.9	3.4	1.0	3.7
FeSO ₄	0.4	1.8	0.7	2.8	0.8	3.1	0.7	2.7	0.7	3.0	0.8	3.2
Interaction	0.9	3.5	1.4	5.5	1.6	NS	1.4	5.4	1.5	NS	1.6	6.3

(DAI = Day after incubation and NS = Non-significant)

treatments. The lowest Pb-displaceable iron content of soils (35.8 ppm) was found in the treatment received no iron (control).

Similar trend of Pb-displaceable iron content of soils was also found due to iron application in soils at other days after incubation.

The interaction effects were significant at 0, 15, 45 and 100 days after incubation. Whereas, there was no significant differences on Pb-displaceable iron due to iron application and CaCO_3 levels in soil at 30 and 60 days after incubation period.

4.2.4 Acid soluble iron (ppm)

Results of the periodical changes in acid soluble iron content of soils due to application of FeSO_4 levels and CaCO_3 levels in soil at 0, 15, 30, 45, 60 and 100 days after incubation are presented in Table 18.

As the period of incubation increased, a gradual increase in acid soluble iron content of soils was noticed up to 30 days after incubation and thereafter decreased at 45 days after incubation onwards.

The acid soluble iron content of soils differed significantly due to applied iron and varying levels of CaCO_3 in soils.

Increased CaCO_3 levels in soil significantly decreased acid soluble iron content of soils at varying period of incubation. Higher levels of CaCO_3 in soil recorded significantly lower acid soluble iron content of soils (1.75, 1.79, 1.86, 1.80, 1.77 and 1.73 ppm) and the highest acid soluble iron content of soils (3.14, 3.26, 3.42, 3.32, 3.29 and 3.25 ppm) was obtained in soil at lower CaCO_3 levels at all period of incubation, respectively.

At 30 days after incubation, application of 100 kg FeSO_4 per ha recorded the highest acid soluble iron content of soils (3.64 ppm) and it was significantly superior over 50 kg FeSO_4 per ha (2.77 ppm) and no iron treatment (1.68 ppm).

At 45 days after incubation, the highest acid soluble iron content of soils (3.55 ppm) due to application of 100 kg FeSO_4 per ha which differ significantly over other treatments. The lowest acid soluble iron content of soils (1.64 ppm) was found in the treatment received no iron (control).

Table 18. Effect of CaCO₃ and FeSO₄ levels on acid soluble iron (ppm) at different days after incubation

Iron levels	CaCO ₃ levels				Mean
	2.51 (%)	7.46 (%)	15.23 (%)	22.47 (%)	
0 DAI					
No Fe (control)	2.08	1.96	1.38	1.01	1.61
50 kg FeSO ₄ ha ⁻¹	3.13	2.85	2.21	1.90	2.52
100 kg FeSO ₄ ha ⁻¹	4.22	3.57	3.15	2.33	3.32
Mean	3.14	2.79	2.25	1.75	
15 DAI					
No Fe (control)	2.11	1.99	1.41	1.04	1.64
50 kg FeSO ₄ ha ⁻¹	3.27	2.97	2.41	1.95	2.65
100 kg FeSO ₄ ha ⁻¹	4.39	3.78	3.28	2.37	3.46
Mean	3.26	2.91	2.37	1.79	
30 DAI					
No Fe (control)	2.14	2.05	1.45	1.07	1.68
50 kg FeSO ₄ ha ⁻¹	3.45	3.11	2.50	2.03	2.77
100 kg FeSO ₄ ha ⁻¹	4.67	3.95	3.46	2.49	3.64
Mean	3.42	3.04	2.47	1.86	
45 DAI					
No Fe (control)	2.12	2.00	1.42	1.02	1.64
50 kg FeSO ₄ ha ⁻¹	3.32	3.10	2.42	1.99	2.71
100 kg FeSO ₄ ha ⁻¹	4.51	3.91	3.39	2.40	3.55
Mean	3.32	3.00	2.41	1.80	
60 DAI					
No Fe (control)	2.09	1.98	1.37	0.94	1.60
50 kg FeSO ₄ ha ⁻¹	3.28	3.03	2.37	1.98	2.67
100 kg FeSO ₄ ha ⁻¹	4.49	3.90	3.36	2.38	3.53
Mean	3.29	2.97	2.37	1.77	
100 DAI					
No Fe (control)	2.07	1.92	1.33	0.87	1.55
50 kg FeSO ₄ ha ⁻¹	3.26	2.98	2.33	1.97	2.64
100 kg FeSO ₄ ha ⁻¹	4.41	3.86	3.31	2.36	3.49
Mean	3.25	2.92	2.32	1.73	

For comparing means of	S.Em±	CD	S.Em±	CD	S.Em±	CD	S.Em±	CD	S.Em±	CD	S.Em±	CD
		(0.01)		(0.01)		(0.01)		(0.01)		(0.01)		(0.01)
	0 DAI		15 DAI		30 DAI		45 DAI		60 DAI		100 DAI	
CaCO ₃	0.07	0.29	0.06	0.25	0.06	0.22	0.05	0.19	0.04	0.19	0.04	0.17
FeSO ₄	0.06	0.25	0.05	0.22	0.05	0.19	0.04	0.17	0.04	0.17	0.04	0.15
Interaction	0.13	NS	0.11	NS	0.09	0.38	0.08	0.33	0.08	0.33	0.08	0.31

(DAI = Day after incubation and NS = Non-significant)

Similar trend of acid soluble iron content of soils was also found due to iron application in soils at other days after incubation.

The interaction effects between iron application and CaCO_3 levels in soils were significant at different days after incubation period except at 0 and 15 days after incubation.

4.2.5 Mn oxide occluded iron (ppm)

Results of the periodical changes in Mn oxide occluded iron content of soil due to application of FeSO_4 levels and CaCO_3 levels in soil at 0, 15, 30, 45, 60 and 100 days after incubation are presented in Table 19.

As the period of incubation increased, a gradual increase in Mn oxide occluded iron content of soils was noticed up to 30 days after incubation and thereafter decreased at 45 days after incubation onwards.

The effect of varying levels of FeSO_4 were not significant with respect to Mn oxide occluded iron content of soil. Whereas, significant differences were observed due to CaCO_3 levels in soil.

Increased CaCO_3 levels in soil significantly decreased Mn oxide occluded iron content of soils at varying period of incubation. Higher levels of CaCO_3 in soil recorded significantly lower Mn oxide occluded iron content of soils (134.7, 139.7, 144.3, 141.3, 139.0 and 136.3 ppm) and the highest Mn oxide occluded iron content of soils (276.3, 283.3, 295.3, 288.3, 285.3 and 282.3 ppm) was obtained in soil at lower CaCO_3 levels at all period of incubation, respectively.

The interaction effects were not significant due to applied iron and CaCO_3 levels in soil at different days after incubation period.

4.2.6 Organically bound iron (ppm)

Result of the periodical changes in organically bound iron content of soils due to application of FeSO_4 levels and different CaCO_3 levels in soil at 0, 15, 30, 45, 60 and 100 days after incubation are presented in Table 20.

Table 19. Effect of CaCO₃ and FeSO₄ levels on Mn oxide occluded iron (ppm) at different days after incubation

Iron levels	CaCO ₃ levels				Mean
	2.51 (%)	7.46 (%)	15.23 (%)	22.47 (%)	
0 DAI					
No Fe (control)	269.0	224.0	167.0	130.0	197.5
50 kg FeSO ₄ ha ⁻¹	276.0	231.0	173.0	135.0	203.8
100 kg FeSO ₄ ha ⁻¹	284.0	241.0	181.0	139.0	211.3
Mean	276.3	232.0	173.7	134.7	
15 DAI					
No Fe (control)	273.0	229.0	171.0	133.0	201.5
50 kg FeSO ₄ ha ⁻¹	285.0	235.0	175.0	139.0	208.5
100 kg FeSO ₄ ha ⁻¹	292.0	248.0	184.0	147.0	217.8
Mean	283.3	237.3	176.7	139.7	
30 DAI					
No Fe (control)	275.0	235.0	174.0	135.0	204.8
50 kg FeSO ₄ ha ⁻¹	298.0	251.0	185.0	146.0	220.0
100 kg FeSO ₄ ha ⁻¹	313.0	265.0	193.0	152.0	230.8
Mean	295.3	250.3	184.0	144.3	
45 DAI					
No Fe (control)	273.0	230.0	171.0	133.0	201.8
50 kg FeSO ₄ ha ⁻¹	293.0	246.0	182.0	141.0	215.5
100 kg FeSO ₄ ha ⁻¹	299.0	253.0	190.0	150.0	223.0
Mean	288.3	243.0	181.0	141.3	
60 DAI					
No Fe (control)	269.0	227.0	169.0	131.0	199.0
50 kg FeSO ₄ ha ⁻¹	291.0	240.0	181.0	139.0	212.8
100 kg FeSO ₄ ha ⁻¹	296.0	251.0	187.0	147.0	220.3
Mean	285.3	239.3	179.0	139.0	
100 DAI					
No Fe (control)	267.0	223.0	166.0	128.0	196.0
50 kg FeSO ₄ ha ⁻¹	286.0	237.0	178.0	138.0	209.8
100 kg FeSO ₄ ha ⁻¹	294.0	248.0	184.0	143.0	217.3
Mean	282.3	236.0	176.0	136.3	

For comparing means of	S.Em±	CD	S.Em±	CD	S.Em±	CD	S.Em±	CD	S.Em±	CD	S.Em±	CD
		(0.01)		(0.01)		(0.01)		(0.01)		(0.01)		(0.01)
	0 DAI		15 DAI		30 DAI		45 DAI		60 DAI		100 DAI	
CaCO ₃	3.5	14.1	3.9	15.3	4.0	15.9	3.3	15.2	3.4	13.5	3.1	12.2
FeSO ₄	3.1	NS	3.3	NS	3.5	NS	3.3	NS	2.9	NS	2.7	NS
Interaction	6.1	NS	6.7	NS	6.9	NS	3.6	NS	5.9	NS	5.3	NS

(DAI = Day after incubation and NS = Non-significant)

Table 20. Effect of CaCO₃ and FeSO₄ levels on organically bound iron (ppm) at different days after incubation

Iron levels	CaCO ₃ levels				Mean
	2.51 (%)	7.46 (%)	15.23 (%)	22.47 (%)	
0 DAI					
No Fe (control)	623.0	548.0	460.0	390.0	505.3
50 kg FeSO ₄ ha ⁻¹	641.0	553.0	469.0	396.0	514.8
100 kg FeSO ₄ ha ⁻¹	659.0	563.0	478.0	403.0	525.8
Mean	641.0	554.7	469.0	393.3	
15 DAI					
No Fe (control)	636.0	553.0	463.0	397.0	512.3
50 kg FeSO ₄ ha ⁻¹	651.0	558.0	476.0	399.0	521.0
100 kg FeSO ₄ ha ⁻¹	663.0	579.0	483.0	407.0	533.0
Mean	650.0	563.3	474.0	401.0	
30 DAI					
No Fe (control)	640.0	556.0	464.0	399.0	514.8
50 kg FeSO ₄ ha ⁻¹	671.0	574.0	481.0	406.0	533.0
100 kg FeSO ₄ ha ⁻¹	695.0	596.0	499.0	420.0	552.5
Mean	668.7	575.3	481.3	408.3	
45 DAI					
No Fe (control)	636.0	546.0	461.0	395.0	509.5
50 kg FeSO ₄ ha ⁻¹	666.0	571.0	478.0	404.0	529.8
100 kg FeSO ₄ ha ⁻¹	689.0	587.0	497.0	417.0	547.5
Mean	663.7	568.0	478.7	405.3	
60 DAI					
No Fe (control)	634.0	543.0	460.0	392.0	507.3
50 kg FeSO ₄ ha ⁻¹	658.0	570.0	476.0	401.0	526.3
100 kg FeSO ₄ ha ⁻¹	681.0	583.0	493.0	410.0	541.8
Mean	657.7	565.3	476.3	401.0	
100 DAI					
No Fe (control)	627.0	541.0	456.0	384.0	502.0
50 kg FeSO ₄ ha ⁻¹	654.0	566.0	475.0	399.0	523.5
100 kg FeSO ₄ ha ⁻¹	672.0	579.0	486.0	408.0	536.3
Mean	651.0	562.0	472.3	397.0	

For comparing means of	S.Em±	CD	S.Em±	CD	S.Em±	CD	S.Em±	CD	S.Em±	CD	S.Em±	CD
		(0.01)		(0.01)		(0.01)		(0.01)		(0.01)		(0.01)
	0 DAI		15 DAI		30 DAI		45 DAI		60 DAI		100 DAI	
CaCO ₃	9.2	36.8	9.6	38.1	8.9	35.5	8.7	34.8	9.3	36.9	8.9	35.5
FeSO ₄	8.0	NS	8.3	NS	7.7	NS	7.6	NS	8.0	NS	7.7	NS
Interaction	16.0	NS	16.6	NS	15.5	NS	15.1	NS	16.0	NS	15.4	NS

(DAI = Day after incubation and NS = Non-significant)

The effect of varying levels of FeSO_4 were not significant with respect to organically bound iron content of soils. Whereas, significant differences were observed due to CaCO_3 levels in soil.

Increased CaCO_3 levels in soil significantly decreased organically bound iron content of soils at varying period of incubation. Higher levels of CaCO_3 in soil recorded significantly lower organically bound iron content of soils (393.3, 401.0, 408.3, 405.3, 401.0 and 397.0 ppm) and the highest organically bound iron content of soils (641.0, 650.0, 668.7, 663.7, 657.7 and 651.0 ppm) was obtained in soils at lower CaCO_3 levels at all period of incubation, respectively.

The interaction effects were not significant due to iron application and CaCO_3 levels in soil at different days after incubation period.

4.2.7 Amorphous iron oxide occluded iron (ppm)

Results of the periodical changes in amorphous iron oxide occluded iron of soils due to application of FeSO_4 levels and different CaCO_3 levels in soil at 0, 15, 30, 45, 60 and 100 days after incubation (DAI) are presented in Table 21.

The effect of varying levels of FeSO_4 was not significant with respect to amorphous iron oxide occluded iron content of soil. Whereas, significant differences were observed due to CaCO_3 levels.

Increased CaCO_3 levels in soil significantly decreased amorphous iron oxide occluded iron content of soils at varying period of incubation. Higher levels of CaCO_3 in soil recorded significantly lower amorphous iron oxide occluded iron content of soils (1315.7, 1324.7, 1341.7, 1329.7, 1324.7 and 1317.3 ppm) and the highest amorphous iron oxide occluded iron content of soils (2222.7, 2235.0, 2259.0, 2251.0, 2242.0 and 2230.3 ppm) was obtained in soils at lower CaCO_3 levels at all period of incubation, respectively.

The interaction effects on were not significant due to iron application and CaCO_3 levels in soil at different days after incubation period.

4.3 FIELD EXPERIMENT

A field experiment was conducted during *Kharif* and *rabi* seasons of 2002-03 and were repeated during 2003-04 in same seasons to study the effect of iron management

Table 21. Effect of CaCO₃ and FeSO₄ levels on amorphous iron oxide occluded (ppm) at different days after incubation

Iron levels	CaCO ₃ levels				Mean
	2.51 (%)	7.46 (%)	15.23 (%)	22.47 (%)	
0 DAI					
No Fe (control)	2205.0	1931.0	1506.0	1311.0	1738.3
50 kg FeSO ₄ ha ⁻¹	2224.0	1946.0	1515.0	1315.0	1750.0
100 kg FeSO ₄ ha ⁻¹	2239.0	1960.0	1527.0	1321.0	1761.8
Mean	2222.7	1945.7	1516.0	1315.7	
15 DAI					
No Fe (control)	2210.0	1934.0	1509.0	1316.0	1742.3
50 kg FeSO ₄ ha ⁻¹	2239.0	1957.0	1546.0	1325.0	1766.8
100 kg FeSO ₄ ha ⁻¹	2256.0	1976.0	1553.0	1333.0	1779.5
Mean	2235.0	1955.7	1536.0	1324.7	
30 DAI					
No Fe (control)	2216.0	1942.0	1521.0	1319.0	1749.5
50 kg FeSO ₄ ha ⁻¹	2264.0	1982.0	1575.0	1339.0	1790.0
100 kg FeSO ₄ ha ⁻¹	2297.0	2013.0	1604.0	1367.0	1820.3
Mean	2259.0	1979.0	1566.7	1341.7	
45 DAI					
No Fe (control)	2209.0	1935.0	1511.0	1312.0	1741.8
50 kg FeSO ₄ ha ⁻¹	2256.0	1967.0	1536.0	1328.0	1771.8
100 kg FeSO ₄ ha ⁻¹	2288.0	1993.0	1582.0	1349.0	1803.0
Mean	2251.0	1965.0	1543.0	1329.7	
60 DAI					
No Fe (control)	2205	1932.0	1508.0	1310.0	1738.8
50 kg FeSO ₄ ha ⁻¹	2247.0	1954.0	1525.0	1323.0	1762.3
100 kg FeSO ₄ ha ⁻¹	2274.0	1979.0	1568.0	1341.0	1790.5
Mean	2242.0	1955.0	1533.7	1324.7	
100 DAI					
No Fe (control)	2201.0	1929.0	1501.0	1305.0	1734.0
50 kg FeSO ₄ ha ⁻¹	2234.0	1950.0	1519.0	1319.0	1755.5
100 kg FeSO ₄ ha ⁻¹	2256.0	1962.0	1539.0	1328.0	1771.3
Mean	2230.3	1947.0	1519.8	1317.3	

For comparing means of	S.Em±	CD	S.Em±	CD	S.Em±	CD	S.Em±	CD	S.Em±	CD	S.Em±	CD
		(0.01)		(0.01)		(0.01)		(0.01)		(0.01)		(0.01)
	0 DAI		15 DAI		30 DAI		45 DAI		60 DAI		100 DAI	
CaCO ₃	26.4	77.5	34.7	138.3	26.4	105.3	25.5	101.4	28.4	83.4	26.6	78.0
FeSO ₄	22.9	NS	30.1	NS	22.9	NS	22.0	NS	24.6	NS	23.0	NS
Interaction	45.8	NS	60.1	NS	45.8	NS	44.1	NS	49.2	NS	46.1	NS

(DAI = Day after incubation and NS = Non-significant)

practices on groundnut- maize cropping sequence in calcareous Vertisol at farmer's field, Durgadevigi, Dharwad. The results of the analysis and observations recorded during the course of the experiment are presented in this chapter under the following headings.

4.3.1 Initial properties of soil and chemical composition of FYM

4.3.2 Growth parameters

4.3.3 Yield parameters

4.3.4 Quality parameters

4.3.5 Biochemical parameters

4.3.6 Nutrient content and uptake

4.3.7 Available nutrients in soil

4.3.8 Iron fractions in soil

4.3.9 Path analysis study and

4.3.10 Economic analysis.

4.3.1 Initial properties of soil and chemical composition of FYM

Physico-chemical properties, available nutrients status of the soil and iron fractions of the experimental site is presented in Table 22.

The experimental site was clayey in texture, alkaline in reaction (pH 8.2), low in electrical conductivity (0.35 dSm^{-1}) and medium in organic carbon (6.1 g kg^{-1}). The CEC of the soil was $45.6 \text{ cmol (p}^+) \text{ kg}^{-1}$ and calcium carbonate content was 12.1 per cent. The available N content was medium (294 kg ha^{-1}), available P_2O_5 content of the soil was low (18.1 kg ha^{-1}) and available K_2O content was high (450 kg ha^{-1}). The available Fe (3.39 mg kg^{-1}) and Zn content (0.54 mg kg^{-1}) was found low, whereas Mn and Cu were high. Among the different soil iron fractions water soluble iron was found to be the lowest (0.81 mg kg^{-1}) and the highest amorphous iron oxide occluded ($1601.70 \text{ mg kg}^{-1}$).

The chemical composition of farmyard manure (FYM) used in the experiment is presented in Table 21. The pH of farmyard manure was 6.9 and EC 0.16 dSm^{-1} . Macronutrient content was 0.70, 0.50 and 0.20 per cent N, P_2O_5 and K_2O respectively. Whereas micronutrient content was 40.8, 26.1, 2.35 and 1.13 mg kg^{-1} iron, zinc, manganese and copper respectively.

Table 22. Physico-chemical properties of initial soil sample of the experimental site and nutrient composition of FYM

Sl. No.	Particulars	Value obtained
I. Physical properties		
1.	Coarse sand (%)	12.46
2.	Fine sand (%)	14.21
3.	Silt (%)	18.10
4.	Clay (%)	53.60
5.	Textural class	Clay
II. Chemical properties		
1.	Soil pH (1:2.5)	8.20
2.	Soil EC (1:2.5) (dSm ⁻¹)	0.35
3.	Organic carbon (g kg ⁻¹)	6.10
4.	Calcium carbonate (%)	12.1
5.	CEC (cmol (p+) kg ⁻¹)	45.60
III. Available Macronutrients		
1.	Available N (kg ha ⁻¹)	254.00
2.	Available P ₂ O ₅ (kg ha ⁻¹)	17.10
3.	Available K ₂ O (kg ha ⁻¹)	410.00
4.	Available SO ₄ (kg ha ⁻¹)	62.4
IV. Available Micronutrients		
1.	DTPA-extractable Fe (mg kg ⁻¹)	3.39
2.	DTPA-extractable Zn (mg kg ⁻¹)	0.54
3.	DTPA-extractable Mn (mg kg ⁻¹)	2.78
4.	DTPA-extractable Cu (mg kg ⁻¹)	0.31
V. Iron fractions		
1.	Water soluble Fe (mg kg ⁻¹)	0.81
2.	Exchangeable Fe (mg kg ⁻¹)	2.64
3.	Pb-displaceable Fe (mg kg ⁻¹)	27.30
4.	Acid soluble Fe (mg kg ⁻¹)	1.12
5.	Mn oxide occluded Fe (mg kg ⁻¹)	168.70
6.	Organically bound Fe (mg kg ⁻¹)	459.20
7.	Amorphous Fe oxide (mg kg ⁻¹)	1601.70
VI. Nutrient composition of farmyard manure (FYM)		
1.	pH (1:2.5)	6.90
2.	EC (1:2.5) (dSm ⁻¹)	0.16
3.	Total Nitrogen (%)	0.50
4.	Total phosphorous (%)	0.20
5.	Total potassium (%)	0.70
6.	Total iron (mg kg ⁻¹)	310.8
7.	Total zinc (mg kg ⁻¹)	126.1
8.	Total manganese (mg kg ⁻¹)	52.35
9.	Total copper (mg kg ⁻¹)	6.13

4.3.2 Growth parameters

The data on effect of iron management practices on plant height, number of green leaves per plant and dry matter production of groundnut-maize cropping sequence at 30 DAS, 60 DAS and at harvest in calcareous Vertisol are presented hereunder

4.3.2.1 Growth parameters of groundnut

4.3.2.1.1 Plant height (cm)

The data pertaining to the direct effect of iron management practices on the plant height of groundnut at 30 DAS, 60 DAS and at harvest are presented in Table 23.

Plant height increased with advancement in age up to harvest

The results of the investigation indicate that methods of iron application and iron levels had significant influence on the plant height of groundnut at 60 DAS and at harvest. However, there were no significant differences at 30 DAS.

At 60 DAS and harvest, soil plus foliar applications of iron registered significantly the higher plant height of 25.9 and 40.3 cm, respectively over soil applications of iron only (23.5 and 38.0 cm, respectively).

Variation in plant height due to iron levels was significant at 60 DAS and at harvest, during which plant height increased with increase in iron levels. Application of 50 kg pyrite per ha recorded the highest plant height (29.0 cm and 45.3 cm, respectively) and it was on par with 100 kg FeSO_4 per ha and significantly superior over 25 kg pyrite per ha and 50 kg FeSO_4 per ha. The lowest plant height (19.0 cm and 31.2 cm) was registered in the treatment receiving no iron (control). Application of 100 kg FeSO_4 per ha was significantly higher plant height over rest of the treatments.

The interaction effects were not significant at different growth stages of groundnut.

4.3.2.1.2 Number of green leaves

The data pertaining to the direct effect of iron management practices on number of green leaves of groundnut at 30, 60 and 80 DAS are presented in Table 24.

In general, there was a steady increase in number of green leaves from 30 DAS up to harvest stage of groundnut.

Table 23. Direct effect of iron management practices on plant height (cm) at different growth stages of groundnut

Iron levels	30 DAS			60 DAS			At harvest		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	9.9	9.9	9.9	18.1	19.9	19.0	29.8	32.6	31.2
S ₁ : 50 kg FeSO ₄ ha ⁻¹	10.2	10.2	10.2	21.4	23.9	22.7	35.2	37.8	36.5
S ₂ : 100 kg FeSO ₄ ha ⁻¹	12.0	12.2	12.1	27.1	30.1	28.6	42.8	44.6	43.7
S ₃ : 25 kg Pyrite ha ⁻¹	10.3	10.4	10.4	23.1	25.4	24.3	38.0	40.2	39.1
S ₄ : 50 kg Pyrite ha ⁻¹	12.4	12.7	12.6	27.7	30.3	29.0	44.1	46.5	45.3
Mean	10.9	11.1		23.5	25.9		38.0	40.3	
For comparing means of	S.E.m±	CD (0.05)		S.E.m±	CD (0.05)		S.E.m±	CD (0.05)	
Methods of Fe application	0.3	NS		0.4	1.7		0.5	2.1	
Iron levels	0.7	NS		0.7	2.1		0.8	2.2	
Interaction	1.0	NS		1.0	NS		1.1	NS	

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

Table 24. Direct effect of iron management practices on number of green leaves at different growth stages of groundnut

Iron levels	30 DAS			60 DAS			80 DAS		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	15.2	13.3	14.3	46.5	52.4	49.5	100.3	119.1	109.7
S ₁ : 50 kg FeSO ₄ ha ⁻¹	15.5	13.7	14.6	56.9	62.5	59.7	125.1	135.5	130.3
S ₂ : 100 kg FeSO ₄ ha ⁻¹	16.2	16.4	16.3	67.9	72.9	70.4	150.3	160.4	155.4
S ₃ : 25 kg Pyrite ha ⁻¹	15.6	15.8	15.7	60.8	66.4	63.6	136.4	148.9	142.7
S ₄ : 50 kg Pyrite ha ⁻¹	16.3	16.4	16.4	73.5	85.0	79.3	167.1	181.3	174.2
Mean	15.8	15.9		61.1	67.8		135.8	149.1	
For comparing means of	S.Em±	CD (0.05)		S.Em±	CD (0.05)		S.Em±	CD (0.05)	
Methods of Fe application	0.35	NS		0.87	3.90		1.89	8.51	
Iron levels	0.34	NS		1.23	3.58		2.82	8.22	
Interaction	0.47	NS		1.74	NS		3.98	NS	

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

The results of the investigations indicate that methods of iron application and iron levels had significant influence on number of green leaves of groundnut at 60 DAS and 80 DAS. However, there were no significant differences at 30 DAS.

At 60 DAS, significantly higher number of green leaves was observed with soil plus foliar application of iron (67.8) over soil application of iron (61.1). At 80 DAS also soil plus foliar application of iron recorded significantly higher number of green leaves (149.1) over soil application of iron (135.8).

Number of green leaves also differed significantly due to iron levels at 60 and 80 DAS. Application of 50 kg pyrite per ha recorded the highest number of green leaves (79.3 and 174.2 respectively) and it was significantly superior over 100 kg FeSO₄ per ha, 25 kg pyrite per ha and 50 kg FeSO₄ per ha. The lowest number of green leaves of 49.5 and 109.7, respectively obtained in control treatment. Application of 100 kg FeSO₄ per ha registered significantly higher number of green leaves over rest of the treatments.

The interaction effects were not significant at different stages of groundnut crop as influenced by iron management practices.

4.3.2.1.3 Total dry matter production (kg ha⁻¹)

The data pertaining to the direct effect of iron management practices on total dry matter production of groundnut at 30, 60 DAS and harvest are presented in Table 25.

The results of the investigation indicate that methods of iron application and iron levels had significant influence on total dry matter production of groundnut at 60 DAS and harvest. However, there was no significant difference at 30 DAS.

Total dry matter production followed similar trend of number of green leaves. At 60 DAS and harvest, soil plus foliar application of iron was significantly higher over soil application of iron (1830.5, 5698.5 and 1693.1, 5563.7 kg per ha, respectively).

At 60 DAS, application of 50 kg pyrite per ha registered the highest total dry matter production (1962.4 kg ha⁻¹) and it was significantly superior over 100 kg FeSO₄ per ha (1852.8 kg ha⁻¹) and 25 kg pyrite per ha (1732.3 kg ha⁻¹) and 50 kg FeSO₄ per ha (1656.6 kg ha⁻¹). The lowest total dry matter production (1604.9 kg ha⁻¹) obtained in the treatment receiving no iron (control). Application of 100 kg FeSO₄ was significantly higher over rest of the treatments.

Table 25. Direct effect of iron management practices on total dry matter production (kg ha^{-1}) at different growth stages of groundnut

Iron levels	30 DAS						60 DAS						At harvest					
	Methods of Fe application			Methods of Fe application			Methods of Fe application			Methods of Fe application			Methods of Fe application					
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean			
S ₀ : No iron (control)	652.0	658.8	655.4	1569.0	1640.8	1604.9	5172.0	5261.8	5216.9	702.8	710.8	706.8	1586.8	1726.3	1656.6	5328.0	5445.8	5386.9
S ₁ : 50 kg FeSO ₄ ha ⁻¹	729.5	731.5	730.5	1801.3	1904.3	1852.8	5756.0	5818.3	5787.2	713.8	722.3	718.1	1651.8	1812.8	1732.3	5495.3	5609.0	5552.2
S ₂ : 100 kg FeSO ₄ ha ⁻¹	748.3	755.3	751.8	1856.5	2068.3	1962.4	6067.0	6356.0	6211.5	709.3	715.6	709.3	1693.1	1830.5	1830.5	5563.7	5698.0	5698.0
Mean																		
For comparing means of	S.E.m \pm		CD (0.05)	S.E.m \pm		CD (0.05)	S.E.m \pm		CD (0.05)	S.E.m \pm		CD (0.05)	S.E.m \pm		CD (0.05)	S.E.m \pm		CD (0.05)
Methods of Fe application	8.7		NS	23.2		104.5	28.7		129.3	23.7		NS	32.1		93.6	94.5		277.2
Iron levels	33.5		NS	45.4		NS	134.3		NS									
Interaction																		

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

Similar trend of total dry matter production was also noticed at harvest stage of groundnut.

The interaction effects were not significant at different stages of groundnut crop.

4.3.2.2 Growth parameters in maize

4.3.2.2.1 Plant height (cm)

The data pertaining to the residual effect of iron management practices on the plant height of maize at 30 DAS, 60 DAS and at 80 DAS are presented in Table 26.

Plant height of maize increased with plant age up to harvest.

The results of the investigation indicate that residual effect of methods of iron application and iron levels had significant influence on the plant height of maize at 60 DAS and at harvest. However, there were no significant differences observed at 30 DAS.

Changes due to methods of iron application were significant at 60 DAS and harvest. At 60 DAS, soil plus foliar application of iron registered significantly higher plant height (175.1) over soil application of iron (147.9). Similar trend was visible at harvest of maize.

Treatments which received 50 kg pyrite per ha recorded the highest plant height (175.1 cm) and it was on par with 100 kg FeSO₄ per ha (165.5 cm), 25 kg pyrite per ha (163.3 cm) and 50 kg FeSO₄ per ha (157.2 cm) and significantly superior over control treatment (146.5 cm).

At harvest, highest plant height observed due to application of 50 kg pyrite per ha (211.3 cm) and it was on par with 25 kg pyrite per ha and 100 kg FeSO₄ per ha and significantly superior over 50 kg FeSO₄ per ha (198.5 cm) and no iron treatment (181.8 cm).

The interaction effects were not significant at different growth stages of maize.

4.3.2.2.2 Number of green leaves

The results indicate that residual effect of methods of iron application and iron levels and their interactions did not differ significantly with respect to number of green leaves of maize at 30, 60 and 80 DAS (Table 27).

Table 26. Residual effect of iron management practices on plant height (cm) at different growth stages of maize

Iron levels	30 DAS				60 DAS				At harvest			
	Methods of Fe application				Methods of Fe application				Methods of Fe application			
	F ₀	F ₁	Mean	CD (0.05)	F ₀	F ₁	Mean	CD (0.05)	F ₀	F ₁	Mean	CD (0.05)
S ₀ : No iron (control)	66.7	68.1	67.4		140.4	152.6	146.5		175.1	188.4	181.8	
S ₁ : 50 kg FeSO ₄ ha ⁻¹	70.9	71.3	71.1		146.7	167.7	157.2		191.3	205.6	198.5	
S ₂ : 100 kg FeSO ₄ ha ⁻¹	74.9	75.3	75.1		150.9	180.1	165.5		201.3	219.1	210.2	
S ₃ : 25 kg Pyrite ha ⁻¹	71.8	72.9	72.4		148.3	178.3	163.3		196.4	212.3	204.4	
S ₄ : 50 kg Pyrite ha ⁻¹	76.7	77.8	77.3		153.4	196.8	175.1		209.6	213.0	211.3	
Mean	72.2	73.1			147.9	175.1			194.8	211.5		
For comparing means of	S.Em±		CD (0.05)		S.Em±		CD (0.05)		S.Em±		CD (0.05)	
Methods of Fe application	2.1		NS		3.2		14.2		2.7		12.2	
Iron levels	3.0		NS		6.2		18.2		4.3		12.5	
Interaction	4.2		NS		8.8		NS		6.1		NS	

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

Table 27. Residual effect of iron management practices on number of green leaves at different growth stages of maize

Iron levels	30 DAS			60 DAS			80 DAS		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	6.47	6.59	6.53	10.93	11.55	11.24	7.78	7.93	7.86
S ₁ : 50 kg FeSO ₄ ha ⁻¹	6.69	6.80	6.75	11.08	12.08	11.58	8.00	8.20	8.10
S ₂ : 100 kg FeSO ₄ ha ⁻¹	6.80	6.96	6.88	11.40	13.03	12.22	8.48	8.68	8.58
S ₃ : 25 kg Pyrite ha ⁻¹	6.72	6.86	6.79	11.20	12.73	11.97	8.18	8.33	8.26
S ₄ : 50 kg Pyrite ha ⁻¹	7.14	7.34	7.24	11.60	13.40	12.50	8.73	8.93	8.83
Mean	6.76	6.91		11.24	12.56		8.23	8.41	
For comparing means of	S.Em±		CD (0.05)	S.Em±		CD (0.05)	S.Em±		CD (0.05)
Methods of Fe application	0.15		NS	0.35		NS	0.10		NS
Iron levels	0.17		NS	0.52		NS	0.27		NS
Interaction	0.24		NS	0.74		NS	0.39		NS

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

4.3.2.2.3 Total dry matter production (kg ha^{-1})

Dry matter production increased with plant age up to harvest (Table 28).

The results indicate that residual effect of methods of iron application and iron levels did not differ significantly with respect to total dry matter production of maize at 30 and harvest. However, there were significant differences due to iron application at 60 DAS.

At 60 DAS, soil plus foliar application of iron recorded distinctly higher total dry matter production ($4622.9 \text{ kg ha}^{-1}$) over soil application of iron ($4468.5 \text{ kg ha}^{-1}$).

Among iron levels, the plot which received 50 kg pyrite per ha recorded the highest total dry matter production ($4864.4 \text{ kg ha}^{-1}$) and it was significantly superior over 100 kg FeSO_4 per ha ($4673.6 \text{ kg ha}^{-1}$), 25 kg pyrite per ha ($4516.9 \text{ kg ha}^{-1}$) and 50 kg FeSO_4 per ha ($4422.3 \text{ kg ha}^{-1}$) at 60 DAS. The lowest total dry matter production ($4250.4 \text{ kg ha}^{-1}$) obtained in the treatment receiving no iron (control). Application of 100 kg FeSO_4 per ha recorded significantly higher over rest of the treatments.

The interaction effects were non-significant at different growth stages of maize.

4.3.3 Yield parameters

The details of data on the effect of iron management practices on yield and yield attributes of groundnut-maize cropping sequence in calcareous Vertisol are presented hereunder

4.3.3.1 Yield parameters of groundnut

4.3.3.1.1 Pod number per plant

Number of pods per plant differed significantly due to methods of iron application as well as iron levels (Table 29).

Pooled data of two years indicate that, soil plus foliar application of iron registered the higher number of pods per plant (22.16) over soil application of iron (20.13).

Among iron levels, application of 50 kg pyrite per ha recorded the highest pod number per plant (26.13) and it was significantly superior over 100 kg FeSO_4 per ha

Table 28. Residual effect of iron management practices on total dry matter production (kg ha⁻¹) at different growth stages of maize

Iron levels	30 DAS				60 DAS				At harvest		
	Methods of Fe application				Methods of Fe application				Methods of Fe application		
	F ₀	F ₁	Mean	CD (0.05)	F ₀	F ₁	Mean	CD (0.05)	F ₀	F ₁	Mean
S ₀ : No iron (control)	485.5	491.8	488.7		4191.3	4309.5	4250.4		15155.0	15348.0	15251.5
S ₁ : 50 kg FeSO ₄ ha ⁻¹	403.0	505.7	454.4		4360.0	4484.5	4422.3		15369.0	15596.0	15482.5
S ₂ : 100 kg FeSO ₄ ha ⁻¹	424.6	527.3	476.0		4587.3	4759.8	4673.6		15606.0	16219.0	15912.5
S ₃ : 25 kg Pyrite ha ⁻¹	509.2	513.8	511.5		4440.3	4593.5	4516.9		15485.0	15816.0	15650.5
S ₄ : 50 kg Pyrite ha ⁻¹	536.5	545.0	540.8		4763.8	4965.0	4864.4		15664.0	16461.0	16062.5
Mean	511.8	516.7			4468.5	4622.9			15456.0	15888.0	
For comparing means of	S.Em±		CD (0.05)		S.Em±		CD (0.05)		S.Em±		CD (0.05)
Methods of Fe application	5.8		NS		34.2		153.8		279.1		NS
Iron levels	17.1		NS		39.1		114.1		375.7		NS
Interaction	24.2		NS		55.3		NS		531.3		NS

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

Table 29. Direct effect of iron management practices on number of pods plant⁻¹ of groundnut

Iron levels	2002-03			2003-04			Pooled		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	17.58	18.80	18.19	15.63	15.98	15.81	16.61	17.39	17.00
S ₁ : 50 kg FeSO ₄ ha ⁻¹	19.58	21.93	20.76	17.13	18.43	17.78	18.36	20.18	19.27
S ₂ : 100 kg FeSO ₄ ha ⁻¹	22.60	25.50	24.05	20.30	23.00	21.65	21.45	24.25	22.85
S ₃ : 25 kg Pyrite ha ⁻¹	20.25	23.00	21.63	18.68	19.88	19.28	19.47	21.44	20.46
S ₄ : 50 kg Pyrite ha ⁻¹	27.00	30.30	28.65	22.48	24.73	23.61	24.74	27.52	26.13
Mean	21.40	23.91		18.84	20.40		20.13	22.16	
For comparing means of	S.Em±	CD (0.05)		S.Em±	CD (0.05)		S.Em±	CD (0.05)	
Methods of Fe application	0.34	1.51		0.23	1.04		0.30	1.35	
Iron levels	0.48	1.41		0.63	1.82		0.83	2.43	
Interaction	0.68	NS		0.88	NS		1.18	NS	

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

(22.85), 25 kg pyrite per ha (20.46) and 50 kg FeSO₄ per ha (19.27). The lowest pod number per plant (17.00) was obtained in the treatment receiving no iron (control). Addition of 100 kg FeSO₄ per ha was on par with 25 kg pyrite per ha and significantly superior over 50 kg FeSO₄ per ha and control treatment. The interaction effects were found to be not significant.

4.3.3.1.2 100-kernel weight (g)

Methods of iron application and iron levels had significant influence on 100-kernel weight of groundnut. (Table 30)

Pooled data of two years indicate that, 100-kernel weight markedly influenced by soil plus foliar application of iron and soil application of iron. Addition of soil plus foliar application of iron recorded significantly higher 100-kernel weight (49.44 g) and it was significantly higher over soil application of iron (46.44 g).

Application of 50 kg pyrite per ha recorded the highest 100-kernel weight (51.67 g) and it was on par with 100 kg FeSO₄ per ha (49.88 g) and 25 kg pyrite per ha (47.43 g) and significantly superior over 50 kg FeSO₄ per ha (46.38 g) and control treatment (44.48 g).

Similar to number of pods per plant, 100-kernel weight did not indicate any significant influence of interaction effects due to iron management practices.

4.3.3.1.3 Shelling (%)

Shelling percentage did not differ significantly due to iron management practices (Table 31).

4.3.3.1.4 Haulm yield (kg ha⁻¹)

The results of the investigation indicate that methods of iron application and iron levels had significant influence on haulm yield of groundnut (Table 32).

Pooled data of two years indicate that, soil plus foliar application of iron registered the higher haulm yield (2820 kg ha⁻¹) and it was on par with soil application of iron (2667 kg ha⁻¹).

Table 30. Direct effect of iron management practices on 100-kernel weight (g) of groundnut

Iron levels	2002-03			2003-04			Pooled		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	42.95	45.45	44.20	44.20	45.31	44.76	43.58	45.38	44.48
S ₁ : 50 kg FeSO ₄ ha ⁻¹	45.38	46.68	46.03	45.58	47.88	46.73	45.48	47.28	46.38
S ₂ : 100 kg FeSO ₄ ha ⁻¹	47.70	52.48	50.09	47.78	51.53	49.66	47.74	52.01	49.88
S ₃ : 25 kg Pyrite ha ⁻¹	46.10	48.13	47.12	46.20	49.26	47.73	46.15	48.70	47.43
S ₄ : 50 kg Pyrite ha ⁻¹	49.88	53.63	51.76	49.08	54.07	51.58	49.48	53.85	51.67
Mean	46.40	49.27		46.57	49.61		46.49	49.44	
For comparing means of	S.Em±	CD (0.05)		S.Em±	CD (0.05)		S.Em±	CD (0.05)	
Methods of Fe application	0.53	2.39		0.67	3.00		0.55	2.48	
Iron levels	1.21	3.52		0.86	2.50		1.45	4.24	
Interaction	1.71	NS		1.21	NS		2.06	NS	

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

Table 31. Direct effect of iron management practices on shelling percentage of groundnut

Iron levels	2002-03			2003-04			Pooled		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	68.53	68.72	68.63	68.14	68.19	68.17	68.34	68.46	68.40
S ₁ : 50 kg FeSO ₄ ha ⁻¹	69.15	69.75	69.45	68.25	68.32	68.29	68.70	69.05	68.88
S ₂ : 100 kg FeSO ₄ ha ⁻¹	69.54	69.97	69.76	68.49	68.59	68.54	69.02	69.28	69.15
S ₃ : 25 kg Pyrite ha ⁻¹	69.22	69.82	69.52	68.40	68.46	68.43	68.81	69.14	68.98
S ₄ : 50 kg Pyrite ha ⁻¹	69.96	70.53	70.25	68.71	68.78	68.75	69.34	69.66	69.50
Mean	69.28	69.76		68.40	68.47		68.84	69.12	
For comparing means of	S.Em±	CD (0.05)		S.Em±	CD (0.05)		S.Em±	CD (0.05)	
Methods of Fe application	1.28	NS		0.83	NS		0.79	NS	
Iron levels	1.61	NS		2.38	NS		3.05	NS	
Interaction	2.27	NS		3.37	NS		4.31	NS	

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

Table 32. Direct effect of iron management practices on haulm yield (kg ha^{-1}) of groundnut

Iron levels	2002-03			2003-04			Pooled		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	2473	2532	2502	2460	2501	2480	2467	2517	2492
S ₁ : 50 kg FeSO ₄ ha ⁻¹	2592	2770	2681	2578	2722	2650	2585	2746	2665
S ₂ : 100 kg FeSO ₄ ha ⁻¹	2805	2930	2867	2789	3027	2908	2797	2979	2888
S ₃ : 25 kg Pyrite ha ⁻¹	2673	2825	2749	2650	2859	2754	2662	2842	2752
S ₄ : 50 kg Pyrite ha ⁻¹	2831	2949	2890	2819	3080	2949	2825	3015	2920
Mean	2675	2802		2659	2838		2667	2820	
For comparing means of	S.Em \pm	CD	(0.05)	S.Em \pm	CD	(0.05)	S.Em \pm	CD	(0.05)
Methods of Fe application	23	104		21	93		40	178	
Iron levels	47	165		98	286		96	281	
Interaction	80	NS		139	NS		136	NS	

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

Among applied iron levels, application of 50 kg pyrite per ha registered the highest haulm yield (2920 kg ha⁻¹) and it was on par with 100 kg FeSO₄ per ha (2888 kg ha⁻¹), 25 kg pyrite per ha (2757 kg ha⁻¹) and 50 kg FeSO₄ per ha (2665 kg ha⁻¹) and significantly superior over the treatment receiving no iron (2492 kg ha⁻¹).

Variations in haulm yield due to interaction effects of soil plus foliar application of iron and soil application of iron were not significant.

4.3.3.1.5 Pod yield (kg ha⁻¹)

The results of the investigation indicate that methods of iron application and iron levels had marked influence on the pod yield of groundnut (Table 33).

Pooled data of two years indicate that, variations in pod yield due to iron application methods followed the same trend as that of haulm yield. The Higher pod yield (2407 kg ha⁻¹) recorded due to soil plus foliar application of iron and it was significantly superior over soil application of iron (2264 kg ha⁻¹).

Among applied iron levels, application of 50 kg pyrite per ha recorded the highest pod yield (2507 kg ha⁻¹) and it was on par with 100 kg FeSO₄ per ha (2467 kg ha⁻¹) and significantly superior over 25 kg pyrite per ha (2340 kg ha⁻¹) and 50 kg FeSO₄ per ha (2260 kg ha⁻¹). The lowest pod yield (2100 kg ha⁻¹) was obtained in the treatment receiving no iron (control). Application of 100 kg FeSO₄ per ha was on par with 25 kg pyrite per ha and significantly superior over 50 kg FeSO₄ per ha and control treatment.

Pod yield did not indicate any significant influence of interaction effects due to foliar and soil application of iron.

4.3.3.1.6 Harvest index

The results of the investigation indicate that methods of iron application and iron levels and their interaction did not differ significantly with respect to harvest index of groundnut (Table 34).

4.3.3.2 Yield parameters of maize

4.3.3.3.1 Cob length (cm)

The results of the investigation indicate that methods of iron application and iron levels and their interactions did not differ significantly with respect to cob length of maize (Table 35).

Table 33. Direct effect of iron management practices on pod yield (kg ha^{-1}) of groundnut

Iron levels	2002-03			2003-04			Pooled		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	2071	2130	2100	2083	2218	2150	2077	2124	2100
S ₁ : 50 kg FeSO ₄ ha ⁻¹	2189	2349	2269	2187	2315	2251	2188	2332	2260
S ₂ : 100 kg FeSO ₄ ha ⁻¹	2391	2511	2451	2373	2594	2483	2382	2552	2467
S ₃ : 25 kg Pyrite ha ⁻¹	2263	2408	2335	2253	2437	2345	2258	2423	2340
S ₄ : 50 kg Pyrite ha ⁻¹	2416	2545	2480	2409	2658	2533	2413	2602	2507
Mean	2266	2389		2261	2424		2264	2407	
For comparing means of	S.Em \pm	CD (0.05)		S.Em \pm	CD (0.05)		S.Em \pm	CD (0.05)	
Methods of Fe application	25	116		27	124		30	135	
Iron levels	41	119		61	179		56	162	
Interaction	58	NS		87	NS		79	NS	

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

Table 34. Direct effect of iron management practices on harvest index of groundnut

Iron levels	2002-03			2003-04			Pooled		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	0.4558	0.4569	0.4564	0.4585	0.4588	0.4587	0.4572	0.4579	0.4576
S ₁ : 50 kg FeSO ₄ ha ⁻¹	0.4579	0.4589	0.4584	0.4590	0.4596	0.4593	0.4585	0.4593	0.4589
S ₂ : 100 kg FeSO ₄ ha ⁻¹	0.4602	0.4615	0.4609	0.4597	0.4623	0.4610	0.4600	0.4619	0.4610
S ₃ : 25 kg Pyrite ha ⁻¹	0.4585	0.4602	0.4594	0.4595	0.4611	0.4603	0.4590	0.4607	0.4599
S ₄ : 50 kg Pyrite ha ⁻¹	0.4605	0.4632	0.4619	0.4608	0.4649	0.4629	0.4607	0.4641	0.4624
Mean	0.4586	0.4603		0.4595	0.4613		0.4591	0.4608	
For comparing means of	S.Em±	CD (0.05)		S.Em±	CD (0.05)		S.Em±	CD (0.05)	
Methods of Fe application	0.0100	NS		0.0070	NS		0.0080	NS	
Iron levels	0.0130	NS		0.0100	NS		0.0170	NS	
Interaction	0.0180	NS		0.0140	NS		0.0240	NS	

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

Table 35. Residual effect of iron management practices on cob length (cm) of maize

Iron levels	2002-03				2003-04				Pooled		
	Methods of Fe application				Methods of Fe application				Methods of Fe application		
	F ₀	F ₁	Mean	CD	F ₀	F ₁	Mean	CD	F ₀	F ₁	Mean
S ₀ : No iron (control)	15.26	15.88	15.57	(0.05)	15.14	15.75	15.45	(0.05)	15.20	15.82	15.51
S ₁ : 50 kg FeSO ₄ ha ⁻¹	16.11	16.75	16.43	NS	16.32	16.40	16.36	NS	16.22	16.58	16.40
S ₂ : 100 kg FeSO ₄ ha ⁻¹	16.83	17.66	17.25	NS	16.96	17.11	17.04	NS	16.90	17.39	17.15
S ₃ : 25 kg Pyrite ha ⁻¹	16.26	17.11	16.69	NS	16.43	16.72	16.58	NS	16.35	16.92	16.64
S ₄ : 50 kg Pyrite ha ⁻¹	17.29	17.91	17.60	NS	17.35	17.69	17.52	NS	17.32	17.80	17.56
Mean	16.35	17.06			16.44	16.73			16.40	16.90	
For comparing means of	S.E.m±	CD			S.E.m±	CD			S.E.m±	CD	
Methods of Fe application	0.27	(0.05)	NS		0.30	(0.05)	NS		0.27	(0.05)	NS
Iron levels	0.62	NS	NS		0.81	NS	NS		0.59	NS	NS
Interaction	0.88	NS	NS		1.14	NS	NS		0.84	NS	NS

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

4.3.3.2.2 Cob diameter (cm)

Similar trend that of cob length, the results of the investigation indicate that methods of iron application and iron levels and their interactions found to be non-significant with regard to cob diameter of maize (Table 36).

4.3.3.2.3 Grain number per cob

Pooled data of two years indicate that, grain number per cob was significantly influenced by methods of iron application and iron levels (Table 37).

Among iron application methods, soil plus foliar application of iron recorded the higher grain number per cob (717.7) and it was significantly superior over soil application of iron (660.7).

As iron application levels increased, grain number per cob also increased. Application of 50 kg pyrite per ha recorded the highest grain number per cob (741.6) and it was on par with 100 kg FeSO_4 per ha and significantly superior over rest of the treatments. Similarly addition of 100 kg FeSO_4 per ha was on par with 25 kg pyrite per ha and significantly superior over rest of the treatments.

Interaction effects of foliar and soil application of iron were not significant.

4.3.3.2.4 Grain weight per cob (g)

The results of the investigation indicate that residual effect of iron application methods and iron levels had significant influence on grain weight per cob of maize (Table 38).

Pooled data of two years indicate that, grain weight per cob differed significantly due to methods of iron application. Soil plus foliar application of iron registered significantly higher grain weight per cob (176.90 g) over soil application of iron only (139.59 g).

The residual effect of applied iron levels, application of 50 kg pyrite per ha recorded the highest grain weight per cob (176.54 g) and it was on par with 100 kg FeSO_4 per ha (169.74 g) and 25 kg pyrite per ha (160.82 g) and significantly superior over 50 kg FeSO_4 per ha (153.66 g) and control (130.44 g). Application of 100 kg FeSO_4 per ha were

Table 36. Residual effect of iron management practices on cob diameter (cm) of maize

Iron levels	2002-03				2003-04				Pooled			
	Methods of Fe application				Methods of Fe application				Methods of Fe application			
	F ₀	F ₁	Mean	CD	F ₀	F ₁	Mean	CD	F ₀	F ₁	Mean	CD
S ₀ : No iron (control)	5.043	5.110	5.077	5.077	5.045	5.112	5.079	5.079	5.044	5.111	5.078	5.078
S ₁ : 50 kg FeSO ₄ ha ⁻¹	5.175	5.190	5.183	5.183	5.178	5.196	5.187	5.187	5.177	5.193	5.185	5.185
S ₂ : 100 kg FeSO ₄ ha ⁻¹	5.293	5.360	5.327	5.327	5.297	5.368	5.333	5.333	5.295	5.364	5.330	5.330
S ₃ : 25 kg Pyrite ha ⁻¹	5.223	5.248	5.236	5.236	5.228	5.252	5.240	5.240	5.226	5.250	5.238	5.238
S ₄ : 50 kg Pyrite ha ⁻¹	5.410	5.518	5.464	5.464	5.415	5.522	5.469	5.469	5.413	5.520	5.467	5.467
Mean	5.229	5.285			5.233	5.290			5.231	5.288		
For comparing means of	S.Em±	CD (0.05)			S.Em±	CD (0.05)			S.Em±	CD (0.05)		
Methods of Fe application	0.108	NS			0.074	NS			0.096	NS		NS
Iron levels	0.201	NS			0.134	NS			0.177	NS		NS
Interaction	0.284	NS			0.189	NS			0.250	NS		NS

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

Table 37. Residual effect of iron management practices on grain number cob⁻¹ of maize

Iron levels	2002-03			2003-04			Pooled		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	615.6	646.8	631.2	619.3	651.8	635.6	617.5	649.3	633.4
S ₁ : 50 kg FeSO ₄ ha ⁻¹	636.8	698.9	667.9	642.5	696.1	669.3	639.7	697.5	668.6
S ₂ : 100 kg FeSO ₄ ha ⁻¹	680.4	742.2	711.3	687.4	732.3	709.9	683.6	737.3	710.5
S ₃ : 25 kg Pyrite ha ⁻¹	655.4	718.9	687.2	661.7	725.4	693.6	658.6	722.7	690.7
S ₄ : 50 kg Pyrite ha ⁻¹	705.8	770.6	738.2	701.6	788.3	745.0	703.7	779.5	741.6
Mean	658.8	715.5		662.5	718.8		660.7	717.7	
For comparing means of	S.Em±		CD (0.05)	S.Em±		CD (0.05)	S.Em±		CD (0.05)
Methods of Fe application	7.9		35.4	8.5		38.3	7.7		34.7
Iron levels	19.6		57.1	20.1		58.6	12.2		35.7
Interaction	27.7		NS	28.4		NS	17.3		NS

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

Table 38. Residual effect of iron management practices on grain weight cob⁻¹ (g) of maize

Iron levels	2002-03			2003-04			Pooled		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	124.53	139.48	132.01	125.61	132.11	128.86	125.07	135.80	130.44
S ₁ : 50 kg FeSO ₄ ha ⁻¹	137.53	169.13	153.33	138.13	169.83	153.98	137.83	169.48	153.66
S ₂ : 100 kg FeSO ₄ ha ⁻¹	145.00	190.13	167.57	145.76	198.07	171.92	145.38	194.10	169.74
S ₃ : 25 kg Pyrite ha ⁻¹	140.80	177.88	159.34	141.38	183.21	162.30	141.09	180.55	160.82
S ₄ : 50 kg Pyrite ha ⁻¹	150.13	198.30	174.22	147.04	210.86	178.95	148.49	204.58	176.54
Mean	139.60	174.98		139.58	178.82		139.59	176.90	
For comparing means of	S.Em±		CD (0.05)	S.Em±		CD (0.05)	S.Em±		CD (0.05)
Methods of Fe application	1.98		8.90	2.52		11.33	1.92		8.62
Iron levels	5.08		14.84	3.87		11.31	6.02		17.57
Interaction	7.19		NS	5.48		15.99	8.52		NS

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

on par with 25 kg pyrite per ha and 50 kg FeSO₄ per ha and significantly higher over no iron (control).

The interaction effects of iron management practices found to be non-significant.

4.3.3.2.5 Test weight (g)

The results of pooled data of both the years indicate that residual effect of iron application methods and iron levels had significant influence on test weight of maize (Table 39).

Among iron application methods, soil plus foliar application of iron recorded significantly higher test weight (25.86 g) over the treatments receiving soil application of iron only (21.38 g).

With respect to iron levels, application of 50 kg pyrite per ha recorded the highest test weight (26.07 g) and it was on par with 100 kg FeSO₄ per ha (24.88 g) and significantly superior over 25 kg pyrite per ha (23.38 g) and 50 kg FeSO₄ per ha (22.53 g) and the treatment receiving no iron (21.27 g). Application of 100 kg FeSO₄ per ha was on par with 25 kg pyrite per ha and significantly higher over rest of the treatments.

Similar to grain weight per cob, test weight did not indicate any significant difference of interaction effects due to iron management practices.

4.3.3.2.6 Grain yield (q ha⁻¹)

The results from pooled data of both the years indicate that residual effect of iron application methods and iron levels had significant influence on grain yield of maize (Table 40).

Variations in grain yield due to methods of iron application differed significantly. Soil plus foliar application of iron recorded significantly higher grain yield (51.79 q ha⁻¹) over soil application of iron (48.23 q ha⁻¹).

The residual effect of applied iron levels, application of 50 kg pyrite per ha recorded the highest grain yield (54.03 q ha⁻¹) and it was on par with 100 kg FeSO₄ per ha (52.24 q ha⁻¹) and significantly superior over 25 kg pyrite per ha (50.06 q ha⁻¹) and 50 kg

Table 39. Residual effect of iron management practices on test weight (g 100 kernel⁻¹) of maize

Iron levels	2002-03			2003-04			Pooled		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	20.11	22.51	21.31	20.18	22.26	21.22	20.15	22.39	21.27
S ₁ : 50 kg FeSO ₄ ha ⁻¹	20.81	24.11	22.46	20.94	24.24	22.59	20.88	24.18	22.53
S ₂ : 100 kg FeSO ₄ ha ⁻¹	21.93	27.41	24.67	21.99	28.17	25.08	21.96	27.79	24.88
S ₃ : 25 kg Pyrite ha ⁻¹	21.29	25.45	23.37	21.35	25.41	23.38	21.32	25.43	23.38
S ₄ : 50 kg Pyrite ha ⁻¹	22.82	29.35	26.09	22.38	29.71	26.05	22.60	29.53	26.07
Mean	21.39	25.77		21.37	25.96		21.38	25.86	
For comparing means of	S.Em±	CD (0.05)		S.Em±	CD (0.05)		S.Em±	CD (0.05)	
Foliar application	0.35	1.58		0.32	1.45		0.35	1.58	
Iron levels	0.52	1.51		0.64	1.88		0.68	1.99	
Interaction	0.73	NS		0.91	NS		0.96	NS	

(F₀: Soil application of iron, F₁: Soil plus foliar application of iron and NS: Non-significant)

Table 40. Residual effect of iron management practices on grain yield ($q\ ha^{-1}$) of maize

Iron levels	2002-03			2003-04			Pooled		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	44.82	46.92	45.87	44.85	46.97	45.91	44.84	46.95	45.90
S ₁ : 50 kg FeSO ₄ ha ⁻¹	46.58	49.21	47.90	46.64	49.66	48.15	46.61	49.44	48.03
S ₂ : 100 kg FeSO ₄ ha ⁻¹	49.82	54.13	51.98	49.94	55.04	52.49	49.88	54.59	52.24
S ₃ : 25 kg Pyrite ha ⁻¹	47.86	51.69	49.78	47.87	52.78	50.33	47.87	52.24	50.06
S ₄ : 50 kg Pyrite ha ⁻¹	51.89	55.89	53.89	51.96	56.37	54.17	51.93	56.13	54.03
Mean	48.19	51.57		48.25	55.76		48.23	51.87	
For comparing means of	S.Em±		CD (0.05)	S.Em±		CD (0.05)	S.Em±		CD (0.05)
Methods of Fe application	0.62		2.79	0.94		4.23	0.78		2.53
Iron levels	1.60		4.67	1.61		3.32	1.09		3.17
Interaction	2.26		NS	1.92		NS	1.54		NS

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

FeSO₄ per ha (48.03 q ha⁻¹). The lowest grain yield (45.90 q ha⁻¹) obtained in the treatment receiving no iron (control). Application of 100 kg FeSO₄ per ha was on par with 25 kg pyrite per ha significantly superior over rest of the treatments.

Variations in grain yield due to interaction effects of soil plus foliar application of iron and soil iron application were not significant.

4.3.3.2.7 Stover yield

The results from pooled data of both the years indicate that residual effect of methods of iron application and iron levels had marked influence on stover yield of maize (Table 41).

Increased stover yield due to iron application methods were significant. Soil plus foliar application of iron found to be significantly higher (84.94 q ha⁻¹) with respect to stover yield. However, the lowest grain yield observed in the treatment receiving soil application of iron (79.21 q ha⁻¹).

Among soil iron application (residual effect), application of 50 kg pyrite per ha produced the highest stover yield (87.80 q ha⁻¹) and it was on par with 100 kg FeSO₄ per ha (85.25 q ha⁻¹) and 25 kg pyrite per ha (82.19 q ha⁻¹) and significantly superior over 50 kg FeSO₄ per ha (79.06 q ha⁻¹) and no iron treatment (76.10 q ha⁻¹). Application of 100 kg FeSO₄ per ha and 25 kg pyrite per ha were on par with each other. However, application of 100 kg FeSO₄ per ha was significantly higher over rest of the treatments.

The interaction effects found to be not significant as influenced by iron management practices.

4.3.3.2.8 Harvest index

The results of the investigation indicate that, residual effect of methods of iron application and iron levels and their interactions did not differ significantly with regard to harvest index of maize (Table 42).

4.3.4 Quality parameters

The data on direct effect of iron management practices on protein content, oil content, saponification value, acid value and iodine value of groundnut and their residual

Table 41. Residual effect of iron management practices on stover yield ($q\ ha^{-1}$) of maize

Iron levels	2002-03				2003-04				Pooled			
	Methods of Fe application				Methods of Fe application				Methods of Fe application			
	F ₀	F ₁	Mean		F ₀	F ₁	Mean		F ₀	F ₁	Mean	
S ₀ : No iron (control)	74.35	77.67	76.01		74.64	77.70	76.17		74.50	77.69	76.10	
S ₁ : 50 kg FeSO ₄ ha ⁻¹	76.61	80.77	78.69		77.02	81.82	79.42		76.82	81.30	79.06	
S ₂ : 100 kg FeSO ₄ ha ⁻¹	81.43	88.12	84.78		81.76	89.66	85.71		81.60	88.89	85.25	
S ₃ : 25 kg Pyrite ha ⁻¹	78.57	84.62	81.60		78.81	86.74	82.78		78.69	85.68	82.19	
S ₄ : 50 kg Pyrite ha ⁻¹	84.41	90.76	87.59		84.51	91.59	88.05		84.46	91.14	87.80	
Mean	79.07	84.39			79.35	85.49			79.21	84.94		
For comparing means of	S.Em±	CD (0.05)			S.Em±	CD (0.05)			S.Em±	CD (0.05)		
Methods of Fe application	0.88	3.98			1.01	4.55			0.99	4.44		
Iron levels	2.01	5.87			1.52	4.44			2.11	6.16		
Interaction	2.85	NS			2.15	NS			2.98	NS		

(F₀ = Soil application of iron, F₁ = Soil plus foliar application of iron and NS = Non-significant)

Table 42. Residual effect of iron management practices on harvest index of maize

Iron levels	2002-03			2003-04			Pooled		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	0.3761	0.3766	0.3764	0.3753	0.3768	0.3761	0.3757	0.3767	0.3762
S ₁ : 50 kg FeSO ₄ ha ⁻¹	0.3781	0.3786	0.3784	0.3772	0.3777	0.3775	0.3777	0.3782	0.3780
S ₂ : 100 kg FeSO ₄ ha ⁻¹	0.3796	0.3808	0.3802	0.3792	0.3804	0.3798	0.3794	0.3806	0.3800
S ₃ : 25 kg Pyrite ha ⁻¹	0.3785	0.3792	0.3789	0.3779	0.3783	0.3781	0.3782	0.3788	0.3785
S ₄ : 50 kg Pyrite ha ⁻¹	0.3807	0.3811	0.3809	0.3807	0.3812	0.3810	0.3807	0.3812	0.3810
Mean	0.3785	0.3793		0.3781	0.3789		0.3783	0.3791	
For comparing means of	S.Em±	CD (0.05)		S.Em±	CD (0.05)		S.Em±	CD (0.05)	
Methods of Fe application	0.0060	NS		0.0050	NS		0.0060	NS	
Iron levels	0.0160	NS		0.0120	NS		0.0090	NS	
Interaction	0.0230	NS		0.0180	NS		0.0130	NS	

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

effect on protein content and starch content of maize in calcareous Vertisol are presented hereunder.

4.3.4.1 Protein content and oil content of groundnut

Protein content in groundnut kernels differed significantly due to methods of iron application and iron levels (Table 43)

Among methods of iron application, soil plus foliar application of iron recorded higher protein content (29.17 %) and it was significantly superior over soil application of iron (28.11 %).

Applied iron levels had distinct influence on protein content of groundnut. Among iron levels, application of 50 kg pyrite per ha recorded the highest protein content (30.27 %) and it was on par with 100 kg FeSO_4 per ha (29.48 %) and significantly superior over 25 kg pyrite per ha (28.55 %) and 50 kg FeSO_4 per ha (28.19 %). The lowest protein content (26.69 %) was obtained in the treatment receiving no iron (control). Application of 100 kg FeSO_4 per ha was on par with 25 kg pyrite per ha and 50 kg FeSO_4 per ha and significantly higher over no iron (control).

In respect of oil content of groundnut kernels, the variations in oil content were significant due to soil plus foliar application of iron and iron application to soil (Table 43).

Among iron application methods, soil plus foliar application of iron registered significantly higher oil content (46.75 %) over soil application of iron (45.36 %).

The oil content increased significantly with increase of iron application levels. Application of 50 kg pyrite per ha noticed the highest oil content (47.96 %) and it was on par with 100 kg FeSO_4 per ha (46.79 %), 25 kg pyrite per ha (45.75 %) and significantly superior over 50 kg FeSO_4 per ha (45.07 %) and no iron treatment (44.60 %). Application of 100 kg FeSO_4 per ha was on par with 25 kg pyrite per ha, 50 kg pyrite per ha and significantly superior over control treatment.

The interaction effects due to iron management practices did not differ significantly.

Table 43. Direct effect of iron management practices on protein and oil content of groundnut kernels

Iron levels	Protein (%)			Oil (%)		
	Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	26.18	27.20	26.69	44.07	45.13	44.60
S ₁ : 50 kg FeSO ₄ ha ⁻¹	27.80	28.57	28.19	44.69	45.45	45.07
S ₂ : 100 kg FeSO ₄ ha ⁻¹	28.78	30.17	29.48	45.86	47.71	46.79
S ₃ : 25 kg Pyrite ha ⁻¹	28.13	28.96	28.55	45.34	46.15	45.75
S ₄ : 50 kg Pyrite ha ⁻¹	29.65	30.89	30.27	46.58	49.33	47.96
Mean	28.11	29.17		45.36	46.75	
For comparing means of	S.Em±		CD (0.05)	S.Em±		CD (0.05)
Methods of Fe application	0.21		0.94	0.27		1.22
Iron levels	0.50		1.47	0.56		2.30
Interaction	0.71		NS	0.79		NS

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

4.3.4.1.2 Saponification value, acid value and iodine number

The results of the investigation indicate that saponification value, acid value and iodine number of groundnut kernels did not differ significantly due to iron management practices (Table 44).

4.3.4.2 Quality parameters of maize

4.3.4.2.1 Protein content and Starch content (%)

Regarding the protein and starch content of maize grains, the results of the investigation recorded that methods of iron application and iron levels significantly influenced the protein content of maize grains. Whereas, starch content did not exhibit any significant differences due to iron management practices (Table 45).

Soil plus foliar application of iron had profound influence on protein content of maize. Soil plus foliar application of iron registered significantly higher protein content (13.04 %) over soil application of iron (12.22 %).

Among iron levels, application of 50 kg pyrite per ha recorded the highest protein content (14.00 %) and it was on par with 100 kg FeSO_4 per ha (13.49 %) and significantly superior over 25 kg pyrite per ha (12.34 %), 50 kg FeSO_4 per ha (12.12 %) and no iron (control) (11.20 %). Addition of 100 kg FeSO_4 per ha was on par with 25 kg pyrite per ha and 50 kg FeSO_4 per ha and significantly higher over control treatment.

The interaction effects of iron management practices on protein content of maize grain were not significant.

4.3.5 Biochemical parameters

The data on the effect of iron management practices on chlorophyll content and organic acids content of groundnut and maize at 30, 60 and 80 DAS in calcareous Vertisol are presented hereunder.

4.3.5.1 Biochemical parameters of groundnut

4.3.5.1.1 Total chlorophyll content (mg g^{-1} f. wt.)

The data pertaining to the direct effect of iron management practices on the chlorophyll content of groundnut at 30, 60 and 80 DAS are presented in Table 46.

Table 44. Direct effect of iron management practices on saponification, acid value and iodine number of groundnut kernels

Iron levels	Saponification (mg g ⁻¹ oil)			Acid value (mg KOH g ⁻¹ oil)			Iodine No. (g iodine 100g ⁻¹ oil)		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	186.25	184.75	185.50	2.51	2.49	2.50	77.23	77.78	77.51
S ₁ : 50 kg FeSO ₄ ha ⁻¹	185.00	183.00	184.00	2.45	2.44	2.45	80.40	80.70	80.55
S ₂ : 100 kg FeSO ₄ ha ⁻¹	181.00	178.75	179.88	2.78	2.35	2.57	85.41	87.68	86.55
S ₃ : 25 kg Pyrite ha ⁻¹	182.75	179.25	181.00	2.46	2.41	2.44	83.56	84.65	84.11
S ₄ : 50 kg Pyrite ha ⁻¹	177.00	174.25	175.63	2.36	2.34	2.35	88.63	89.78	89.21
Mean	182.40	180.00		2.43	2.41		83.05	84.12	
For comparing means of	S.E.m±	CD (0.05)		S.E.m±	CD (0.05)		S.E.m±	CD (0.05)	
Methods of Fe application	2.12	NS		0.06	NS		2.83	NS	
Iron levels	3.24	NS		0.08	NS		3.39	NS	
Interaction	4.49	NS		0.11	NS		4.80	NS	

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

Table 45. Residual effect of iron management practices on protein and starch content of maize grains

Iron levels	Protein (%)			Starch content (%)		
	Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	10.85	11.54	11.20	77.22	76.90	77.06
S ₁ : 50 kg FeSO ₄ ha ⁻¹	11.67	12.56	12.12	76.27	75.83	76.05
S ₂ : 100 kg FeSO ₄ ha ⁻¹	13.14	13.84	13.49	74.18	73.67	73.93
S ₃ : 25 kg Pyrite ha ⁻¹	11.88	12.79	12.34	75.78	75.60	75.69
S ₄ : 50 kg Pyrite ha ⁻¹	13.54	14.46	14.00	73.85	73.31	73.58
Mean	12.22	13.04		75.46	75.06	
For comparing means of	S.Em±		CD (0.05)	S.Em±		CD (0.05)
Methods of Fe application	0.16		0.74	2.15		NS
Iron levels	0.48		1.40	2.97		NS
Interaction	0.68		NS	4.19		NS

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

Table 46. Direct effect of iron management practices on total chlorophyll (mg g^{-1} f. wt.) at different growth stages of groundnut

Iron levels	30 DAS			60 DAS			80 DAS		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	0.586	0.614	0.600	0.545	0.670	0.608	0.421	0.520	0.471
S ₁ : 50 kg FeSO ₄ ha ⁻¹	0.673	0.682	0.678	0.754	0.773	0.764	0.603	0.608	0.606
S ₂ : 100 kg FeSO ₄ ha ⁻¹	0.734	0.754	0.744	0.890	0.898	0.894	0.658	0.665	0.662
S ₃ : 25 kg Pyrite ha ⁻¹	0.680	0.696	0.688	0.764	0.778	0.771	0.614	0.632	0.623
S ₄ : 50 kg Pyrite ha ⁻¹	0.749	0.765	0.757	0.907	0.925	0.916	0.673	0.694	0.684
Mean	0.684	0.702		0.772	0.809		0.594	0.624	
For comparing means of	S.Em \pm	CD (0.05)		S.Em \pm	CD (0.05)		S.Em \pm	CD (0.05)	
Methods of Fe application	0.023	NS		0.006	0.026		0.006	0.028	
Iron levels	0.039	NS		0.004	0.012		0.008	0.024	
Interaction	0.055	NS		0.006	0.017		0.012	0.034	

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

The results of the investigation indicate that methods of iron application and iron levels and their interactions significantly influenced the chlorophyll content of groundnut at 60 and 80 DAS. However, no significant differences found at 30 DAS.

Iron application methods distinctly influenced the chlorophyll content of groundnut. At 60 and 80 DAS, soil plus foliar application of iron registered significantly higher chlorophyll content of 0.809 and 0.624 mg g⁻¹ f. wt., respectively over soil application of iron (0.772 and 0.594 mg g⁻¹ f. wt., respectively).

At 60 DAS, among iron levels, application of 50 kg pyrite per ha recorded the highest chlorophyll content (0.916 mg g⁻¹ f. wt.) and it was significantly superior over 100 kg FeSO₄ per ha (0.894 mg g⁻¹ f. wt.), 25 kg pyrite per ha (0.771 mg g⁻¹ f. wt.) and 50 kg FeSO₄ per ha (0.764 mg g⁻¹ f. wt.). The lowest chlorophyll content (0.608 mg g⁻¹ f. wt.) yielded in the treatment receiving no iron (control). Whereas, at 80 DAS, application of 50 kg pyrite recorded significantly higher chlorophyll content (0.684 mg g⁻¹ f. wt.) which was on par with 100 kg FeSO₄ per ha and significantly superior over 25 kg pyrite and 50 kg FeSO₄ per ha and control (0.471 mg g⁻¹ f. wt.).

Interaction effects due to iron management practices found to be significant at 60 and 80 DAS.

4.3.5.1.2 Citric acid and Malic acid content (mg g⁻¹ dry wt.)

The data on the direct effect of iron management practices on citric and malic acids content of groundnut at 60 DAS in calcareous Vertisol are presented in Table 47.

The results of the investigation indicate that methods of iron application and iron levels had significant influence on citric acid and malic acid content of groundnut at 60 DAS.

Iron application methods significantly influenced the organic acid content of groundnut. Soil plus foliar application of iron registered significantly lower citric and malic acid (16.20 and 17.33 mg g⁻¹ dry wt.) over soil application of iron (17.15 and 18.70 mg g⁻¹ dry wt., respectively).

Among iron levels, application of 50 kg pyrite per ha recorded the lowest citric acid and malic acid content (14.32 and 15.66 mg g⁻¹ dry wt.) and it was on par with 100 kg

Table 47. Direct effect of iron management practices on organic acid content (mg g⁻¹ dry wt.) at 60 days after sowing of groundnut

Iron levels	Citric acid (mg g ⁻¹ dry wt.)			Malic acid (mg g ⁻¹ dry wt.)		
	Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	20.25	19.45	19.85	21.95	20.10	21.03
S ₁ : 50 kg FeSO ₄ ha ⁻¹	18.63	17.95	18.29	19.90	18.40	19.15
S ₂ : 100 kg FeSO ₄ ha ⁻¹	15.48	14.65	15.07	17.23	15.93	16.58
S ₃ : 25 kg Pyrite ha ⁻¹	16.65	15.08	15.87	18.28	17.03	17.66
S ₄ : 50 kg Pyrite ha ⁻¹	14.75	13.88	14.32	16.13	15.18	15.66
Mean	17.15	16.20		18.70	17.33	
For comparing means of	S.Em±		CD (0.05)	S.Em±		CD (0.05)
Methods of Fe application	0.20		0.90	0.25		1.13
Iron levels	0.46		1.35	0.44		1.29
Interaction	0.65		NS	0.63		NS

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

FeSO₄ per ha and significantly lower than 25 kg pyrite per ha and 50 kg FeSO₄ per ha. The highest citric and malic acid content (19.85 and 21.03 mg g⁻¹ dry wt) registered in the treatment receiving no iron (control). Application of 100 kg FeSO₄ per ha was on par with 25 kg pyrite per ha and significantly lower over 50 kg FeSO₄ per ha and control treatment. The interaction effects found to be non-significant.

4.3.5.2 Biochemical parameters of maize

4.3.5.2 .1 Total chlorophyll content

The results of the investigation indicate that methods of iron application and iron levels significantly influenced the chlorophyll content of maize at 60 and 80 DAS. However, no significant differences found at 30 DAS (Table 48).

Methods of iron application markedly influenced the chlorophyll content of maize. At 60 and 80 DAS, soil plus foliar application of iron registered significantly higher chlorophyll content of 1.936 mg g⁻¹ f. wt. and 1.735 mg g⁻¹ f. wt., respectively over soil application of iron treatments (1.699 and 1.472 mg g⁻¹ f. wt., respectively).

Among iron levels, application of 50 kg pyrite per ha recorded the highest chlorophyll content (2.006 mg g⁻¹ f. wt.) and it was on par with 100 kg FeSO₄ per ha (1.937 mg g⁻¹ f. wt.) and 25 kg pyrite per ha (1.887 mg g⁻¹ f. wt.) and significantly superior over 50 kg FeSO₄ per ha (1.727 mg g⁻¹ f. wt.) and control treatment (1.533 mg g⁻¹ f. wt.) at 60 DAS. Whereas, at 80 DAS, application of 50 kg pyrite noticed significantly higher chlorophyll content (1.732 mg g⁻¹ f. wt.) which was on par with 100 kg FeSO₄ per ha and significantly superior over 25 kg pyrite and 50 kg FeSO₄ per ha and control (1.424 mg g⁻¹ f. wt.).

The interaction effects were non-significant at different stages of maize crop as influenced by iron management practices.

4.3.5.2.2 Citric acid and Malic acid content (mg g⁻¹ dry wt.)

The results of the investigation indicate that methods of iron application and iron levels had significant influence on citric acid and malic acid content of maize at 60 DAS (Table 49).

Table 48. Residual effect of iron management practices on total chlorophyll (mg g^{-1} f. wt.) at different growth stages of maize

Iron levels	30 DAS			60 DAS			80 DAS		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	1.452	1.514	1.483	1.409	1.657	1.533	1.243	1.604	1.424
S ₁ : 50 kg FeSO ₄ ha ⁻¹	1.552	1.583	1.568	1.693	1.760	1.727	1.477	1.704	1.591
S ₂ : 100 kg FeSO ₄ ha ⁻¹	1.607	1.631	1.619	1.785	2.089	1.937	1.535	1.788	1.662
S ₃ : 25 kg Pyrite ha ⁻¹	1.569	1.594	1.582	1.752	2.021	1.887	1.497	1.724	1.611
S ₄ : 50 kg Pyrite ha ⁻¹	1.622	1.654	1.638	1.857	2.155	2.006	1.610	1.853	1.732
Mean	1.560	1.595		1.699	1.936		1.472	1.735	
For comparing means of	S.Em \pm	CD (0.05)		S.Em \pm	CD (0.05)		S.Em \pm	CD (0.05)	
Methods of Fe application	0.021	NS		0.052	0.233		0.032	0.146	
Iron levels	0.078	NS		0.080	0.236		0.039	0.114	
Interaction	0.110	NS		0.113	NS		0.055	NS	

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

Table 49. Residual effect of iron management practices on organic acid content (mg g⁻¹ dry wt.) at 60 days after sowing of maize

Iron levels	Citric acid (mg g ⁻¹ dry wt.)			Malic acid (mg g ⁻¹ dry wt.)		
	Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	26.32	24.87	25.60	27.22	24.35	25.79
S ₁ : 50 kg FeSO ₄ ha ⁻¹	24.88	22.48	23.68	25.78	24.12	24.95
S ₂ : 100 kg FeSO ₄ ha ⁻¹	22.96	20.77	21.87	23.56	21.62	22.59
S ₃ : 25 kg Pyrite ha ⁻¹	23.91	21.56	22.74	24.37	22.23	23.30
S ₄ : 50 kg Pyrite ha ⁻¹	21.82	19.44	20.63	22.72	20.11	21.42
Mean	23.98	21.82		24.73	22.49	
For comparing means of	S.E.m±		CD (0.05)	S.E.m±		CD (0.05)
Methods of Fe application	0.29		1.30	0.26		1.19
Iron levels	0.61		1.79	0.76		2.21
Interaction	0.87		NS	1.07		NS

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

Methods of iron application significantly influenced the organic acid content of maize. Soil plus foliar application of iron registered significantly lower citric and malic acid (21.82 and 22.49 mg g⁻¹ dry wt.) over soil application of iron (23.98 and 24.73 mg g⁻¹ dry wt.), respectively.

Among iron levels, application of 50 kg pyrite per ha recorded the lowest citric acid content (20.63 mg g⁻¹ dry wt.) and it was on par with 100 kg FeSO₄ per ha and significantly lower than 25 kg pyrite per ha and 50 kg FeSO₄ per ha. The highest citric acid content (25.60 mg g⁻¹ dry wt) noticed in the treatment receiving no iron (control). Application of 100 kg FeSO₄ per ha was on par with 25 kg pyrite per ha and significantly lower over 50 kg FeSO₄ per ha and control treatment

Regarding to malic acid content of maize, application of 50 kg pyrite per ha recorded the lowest malic acid content (21.42 mg g⁻¹ dry wt.) and it was on par with 100 kg FeSO₄ per ha and 25 kg pyrite per ha and significantly lower than 50 kg FeSO₄ per ha. The highest malic acid content (25.79 mg g⁻¹ dry wt) noticed in the treatment receiving no iron (control).

The interaction effects found to be non-significant as influenced by iron management practices.

4.3.6 Nutrient content and uptake by plants

4.3.6.1 Major nutrient content of groundnut

The data on the direct effect of iron management practices on the content of N, P and K by groundnut at harvest in calcareous Vertisol are presented in Table 50.

A perusal of the data revealed that methods of iron application and iron levels and their interaction was proved non-significant with respect to these nutrient content (N, P and K) at harvest of groundnut.

4.3.6.2 Major nutrient uptake of groundnut

The data pertaining to the direct effect of iron management practices on the uptake of N, P and K by groundnut at harvest in calcareous Vertisol are presented in Table 50.

4.3.6.2.1 Nitrogen uptake (kg ha^{-1})

Variations in nitrogen uptake by groundnut differed significantly due to methods of iron application and iron levels (Table 50).

Among iron application methods, soil plus foliar application of iron recorded higher nitrogen uptake ($139.32 \text{ kg ha}^{-1}$) and it was significantly superior over soil application of iron ($135.87 \text{ kg ha}^{-1}$).

Applied iron levels had distinct influence on nitrogen uptake of groundnut. Application of 50 kg pyrite per ha recorded the highest nitrogen uptake ($156.07 \text{ kg ha}^{-1}$) and it was markedly higher over 100 kg FeSO_4 per ha ($143.87 \text{ kg ha}^{-1}$), 25 kg pyrite per ha ($135.39 \text{ kg ha}^{-1}$) and 50 kg FeSO_4 per ha ($130.45 \text{ kg ha}^{-1}$). The lowest nitrogen uptake ($122.21 \text{ kg ha}^{-1}$) was obtained in the treatment receiving no iron. Application of 100 kg FeSO_4 per ha was significantly higher over 25 kg pyrite per ha, 50 kg FeSO_4 per ha and no iron (control).

The interaction effects found to be non-significant at harvest of groundnut as influenced by iron management practices.

4.3.6.2.2 Phosphorus uptake (kg ha^{-1})

The results of the investigation indicate that methods of iron application and iron levels and their interaction had non-significant influence on phosphorus uptake by groundnut at harvest.

4.3.6.2.3 Potassium uptake (kg ha^{-1})

Potassium uptake due to methods of iron application and iron levels varied significantly (Table 50).

Among iron applications methods, the effect of soil plus foliar application of iron recorded significantly higher potassium uptake (93.77 kg ha^{-1}) over soil application of iron (91.45 kg ha^{-1}).

Among iron levels, application of 50 kg pyrite per ha recorded the highest potassium uptake ($105.57 \text{ kg ha}^{-1}$) and it was significantly superior over 100 kg FeSO_4 per

Table 50. Direct effect of iron management practices on major nutrients content (%) and uptake (kg ha⁻¹) by groundnut at harvest

Iron levels	Nitrogen			Phosphorus			Potassium		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	(2.340)	(2.345)	(2.343)	(0.470)	(0.470)	(0.470)	(1.586)	(1.586)	(1.586)
S ₁ : 50 kg FeSO ₄ ha ⁻¹	121.020	123.390	122.210	24.31	24.77	24.54	82.030	83.450	82.740
S ₂ : 100 kg FeSO ₄ ha ⁻¹	(2.421)	(2.422)	(2.422)	(0.474)	(0.475)	(0.475)	(1.617)	(1.620)	(1.619)
	128.990	131.900	130.45	25.25	25.87	25.56	86.150	88.220	87.190
S ₃ : 25 kg pyrite ha ⁻¹	(2.486)	(2.486)	(2.486)	(0.478)	(0.479)	(0.479)	(1.675)	(1.676)	(1.646)
	143.090	144.640	143.870	27.51	27.87	27.69	96.410	97.510	96.960
S ₄ : 50 kg pyrite ha ⁻¹	(2.437)	(2.440)	(2.439)	(0.475)	(0.476)	(0.476)	(1.631)	(1.632)	(1.632)
	133.920	136.860	135.390	26.27	26.70	26.49	89.670	91.540	90.610
Mean	(2.511)	(2.514)	(2.513)	(0.481)	(0.481)	(0.481)	(1.698)	(1.701)	(1.700)
	152.340	159.790	156.070	29.18	30.57	29.88	103.020	108.120	105.570
For comparing means of	(2.439)	(2.441)		(0.476)	(0.476)		(1.641)	(1.643)	
Methods of Fe application	135.870	139.320		26.500	27.150		91.450	93.770	
	S.E.m±	CD (0.05)		S.E.m±	CD (0.05)		S.E.m±	CD (0.05)	
	(0.103)	(NS)		(0.006)	(NS)		(0.058)	(NS)	
	0.580	2.590		0.630	NS		0.490	2.180	
Iron levels	(0.174)	(NS)		(0.009)	(NS)		(0.131)	(NS)	
	1.940	5.650		1.380	NS		1.840	5.360	
Interaction	(0.246)	(NS)		(0.013)	(NS)		(0.185)	(NS)	
	2.740	NS		1.940	NS		2.600	NS	

(F₀: Soil application of iron, F₁: Soil plus foliar application of iron and values in the parentheses indicate macronutrients content)

ha (96.96 kg ha⁻¹), 25 kg pyrite per ha (90.61 kg ha⁻¹) and 50 kg FeSO₄ per ha (87.19 kg ha⁻¹). The lowest potassium uptake (82.74 kg ha⁻¹) was obtained in the treatment receiving no iron (control). Application of 100 kg FeSO₄ per ha was significantly superior over 25 kg pyrite per ha and 50 kg FeSO₄ per ha and control treatment.

The interaction effects found to be non-significant at harvest stage of groundnut as influenced by iron management practices.

4.3.6.3 Major nutrient content of maize

The data on the residual effect of iron management practices on the content of N, P and K of maize at harvest in calcareous Vertisol at harvest are presented hereunder.

A perusal of the data in Table 50 revealed that methods of iron application and iron levels and their interaction were proved non-significant with respect to these nutrient content (N, P and K) of maize at harvest.

4.3.6.4.1 Major nutrient uptake by maize

4.3.6.4.2 Nitrogen uptake (kg ha⁻¹)

Changes in nitrogen uptake due to residual effect of iron application methods differed significantly whereas iron levels had non-significant influence on nitrogen uptake by maize at harvest (Table 51).

Nitrogen uptake increased with increase in levels of iron application. Among iron levels, application of 50 kg pyrite per ha recorded the highest nitrogen uptake (186.7 kg ha⁻¹) and it was on par with 100 kg FeSO₄ per ha (181.8 kg ha⁻¹) and 25 kg pyrite per ha (178.7 kg ha⁻¹) and significantly superior over 50 kg FeSO₄ per ha (164.5 kg ha⁻¹). The lowest nitrogen uptake (154.2 kg ha⁻¹) obtained in the treatment receiving no iron (control). Application of 100 kg FeSO₄ per ha was on par with 25 kg pyrite per ha and significantly superior over 50 kg FeSO₄ per ha and control treatment.

The interaction effects were non-significant as influenced by iron management practices.

4.3.6.4.3. Phosphorus uptake (kg ha^{-1})

The results of the investigation indicate that residual effect of methods of iron application and iron levels and their interactions had non-significant influence on phosphorus uptake by maize at harvest (Table 51).

4.3.6.4.4 Potassium uptake (kg ha^{-1})

Variations in potassium uptake due to residual effect of methods of iron application and iron levels had non-significant influence on potassium uptake by maize at harvest (Table 51).

4.3.6.5 Micronutrient content of groundnut

4.3.6.5.1 Ferrous iron content (ppm)

The data on direct effect of iron management practices on ferrous iron content of groundnut at 30, 60 and 80 DAS in calcareous Vertisol are presented in Table 52.

The results of the investigation indicate that methods of iron application and iron levels had significant influence on the ferrous iron content of groundnut at 30, 60 and 80 DAS.

Methods of iron application significantly influenced the ferrous iron content of maize. At 60 and 80 DAS, soil plus foliar application of iron registered significantly higher ferrous iron content (71.0 and 38.4 ppm) over soil application of iron (46.0 and 35.8 ppm), respectively.

At 60 DAS, iron levels, application of 50 kg pyrite per ha recorded the highest ferrous iron content (65.2 ppm) and it was on par with 100 kg FeSO_4 per ha (62.9 ppm) and significantly superior over 25 kg pyrite per ha (58.2 ppm) and 50 kg FeSO_4 per ha (55.7 ppm). The lowest ferrous iron content (45.6 ppm) was obtained in the treatment receiving no iron (control).

At 80 DAS also, highest ferrous iron content observed with application of 50 kg pyrite per ha (40.9 ppm) and it was on par with 100 kg FeSO_4 per ha and significantly superior over 25 kg pyrite per ha and 50 kg FeSO_4 per ha (37.7 ppm) and no iron treatment

Table 51. Residual effect of iron management practices on major nutrients content (%) and uptake (kg ha^{-1}) by maize at harvest

Iron levels	Nitrogen						Phosphorus						Potassium					
	Methods of Fe application						Methods of Fe application						Methods of Fe application					
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean			
S ₀ : No iron (control)	(1.010)	(1.011)	(1.011)	(0.204)	(0.205)	(0.205)	(0.204)	(0.205)	(0.205)	(0.980)	(0.981)	(0.981)	(0.980)	(0.981)	(0.981)			
S ₁ : 50 kg FeSO ₄ ha ⁻¹	153.100	155.200	154.200	30.900	31.500	31.200	30.900	31.500	31.200	148.500	150.600	149.600	148.500	150.600	149.600			
S ₂ : 100 kg FeSO ₄ ha ⁻¹	(1.061)	(1.063)	(1.062)	(0.207)	(0.208)	(0.208)	(0.207)	(0.208)	(0.208)	(0.986)	(0.986)	(0.986)	(0.986)	(0.986)	(0.986)			
S ₃ : 25 kg pyrite ha ⁻¹	163.100	165.800	164.500	31.800	32.400	32.100	31.800	32.400	32.100	151.500	153.800	152.700	151.500	153.800	152.700			
S ₄ : 50 kg pyrite ha ⁻¹	(1.131)	(1.132)	(1.132)	(0.211)	(0.211)	(0.211)	(0.211)	(0.211)	(0.211)	(0.991)	(0.992)	(0.992)	(0.991)	(0.992)	(0.992)			
Mean	179.900	183.600	181.800	32.900	34.200	33.600	32.900	34.200	33.600	154.700	160.900	157.800	154.700	160.900	157.800			
	(1.080)	(1.081)	(1.081)	(0.209)	(0.209)	(0.209)	(0.209)	(0.209)	(0.209)	(0.989)	(0.990)	(0.990)	(0.989)	(0.990)	(0.990)			
	176.500	180.900	178.700	32.400	33.600	33.000	32.400	33.600	33.000	153.100	156.600	154.900	153.100	156.600	154.900			
	(1.162)	(1.162)	(1.162)	(0.214)	(0.215)	(0.215)	(0.214)	(0.215)	(0.215)	(0.994)	(0.994)	(0.994)	(0.994)	(0.994)	(0.994)			
	182.000	191.300	186.700	33.500	35.400	34.500	33.500	35.400	34.500	155.700	163.600	159.700	155.700	163.600	159.700			
For comparing means of	(1.089)	(1.090)		(0.209)	(0.210)		(0.209)	(0.210)		(0.988)	(0.989)		(0.988)	(0.989)				
Methods of Fe application	170.900	175.400		32.300	33.400		32.300	33.400		152.700	157.100		152.700	157.100				
	S.Em±	CD (0.05)		S.Em±	CD (0.05)		S.Em±	CD (0.05)		S.Em±	CD (0.05)		S.Em±	CD (0.05)				
Iron levels	(0.012)	(NS)	(NS)	(0.011)	(NS)	(NS)	(0.011)	(NS)	(NS)	(0.011)	(NS)	(NS)	(0.011)	(NS)	(NS)			
Interaction	2.100	NS	NS	0.530	NS	NS	0.530	NS	NS	2.160	NS	NS	2.160	NS	NS			
	(0.039)	(NS)	(NS)	(0.013)	(NS)	(NS)	(0.013)	(NS)	(NS)	(0.030)	(NS)	(NS)	(0.030)	(NS)	(NS)			
	3.320	9.640	9.640	0.970	NS	NS	0.970	NS	NS	3.310	NS	NS	3.310	NS	NS			
	(0.056)	(NS)	(NS)	(0.018)	(NS)	(NS)	(0.018)	(NS)	(NS)	(0.043)	(NS)	(NS)	(0.043)	(NS)	(NS)			
	4.750	NS	NS	1.350	NS	NS	1.350	NS	NS	4.720	NS	NS	4.720	NS	NS			

(F₀: Soil application of iron, F₁: Soil plus foliar application of iron and values in the parentheses indicate macronutrients content)

Table 52. Direct effect of iron management practices on ferrous iron content (ppm) at different growth stages of groundnut

Iron levels	30 DAS			60 DAS			80 DAS		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	41.7	52.7	47.2	33.8	57.3	45.6	28.3	29.3	28.8
S ₁ : 50 kg FeSO ₄ ha ⁻¹	63.3	56.2	59.8	41.9	69.5	55.7	36.5	38.9	37.7
S ₂ : 100 kg FeSO ₄ ha ⁻¹	67.0	69.9	68.5	49.4	76.4	62.9	38.3	41.3	39.8
S ₃ : 25 kg Pyrite ha ⁻¹	65.6	66.1	65.9	44.1	72.2	58.2	37.2	39.6	38.4
S ₄ : 50 kg Pyrite ha ⁻¹	69.4	71.8	70.6	50.8	79.5	65.2	38.9	42.9	40.9
Mean	61.4	65.1		46.0	71.0		35.8	38.4	
For comparing means of	S.Em±	CD (0.05)		S.Em±	CD (0.05)		S.Em±	CD (0.05)	
Methods of Fe application	0.8	3.7		0.7	3.0		0.5	2.3	
Iron levels	0.9	2.6		1.2	3.5		0.8	2.2	
Interaction	1.3	3.6		1.7	NS		1.1	NS	

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

(28.8 ppm). Application of 100 kg FeSO₄ per ha was on par with 25 kg pyrite per ha and 50 kg FeSO₄ per ha and significantly superior over control treatment.

The interaction effects were found to be significant only at 30 DAS of groundnut.

4.3.6.5.2 Total iron content (ppm)

The data pertaining to the direct effect of iron management practices on total iron content of groundnut at 30, 60 DAS and harvest in calcareous Vertisol are presented in Table 53.

The results of the investigation indicate that methods of iron application and iron levels had significant influence on total iron content at different growth stages of groundnut.

Methods of iron applications had profound influence on total iron content of groundnut. At 60 DAS and at harvest, soil plus foliar application of iron registered the higher total iron content (584.2 and 471.1 ppm) over soil application of iron (502.9 and 430.0 ppm), respectively.

At 60 DAS, among iron levels, application of 50 kg pyrite per ha recorded the highest total iron content (573.9 ppm) and it was on par with 100 kg FeSO₄ per ha (564.2 ppm) and 25 kg pyrite per ha (550.0 ppm) and significantly superior over 50 kg FeSO₄ per ha (537.0 ppm). The lowest total iron content (492.8 ppm) was obtained in the treatment receiving no iron (control). Application of 100 kg FeSO₄ per ha was on par with 25 kg pyrite per ha and significantly higher over rest of the treatments.

The interaction effects found to be significant only at 60 DAS of groundnut.

4.3.6.5.3 Iron uptake (g ha⁻¹)

The data pertaining to the direct effect of iron management practices on iron uptake of groundnut at 30 DAS, 60 DAS and at harvest in calcareous Vertisol are presented in Table 53.

The results of the investigation indicate that methods of iron application and iron levels had significant influence on total iron uptake by groundnut at 30 DAS, 60 DAS and at harvest.

Table 53. Direct effect of iron management practices on total iron content (ppm) and uptake (g ha^{-1}) by groundnut at different growth stages

Iron levels	30 DAS				60 DAS				At harvest			
	Methods of Fe application				Methods of Fe application				Methods of Fe application			
	F ₀	F ₁	Mean	CD	F ₀	F ₁	Mean	CD	F ₀	F ₁	Mean	CD
S ₀ : No iron (control)	(478.5)	(518.0)	(498.3)	(0.05)	(426.0)	(559.5)	(492.8)	(0.05)	(318.5)	(412.3)	(365.4)	(0.05)
S ₁ : 50 kg FeSO ₄ ha ⁻¹	312.0	341.3	326.7	8.6	668.4	918.0	793.2	23.7	1647.3	2169.4	1908.4	113.5
S ₂ : 100 kg FeSO ₄ ha ⁻¹	(531.3)	(546.3)	(538.8)	(23.7)	(504.5)	(569.5)	(537.0)	(8.1)	(433.0)	(458.3)	(445.7)	(25.9)
	373.4	388.3	380.9	15.5	800.5	983.1	891.8	41.1	2307.0	2495.8	2401.4	206.4
S ₃ : 25 kg pyrite ha ⁻¹	(559.0)	(569.3)	(564.2)	(NS)	(528.0)	(600.3)	(564.2)	(NS)	(467.0)	(495.5)	(481.3)	(NS)
	407.8	416.4	412.1	7.5	951.1	1143.2	1047.2	8.2	2688.1	2883.0	2785.6	100.0
S ₄ : 50 kg pyrite ha ⁻¹	(543.0)	(556.5)	(549.8)	(NS)	(517.5)	(582.5)	(550.0)	(NS)	(448.3)	(475.5)	(461.9)	(NS)
	387.7	402.0	394.9	8.2	854.8	1056.0	955.4	8.2	2463.5	2667.1	2565.3	100.0
Mean	(577.3)	(584.5)	(580.9)	(NS)	(538.5)	(609.3)	(573.9)	(NS)	(482.8)	(513.8)	(498.3)	(NS)
	432.0	414.5	423.3	8.2	999.7	1260.2	1130.0	8.2	2929.1	3265.7	3097.4	100.0
For comparing means of	(537.8)	(554.9)	(546.3)	(NS)	(502.9)	(584.2)	(543.5)	(NS)	(430.0)	(471.1)	(450.5)	(NS)
	382.6	392.5	387.5	7.5	854.9	1072.1	963.5	7.5	2407.0	2696.2	2551.6	100.0
Methods of Fe application	(3.2)	(3.2)	(3.2)	(0.05)	(6.2)	(6.2)	(6.2)	(0.05)	(3.9)	(3.9)	(3.9)	(0.05)
	1.9	1.9	1.9	8.6	17.6	17.6	17.6	8.6	25.2	25.2	25.2	113.5
Iron levels	(8.1)	(8.1)	(8.1)	(23.7)	(8.4)	(8.4)	(8.4)	(24.4)	(8.9)	(8.9)	(8.9)	(25.9)
	5.3	5.3	5.3	15.5	41.1	41.1	41.1	120.1	70.7	70.7	70.7	206.4
Interaction	(11.5)	(11.5)	(11.5)	(NS)	(11.8)	(11.8)	(11.8)	(34.6)	(12.6)	(12.6)	(12.6)	(NS)
	7.5	7.5	7.5	NS	58.2	58.2	58.2	NS	100.0	100.0	100.0	NS

(F₀: Soil application of iron, F₁: Soil plus foliar application of iron and values in the parentheses indicate total iron content)

At 60 DAS, soil plus foliar application of iron registered significantly higher total iron uptake (1072.1 g ha^{-1}) over soil application of iron (854.9 g ha^{-1}).

Among iron levels, application of 50 kg pyrite per ha recorded the highest iron uptake (1130.0 g ha^{-1}) and it was on par with 100 kg FeSO_4 per ha (1047.2 g ha^{-1}) and significantly superior over 25 kg pyrite per ha (955.4 g ha^{-1}) and 50 kg FeSO_4 per ha (891.8 g ha^{-1}). The lowest iron uptake (793.2 g ha^{-1}) was registered in the treatment receiving no iron (control). Application of 100 kg FeSO_4 per ha was on par with 25 kg pyrite per ha and registered significantly higher iron uptake over 50 kg FeSO_4 per ha and no iron (control).

Similar trend of iron uptake was also noticed 30 DAS and at harvest of groundnut.

The interaction effects found to be non-significant at all growth stages of groundnut as influenced by iron management practices.

4.3.6.5.4 Zn, Mn and Cu content (ppm)

The data pertaining to the direct effect of iron management practices on the content of Zn, Mn and Cu of groundnut at harvest in calcareous Vertisol are presented in Table 54.

A perusal of the data revealed that methods of iron application and iron levels and their interactions was proved non-significant with respect to these nutrient content at harvest of groundnut.

4.3.6.5.5 Zinc uptake (g ha^{-1})

The results of the investigation indicate that methods of iron application, iron levels and their interactions had non-significant influence on zinc uptake by groundnut at harvest in calcareous Vertisol are presented in Table 54.

4.3.6.5.6 Manganese uptake (g ha^{-1})

Manganese uptake by groundnut varied significantly due to methods of iron application and iron levels (Table 54).

Soil plus foliar application of iron recorded higher manganese uptake (306.3 g ha^{-1}) and it was significantly superior over soil application of iron (298.7 g ha^{-1}).

Among iron levels, application of 50 kg pyrite per ha recorded the highest manganese uptake (334.2 g ha^{-1}) and it was significantly superior over 100 kg FeSO_4 per ha (311.2 g ha^{-1}) and 25 kg pyrite per ha (297.4 g ha^{-1}) and 50 kg FeSO_4 per ha (289.5 g ha^{-1}). The lowest manganese uptake (280.2 g ha^{-1}) was recorded in the treatment receiving no iron. Addition of 100 kg FeSO_4 per ha was on par with 25 kg pyrite per ha and 50 kg FeSO_4 per ha. The interaction effects found to be non-significant.

4.3.6.5.7 Copper uptake (g ha^{-1})

Copper uptake due to methods of iron application and iron levels varied significantly (Table 54).

Among iron applications methods, the effect of soil plus foliar application of iron recorded significantly higher copper uptake (69.5 g ha^{-1}) over soil application of iron (68.0 g ha^{-1}).

Among iron levels, application of 50 kg pyrite per ha recorded the highest copper uptake (76.2 g ha^{-1}) and it was significantly superior over 100 kg FeSO_4 per ha (70.7 g ha^{-1}), 25 kg pyrite per ha (67.8 g ha^{-1}) and 50 kg FeSO_4 per ha (65.7 g ha^{-1}). The lowest copper uptake (63.4 g ha^{-1}) obtained in the treatment receiving no iron (control). Application of 100 kg FeSO_4 per ha registered significantly higher copper uptake over 25 kg pyrite per ha, 50 kg FeSO_4 per ha, and no iron (control).

The interaction effects found to be non-significant as influenced by iron management practices.

4.3.6.6 Micronutrient content and uptake by maize

4.3.6.6.1 Ferrous iron content (ppm)

The results of the investigations indicate that methods of iron application and iron levels had significant influence on the ferrous iron content of maize at 30, 60 and 80 DAS (Table 55).

Methods of iron application significantly influenced the ferrous iron content of maize. At 60 DAS, soil plus foliar application of iron registered significantly higher ferrous iron content (64.6 ppm) over soil application of iron (31.9 ppm).

Table 54. Direct effect of iron management practices on micronutrients content (ppm) and uptake (g ha^{-1}) by groundnut at harvest

Iron levels	Zinc			Manganese			Copper		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	(22.41)	(22.40)	(22.41)	(53.70)	(53.69)	(53.70)	(12.16)	(12.15)	(12.16)
S ₁ : 50 kg FeSO ₄ ha ⁻¹	(22.46)	(22.46)	(22.46)	(53.74)	(53.74)	(53.74)	(12.20)	(12.21)	(12.21)
S ₂ : 100 kg FeSO ₄ ha ⁻¹	(22.53)	(22.52)	(22.53)	(53.79)	(53.81)	(53.80)	(12.23)	(12.23)	(12.23)
S ₃ : 25 kg pyrite ha ⁻¹	(22.49)	(22.48)	(22.49)	(53.75)	(53.75)	(53.75)	(12.21)	(12.22)	(12.22)
S ₄ : 50 kg pyrite ha ⁻¹	(22.55)	(22.55)	(22.55)	(53.82)	(53.83)	(53.83)	(12.26)	(12.27)	(12.27)
Mean	(22.49)	(22.48)		(53.76)	(53.76)		(12.21)	(12.22)	
For comparing means of	S.E.m±		CD	S.E.m±		CD	S.E.m±		CD
Methods of Fe application	(1.03)		(0.05)	(0.73)		(0.05)	(0.32)		(0.05)
Iron levels	2.50		(NS)	1.60		(NS)	0.30		(NS)
Interaction	(0.81)		(NS)	(1.72)		(NS)	(0.43)		(NS)
	11.70		(NS)	10.60		(NS)	1.10		(NS)

(F₀: Soil application of iron, F₁: Soil plus foliar application of iron and values in the parentheses indicate micronutrients content)

Table 55. Residual effect of iron management practices on ferrous iron content (ppm) at different growth stages of maize

Iron levels	30 DAS			60 DAS			80 DAS		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	27.0	42.7	34.9	19.7	56.0	37.9	13.0	26.7	19.9
S ₁ : 50 kg FeSO ₄ ha ⁻¹	38.7	51.7	45.2	31.3	61.7	46.5	27.7	31.7	29.7
S ₂ : 100 kg FeSO ₄ ha ⁻¹	45.0	60.0	52.5	36.7	68.0	52.4	32.0	41.3	36.7
S ₃ : 25 kg Pyrite ha ⁻¹	40.3	54.7	47.5	32.3	64.0	48.2	29.3	36.0	32.7
S ₄ : 50 kg Pyrite ha ⁻¹	47.4	63.0	55.2	39.3	73.3	56.3	35.1	51.3	43.2
Mean	39.7	54.6		31.9	64.6		27.4	37.4	
For comparing means of	S.E.m±	CD (0.05)		S.E.m±	CD (0.05)		S.E.m±	CD (0.05)	
Methods of Fe application	0.8	3.5		0.7	3.1		0.8	3.7	
Iron levels	1.0	2.9		1.1	3.1		1.5	4.4	
Interaction	1.4	NS		1.5	NS		2.1	NS	

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

At 60 DAS, among iron levels, application of 50 kg pyrite per ha recorded the highest ferrous iron content (56.3 ppm) and it was on par with 100 kg FeSO₄ per ha (52.4 ppm) and significantly superior over 25 kg pyrite per ha (48.2 ppm) and 50 kg FeSO₄ per ha (46.5 ppm). The lowest ferrous iron content (37.9 ppm) was obtained in the treatment receiving no iron (control). Application of 100 kg FeSO₄ per ha registered significantly higher ferrous iron over 25 kg pyrite per ha, 50 kg FeSO₄ per ha, and no iron (control).

Similar trend of ferrous iron content was also noticed at 30 and 80 DAS of maize as influenced by iron management practices.

The interaction effects were not significant throughout different stages of maize.

4.3.6.6.2 Total iron content (ppm)

Total iron content of maize varied significantly at 30 DAS and 60 DAS due to methods of iron application and iron levels (Table 56).

At 60 DAS, among iron application methods, the effect soil plus foliar application of iron recorded significantly higher total iron content (315.2 ppm) over soil plus foliar application of iron (229.7 ppm)

Application of 50 kg pyrite per ha registered the highest total iron content (239.7 ppm) and it was on par with 100 kg FeSO₄ per ha (234.1 ppm) and significantly superior over 25 kg pyrite per ha (229.8 ppm), 50 kg FeSO₄ per ha (227.3 ppm) and no iron treatment (217.7 ppm). Application of 100 kg FeSO₄ per ha was on par with 25 kg pyrite per ha and 50 kg FeSO₄ per ha and significantly higher over no iron (control). The interaction effects were non-significant at different growth stages of maize.

4.3.6.6.3 Iron uptake (g ha⁻¹)

The results of the investigation indicate that methods of iron application and iron levels had significant influence on iron uptake by maize at 30, 60 DAS and harvest (Table 56).

Iron applications methods had distinct influence on total iron content of maize. At 60 DAS, soil plus foliar application of iron registered the higher total iron uptake (1461.0 g ha⁻¹) over soil application of iron (1027.9 g ha⁻¹), respectively.

Table 56. Residual effect of iron management practices on total iron content (ppm) and uptake (g ha^{-1}) by maize at different growth stages

Iron levels	30 DAS				60 DAS				At harvest			
	Methods of Fe application				Methods of Fe application				Methods of Fe application			
	F ₀	F ₁	Mean	CD	F ₀	F ₁	Mean	CD	F ₀	F ₁	Mean	CD
S ₀ : No iron (control)	(256.3) 124.4	(267.5) 131.6	(261.9) 128.0	(0.05)	(217.7) 912.4	(289.6) 1248.0	(253.7) 1080.2	(0.05)	(131.2) 1988.3	(133.1) 2042.8	(132.2) 2015.6	(0.05)
S ₁ : 50 kg FeSO ₄ ha ⁻¹	(271.7) 136.7	(293.1) 148.2	(282.4) 142.5	(17.9)	(227.3) 991.0	(307.6) 1379.4	(267.5) 1185.2	(17.9)	(134.3) 2064.1	(139.9) 2181.9	(137.1) 2123.0	(0.05)
S ₂ : 100 kg FeSO ₄ ha ⁻¹	(281.6) 147.7	(317.6) 167.5	(299.6) 157.6	(24.9)	(234.1) 1073.9	(324.5) 1544.6	(279.3) 1309.3	(18.3)	(136.8) 2134.9	(142.1) 2304.7	(139.5) 2219.8	(0.05)
S ₃ : 25 kg pyrite ha ⁻¹	(274.9) 140.0	(301.7) 155.0	(288.3) 147.5	(24.9)	(229.8) 1020.4	(313.2) 1439.3	(271.5) 1229.9	(18.3)	(134.7) 2085.8	(140.2) 2217.4	(137.5) 2151.6	(0.05)
S ₄ : 50 kg pyrite ha ⁻¹	(289.3) 155.2	(326.3) 177.8	(307.8) 166.5	(24.9)	(239.7) 1141.9	(341.2) 1694.1	(290.5) 1418.0	(18.3)	(137.2) 2149.1	(146.2) 2406.6	(141.7) 2277.9	(0.05)
Mean	(274.7) 140.8	(301.3) 156.0			(229.7) 1027.9	(315.2) 1461.0			(134.8) 2084.4	(140.3) 2230.7		
For comparing means of	S.E.m \pm		CD		S.E.m \pm		CD		S.E.m \pm		CD	
Methods of Fe application	(4.0) 1.9		(0.05) 8.6		(3.8) 15.7		(0.05) 70.8		(2.1) 28.9		(0.05) 129.9	
Iron levels	(8.5) 4.0		(24.9) 11.6		(5.8) 33.6		(18.3) 97.9		(3.2) 50.0		(NS) 145.9	
Interaction	(12.1) 5.6		(NS) NS		(8.2) 47.5		(NS) NS		(4.5) 70.7		(NS) NS	

(F₀: Soil application of iron, F₁: Soil plus foliar application of iron and values in the parentheses indicate total iron content)

Among iron levels (residual effect), application of 50 kg pyrite per ha registered the highest iron uptake (1418.0 g ha^{-1}) and it was significantly superior over 100 kg FeSO_4 per ha (1309.3 g ha^{-1}) and 25 kg pyrite per ha (1229.9 g ha^{-1}) and 50 kg FeSO_4 per ha (1185.2 g ha^{-1}). The lowest iron uptake (1080.2 g ha^{-1}) obtained in the treatment receiving no iron (control). Application of 100 kg FeSO_4 per ha was on par with 50 kg pyrite per ha and significantly superior over rest of the treatments. Similar trend of iron uptake was also noticed at 30 DAS and harvest of maize.

The interaction effects were non-significant at different growth stages of maize.

4.3.6.6.4 Zn, Mn and Cu content (ppm) and uptake (g ha^{-1})

A perusal of the data revealed that iron application methods and iron levels and their interactions was proved non-significant with respect to these nutrient content and uptake at harvest of maize (Table 57).

4.3.7 Available nutrient in soil

The data on effect of iron management practices on the available N, P, K, Zn, Mn, and Cu at harvest and available iron at 30, 60 DAS and harvest of groundnut and maize crops in calcareous Vertisol are presented hereunder

4.3.7.1 Available major nutrients at groundnut harvest

The data on the direct effect of iron management practices on available nitrogen, phosphorus and potassium in calcareous Vertisol at groundnut harvest are presented in Table 58.

The results of the investigation indicate that methods of iron application and iron levels and their interaction had non-significant influence on the available nitrogen, phosphorus and potassium at harvest stage of groundnut.

4.3.7.2 Available major nutrients at maize harvest

4.3.7.2.1 Available nitrogen in soil (kg ha^{-1})

The data on the residual effect of iron management practices on available nitrogen in calcareous Vertisol at harvest stage of maize are presented in Table 59.

Table 57. Residual effects of iron management practices on micronutrients content (ppm) and uptake (g ha^{-1}) by maize at harvest

Iron levels	Zinc			Manganese			Copper		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	(15.14) 229.40	(15.14) 232.40	(15.14) 230.90	(21.26) 327.70	(21.63) 331.90	(21.45) 329.80	(4.33) 65.60	(4.34) 66.60	(4.34) 66.10
S ₁ : 50 kg FeSO ₄ ha ⁻¹	(15.21) 233.80	(15.22) 237.40	(15.22) 235.60	(21.69) 333.40	(21.70) 338.40	(21.70) 335.90	(4.38) 67.30	(4.39) 68.50	(4.39) 67.90
S ₂ : 100 kg FeSO ₄ ha ⁻¹	(15.26) 238.1	(15.26) 247.50	(15.26) 242.80	(21.76) 339.60	(21.76) 352.90	(21.76) 346.30	(4.42) 68.80	(4.43) 71.50	(4.43) 70.20
S ₃ : 25 kg pyrite ha ⁻¹	(15.22) 235.70	(15.23) 240.80	(15.23) 238.30	(21.70) 336.00	(21.72) 343.50	(21.71) 339.80	(4.39) 67.90	(4.40) 69.60	(4.40) 68.80
S ₄ : 50 kg pyrite ha ⁻¹	(15.31) 239.80	(15.30) 251.90	(15.31) 245.90	(21.79) 341.30	(21.79) 358.70	(21.79) 350.0	(4.45) 69.70	(4.46) 73.40	(4.46) 71.60
Mean	(15.22) 235.40	(15.23) 242.00		(21.71) 335.60	(21.72) 345.10		(4.39) 67.90	(4.40) 69.90	
For comparing means of	S.Em \pm	CD		S.Em \pm	CD		S.Em \pm	CD	
Methods of Fe application	(0.42) 2.90	(0.05) NS		(0.41) 4.00	(0.05) NS		(0.20) 1.00	(0.05) NS	
Iron levels	(0.56) 6.70	(NS) NS		(0.44) 8.40	(NS) NS		(0.26) 2.30	(NS) NS	
Interaction	(0.79) 9.40	(NS) NS		(0.63) 11.90	(NS) NS		(0.36) 3.20	(NS) NS	

(F₀: Soil application of iron, F₁: Soil plus foliar application of iron and values in the parentheses indicate micronutrients content)

Table 58. Direct effect of iron management practices on major nutrients status in soil at harvest stage of groundnut

Iron levels	N (kg ha ⁻¹)			P ₂ O ₅ (kg ha ⁻¹)			K ₂ O (kg ha ⁻¹)		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	279.1	276.7	277.9	20.7	20.3	20.5	448.1	446.9	447.5
S ₁ : 50 kg FeSO ₄ ha ⁻¹	271.1	268.2	269.7	19.8	19.2	19.5	444.2	441.8	443.0
S ₂ : 100 kg FeSO ₄ ha ⁻¹	257.2	255.6	256.4	17.3	17.2	17.3	433.8	432.7	443.3
S ₃ : 25 kg Pyrite ha ⁻¹	266.3	263.2	264.8	18.8	18.3	18.6	440.6	438.6	439.6
S ₄ : 50 kg Pyrite ha ⁻¹	247.7	240.3	244.0	15.9	14.9	15.4	427.1	421.9	424.5
Mean	264.2	260.8		18.5	18.0		444.3	441.4	
For comparing means of	S.Em±		CD (0.05)	S.Em±		CD (0.05)	S.Em±		CD (0.05)
Methods of Fe application	7.4		NS	0.7		NS	5.2		NS
Iron levels	10.0		NS	1.3		NS	8.7		NS
Interaction	14.1		NS	1.9		NS	12.3		NS

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

The results indicate that methods of iron application did not differ significantly. Whereas, residual effect of iron levels had significant influence on available nitrogen at harvest stage of maize.

Among iron levels, application of 50 kg pyrite per ha registered lower available nitrogen (167.7 kg ha^{-1}) and it was on par with 100 kg FeSO_4 per ha (186.5 kg ha^{-1}) and recorded significantly lower available nitrogen over 25 kg pyrite per ha (199.6 kg ha^{-1}) and 50 kg FeSO_4 per ha (215.8 kg ha^{-1}) and control treatment. The highest available nitrogen of (224.9 kg ha^{-1}) was noticed in no iron (control). Similarly, application of 100 kg FeSO_4 per ha were on par with 25 kg pyrite per ha and 50 kg FeSO_4 per ha. However, application of 100 kg FeSO_4 per ha noticed significantly lower over no iron.

The interaction effects were non-significant as influenced by iron management practices.

4.3.7.2.2 Available P_2O_5 and available K_2O in soil (kg ha^{-1})

The results of the investigation indicate that methods of iron application and iron levels and their interaction had non-significant influence on the available P_2O_5 and K_2O at maize harvest (Table 59).

4.3.7.3 Available micronutrients in soil at groundnut harvest

The data on effect of iron management practices on the available iron at 30, 60 DAS and harvest and Zn, Mn, and Cu at harvest and of groundnut-maize cropping sequence in calcareous Vertisol are presented hereunder

4.3.7.3.1 DTPA- extractable iron in soil (ppm)

The data pertaining to the direct effect of iron management practices on DTPA-extractable iron in calcareous Vertisol at 30, 60 DAS and harvest stage of groundnut are presented in Table 60.

The results of the investigation indicate that methods of iron application did not influence DTPA-extractable iron significantly at all stages of groundnut crop. Whereas, applied iron levels had significant influence at 30, 60 and harvest stage of groundnut.

Table 59. Residual effect of iron management practices on major nutrients status in soil at harvest stage of maize

Iron levels	N (kg ha ⁻¹)			P ₂ O ₅ (kg ha ⁻¹)			K ₂ O (kg ha ⁻¹)		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	235.9	213.8	224.9	24.8	23.8	24.3	394.8	391.7	393.3
S ₁ : 50 kg FeSO ₄ ha ⁻¹	218.6	212.9	215.8	23.2	21.9	22.6	387.8	383.1	385.5
S ₂ : 100 kg FeSO ₄ ha ⁻¹	190.7	182.3	186.5	19.6	18.5	19.1	374.3	366.9	370.6
S ₃ : 25 kg Pyrite ha ⁻¹	196.4	202.8	199.6	21.8	19.7	20.8	382.5	377.2	379.9
S ₄ : 50 kg Pyrite ha ⁻¹	175.7	159.6	167.7	17.7	14.5	16.1	366.4	353.8	360.1
Mean	203.5	197.9		21.4	19.7		381.2	374.5	
For comparing means of	S.Em±	CD (0.05)		S.Em±	CD (0.05)		S.Em±	CD (0.05)	
Methods of Fe application	2.2	NS		0.6	NS		4.9	NS	
Iron levels	10.7	31.2		0.8	NS		16.4	NS	
Interaction	15.1	NS		1.1	NS		23.2	NS	

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

Table 60. Direct effect of iron management practices on DTPA-extractable iron (ppm) at different growth stages of groundnut

Iron levels	30 DAS			60 DAS			At harvest		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	3.47	3.47	3.47	3.41	3.42	3.42	3.27	3.27	3.27
S ₁ : 50 kg FeSO ₄ ha ⁻¹	4.96	4.96	4.96	4.81	4.83	4.82	4.67	4.67	4.67
S ₂ : 100 kg FeSO ₄ ha ⁻¹	5.35	5.36	5.36	5.11	5.13	5.12	5.03	5.04	5.04
S ₃ : 25 kg Pyrite ha ⁻¹	4.98	4.98	4.98	4.87	4.88	4.88	4.70	4.70	4.70
S ₄ : 50 kg Pyrite ha ⁻¹	5.67	5.68	5.68	5.51	5.52	5.52	5.37	5.38	5.38
Mean	4.88	4.89		4.74	4.76		4.60	4.61	
For comparing means of	S.Em±		CD (0.05)	S.Em±		CD (0.05)	S.Em±		CD (0.05)
Methods of Fe application	0.17		NS	0.06		NS	0.06		NS
Iron levels	0.14		0.42	0.14		0.42	0.14		0.42
Interaction	0.20		NS	0.20		NS	0.20		NS

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

At 60 DAS, among iron levels, application of 50 kg pyrite per ha recorded the highest DTPA-extractable iron (5.52 ppm) and it was on par with 100 kg FeSO₄ per ha (5.12 ppm) and significantly superior over 25 kg pyrite per ha (4.88 ppm) and 50 kg FeSO₄ per ha (4.82 ppm). The lowest DTPA-extractable iron (3.42 ppm) obtained in the treatment receiving no iron treatment (control). Application of 100 kg FeSO₄ per ha were on par with 25 kg pyrite per ha and 50 kg FeSO₄ per ha. However, they were significantly higher over no iron (control).

Similar trend of DTPA-extractable iron was also noticed at 30 DAS and harvest stage of groundnut.

The interaction effects were found to be non-significant at all growth stages of groundnut.

4.3.7.3.2 DTPA- extractable zinc, manganese and copper in soil

The results of the investigation indicate that methods of iron application, iron levels and their interaction had non-significant influence on the DTPA-extractable zinc, manganese and copper at groundnut harvest (Table 61).

4.3.7.4 DTPA-extractable micronutrients in soil at maize harvest

4.3.7.4.1 DTPA-extractable iron in soil (ppm)

The data pertaining to the residual effect of iron management practices on DTPA-extractable iron in soil at 30, 60 DAS and harvest are presented in Table 62.

The results of the investigation indicate that methods of iron application did not influence DTPA-extractable iron in soil significantly at all growth stages of maize. Whereas, the residual effect of iron levels had significant influence at 30, 60 DAS and harvest.

At 60 DAS, among iron levels, application of 50 kg pyrite per ha recorded the highest DTPA-extractable iron (5.12 ppm) and it was on par with 100 kg FeSO₄ per ha (5.02 ppm), 25 kg pyrite per ha (4.68 ppm) and 50 kg FeSO₄ per ha (4.65 ppm) and significantly superior over control treatment (3.17 ppm).

Table 61. Direct effect of iron management practices on DTPA-extractable micronutrients status in soil at harvest stage of groundnut

Iron levels	Zn (ppm)			Mn (ppm)			Cu (ppm)		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	0.486	0.486	0.486	2.511	2.512	2.512	0.367	0.366	0.367
S ₁ : 50 kg FeSO ₄ ha ⁻¹	0.490	0.491	0.491	2.542	2.542	2.542	0.372	0.372	0.372
S ₂ : 100 kg FeSO ₄ ha ⁻¹	0.495	0.496	0.496	2.573	2.573	2.573	0.377	0.377	0.377
S ₃ : 25 kg Pyrite ha ⁻¹	0.491	0.492	0.492	2.554	2.555	2.555	0.373	0.373	0.373
S ₄ : 50 kg Pyrite ha ⁻¹	0.498	0.498	0.498	2.601	2.602	2.602	0.378	0.379	0.379
Mean	0.492	0.493		2.556	2.557		0.373	0.373	
For comparing means of	S.Em±	CD (0.05)		S.Em±	CD (0.05)		S.Em±	CD (0.05)	
Methods of Fe application	0.006	NS		0.035	NS		0.005	NS	
Iron levels	0.013	NS		0.067	NS		0.018	NS	
Interaction	0.018	NS		0.094	NS		0.025	NS	

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

Table 62. Residual effect of iron management practices on on DTPA-extractable iron (ppm) at different growth stages of maize

Iron levels	30 DAS			60 DAS			At harvest		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	3.33	3.34	3.34	3.16	3.17	3.17	3.02	3.02	3.02
S ₁ : 50 kg FeSO ₄ ha ⁻¹	4.81	4.82	4.82	4.64	4.66	4.65	4.50	4.51	4.51
S ₂ : 100 kg FeSO ₄ ha ⁻¹	5.21	5.22	5.22	5.01	5.02	5.02	4.84	4.84	4.84
S ₃ : 25 kg Pyrite ha ⁻¹	4.86	4.86	4.86	4.67	4.68	4.68	4.52	4.53	4.53
S ₄ : 50 kg Pyrite ha ⁻¹	5.42	5.42	5.42	5.11	5.12	5.12	4.91	4.91	4.91
Mean	4.72	4.73		4.51	4.53		4.35	4.36	
For comparing means of	S.Em±	CD (0.05)		S.Em±	CD (0.05)		S.Em±	CD (0.05)	
Methods of Fe application	0.15	NS		0.09	NS		0.09	NS	
Iron levels	0.21	0.62		0.26	0.77		0.20	0.59	
Interaction	0.30	NS		0.37	NS		0.29	NS	

(F₀: Soil application of iron, F₁: Soil plus foliar application of iron and NS: Non-significant)

Similar trend of DTPA-extractable iron was also noticed at 30 DAS and harvest stage of maize.

The interaction effects were non-significant at different growth stages of maize as influenced by iron management practices.

4.3.7.4.2 DTPA-extractable zinc, manganese and copper in soil

The results of the investigation indicate that methods of iron application and residual effect of iron levels and their interaction had non-significant influence on DTPA-extractable zinc, manganese and copper at harvest stage of maize (Table 63).

4.3.8 Iron fractions in soil

The data on direct and residual effect of iron management practices on the different iron fractions in calcareous Vertisol at harvest stage of groundnut and maize are presented hereunder

4.3.8.1 Iron fractions in soil at groundnut harvest

4.3.8.1.1 Water soluble iron and exchangeable iron content

The results of the investigation indicate methods of iron application did not vary these fractions significantly. Whereas, applied iron levels had significant influence on water soluble iron and exchangeable iron content at harvest stage of groundnut (Table 64).

Among iron levels, application of 50 kg pyrite per ha recorded the highest water soluble iron (1.39 ppm) and it was on par with 100 kg FeSO₄ per ha (1.32 ppm) and distinctly superior over 25 kg pyrite per ha (1.16 ppm), 50 kg FeSO₄ per ha (1.13 ppm) and control treatment (0.64 ppm). Application of 100 kg FeSO₄ per ha was significantly superior over 25 kg pyrite per ha and 50 kg FeSO₄ per ha and control treatment.

Similarly, application of 50 kg pyrite per ha recorded the highest exchangeable iron (3.89 ppm) and it was on par with 100 kg FeSO₄ per ha (3.70 ppm), 25 kg pyrite per ha (3.38 ppm) and markedly superior over 50 kg FeSO₄ per ha (3.16 ppm). The lowest exchangeable iron of (2.49 ppm) was recorded in no iron treatment (control). Application of 100 kg FeSO₄ per ha were on par with 25 kg pyrite per ha and significantly superior

Table 63. Residual effect of iron management practices on DTPA-extractable micronutrients status in soil at harvest stage of maize

Iron levels	Zn (ppm)			Mn (ppm)			Cu (ppm)		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	0.423	0.423	0.423	2.140	2.142	2.141	0.274	0.275	0.275
S ₁ : 50 kg FeSO ₄ ha ⁻¹	0.428	0.429	0.429	2.144	2.145	2.145	0.278	0.278	0.278
S ₂ : 100 kg FeSO ₄ ha ⁻¹	0.433	0.433	0.433	2.148	2.149	2.149	0.284	0.285	0.285
S ₃ : 25 kg Pyrite ha ⁻¹	0.429	0.430	0.430	2.145	2.146	2.146	0.279	0.279	0.279
S ₄ : 50 kg Pyrite ha ⁻¹	0.437	0.438	0.438	2.155	2.155	2.155	0.287	0.289	0.288
Mean	0.430	0.431		2.146	2.147		0.280	0.281	
For comparing means of	S.Em±	CD (0.05)		S.Em±	CD (0.05)		S.Em±	CD (0.05)	
Methods of Fe application	0.010	NS		0.059	NS		0.007	NS	
Iron levels	0.016	NS		0.093	NS		0.019	NS	
Interaction	0.023	NS		0.132	NS		0.027	NS	

(F₀: Soil application of iron, F₁: Soil plus foliar application of iron and NS: Non-significant)

Table 64. Direct effect of iron management practices on water soluble iron and exchangeable iron status in soil at harvest stage of groundnut

Iron levels	Water soluble iron (ppm)			Exchangeable iron (ppm)		
	Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	0.63	0.64	0.64	2.48	2.49	2.49
S ₁ : 50 kg FeSO ₄ ha ⁻¹	1.12	1.13	1.13	3.16	3.15	3.16
S ₂ : 100 kg FeSO ₄ ha ⁻¹	1.32	1.32	1.32	3.70	3.70	3.70
S ₃ : 25 kg Pyrite ha ⁻¹	1.16	1.16	1.16	3.37	3.38	3.38
S ₄ : 50 kg Pyrite ha ⁻¹	1.38	1.39	1.39	3.89	3.89	3.89
Mean	1.22	1.22		3.32	3.32	
For comparing means of	S.Em±		CD (0.05)	S.Em±		CD (0.05)
Methods of Fe application	0.02		NS	0.06		NS
Iron levels	0.04		0.12	0.14		0.42
Interaction	0.06		NS	0.20		NS

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

over 50 kg FeSO₄ per ha and control treatment. The interaction effects on were non-significant.

4.3.8.1.2 Acid soluble iron and Pb-displaceable iron content

The results of the investigation indicate that methods of iron application did not influence these fractions significantly. Whereas, applied iron levels had significant influence on acid soluble iron and pb-displaceable content in soil at groundnut harvest (Table 65).

Among iron levels, application of 50 kg pyrite per ha recorded the highest acid soluble iron (3.12 ppm) and it was on par with 100 kg FeSO₄ per ha (3.02 ppm) and markedly superior over 25 kg pyrite per ha (2.18 ppm) and 50 kg FeSO₄ per ha (2.13 ppm). The lowest acid soluble iron of (1.09 ppm) was noticed in no iron treatment (control). Application of 100 kg FeSO₄ per ha were significantly superior over 25 kg pyrite per ha and 50 kg FeSO₄ per ha and control treatment.

Similarly, application of 50 kg pyrite per ha recorded the highest pb-displaceable iron (42.89 ppm) and it was markedly superior over 100 kg FeSO₄ per ha (38.62 ppm), 25 kg pyrite per ha (34.04 ppm) and 50 kg FeSO₄ per ha (31.17 ppm) respectively. The lowest Pb-displaceable iron (25.70 ppm) was registered in control. Application of 100 kg FeSO₄ per ha was significantly superior over 25 kg pyrite per ha and 50 kg FeSO₄ per ha and control.

The interaction effects were non-significant as influenced by iron management practices.

4.3.8.1.3 Mn oxide occluded iron, organically bound iron and amorphous iron oxide occluded iron content (ppm)

The results of the investigation indicate that methods of iron application and iron levels and their interactions had non-significant influence on Mn oxide occluded iron, organically bound iron and amorphous iron oxide occluded iron content in soil at harvest stage of groundnut (Table 66).

4.3.8.2 Iron fractions in soil at maize harvest

4.3.8.2.1 Water soluble iron and exchangeable iron content (ppm)

The results of the investigation indicate that methods of iron application did not differ significantly. Whereas, residual effect of applied iron levels had significant

Table 65. Direct effect of iron management practices on acid soluble and Pb-displaceable iron status in soil at harvest stage of groundnut

Iron levels	Acid soluble iron (ppm)			Pb-displaceable iron (ppm)		
	Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	1.09	1.09	1.09	25.70	25.70	25.70
S ₁ : 50 kg FeSO ₄ ha ⁻¹	2.12	2.13	2.13	31.17	31.17	31.17
S ₂ : 100 kg FeSO ₄ ha ⁻¹	3.01	3.02	3.02	38.61	38.62	38.62
S ₃ : 25 kg Pyrite ha ⁻¹	2.18	2.18	2.18	34.03	34.05	34.04
S ₄ : 50 kg Pyrite ha ⁻¹	3.11	3.12	3.12	42.88	42.89	42.89
Mean	2.30	2.31		34.48	34.49	
For comparing means of	S.E.m±		CD (0.05)	S.E.m±		CD (0.05)
Methods of Fe application	0.05		NS	0.55		NS
Iron levels	0.09		0.27	0.81		2.35
Interaction	0.12		NS	1.14		NS

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

Table 66. Direct effect of iron management practices on Mn oxide occluded iron, organically bound iron and amorphous iron oxide occluded iron status in soil at harvest stage of groundnut

Iron levels	Mn oxide occluded iron (ppm)			Organically bound iron (ppm)			Amorphous iron oxide occluded iron (ppm)		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	153.26	153.27	153.27	426.11	426.10	426.11	1567.10	1567.11	1567.11
S ₁ : 50 kg FeSO ₄ ha ⁻¹	165.71	165.72	165.72	436.36	436.37	436.37	1581.62	1581.60	1581.61
S ₂ : 100 kg FeSO ₄ ha ⁻¹	171.40	171.40	171.40	448.05	448.07	448.06	1597.41	1597.40	1597.41
S ₃ : 25 kg Pyrite ha ⁻¹	168.11	168.12	168.12	441.89	441.88	441.89	1586.13	1586.15	1586.14
S ₄ : 50 kg Pyrite ha ⁻¹	175.31	175.32	175.32	456.72	456.74	456.73	1609.71	1609.72	1609.72
Mean	166.76	166.77		441.83	441.83		1588.40	1588.39	
For comparing means of	S.Em±		CD (0.05)	S.Em±		CD (0.05)	S.Em±		CD (0.05)
Methods of Fe application	2.23		NS	5.00		NS	20.00		NS
Iron levels	5.92		NS	9.68		NS	40.82		NS
Interaction	8.37		NS	13.69		NS	57.73		NS

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

influence on water soluble iron and exchangeable iron content in soil at maize harvest (Table 67).

Among iron levels, application of 50 kg pyrite per ha recorded the highest water soluble iron (1.23 ppm) and it was on par with 100 kg FeSO₄ per ha (1.17 ppm) and distinctly superior over 25 kg pyrite per ha (1.05 ppm), 50 kg FeSO₄ per ha (0.90 ppm) and control treatment. The lowest water soluble iron of (0.41 ppm) was recorded in no iron treatment (control). Application of 100 kg FeSO₄ per ha were significantly superior over 25 kg pyrite per ha and 50 kg FeSO₄ per ha and control treatment.

Similarly, application of 50 kg pyrite per ha recorded the highest exchangeable iron (3.19 ppm) and it was on par with 100 kg FeSO₄ per ha (3.12 ppm) and distinctly superior over 25 kg pyrite per ha (2.84 ppm) and 50 kg FeSO₄ per ha (2.73 ppm) and control treatment (2.07 ppm). Application of 100 kg FeSO₄ per ha were significantly superior over 25 kg pyrite per ha and 50 kg FeSO₄ per ha and control treatment.

The interaction effects were non-significant as influenced by iron management practices.

4.3.8.2.2 Acid soluble iron and Pb-displaceable iron content (ppm)

The results of the investigation indicate that methods of iron application did not influence these fractions significantly. Whereas, residual effect of applied iron levels had significant influence on acid soluble iron and Pb-displaceable content of soil at harvest stage of maize (Table 68).

Among iron levels, application of 50 kg pyrite per ha recorded the highest acid soluble iron (1.52 ppm) and Pb-displaceable iron (34.10 ppm) and it was on par with 100 kg FeSO₄ per ha (1.43 ppm) and (32.64 ppm) and markedly superior over 25 kg pyrite per ha (1.21 ppm) and (28.26 ppm) and 50 kg FeSO₄ per ha (1.12 ppm) and (27.13 ppm) respectively. The lowest acid soluble iron of (0.87 ppm) and Pb-displaceable iron (20.07 ppm) was noticed in no iron treatment (control). Application of 100 kg FeSO₄ per ha was significantly superior over 25 kg pyrite per ha and 50 kg FeSO₄ per ha and control. The interaction effects were non-significant.

Table 67. Residual effect of iron management practices on water soluble iron and exchangeable iron status in soil at harvest stage of maize

Iron levels	Water soluble iron (ppm)			Exchangeable iron (ppm)		
	Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	0.41	0.41	0.41	2.06	2.07	2.07
S ₁ : 50 kg FeSO ₄ ha ⁻¹	0.90	0.90	0.90	2.73	2.73	2.73
S ₂ : 100 kg FeSO ₄ ha ⁻¹	1.16	1.17	1.17	3.11	3.12	3.12
S ₃ : 25 kg Pyrite ha ⁻¹	1.04	1.05	1.05	2.84	2.83	2.84
S ₄ : 50 kg Pyrite ha ⁻¹	1.23	1.23	1.23	3.19	3.19	3.19
Mean	0.94	0.95		2.79	2.79	
For comparing means of	S.Em±		CD (0.05)	S.Em±		CD (0.05)
Methods of Fe application	0.02		NS	0.06		NS
Iron levels	0.02		0.07	0.09		0.27
Interaction	0.03		NS	0.13		NS

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

Table 68. Residual effect of iron management practices on acid soluble and Pb-displaceable iron status in soil at harvest stage of maize

Iron levels	Acid soluble iron (ppm)			Pb-displaceable iron (ppm)		
	Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	0.86	0.87	0.87	20.06	20.07	20.07
S ₁ : 50 kg FeSO ₄ ha ⁻¹	1.12	1.12	1.12	27.13	27.12	27.13
S ₂ : 100 kg FeSO ₄ ha ⁻¹	1.43	1.43	1.43	32.64	32.64	32.64
S ₃ : 25 kg Pyrite ha ⁻¹	1.20	1.21	1.21	28.25	28.26	28.26
S ₄ : 50 kg Pyrite ha ⁻¹	1.51	1.52	1.52	34.09	34.10	34.10
Mean	1.22	1.23		28.43	28.44	
For comparing means of	S.Em±		CD (0.05)	S.Em±		CD (0.05)
Methods of Fe application	0.02		NS	0.50		NS
Iron levels	0.04		0.10	0.78		2.26
Interaction	0.05		NS	1.10		NS

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

4.3.8.2.3 Mn oxide occluded iron, organically bound iron and amorphous iron oxide occluded iron content

The results of the investigation indicate that methods of iron application and residual effect of applied iron levels and their interactions had non-significant influence on Mn oxide occluded iron, organically bound iron and amorphous iron oxide occluded iron at harvest stage of maize (Table 69).

4.3.9 Path analysis study

Path coefficient analysis was carried out to find out the direct and indirect contribution of different soil and plant iron fractions to pod yield of groundnut and grain yield of maize. The correlations were partitioned into direct and indirect effects from iron fractions on pod yield of groundnut and grain yield of maize. The direct and indirect effects are given in Table 70 and 71.

4.3.9.1 Path analysis in groundnut

The correlation coefficients of different soil and plant iron fractions with groundnut pod yield were subjected to path analysis. The results of this analysis indicating the direct and indirect effects of these factors are shown in Table 70.

A perusal of the Table 70 indicates that all the forms of iron fractions of soil and plant iron showed significant correlation with pod yield. However, the resolution of these correlation coefficients indicates very high positive direct effect of exchangeable iron (1.613) followed by acid soluble iron (0.607) among soil iron fractions.

The water soluble iron fraction showed very high negative direct effect (-1.666). The available iron had negligible direct effect (0.009) on pod yield of groundnut. In fact, the other fractions of soil iron and even plant iron had very high indirect effect on pod yield through exchangeable iron and available iron in soil.

Among the iron fractions in plant, Fe^{2+} at 80 DAS had the maximum positive direct effect (0.664) followed by that at 60 DAS (0.402). The direct effect of plant Fe^{2+} at 30 DAS was negligible (0.002). Fe^{2+} at 80 DAS followed by 60 DAS showed high positive indirect effect of other soil iron fractions through them.

Table 69. Residual effect of iron management practices on Mn oxide occluded iron, organically bound iron and amorphous iron oxide occluded iron status in soil at harvest stage of maize

Iron levels	Mn oxide occluded iron (ppm)			Organically bound iron (ppm)			Amorphous iron oxide occluded iron (ppm)		
	Methods of Fe application			Methods of Fe application			Methods of Fe application		
	F ₀	F ₁	Mean	F ₀	F ₁	Mean	F ₀	F ₁	Mean
S ₀ : No iron (control)	145.46	145.47	145.47	418.01	418.02	418.02	1461.36	1461.38	1461.37
S ₁ : 50 kg FeSO ₄ ha ⁻¹	154.83	154.82	154.83	425.14	425.13	425.14	1476.11	1476.12	1476.12
S ₂ : 100 kg FeSO ₄ ha ⁻¹	159.07	159.09	159.08	434.20	434.21	434.21	1484.20	1484.20	1484.20
S ₃ : 25 kg Pyrite ha ⁻¹	156.18	156.17	156.18	430.86	430.88	430.87	1479.67	1479.68	1479.68
S ₄ : 50 kg Pyrite ha ⁻¹	163.11	163.12	163.12	439.13	439.15	439.14	1490.34	1490.36	1490.35
Mean	155.73	155.73		429.47	429.48		1478.34	1478.35	
For comparing means of	S.Em±	CD (0.05)		S.Em±	CD (0.05)		S.Em±	CD (0.05)	
Methods of Fe application	2.00	NS		5.04	NS		19.99	NS	
Iron levels	5.16	NS		9.09	NS		64.55	NS	
Interaction	7.30	NS		12.85	NS		91.29	NS	

(F₀ : Soil application of iron, F₁ : Soil plus foliar application of iron and NS : Non-significant)

Table 70. Path coefficients from soil and plant iron fractions to pod yield of groundnut

	Available iron	Water soluble iron	Acid soluble iron	Exchangeable iron	Pb-displaceable iron	Fe ²⁺ at 30 DAS	Fe ²⁺ at 60 DAS	Fe ²⁺ at 80 DAS	Total iron	Correlation coefficient
Available iron	0.090	-1.704	0.584	1.574	-0.288	0.002	0.180	0.629	-0.223	0.842**
Water soluble iron	0.090	-1.710	0.591	1.586	-0.290	0.002	0.184	0.630	-0.225	0.857**
Acid soluble iron	0.087	-1.666	0.607	1.592	-0.302	0.002	0.181	0.595	-0.217	0.879**
Exchangeable iron	0.088	-1.681	0.599	1.613	-0.305	0.002	0.182	0.607	-0.222	0.884**
Pb-displaceable iron	0.083	-1.593	0.589	1.580	-0.311	0.002	0.177	0.562	-0.211	0.878**
Fe ²⁺ at 30 DAS	0.082	-1.581	0.546	1.499	-0.275	0.002	0.202	0.591	-0.237	0.829**
Fe ²⁺ at 60 DAS	0.040	-0.781	0.273	0.730	-0.137	0.001	0.402	0.448	-0.186	0.791**
Fe ²⁺ at 80 DAS	0.085	-1.622	0.544	1.474	-0.263	0.002	0.271	0.664	-0.235	0.920**
Total iron in plant	0.079	-1.515	0.520	1.411	-0.259	0.002	0.295	0.614	-0.254	0.893**

The diagonal values indicate direct effects

* Significant at 5 per cent level

** Significant at 1 per cent level

Both the direct effects as well as indirect effects in respect of water soluble iron, total iron and Pb-displaceable iron were all negative while, Fe^{2+} at 30 DAS and available iron were negligible.

4.3.9.2 Path analysis in maize

The role of different fractions of iron and the stage of plant growth at which the available iron showed the impact on maize yield are provided in Table 71.

Maize was taken after harvest of groundnut and the objective of this experiment was to see the residual effect of applied iron to groundnut on the subsequent crop maize and also the stage at which the iron fractions have maximum influence on yield.

As observed from Table 71, the Pb-displaceable iron and water soluble iron had the maximum positive direct effect (3.817 and 1.562, respectively) whereas, the other fractions of iron had negative direct effect.

Among the iron fractions in plant, the maximum positive direct effect was observed from Fe^{2+} at 30 DAS (4.143) and incidentally the indirect effects from Fe^{2+} at 60 and 80 DAS through Fe^{2+} at 30 DAS were positive and high.

4.3.10 Economics

The data on economics of groundnut and maize as influenced by iron management practices in calcareous Vertisol are presented in (Appendix I, II and III).

In respect of the economic analysis of groundnut, among iron application to soil, the highest gross returns (Rs. 28956/-), net returns (Rs. 17137/-) and Benefit: cost ratio (2.45) was observed in the treatment receiving 50 kg pyrite per ha as compared to other treatments.

Application of iron to soil and foliar spray together had increased gross returns, net returns and Benefit: cost ratio of groundnut crop. The plots receiving 50 kg pyrite per ha + Fe foliar spray registered the highest gross returns (Rs. 31224/-), net returns (Rs. 18834/-), Benefit: cost ratio (2.52) as compared to other treatments. (Appendix II).

Whereas, in case of the economic analysis of maize crop, among iron application to soil (residual effect), the highest gross returns (Rs. 26484.30/-), net returns (Rs. 15403.01/-)

Table 71. Path coefficients from soil and plant iron fractions to grain yield of maize

	Available iron	Water soluble iron	Acid soluble iron	Exchangeable iron	Pb-displaceable iron	Fe ²⁺ at 30 DAS	Fe ²⁺ at 60 DAS	Fe ²⁺ at 80 DAS	Total iron	Correlation coefficient
Available iron	-0.654	1.532	-1.304	-4.333	3.622	2.745	-0.879	-0.111	0.097	0.715*
Water soluble iron	-0.641	1.562	-1.375	-4.405	3.736	2.844	-0.921	-0.117	0.100	0.781**
Acid soluble iron	-0.592	1.492	-1.439	-4.311	3.790	2.869	-0.954	-0.121	0.101	0.835**
Exchangeable iron	0.640	1.553	-1.401	-4.430	3.789	2.856	-0.922	-0.118	0.100	0.788**
Pb-displaceable iron	-0.621	1.529	-1.429	-4.397	3.817	2.857	-0.926	-0.119	0.101	0.811**
Fe ²⁺ at 30 DAS	-0.433	1.072	-0.997	-3.053	2.632	4.143	-2.417	-0.141	0.133	0.940**
Fe ²⁺ at 60 DAS	-0.219	0.547	-0.522	-1.554	1.345	3.809	-2.629	-0.118	0.117	0.777**
Fe ²⁺ at 80 DAS	-0.490	1.230	-1.168	-3.516	3.066	3.925	-2.081	-0.149	0.130	0.947**
Total iron in plant	-0.454	1.116	-1.043	-3.187	2.764	3.959	-2.212	-0.139	0.139	0.944**

The diagonal values indicate direct effects

* Significant at 5 per cent level

** Significant at 1 per cent level

and Benefit: cost ratio (2.39) was observed in the treatment receiving 50 kg pyrite per ha as compared to other treatments.

The residual effect of iron application to soil and foliar spray together had increased gross returns, net returns and Benefit: cost ratio of maize crop. The plots receiving 50 kg pyrite per ha + Fe foliar spray registered the highest gross returns (Rs. 28626.30/-), net returns (Rs. 17036.70/-), Benefit: cost ratio (2.47) as compared to other treatments (Appendix III).

DISCUSSION

V. DISCUSSION

The results obtained from the research work carried out to study the effect of iron management practices for the cropping sequences of groundnut and maize in calcareous Vertisol are discussed in this chapter under three headings.

5.1 Characterization studies

5.2 Incubation study and

5.3 Field experiment.

5.1 CHARACTERIZATION STUDIES

The results of the investigation are discussed under the following headings:

5.1.1 Distribution of total and available iron in soil bodies,

5.1.2 Distribution of different iron fractions in soil and

5.1.3 Per cent contribution of iron fractions to total iron.

5.1.1 Distribution of total and available iron in soil bodies

5.1.1.1 Total iron

The total iron content in soil bodies of different sites varied from 2.71 to 3.76 per cent in Table 10. The total iron was less in surface than in subsurface layers and found to increase with depth (Fig.2). This increase in total iron in subsurface layers may be due to the accumulation of clay and free CaCO_3 . Statistical analysis from Table 13 revealed a significant positive correlation between total iron and clay ($r = 0.451^*$) and also with free CaCO_3 ($r = 0.508^{**}$). Similar results were recorded by Kumar *et al.* (1981) and Thakur *et al.* (1995). Statistical analysis also revealed significant negative correlation of total iron with organic carbon ($r = -0.492^*$). Correlations studies indicated that the distribution of total iron in soils predominantly controlled by the clay, pH, free CaCO_3 and organic carbon content of soils.

5.1.1.2 Available iron (DTPA-extractable)

The DTPA-extractable iron in soil bodies varied from 2.28 to 4.76 ppm in Table 10. No definite trend in the distribution pattern of DTPA-extractable iron was observed (Fig.3). Significant negative correlation (Table 13) was observed between DTPA-extractable iron and soil pH ($r = -0.914^{**}$) and with calcium carbonate ($r = -0.941^{**}$)

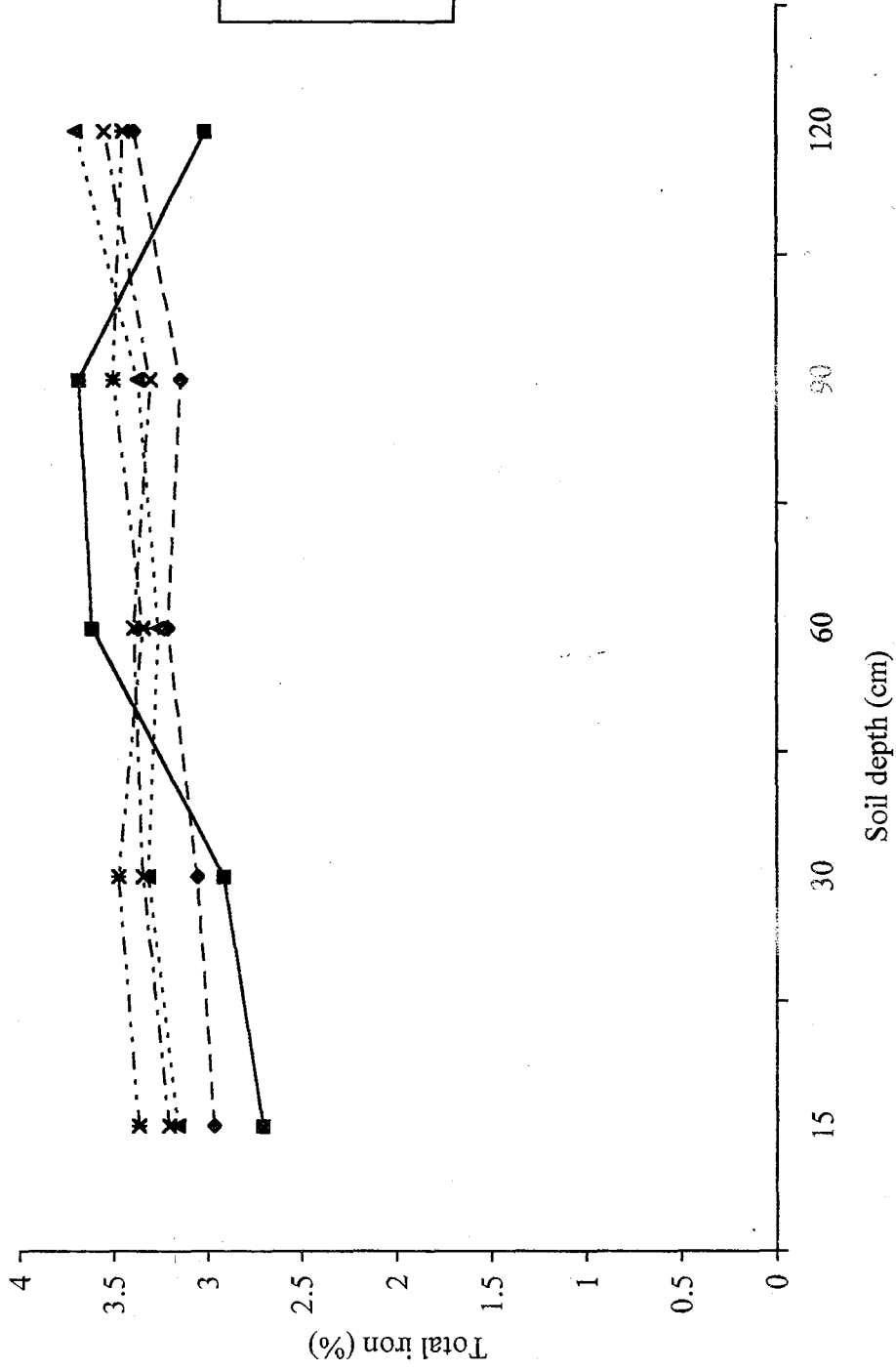


Fig. 2. Distribution of total iron in different soil profiles

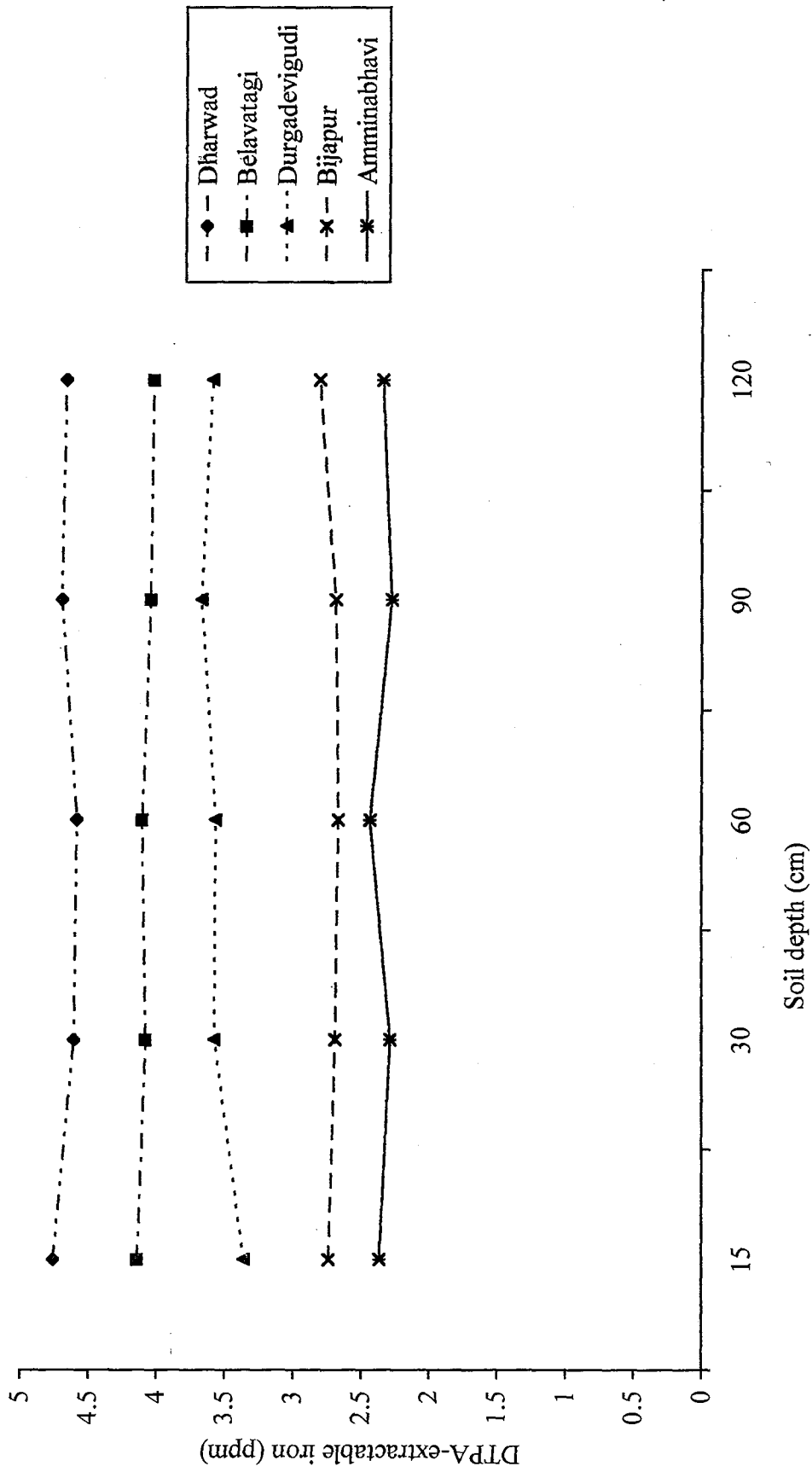


Fig. 3. Distribution of available iron (DTPA-extractable iron) in different soil profiles

indicating their role in conversion of soluble form of iron into insoluble form either by precipitation reactions or by fixation mechanism (Mahendra Singh and Dahiya, 1975). Similar results were observed by Dhange *et al.* (1985) in soils of Rahuri, Maharashtra. A highly significant positive correlation between DTPA-extractable iron with organic carbon ($r = 0.595^{**}$) and clay ($r = 0.912^{**}$) indicated that movement of iron in soils might be associated with the formation of organic chelates and clay. Similar results were observed by Raut *et al.* (1998) in soils of Jayakwadi command area of Maharashtra.

5.1.2 Distribution of different iron fractions in soil

5.1.2.1 Water soluble iron

Water soluble iron content in soil bodies was found to be very low. It ranged between 0.23 and 1.16 ppm in different soil bodies. The lowest value of water soluble iron was generally recorded in subsurface layers than in surface layers (Table 11). Figure 4 indicated that water soluble iron generally decreased with depth. Relatively higher amounts of water soluble iron in surface layers may be due to higher organic carbon content. This was further justified by the positive correlation that was observed between water soluble iron, organic carbon ($r = 0.671^{**}$). The above results are in conformity with the finding of Thakur *et al.* (1995) and Yelvikar *et al.* (1996). Statistical analysis from Table 14 revealed significant negative correlation between water soluble iron and pH ($r = -0.922^{**}$), clay ($r = 0.831^{**}$) and with CaCO_3 ($r = -0.958^{**}$), suggesting that clay, pH and CaCO_3 are responsible for retaining water soluble iron in a form which is not readily available for plant growth.

5.1.2.2 Exchangeable iron

The data from Table 11 revealed that the exchangeable iron was in the range of 4.43 to 1.82 ppm. This fraction of iron in soil bodies increased with depth (Fig.5). It can be observed from Fig. (5) and that the distribution of exchangeable iron is reverse to that of water soluble iron. Statistical analysis from Table 14 revealed significant positive correlation between exchangeable iron and organic carbon ($r = 0.559^{**}$), clay content ($r = 0.950^{**}$) and cation exchange capacity ($r = 0.607^{**}$). However, pH ($r = -0.878^{*}$) and CaCO_3 ($r = -0.814^{**}$) recorded significant negative correlation with exchangeable iron.

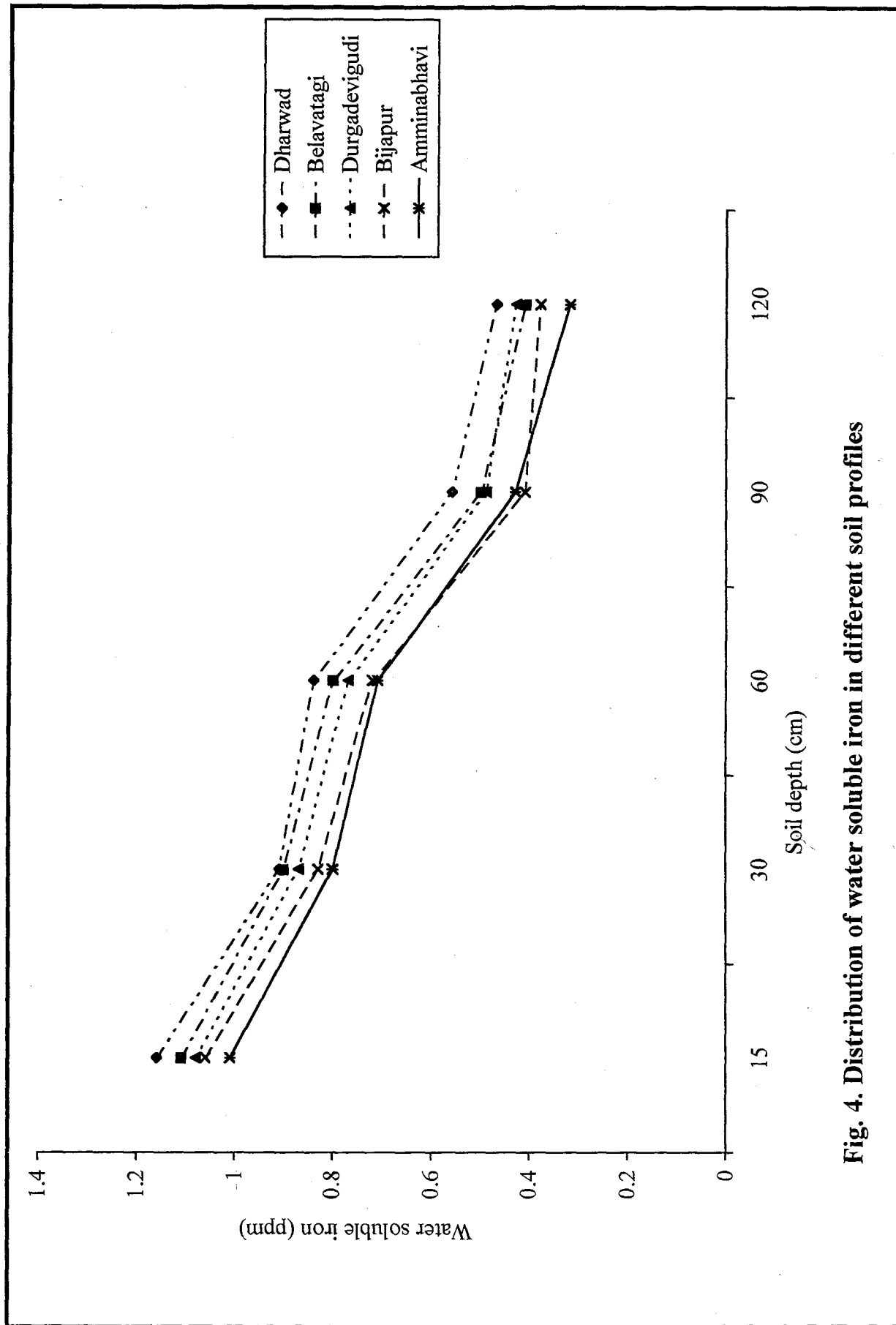


Fig. 4. Distribution of water soluble iron in different soil profiles

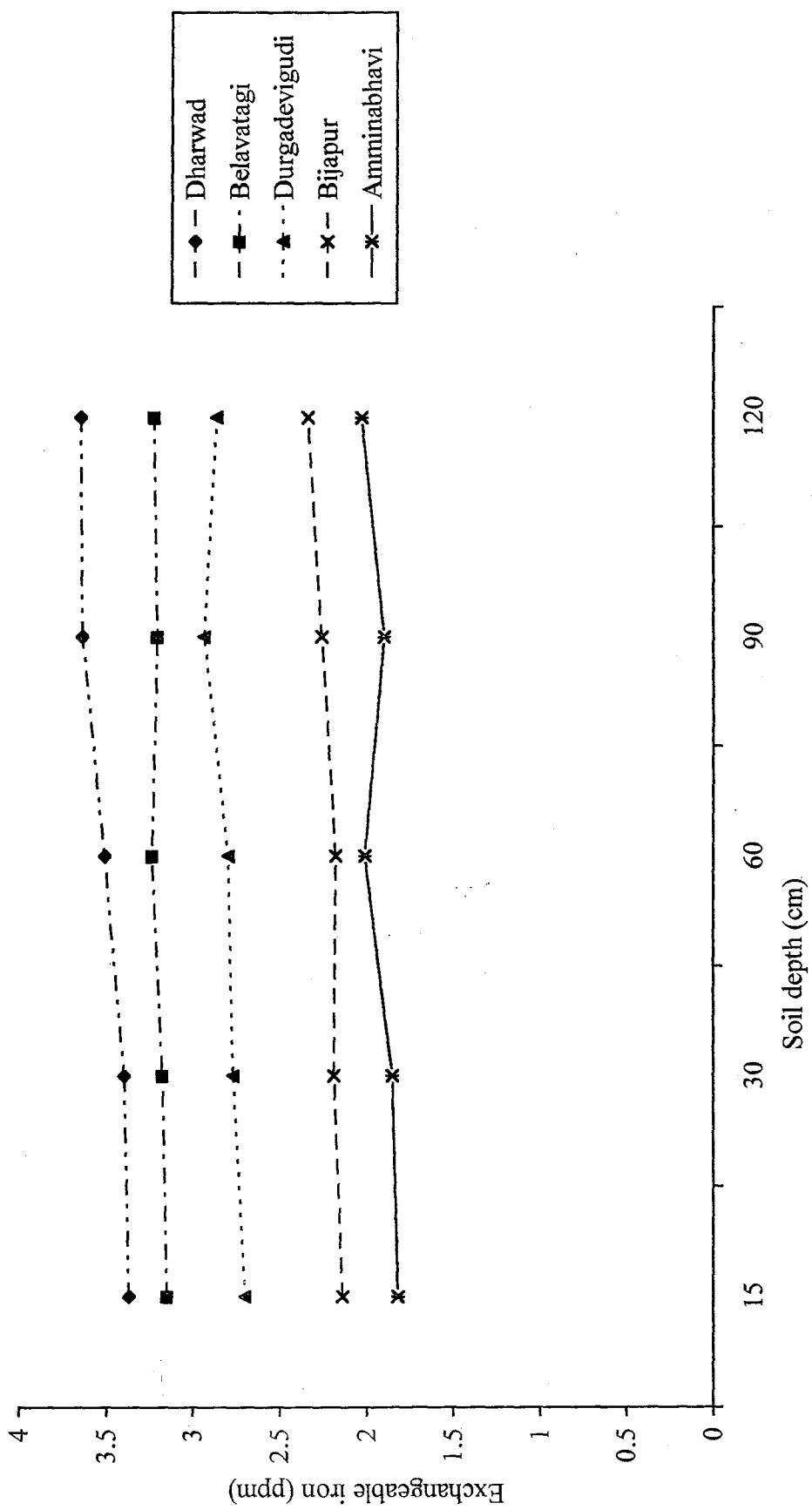


Fig. 5. Distribution of exchangeable iron in different soil profiles

This suggests that the distribution of exchangeable iron in soils controlled by clay content, organic carbon, pH and CaCO_3 . Similar types of observation were recorded by Yelvikar *et al.* (1996) in Vertisol of Maharashtra and Joshi *et al.* (1983) in arid soils of Rajasthan.

5.1.2.3 Pb-displaceable iron

Pb-displaceable iron in soil series varied from 17.40 to 64.80 ppm and found to increase with the depth in all the soil bodies (Fig. 6). According to Sposito (1984) this fraction was considered to be adsorbed iron, which was covalently bonded with oxidic functional group. Statistical analysis from Table 14 revealed a significant positive correlation between Pb-displaceable iron and cation exchange capacity ($r = 0.793^{**}$) and clay content ($r = 0.879^{**}$) indicating that clay might have adsorbed this fraction due to their high surface area.

Significant positive correlation between Pb-displaceable iron and soil pH ($r = 0.833^{**}$) and calcium carbonate ($r = 0.814^{**}$) indicating high soil pH and calcium carbonate might have increased the sorbing capacity of clay and free iron oxides by decreasing the solubility of iron as suggested by Shuman (1985).

5.1.2.4 Acid soluble iron

Perusal of the data from Table 11 showed that acid soluble iron was in the range of 0.91 to 3.26 ppm in different soil bodies (Fig. 7). This fraction was extracted by acetic acid being an acid, was capable of dissolving poorly crystalline-hydroxy-carbonate phase of the metal (Miller, 1981). This was strongly justified by the positive correlation that was observed between acid soluble iron and calcium carbonate ($r = 0.513^*$). Tessier *et al.* (1979) recorded similar type of association between acid soluble iron and calcium carbonate.

5.1.2.5 Manganese oxide occluded iron

The data from Table 11 revealed that the manganese oxide occluded iron in soil bodies varied from 101.2 to 245.2 ppm. Generally this fraction of iron decreased with the depth (Fig. 8). Similar observations were recorded by Choudhari *et al.* (1979) in major soil groups of Rajasthan. The differences in the contents of this fraction in surface and

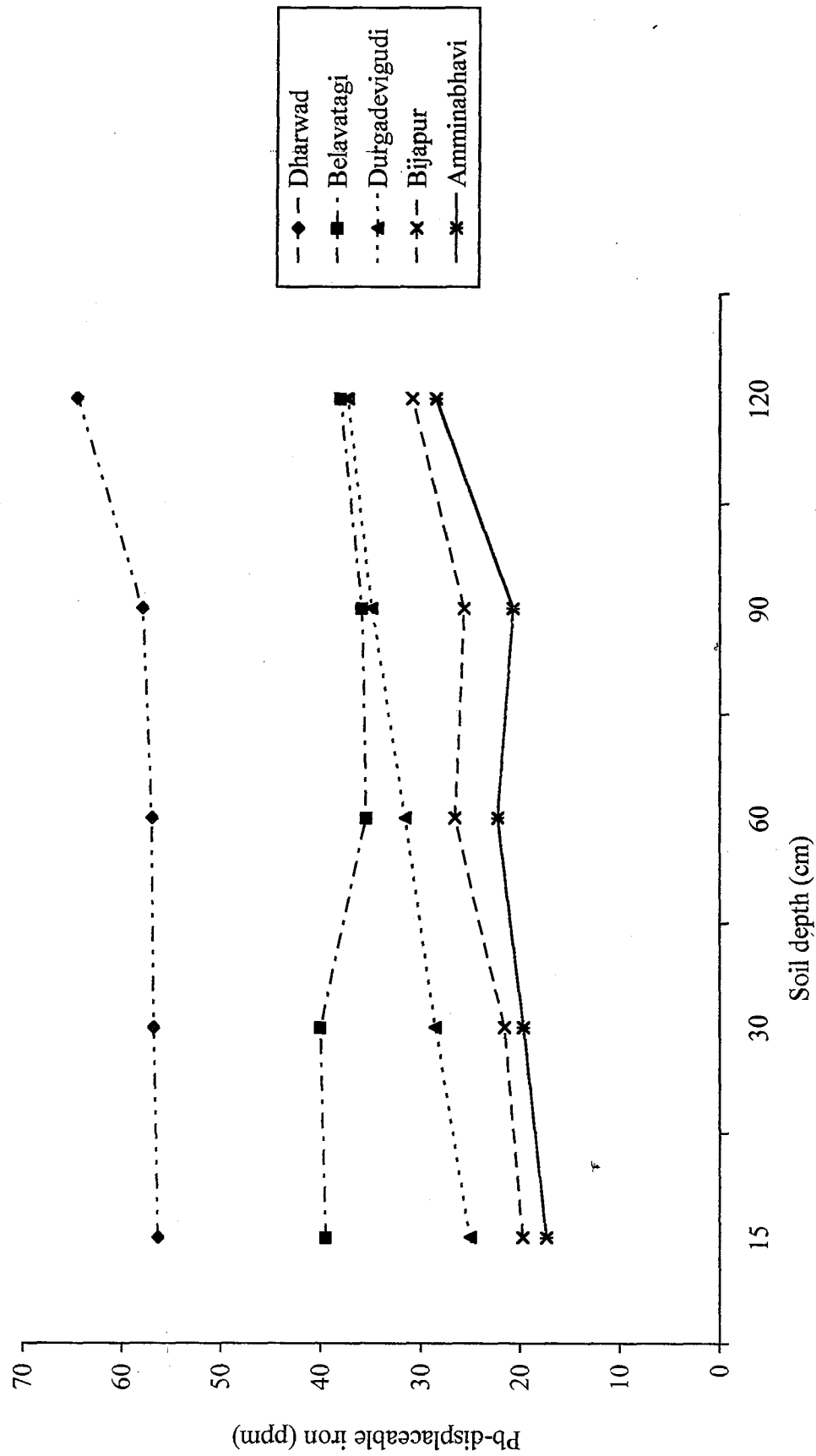


Fig. 6. Distribution of Pb-displaceable iron in different soil profiles

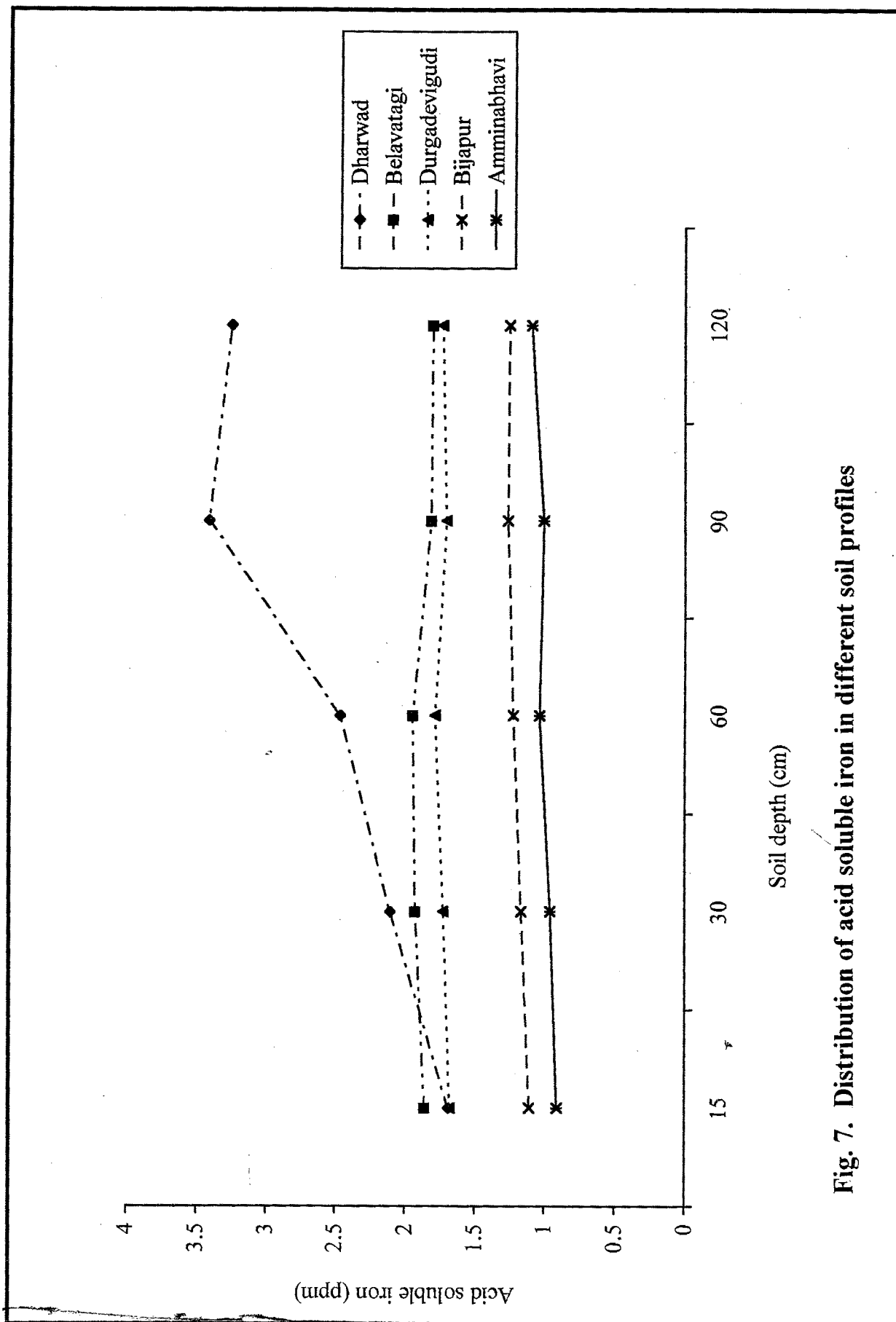


Fig. 7. Distribution of acid soluble iron in different soil profiles

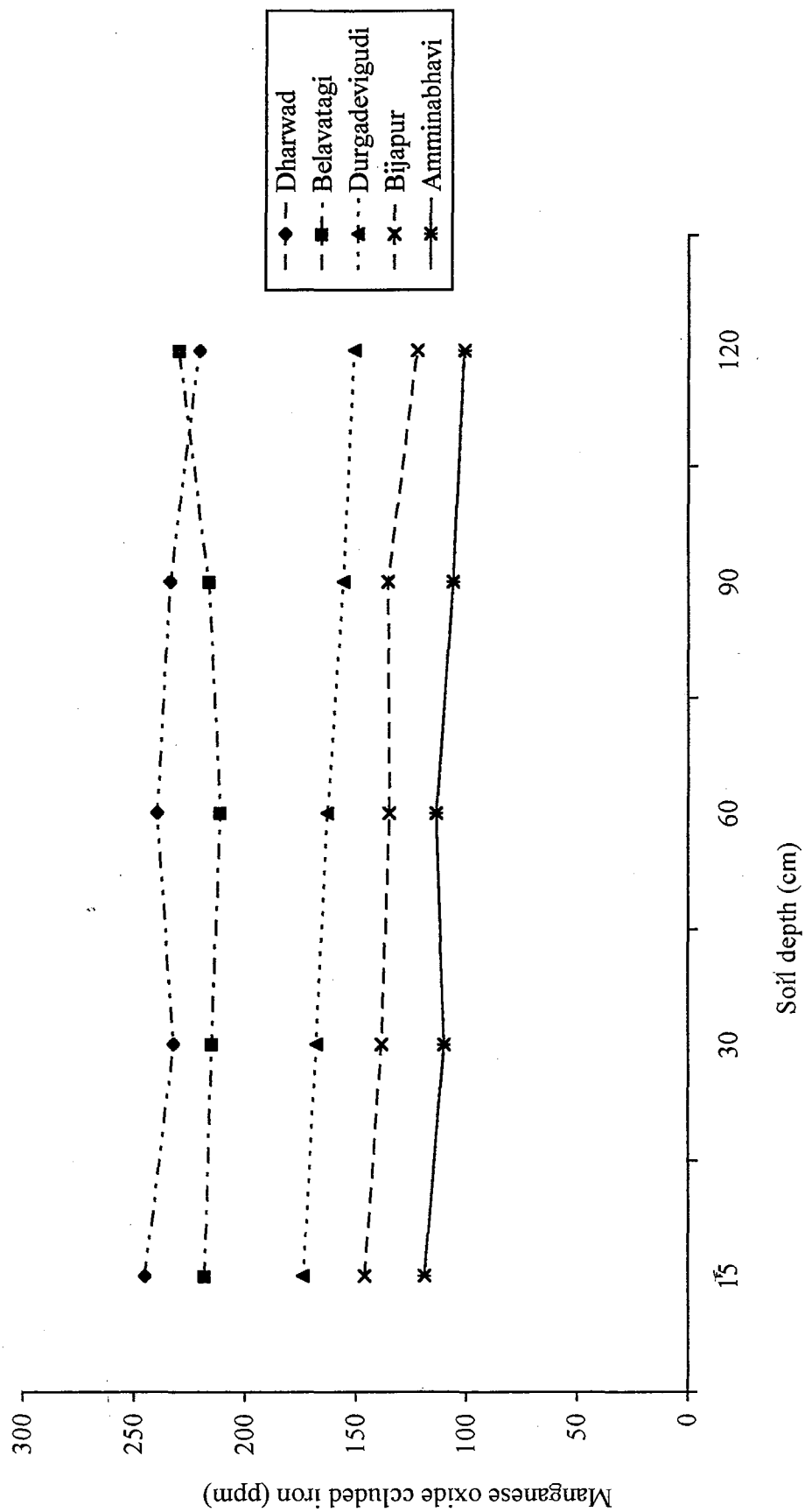


Fig. 8. Distribution of manganese oxide occluded iron in different soil profiles

subsurface layers might be due to the differences in the organic matter and clay content of soils. Further, this was supported by significant positive correlation between this fraction and organic carbon ($r = 0.697^*$), clay ($r = 0.851^{**}$) and cation exchange capacity ($r = 0.699^{**}$). These results are in conformity with the findings of Shuman (1985). Statistical analysis also revealed a significant positive correlation between this fraction and calcium carbonate ($r = 0.977^{**}$) indicating association of this fraction and carbonate of the soil through precipitation reaction (Loeppert and Clarke, 1984).

5.1.2.6 Organically bound iron

Organically bound iron in soil bodies varied from 345.8 to 693.3 ppm. Similar to manganese oxide occluded iron, this fraction of iron also decreased with the depth of the soil body (Table 11 and Fig. 9). Statistical analysis revealed a significant positive correlation between this fraction and organic carbon indicating that organically bound iron might be present in its occluded form on the surfaces of organic matter by retention phenomena as suggested by Jenne (1977). The results are in conformity with the findings of Misra and Pande (1975) and Shuman (1985). Statistical analysis in Table 9 also revealed significant negative correlation between this fraction and pH ($r = -0.931^{**}$) and with CaCO_3 ($r = -0.935^{**}$) indicating these factors are also responsible for decreased organically bound iron content at lower depths.

5.1.2.7 Amorphous iron oxide occluded iron

Perusal of the data from Table 11 showed that the amorphous iron oxide occluded iron varied from 1317.0 to 2306.7 ppm in different soil bodies. This fraction was less in surface than in the subsurface layers and found to increase with depth (Fig. 10). Figures indicated that distribution trend of amorphous iron oxide occluded iron was reverse to that of other two occluded forms of iron *viz.* manganese oxide occluded and organically bound iron. Statistical analysis revealed significant positive correlation between this fraction and clay ($r = 0.890^{**}$), organic carbon ($r = 0.483^*$) with cation exchange capacity ($r = 0.805^{**}$). Hawkes and Webb (1962) were of the opinion that amorphous iron oxide occluded iron might have either incorporated within the crystal lattice or sorbed on the surface and interlayers of clay. Similar type of relationship between this fraction and clay was recorded by Shuman (1985) and in south eastern soils of United States and Yerriswamy *et al.* (1995) in Malaprabha common area of Karnataka. The decrease in

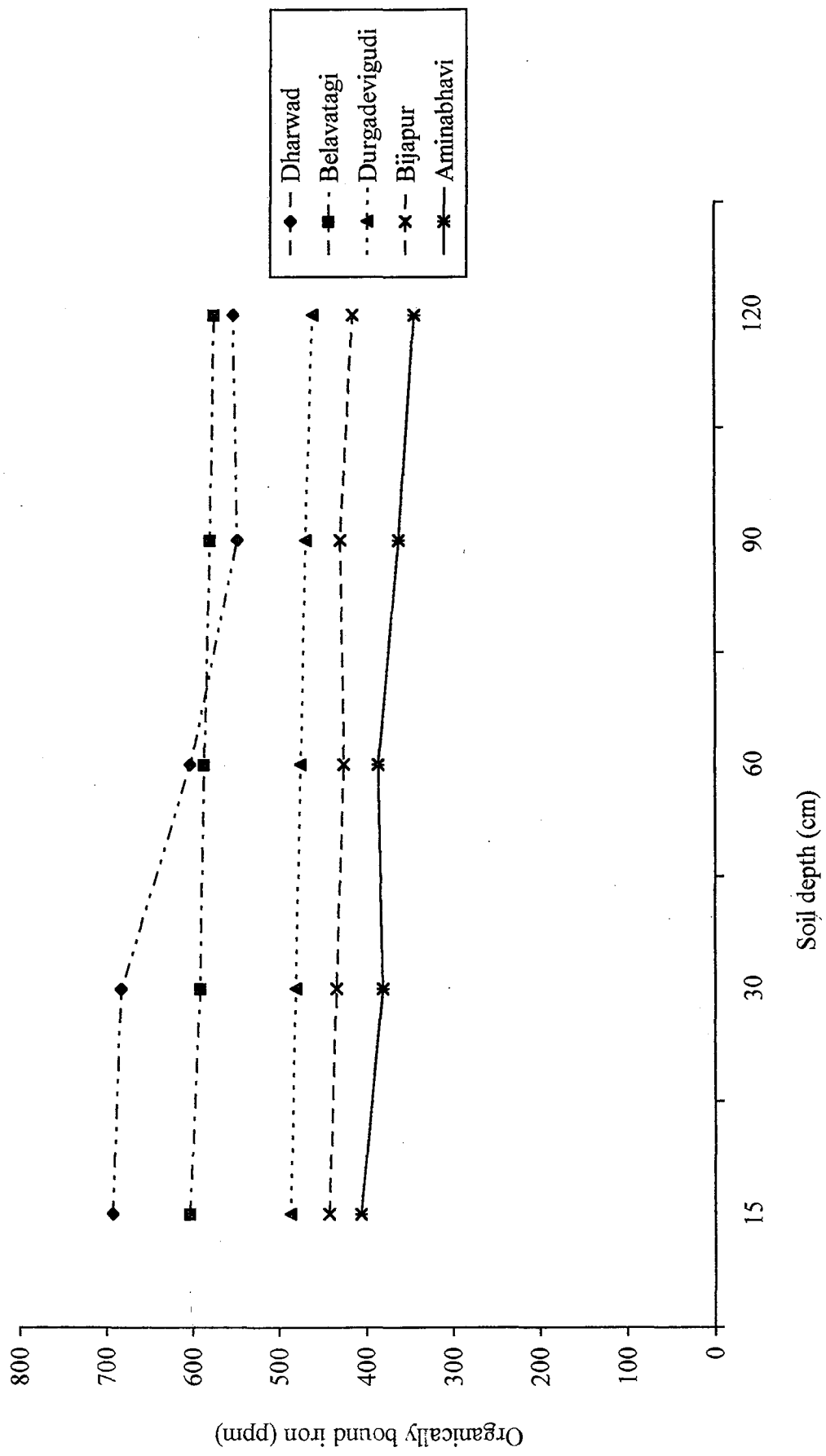


Fig. 9. Distribution of organically bound iron in different soil profiles

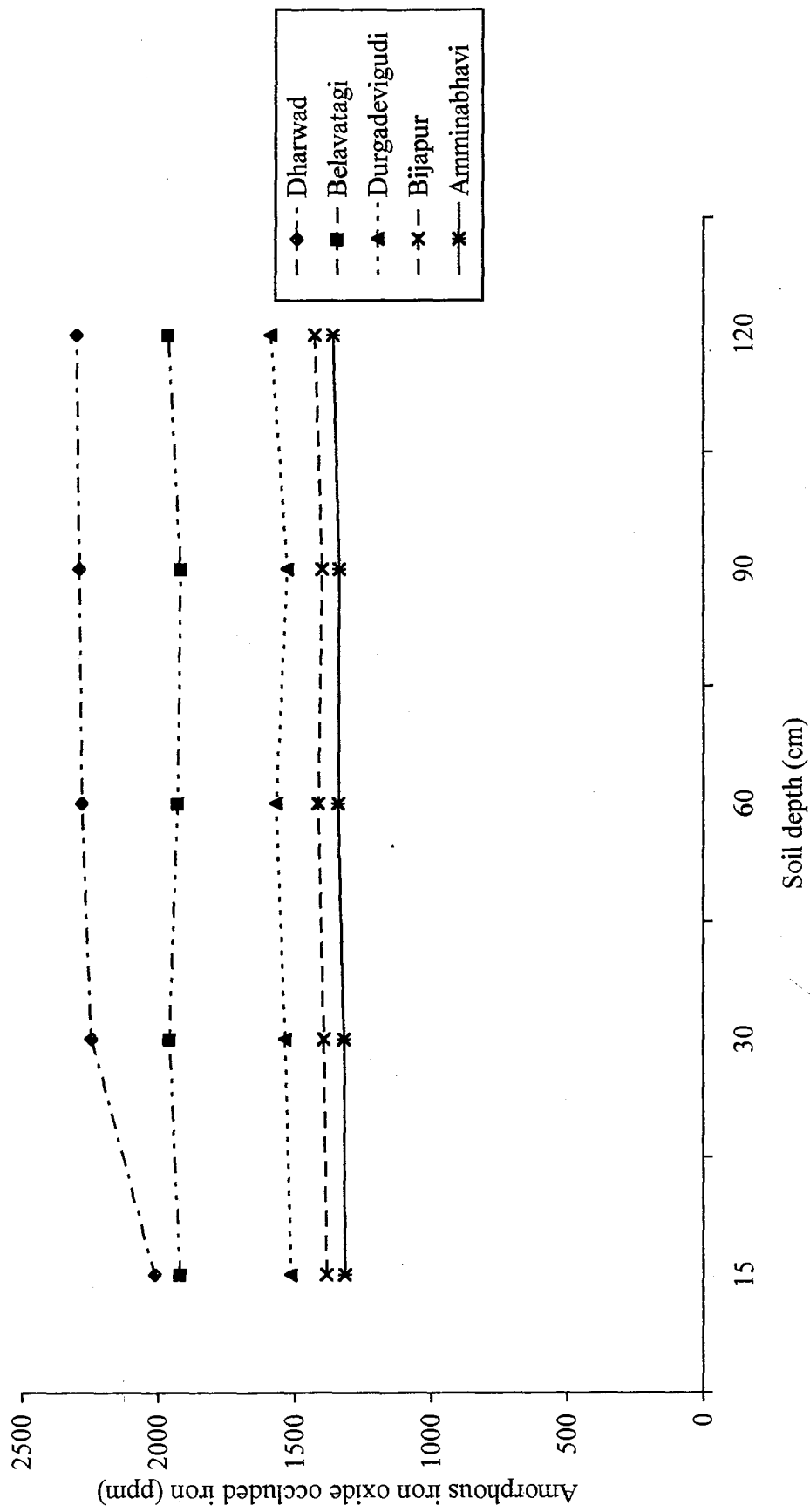


Fig. 10. Distribution of amorphous iron oxide occluded iron in different soil profiles

amorphous iron oxide occluded iron in surface soil was only due to lower content of clay and CaCO_3 in soil.

5.1.2.8 Residual iron

Results indicated that the residual iron in the soil bodies was in the range of 2.43 to 3.58 per cent (Table 11). It is the major fraction that is contributing to the total iron in the soils. The residual iron was generally more in the subsurface layers than in the surface layers (Fig.11). This may be due to accumulation of clay at lower depth. Statistical analysis also indicated significant positive correlation between this fraction and clay content ($r = 0.454^*$) and with soil pH ($r = 0.705^{**}$) indicating this fraction might be present within the crystal lattices of clay as suggested by Tessier *et al.* (1979). Statistical analysis also revealed significant negative correlation between residual iron and organic carbon ($r = -0.650^{**}$) and calcium carbonate ($r = -0.732^{**}$).

5.1.3 Percentage contribution of soil iron fractions to total iron

Regarding to the percentage contribution of different fractions of soil iron to total iron (Table 12), the contribution of water soluble (0.0034 %), acid soluble (0.0082 %), exchangeable iron (0.0109 %) was minimum in Dharwad profile. Whereas, residual iron contributed more than 90 percent to the total iron followed by amorphous iron oxide occluded, organically bound iron, Mn oxide occluded iron and Pb-displaceable iron. Similar trend was noticed in Belavatagi, durgadvigudi and Bijabur. In Amminabhavi soil profile, the highest percent contribution of iron fraction to total iron was (94.84 %) of residual iron. Whereas, the lowest was registered in water soluble iron (0.0011 %).

The percentage contribution of different fraction to total iron decreased in the following order: Residual > amorphous iron oxide occluded > organically bound > Mn oxide occluded > Pb-displaceable > exchangeable > acid soluble > water soluble. These results are in conformity with the findings of Miller *et al.* (1986) and Yerriswamy *et al.* (1995).

5.2 INCUBATION STUDY

Incubation study was conducted in the laboratory to study the effect of ferrous sulphate application on the periodical changes of different iron fractions on soil varying in calcium carbonate level.

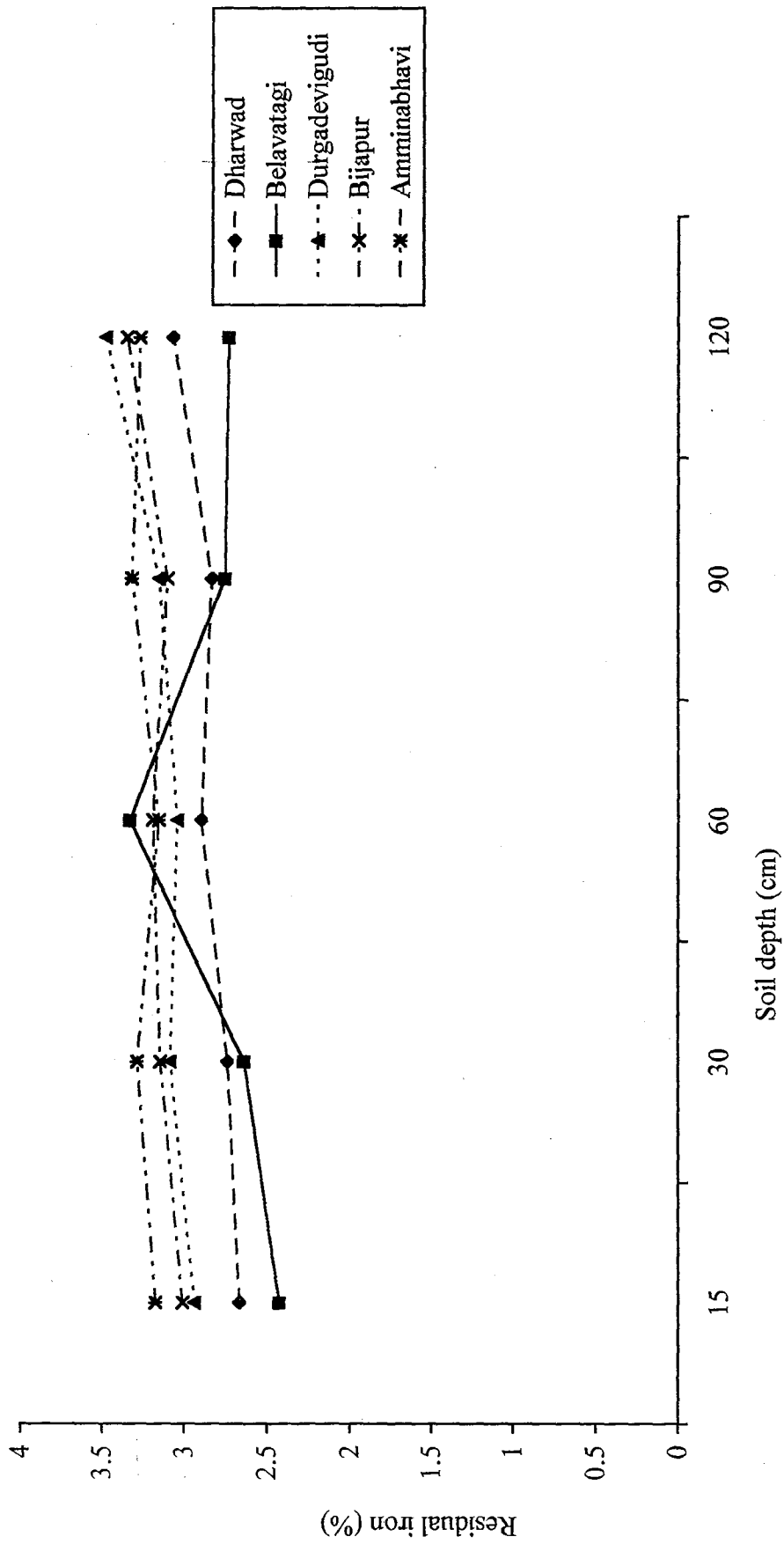


Fig. 11. Distribution of residual iron in different soil profiles

The data on the effect of ferrous sulphate application to soils varying calcium carbonate levels on the periodical changes of water soluble, acid soluble, exchangeable, Pb-displaceable, Mn oxide occluded iron, organically bound iron and amorphous iron oxide occluded at 0, 15, 30, 45, 60 and 100 days after incubation are presented in Table 15-21.

In the present study, it observed that, there was a gradual increase in different iron fractions with increased time after incubation period. The highest water soluble iron, acid soluble iron, exchangeable iron, pb-displceable, Mn oxide occluded iron, organically bound iron, amorphous iron oxide occluded was noticed at 30 days after incubation and thereafter it started declining from 45 days after incubation onwards till 100 days of incubation period. However, The lowest water soluble iron, acid soluble iron, exchangeable iron, Pb-displceable, Mn oxide occluded iron, organically bound iron, amorphous iron oxide occluded was observed at 0 day after incubation. The results observed in this study are in accordance with the reports of Babarai and Patel (1980) and Jagtap and Mohite (1994). Yerriswamy *et al.* (1994) conducted an incubation study in calcareous soil collected from Hirekumbi and Belavatagi farms in Karnataka, results indicated that DTPA extractable iron continuously increased up to 20 days and thereafter decreased when only FeSO_4 or manure was added. However, the application of FeSO_4 with manure increased DTPA extractable iron after 20 day after incubation and the highest DTPA extractable iron was recorded at 30 days after incubation.

The decrease in iron fractions content of soil at 45 days onwards may be due to conversion of soluble form of iron into insoluble form through precipitation reactions of FeCO_3 and $\text{Fe}_3(\text{OH})_8$. Similar results were observed by Patel *et al.* (1982) in calcareous soil of Junagadh, Gujarat. Zmiuthar *et al.* (1992) studied the effect of lime, sulphur, iron and moisture on iron availability under varying incubation period in calcareous soil of Junagadh, Gujarat. They concluded that, addition of iron (10 ppm Fe) increased the availability of iron significantly over control at all incubation period. However, liming decreased significantly the iron availability at all incubation periods.

An inference could be drawn from these observations that more iron was present in available form (water soluble + exchangeable) for a longer duration. This may be due to the formation of complexation with the added iron by organic compounds found in the

organic manure (FYM). Similar results were recorded by many workers (Krishnamurthy and Raj, 1975 and Babaria and Patel, 1980).

Increased CaCO_3 levels in soil significantly decreased water soluble iron, acid soluble iron, exchangeable iron and Pb-displaceable iron, Mn oxide occluded iron, organically bound iron and amorphous iron oxide occluded at different days after incubation period. The interaction effect did not differ significantly with respect to Mn oxide occluded iron, organically bound iron and amorphous iron oxide occluded. Thus, the overall effect of increased CaCO_3 levels in soil decreased all iron fractions.

The significant depressing effect of CaCO_3 levels in soil on the availability of iron could be due to oxidation of soluble native iron through direct reaction with CaCO_3 and the increased soil pH due to hydrolysis of CaCO_3 . The magnitude of oxidation depends on the amount of CaCO_3 (2-16 %) and pH (8.2 to 8.5). The oxidation states which, in fact, represent forms of iron greatly depended on pH value below 8.0, it generally remains at dimer $[\text{Fe}_2(\text{OH})_3^{4+}]$ form and can be extracted with acidic extractants and reducing agents (Thorne and Wallace 1944). The results observed in this study corroborate the findings of earlier worker. A large number of workers also noticed negative correlation between iron forms and CaCO_3 of soil (Singh and Patiram, 1975 and Joshi *et al.*, 1983).

The effect of varying levels of FeSO_4 was significant with respect to water soluble iron, acid soluble iron, exchangeable iron and Pb-displaceable iron in soil. Whereas, the effect of applied iron at different levels of ferrous sulphate (0, 50 and 100 kg $\text{FeSO}_4 \text{ ha}^{-1}$) on Mn oxide occluded iron, organically bound iron and amorphous iron oxide occluded found to be non-significant.

Application of 100 kg $\text{FeSO}_4 \text{ ha}^{-1}$ recorded the highest water soluble iron, acid soluble iron, exchangeable iron and Pb-displaceable iron and this was markedly superior over 50 kg FeSO_4 per ha and no iron (control). However, the lowest water soluble iron, acid soluble iron, exchangeable iron and pb-displaceable iron registered in the treatments receiving no iron over all days after incubation period.

When iron in the form of ferrous sulphate was added to these soils, all the forms of iron increased with the doses, which was probably due to slow oxidation of soluble iron into various insoluble higher oxidation states. The time of incubation under optimum

moisture and temperature conditions has resulted in the decrease of iron extracted because some of the added soluble iron might have changed to such higher oxides and hydroxides. The results of this investigation are in consonance with the findings of Mahendra Singh and Dahiya (1975).

According to Norvell (1971) the equilibrium constant value for the reaction of $\text{Fe}^{3+} + 3 \text{OH} = \text{Fe}(\text{OH})_3$ is $10^{39.4}$ (-log of activity) which he extrapolated to zero ionic concentration. On addition of soluble salt this value changed to $10^{33.6}$ and slowly returned to $10^{39.4}$ in a period of one month. Since these are the values of constant for negative log, the value $10^{33.6}$ indicates higher solubility of iron, which reduced to $10^{39.4}$ due to oxidation. Evidently the same situation is true in the present case due to oxidation of soluble iron into insoluble iron as indicated by decrease in all forms with the time of incubation. The amount of all forms was higher at higher rate of added iron due to longer time taken for the oxidation and hydration of higher amount of iron.

5.3 FIELD EXPERIMENT

The results obtained from the field experiment conducted on calcareous Vertisol under irrigated condition at farmers field, Durgadevigudi, Dharwad during *Kharif* season of 2002-03 and *rabi* season of 2003 and 2003-04 to study the effect of iron management practices on growth, yield, certain biochemical and quality parameters and nutrient uptake of groundnut-maize cropping sequence are discussed under the following headings.

5.3.1 Growth parameters

5.3.2 Yield parameters

5.3.3 Quality parameters

5.3.4 Biochemical parameters

5.3.5 Nutrient uptake

5.3.6 Available nutrient in soil

5.3.7 Iron fractions in soil

5.3.8 Path analysis study and

5.3.9 Economic analysis

5.3.1 Growth parameters

5.3.1.1 Growth parameters of groundnut

The results of the investigation indicate that methods of iron application and iron levels had significant influence on the plant height, number of green leaves and total dry matter production at 60 DAS and at harvest of groundnut crop (Tables 23-25 and plate 1).

Methods of iron application had distinct influence on growth parameters of groundnut. The treatment F_1 (soil plus foliar application of iron) was found to be significantly superior over soil application of iron (F_0), which resulted in increase the plant height and number of green leaves by 10.2 and 11.0 per cent at 60 DAS and 6.1 and 9.8 per cent at harvest, respectively over soil application of iron. The beneficial effect of iron application to soil along with foliar spray increased iron availability in soil and ferrous iron uptake by plant leaves resulting in better absorption and translocation of iron, which in turn might have helped in increasing various growth parameters of groundnut. Findings of Patil (1975), Chandrashaker Reddy (1976) and Sarkar *et al.* (1998) corroborate with the present study.

The direct effect of application of 50 kg pyrite per ha (S_4) significantly increased the plant height and number of green leaves by 52.6 and 62.2 per cent at 60 DAS and 45.2 and 58.8 per cent at harvest, respectively over no iron treatment (control). It was found to be significantly superior over S_3 , S_1 and control (S_0) and on par with S_2 with respect to plant height over a period of crop growth. Number of green leaves significantly increased due to application of S_4 , which found to be significantly superior over all other treatments. Application of 50 kg pyrite per ha (S_4) was considered as a multipurpose soil amendment, an acidifier, plant nutrient mobilizer and a co-fertilizer to supply sulphur and iron to plants in soils deficient in these nutrients (Tiwari *et al.* 1984). Thus, treatment S_4 might have helped in vigorous root growth, higher nitrogen fixation, formation of chlorophyll, cell division, respiration and enzymatic activities resulting in higher photosynthesis. The results of this investigation are in consonance with the findings of Verma and Bajai (1964) in groundnut and Francis and Rajagopal (1978) in sorghum.

Similarly, the total dry matter production in various plant parts was varied significantly due to iron application methods and iron levels at 60 DAS and at harvest of groundnut crop (Table 25).

Application iron methods had significant influence on total dry matter production at 60 DAS and at harvest of groundnut. It may be recalled that, soil plus foliar application of



UNIVERSITY OF AGRICULTURAL SCIENCES - ENNHARAD
 DEPARTMENT OF SOIL SCIENCES AND AGRICULTURAL CHEMISTRY
 IRON MANAGEMENT IN GROUNDNUT-MAIZE CROPPING SEQUENCES IN
 CALCIUM SOIL

TREATMENTS
 T₀ - RDC ONLY
 T₁ - 50% F. 50% S. SOIL APPLICATION
 T₂ - 30% F. 50% S.
 T₃ - 25% F. 50% S.
 T₄ - 50% F. 50% S.
 SOIL APPLICATION AT THE FOLLOWING
 SEASON: SEPTEMBER-2003
 DESIGN - SPLIT PLOT DESIGN
 PLOT SIZE - 3.4m x 4.5m
 SPACING - 30cm x 90cm
 REPLICATES - 3
 VARIETIES - GROUNDNUT (MAGNUS)
 MAIZE (21-24)

T₅ - 25% F. 25% CITRIC ACID SPREAD
 T₆ - T₀ + T₅
 T₇ - T₁ + T₅
 T₈ - T₂ + T₅
 T₉ - T₃ + T₅
 T₁₀ - T₄ + T₅
 FERTILIZATION AT HARVEST DATE

Plate 1. General view of experimental field - groundnut

iron (F_1) significantly increased total dry matter production by (8.1 and 2.4 %) over soil application of iron (F_0) at 60 DAS and at harvest, respectively.

The total dry matter production increased significantly with increase iron levels. The dry matter production increased by (22.3 and 21.2 %) in the treatment S_4 as compared to S_2 (15.4 and 12.9 %), S_3 (7.9 and 8.3 %) and S_1 (3.2 and 5.1 %) over no iron treatment over a period of crop growth 60 DAS and at harvest, respectively. It was significantly superior over all other treatments at 60 DAS. However, the lowest total dry matter production was recorded in the treatment receiving no iron (control). The increasing trend in growth components with applied iron may be attributed to the increased availability of this nutrient in an inherently iron deficient soil and the process of its absorption and translocation in the plant. Thus, the effect of applied iron was found to be beneficial on growth and yield components of groundnut crop. Similar results were reported by Patil (1975) in groundnut, Channal (1978) in sunflower and Singh and Chaudhari (1997) in groundnut.

5.3.1.2 Growth parameters of maize

The results of the investigation indicate that residual effect of iron application methods and iron levels had significant influence on the plant height at 60 DAS and harvest, and total dry matter production at 60 DAS of maize (Tables 26 and 28 and Plate 2).

Soil plus foliar application of iron had profound influence on plant height of maize crop. Soil plus foliar application of iron Application (F_1) significantly increased the plant height by 18.4 and 8.6 per cent over the treatment of soil application of iron (F_0) at 60 DAS and at harvest, respectively. This might be due to various physiological characters in plants, one can exploit full genetic potential of a crop, when its grown under favorable conditions and well balanced supply of nutrients to the crop.

The residual effect of application of 50 kg pyrite per ha (S_4) recorded significant increase in plant height by 19.3 and 16.2 per cent as compared to S_2 (13.0 and 15.6 %), S_3 (11.5 and 12.4 %) and S_1 (7.3 and 9.2 %) over no iron treatment at 60 DAS and at harvest, respectively. Sakal *et al.* (1982) studied the direct effect of iron carriers and compost on yield and Fe uptake by rice and their residual effect on winter maize and reported that the



Plate 2. General view of experimental field - maize

residual effect of FeSO_4 alone on maize yield was not so distinct while that of pyrite alone was about four times greater which may be due to acidulating action of pyrite and the residual response was magnified when these Fe carriers were applied in conjunction with organic manure.

Similarly, the total dry matter production in various plant parts varied significantly due to methods of iron application and iron levels at 60 DAS of maize (Table 28).

Soil plus foliar spray of iron had significant influence on total dry matter production at 60 DAS of maize. The treatment F_1 found to increase significantly the total dry matter production by 3.5 per cent over soil application of iron treatment (F_0). The results are in conformity with the findings of Prasad (1981) in maize Dahiya and Singh (1982) in oat.

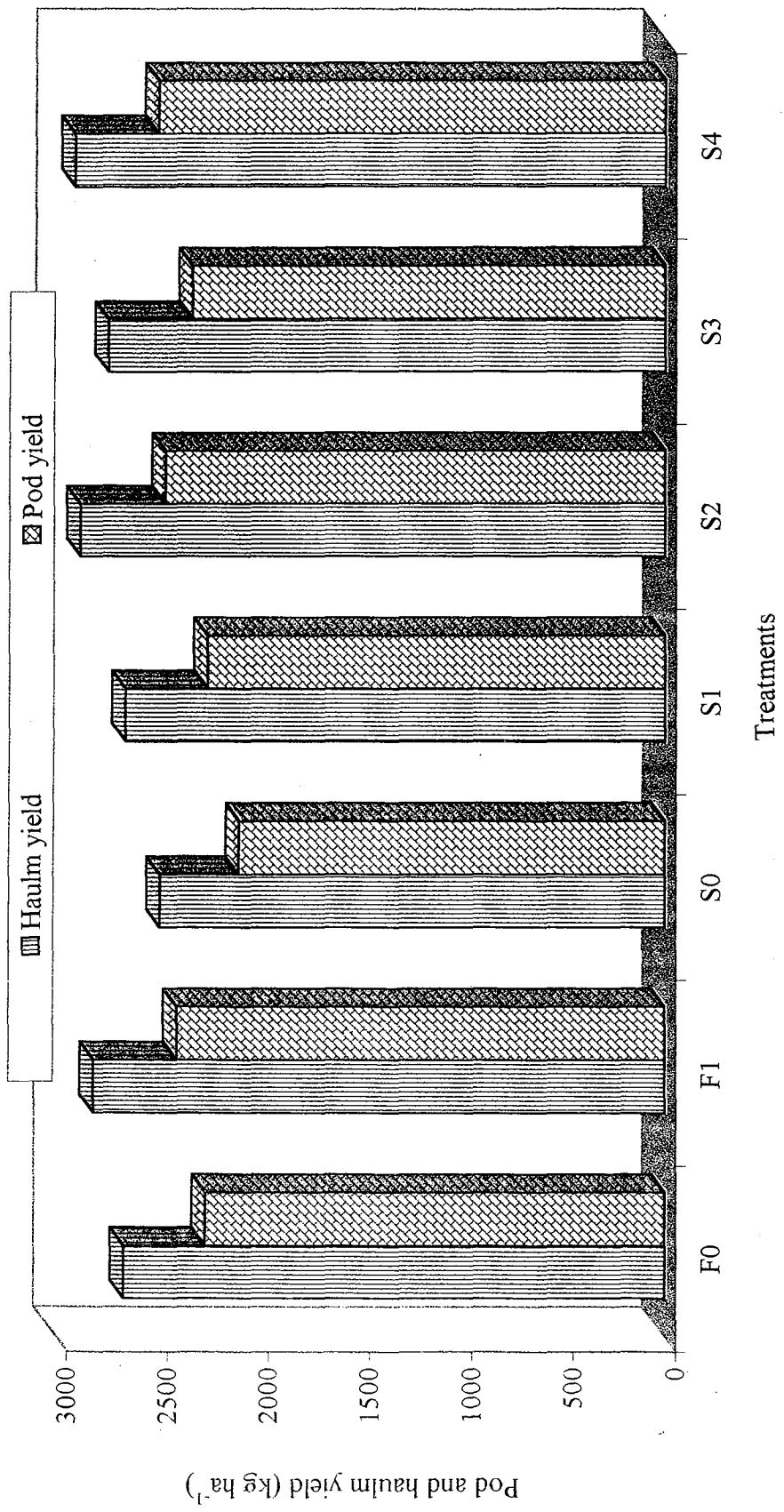
The total dry matter production increased with increased iron levels. The total dry matter production increased significantly by 14.7 per cent in the treatment receiving 50 kg pyrite per ha (S_4) followed by S_2 (10.0 %), S_3 (6.3 %) and S_1 (3.9 %) over control. Application of S_4 treatment found to be significantly superior over all other treatments. However, the lowest total dry matter production was recorded in the treatment receiving no iron (control). Tupatkar and Sonar (1995) concluded that, increasing rates of iron pyrite increased the dry matter accumulation in rice plant at all stages, number of tiller, grain yield and straw yield. This may be due to release of native iron from soil as a result of acidulation effect of pyrite as well as iron released by oxidation of iron pyrite.

5.3.2 Yield parameters

5.3.2.1 Yield parameters of groundnut

The yield determining components of groundnut crop such as number of pods per plant, 100-kernel weight, haulm yield and pod yield were significantly influenced by iron management practices in calcareous Vertisol (Tables 29-33, Fig.12 and plate 3 and 4).

Soil plus foliar spray of iron had marked influence on yield components of groundnut crop. The treatment F_1 found to be significantly increased the pod number per plant and 100-kernel weight by 10.1 and 6.3 per cent, respectively over the treatment receiving soil application of iron. The study of Mortvedt (1986), Patel *et al.* (1993) and Uday Kumar (2002) corroborate with the present study.



F₀: Soil application of Fe, F₁: Soil plus foliar application of Fe, S₀: No iron (control),
 S₁: 50 kg FeSO₄ ha⁻¹, S₂: 100 kg FeSO₄ ha⁻¹, S₃: 25 kg pyrite ha⁻¹, S₄: 50 kg pyrite ha⁻¹

Fig. 12. Direct effect of iron management practices on pod and haulm yield of groundnut



F_0S_0 : No iron (control)



F_0S_1 : 50 kg $FeSO_4$ ha⁻¹



F_0S_2 : 100 kg $FeSO_4$ ha⁻¹



F_0S_3 : 25 kg Pyrite ha⁻¹



F_0S_4 : 50 kg pyrite ha⁻¹

Plate 3. Direct effect of soil application of iron on yield parameters of groundnut



F₁S₀: Fe foliar only



F₁S₁: 50 kg FeSO₄ ha⁻¹ + Fe foliar



F₁S₂: 100 kg FeSO₄ ha⁻¹ + Fe foliar



F₁S₃: 25 kg Pyrite ha⁻¹ + Fe foliar



F₁S₄: 50 kg pyrite ha⁻¹ + Fe Foliar

Plate 4. Direct effect of soil plus foliar application of iron on yield parameters of groundnut

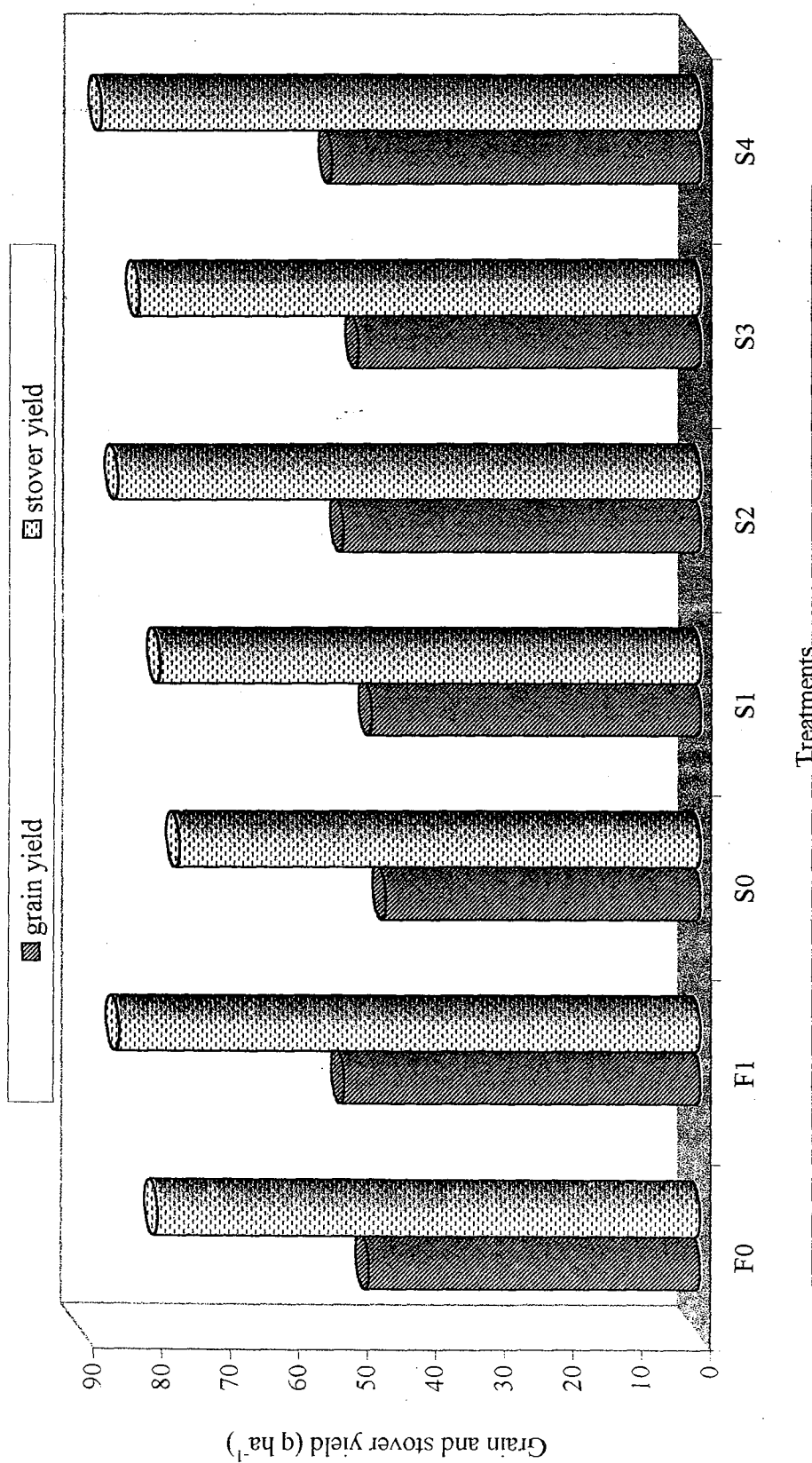
The addition of 50 kg pyrite per ha (S_4) significantly increased the pod number per plant by (53.7 %) and 100 kernel weight (16.2 %) over no Fe treatment followed by S_2 (34.4 and 12.1 %), S_3 (20.4 and 6.6 %) and S_1 (13.4 and 4.3 %), respectively. It was significantly superior over all other treatments with respect to pod number per plant. However, application of S_4 treatment recorded markedly higher 100-kernel weight and was significantly superior over S_1 and S_0 and on par with S_2 and S_3 . The lowest pod number per plant and 100-kernel weight was recorded in the treatment receiving no iron (S_0). Similar results were noticed by Hartzook *et al.* (1971) and Potdar (1994).

Soil and foliar spray of iron had significant influence on pod yield of groundnut. Application F_1 was significantly increased pod yield by (6.3 %) over the treatment receiving soil application of iron. This may be due to increased iron availability of iron in soil which is inherently deficient in available iron and higher concentration of iron in groundnut leaves due to foliar iron application. Thus, the overall effect of iron application on pod yield seems to be beneficial. Similarly, the response of groundnut to iron application was reported by several workers (Patil *et al.*, 1979, Singh and Dayal, 1992 and Singh *et al.* 1993).

Acid forming materials like pyrites as a source of Fe and S were used to increase availability of nutrients and to improve soil properties by reducing the pH and creating favorable conditions for the growth of the plants. Thus, the highest haulm yield and pod yield was obtained with the highest iron level (S_4). However, haulm and pod yield decreased with decrease in iron levels. The treatment S_4 increased the haulm yield by (17.2 %) and pod yield (19.4 %) followed by S_2 (15.9 and 17.5 %), S_3 (10.4 and 11.4 %) and S_1 (6.9 and 7.6 %), respectively over the treatment receiving no iron (S_0). The results of this investigation are in consonance with the findings of Potdar *et al.* (1995), Singh *et al.* (1995) and Sarkar (2000).

5.3.2.2 Yield parameters of maize

The yield determining components of maize crop such as grain number per cob, grain weight per cob, test weight, grain yield and stover yield were significantly influenced residual effect iron management practices in calcareous Vertisol (Tables 37-41, Fig.13 and plate 5 and 6).



F₀: Soil application of Fe, F₁: Soil plus foliar application of Fe, S₀: No iron (control), S₁: 50 kg FeSO₄ ha⁻¹, S₂: 100 kg FeSO₄ ha⁻¹, S₃: 25 kg pyrite ha⁻¹, S₄: 50 kg pyrite ha⁻¹

Fig. 13. Residual effect of iron management practices on grain and stover yield of maize



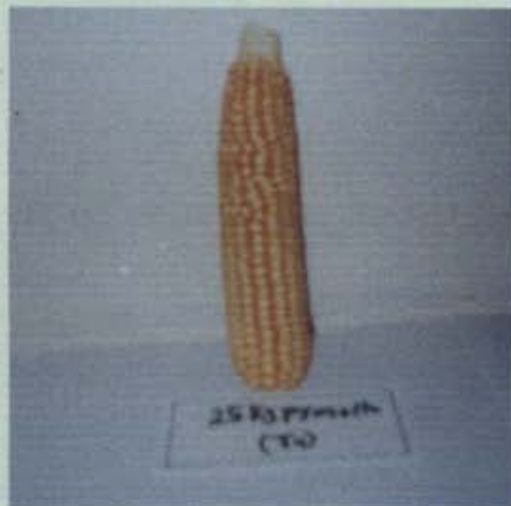
F_0S_0 : No iron (control)



F_0S_1 : 50 kg $FeSO_4$ ha⁻¹



F_0S_2 : 100 kg $FeSO_4$ ha⁻¹



F_0S_3 : 25 kg pyrite ha⁻¹



F_0S_4 : 50 kg pyrite ha⁻¹

Plate 5. Residual effect of soil application of iron on yield parameters of maize



F₁S₀: Fe foliar only



F₁S₁: 50 kg FeSO₄ ha⁻¹ + Fe foliar



F₁S₂: 100 kg FeSO₄ ha⁻¹ + Fe foliar



F₁S₃: 25 kg Pyrite ha⁻¹ + Fe foliar



F₁S₄: 50 kg Pyrite ha⁻¹ + Fe foliar

Plate 6. Residual effect of soil plus foliar application of iron on yield parameters of maize

Methods of iron application had distinctly influenced yield components of maize. The treatment F_1 significantly increased grain number per cob by (8.6 %), grain weight per cob (26.7 %) and test weight (21.0 %) and it was significantly superior over soil application of iron (F_0). Foliar spray of Fe increased its assimilation in plants and grains, singly or in combination with soil application because of more availability of iron through leaves of plant resulted in increase grain yield of maize.

With respect to the residual effect of applied iron levels, the highest per cent increase in grain number per cob (17.1 %), grain weight per cob (35.3 %) and test weight (22.6 %) was recorded in the treatment S_4 over S_0 followed by S_2 (12.2, 30.1 and 17.9 %), S_3 (9.0, 23.3 and 9.9 %) and S_1 (5.6, 17.8 and 5.9 %), respectively. The lowest grain number per cob, grain weight per cob and test weight recorded in the treatment receiving no iron (S_0). This might be due to higher yield components that are directly responsible for grain yield appeared to have been determined by physiological characters, both during vegetative and reproductive phase of the crop growth. Similar results of these investigations were observed by Savithri and Sree Ramulu (1980) and Sakal *et al.* (1982).

Iron applications as soil along with foliar spray had profound influence grain and stover yield of maize. Application of F_1 treatment was significantly increased the grain yield by (7.5 %) and stover yield (7.2 %) over treatment (F_0). The lowest grain and stover yield registered in F_0 treatment. The results are in consonance with the finding of Nagasundram *et al.* (1986) in sorghum and Ramaswami (1992) in sugarcane. The differences in the grain yield were largely because of variations in the yield components viz., grain number per cob, grain weight per cob and 100-kernel weight.

Similarly, the highest per cent increase in grain yield (17.7 %) and stover yield (15.4 %) was obtained with the highest iron level (S_4) over control as compare to S_2 (13.8 and 12.0 %), S_3 (9.1 and 8.0 %) and S_1 (4.6 and 3.9 %), respectively. The residual effect of application of S_4 was on par with S_2 and significantly superior over rest of the treatments with respect to grain yield. However, stover yield increased significantly due to application of S_4 treatment over S_1 and S_0 and on par with S_2 and S_3 . The lowest grain and stover yield was recorded in the treatment receiving no iron (control). Tupatkar and Sonar (1995) stated that, increasing rates of iron pyrite increased the dry matter accumulation in rice plant at all stages, number of tiller, grain and straw yield. Also, increasing rates of pyrite gradually increased DTPA-Fe in soil at all the growth stages of rice. This may be

due to release of native iron from soil as a result of acidulation effect of pyrite as well as iron released by oxidation of iron pyrite. This might be due to various physiological characters in plants, one can exploit full genetic potential of a crop, when it is grown under favorable conditions and well balanced supply of nutrients to the crop. The results of the present study are in conformity with the findings of Sharma and Lal (1992) in wheat and Srinivas and Srinivas Raju (1998) in maize.

5.3.3 Quality parameters

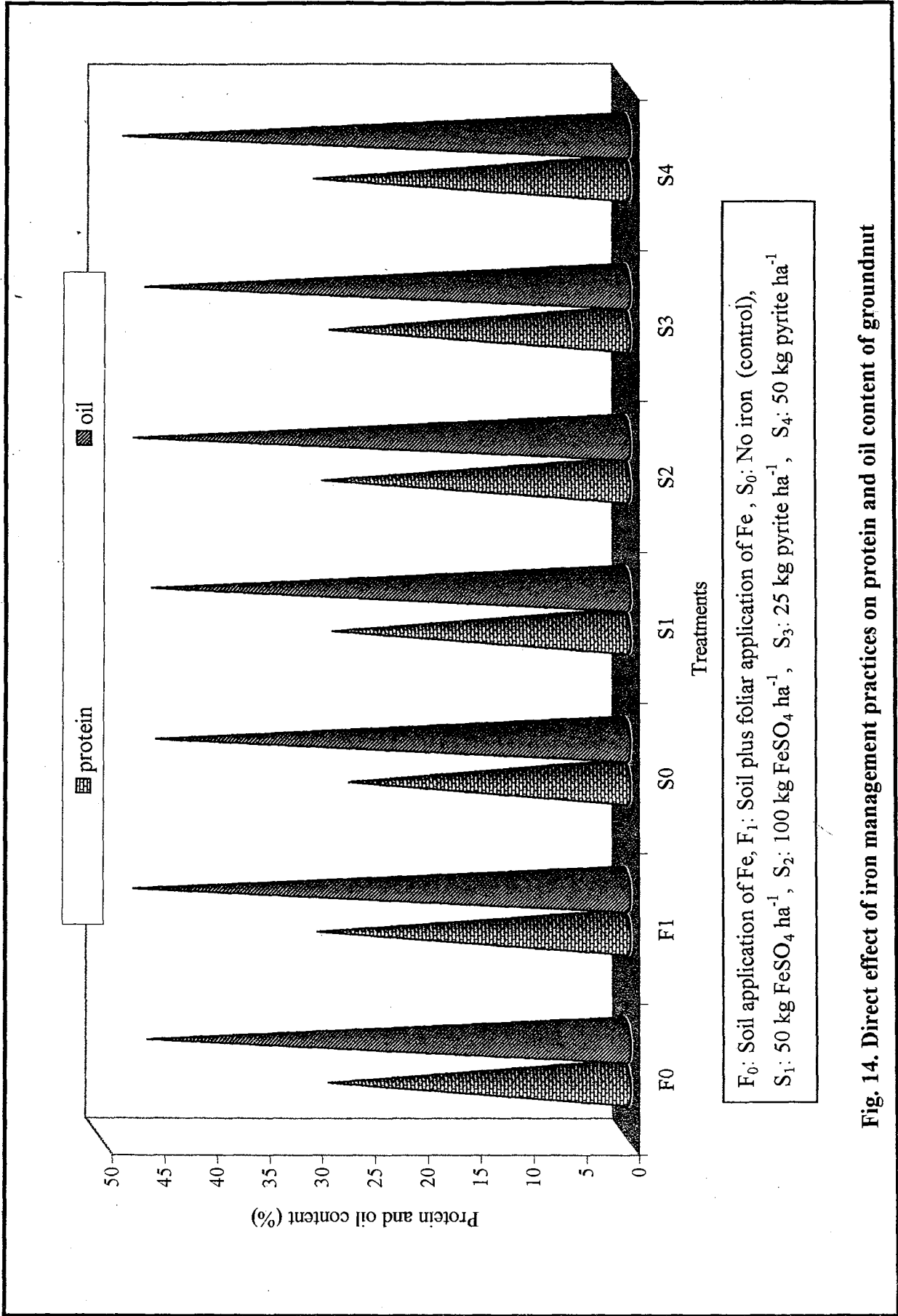
5.3.3.1 Quality parameters of groundnut

Quality parameters of groundnut kernels like protein and oil content increased significantly due to direct effect of iron management practices in calcareous Vertisol (Table 43 and Fig.14)

Methods of iron application had significant influence on quality parameters of groundnut kernels. Application of F_1 treatment significantly increased protein content by (3.8 %) and it was significantly superior over F_0 . The lower protein content was registered in the treatment receiving soil application of iron only (F_0). The results of these investigations are in consonance with the finding of Channal (1978) in sunflower, Patil *et al.* (1979) in groundnut and Ravi (2004) in safflower.

Significant differences were manifested in the protein content of groundnut kernels due to applied iron levels. The treatment S_4 resulted in increased protein content by (13.4 %) over S_0 followed by S_2 (10.5 %), S_3 (7.0 %) and S_1 (5.6 %) and it was on par with S_2 and significantly superior over rest of the treatments. The lowest protein content was recorded in the treatment receiving no iron (control). It could be due to iron and sulphur role in enzyme activities and amino acids synthesis (Methionine, Cysteine and Cystine). It helps in conversion of these amino acids to high quality protein. This confirms the findings of Patil (1975), Jambunathan *et al.* (1992) and Maya *et al.* (1999 b).

Application of iron as soil along with foliar spray had marked influence on oil content of groundnut kernels. The treatment F_1 was recorded the higher oil content and resulted in increased oil content by (3.1 %) and it was significantly superior over soil application of iron (F_1). Obviously, there was a significant increase in the oil content in groundnut kernels due to iron application. This might be due to higher concentration of



F₀: Soil application of Fe, F₁: Soil plus foliar application of Fe, S₀: No iron (control),
 S₁: 50 kg FeSO₄ ha⁻¹, S₂: 100 kg FeSO₄ ha⁻¹, S₃: 25 kg pyrite ha⁻¹, S₄: 50 kg pyrite ha⁻¹

Fig. 14. Direct effect of iron management practices on protein and oil content of groundnut

iron and sulphur in groundnut leaves due to higher levels of iron application to soil as well as foliar application. The results are in conformity with the findings of Krishnappa *et al.* (1994) in groundnut and Ravi (2004) in sunflower.

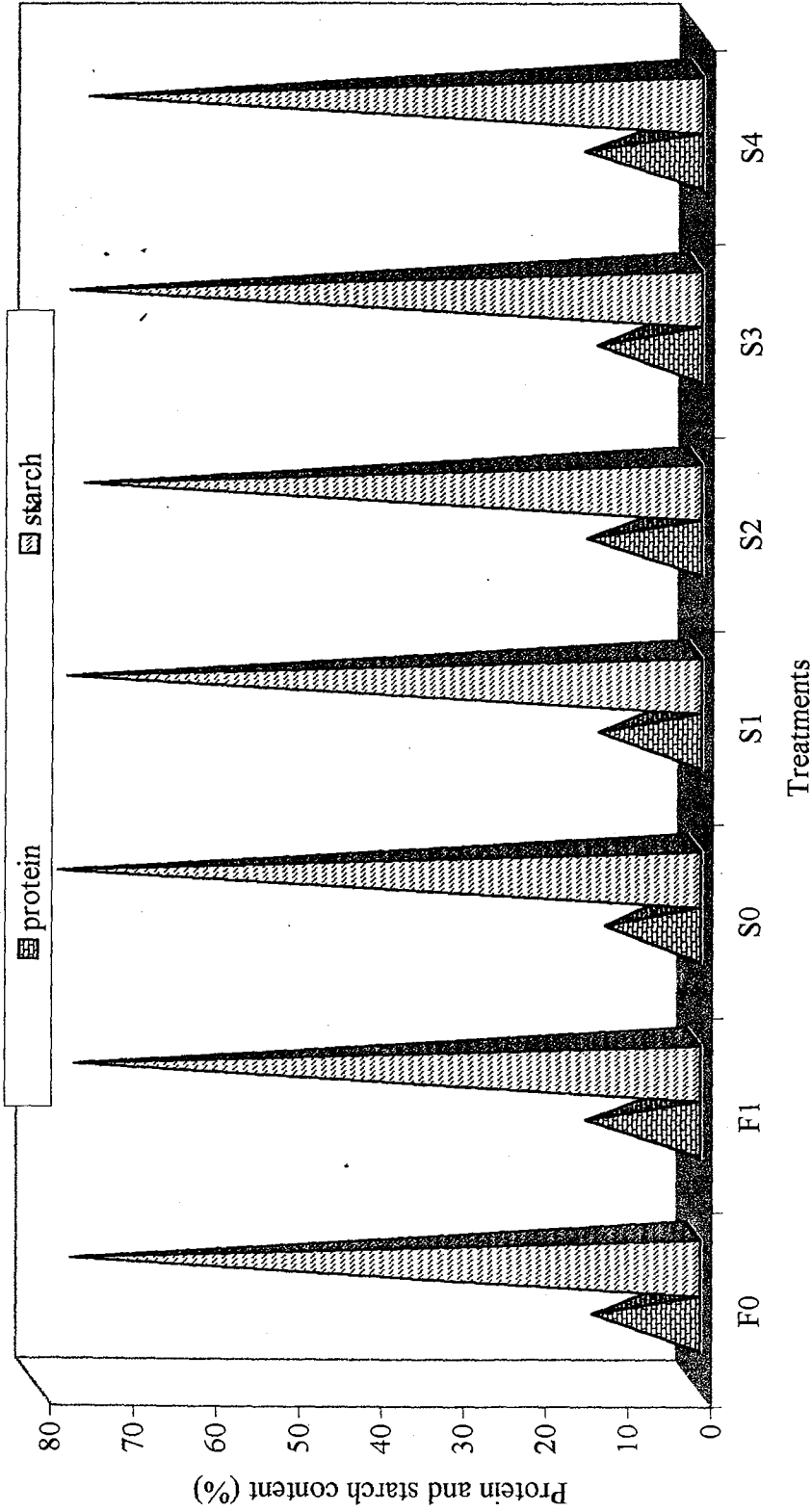
Similarly, the highest per cent increase in oil content of groundnut kernels (7.5 %) was obtained with the highest iron level (S_4) over S_0 and followed by S_2 (4.9 %), S_3 (2.6 %) and S_1 (1.1 %). However, oil content decreased with decrease in iron levels. Application of S_4 treatment was on par with S_2 and S_3 and significantly superior over S_1 and S_0 . The lowest oil content was registered in the treatment receiving no iron (S_0). Acid forming material like pyrites as a source of Fe (45 %) and S (22 %) was used to improve the quantity parameters of groundnut. This may be due to the interaction effect between iron and sulphur. Iron and sulphur involves in enzymes activities, which aid biochemical reaction within the plant and in the formation of glucosides and glucosinolates and sulphhydryl – linkages and thus helps in increasing oil content of groundnut. Similar results were recorded by Poleshi (1984) and Singh and Chaudhari (1997).

5.3.3.2 Quality parameters of maize

Protein content of maize kernels markedly increased due to residual effect of iron application in calcareous Vertisol (Table 45 and Fig.15).

Soil plus foliar spray of iron had markedly influenced protein content of maize kernels. Application of F_1 treatment recorded the higher increase in protein content (6.7 %) and it was significantly superior over F_0 . The lower protein content was registered in F_0 treatment. This may be due to higher concentration of iron in maize leaves as a result of higher levels of iron application to soil. Finding of Patil *et al.* (1979) in wheat grains corroborate with these results.

It is relevant to discuss at this juncture, the influence of the residual effect of applied iron on protein content of maize kernels. The treatment S_4 recorded significant increase in protein content by (25.0 %) over S_0 as compare S_2 (20.4 %), S_3 (10.2 %) and S_1 (8.2 %) and it was on par with S_2 and significantly superior over rest of the treatments. The lowest protein content was recorded in S_0 treatment (control). It could be due to higher content of iron and sulphur in applied iron sources especially iron pyrite and their role in enzyme activities and amino acids synthesis. Thus, the residual effect of applied iron was found to be beneficial on protein content of maize kernels.



F₀: Soil application of Fe, F₁: Soil plus foliar application of Fe, S₀: No iron (control),
 S₁: 50 kg FeSO₄ ha⁻¹, S₂: 100 kg FeSO₄ ha⁻¹, S₃: 25 kg pyrite ha⁻¹, S₄: 50 kg pyrite ha⁻¹

Fig. 15. Residual effect of iron management practices on protein and starch content of maize

5.3.4 Biochemical parameters

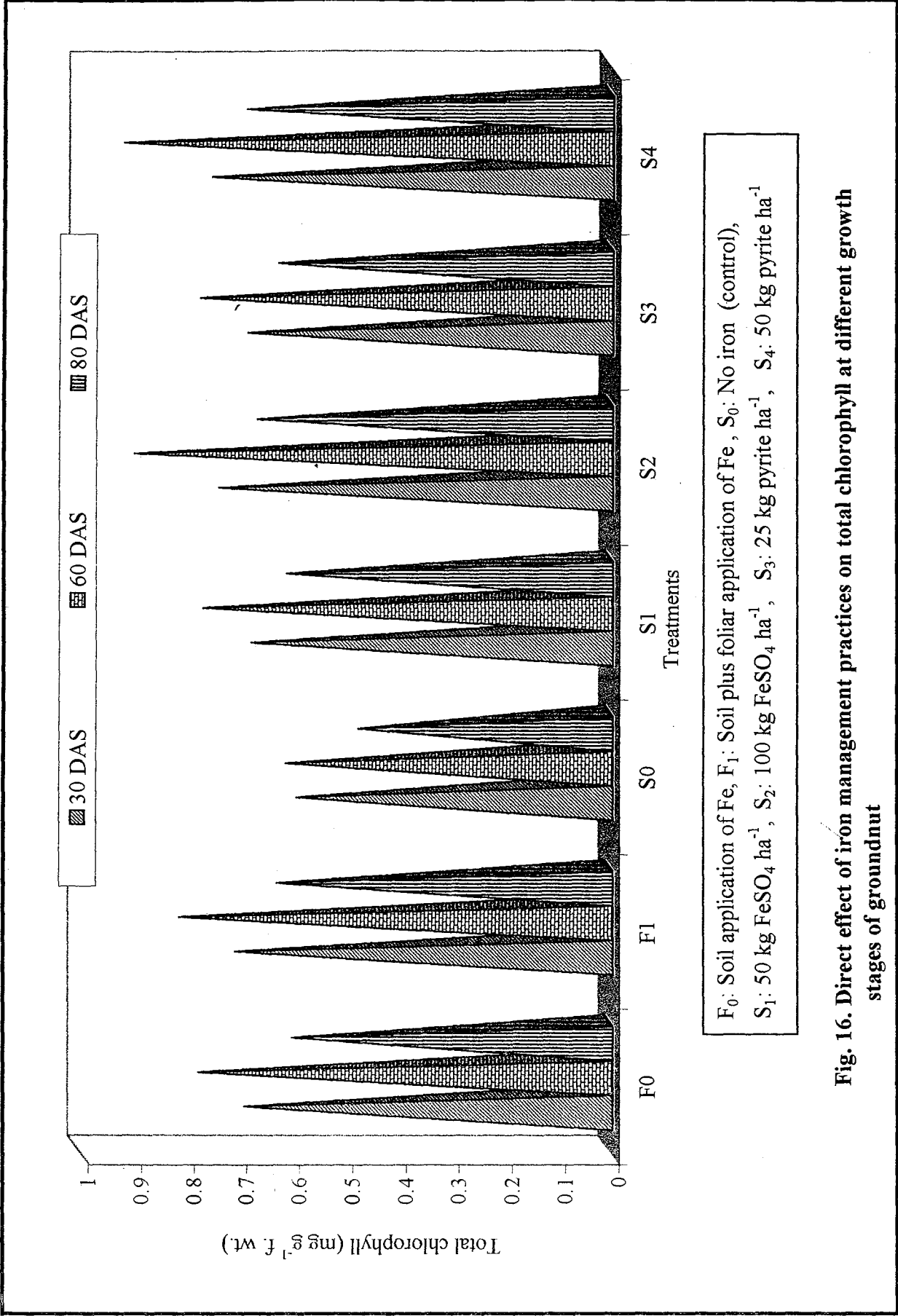
5.3.4.1 Biochemical parameters of groundnut

Although iron is not an integral part of chlorophyll molecule, it is essential for its synthesis, normally 60-80 per cent of iron content of leaves is found in chloroplast. Iron chlorosis refers to the yellowing of plants due to lack of chlorophyll. The severity of chlorosis depends on the extent of iron deficiency in the plant.

In the present study, it was observed that, the chlorophyll content at 60 DAS and harvest and organic acids at 60 DAS markedly differed due to iron application methods and iron levels in groundnut. (Tables 46 and 47 and Fig.16 and 17).

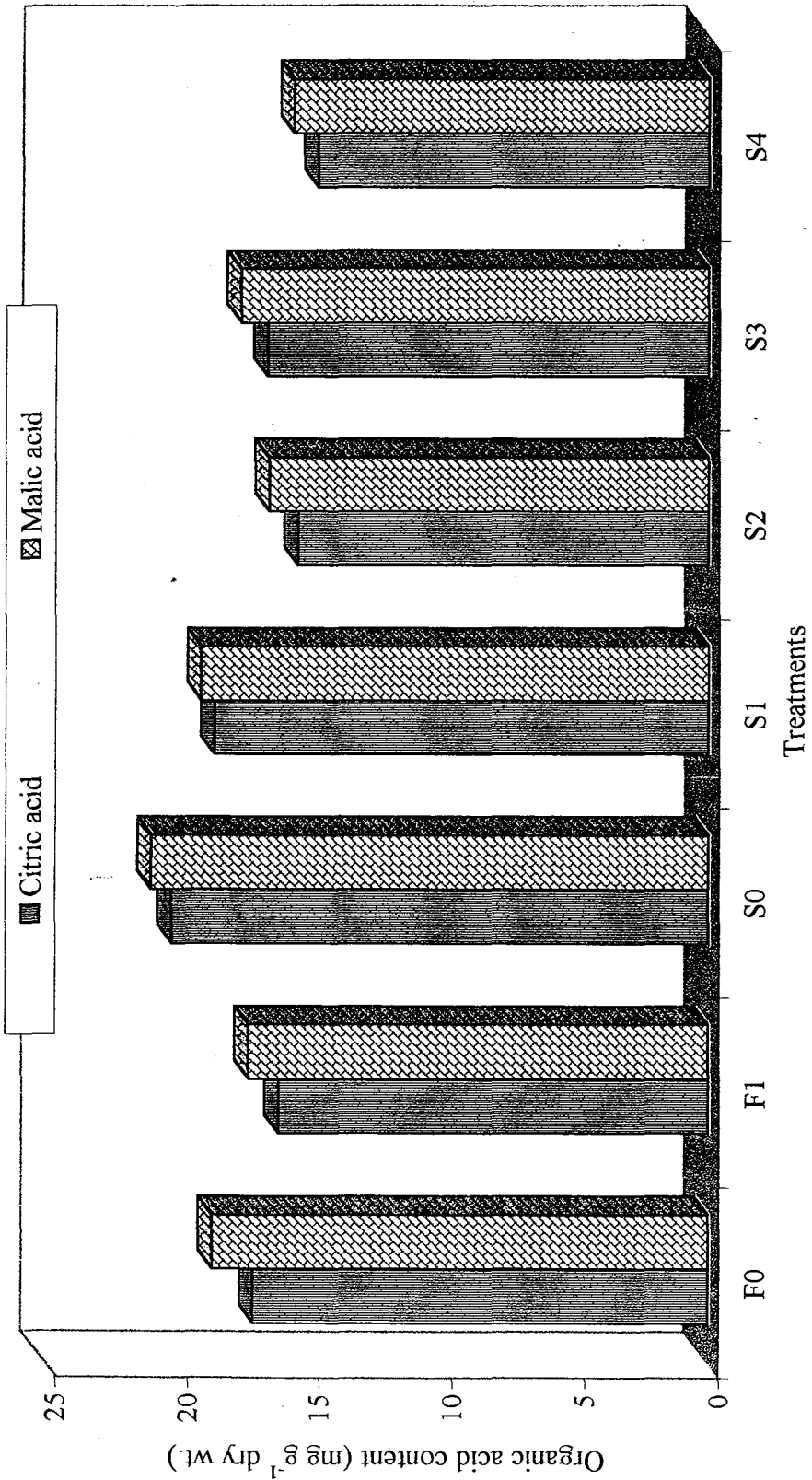
With respect to chlorophyll content, the variation in the levels of applied iron to soil as well as foliar spray distinctly influenced chlorophyll content of groundnut leaves. The treatment F₁ significantly increased the chlorophyll content by (4.8 and 5.1 %) over soil application of iron only over a period of crop growth. The beneficial effect of iron application to soil along with foliar spray increased iron availability in soil and ferrous iron uptake by plant leaves resulted in increased chlorophyll formation and various growth parameters of groundnut. The findings of Singh *et al.* (1995) and Biradar (1996) in groundnut lend support this study.

The chlorophyll content significantly increased by (50.7 and 45.2 %) due to application of S₄ treatment followed by S₂ (47.0 and 40.6 %), S₃ (26.8 and 32.3 %) and S₁ (25.7 and 28.7 %) over control at 60 and 80 DAS, respectively. The lowest chlorophyll content was obtained in control treatment. Application of 50 kg pyrite per ha (S₄) was considered as a multipurpose soil amendment, an acidifier, a plant nutrient mobilizer and a co-fertilizer to supply sulphur and iron to plants in soils deficient in these nutrients. Thus, application of 50 kg pyrite per ha might have helped in formation of chlorophyll, respiration and enzymatic activities resulting in higher photosynthesis. Singh *et al.* (1993) studied the effect of iron application on groundnut varieties grown in calcareous soil and reported that, iron application under chlorotic condition brought about 24-80 per cent increase in leaf chlorophyll content during active growth stage. The results observed in this study corroborate the findings of earlier worker.



F₀: Soil application of Fe, F₁: Soil plus foliar application of Fe, S₀: No iron (control),
 S₁: 50 kg FeSO₄ ha⁻¹, S₂: 100 kg FeSO₄ ha⁻¹, S₃: 25 kg pyrite ha⁻¹, S₄: 50 kg pyrite ha⁻¹

Fig. 16. Direct effect of iron management practices on total chlorophyll at different growth stages of groundnut



F₀: Soil application of Fe, F₁: Soil plus foliar application of Fe, S₀: No iron (control),
 S₁: 50 kg FeSO₄ ha⁻¹, S₂: 100 kg FeSO₄ ha⁻¹, S₃: 25 kg pyrite ha⁻¹, S₄: 50 kg pyrite ha⁻¹

Fig. 17. Direct effect of iron management practices on organic acid content at 60 days after sowing of groundnut

Similarly, the organic acids content (citric acid and malic acid) in groundnut leaves varied significantly due to foliar iron application and soil iron application at 60 DAS of groundnut (Table 47 and Fig.17).

The accumulation of various organic compounds, especially organic acids, in roots and shoots, as well as their presence in limited amounts in nutrient solutions of plants growing under iron stress condition has been postulated to account for species differences in iron use efficiency, pH changes, chelation of iron, and transport in the xylem. Iljin (1951) found higher concentration of amino acids and organic acids in chlorotic leaves of grape plants than in normal leaves.

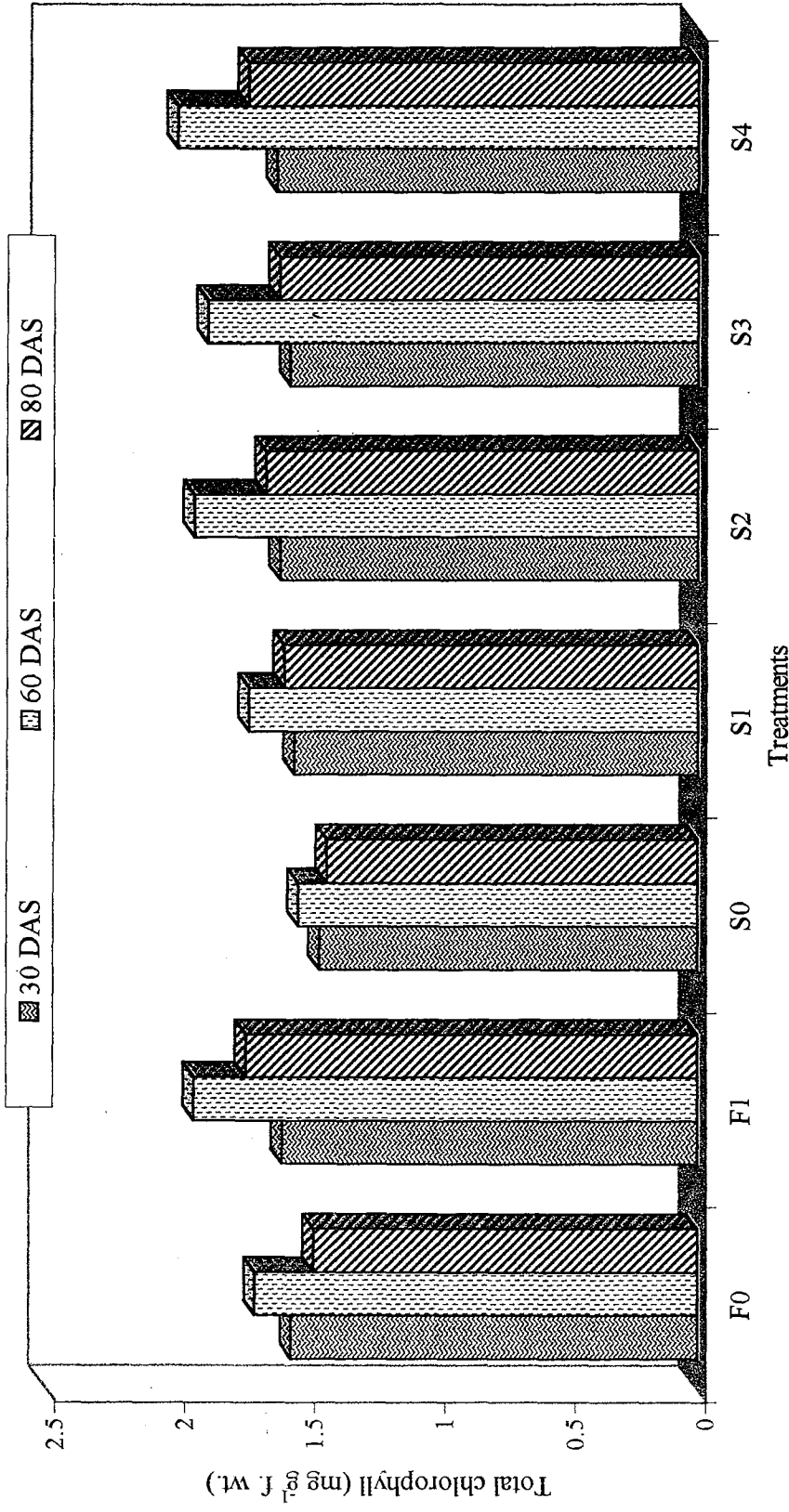
Soil plus foliar spray of iron had significant influence on citric acid and malic acid content at 60 DAS of groundnut. The treatment F_1 registered significant decrease in citric acid and malic acid content by (5.5 %) and (7.3 %) respectively over soil application of iron treatment (F_0). It was significantly lower than F_0 .

The accumulation of citric acid and malic acid decreased with increase iron levels, the citric acid and malic acid content decreased significantly by (27.9 %) and (34.3 %) respectively in the S_4 treatment over control. It was on par with S_2 and significantly lower over rest of the treatments. However, the highest citric acid and malic acid content was recorded in the treatment receiving no iron (control). The decreasing trend in citric acid and malic acid content due to iron application may be attributed to the increased availability of iron in an inherently deficient soil and the process of its absorption and translocation in the plant. Similar observations were made by Su and Miller (1961) in soybean and Pich and Scholl (1992) in beans.

5.3.4.2 Biochemical parameters of maize

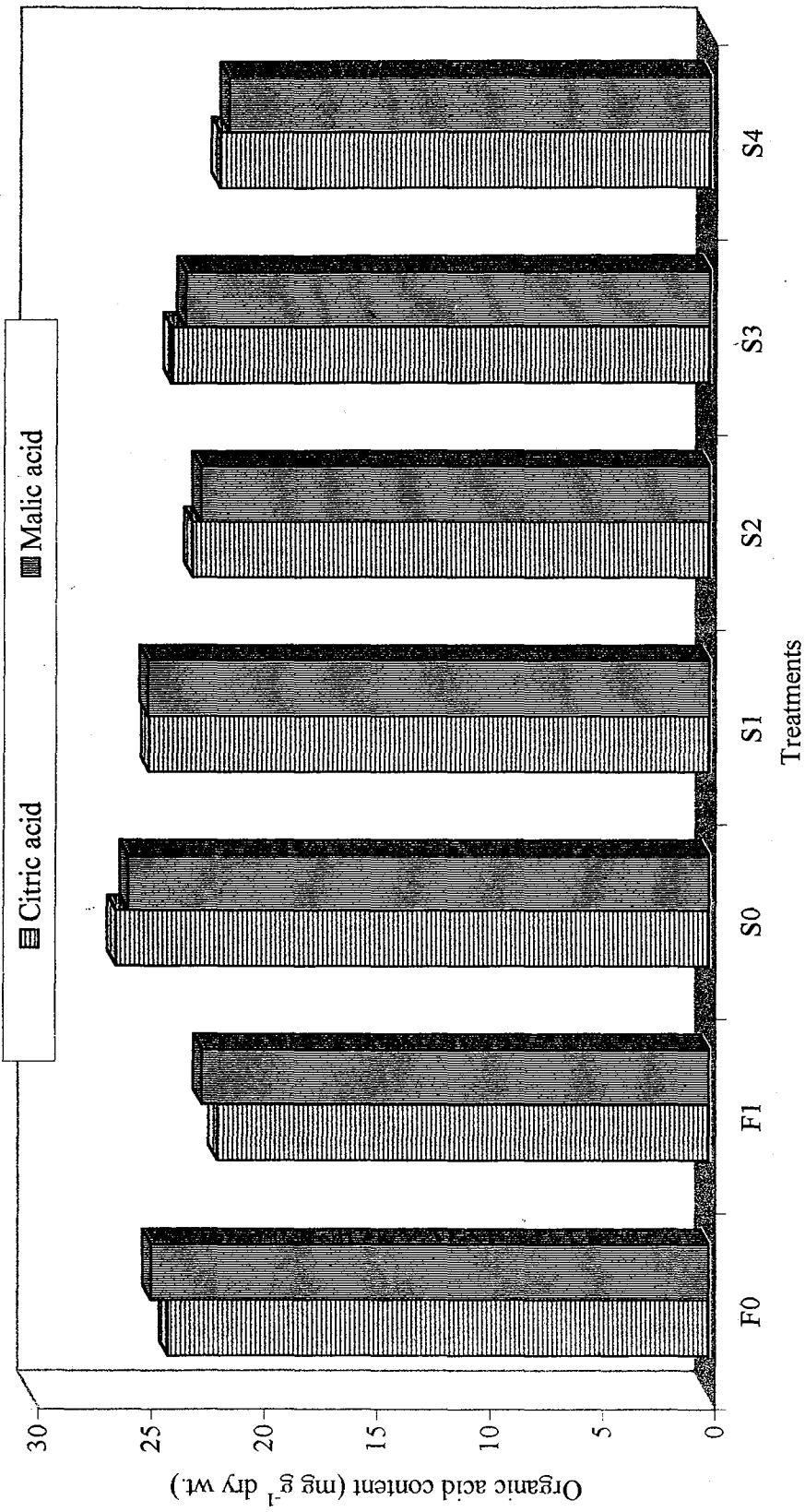
The results of the present investigation revealed that the residual effect of iron management practices had significant influence on the leaf chlorophyll content at 60 DAS and at harvest and organic acids at 60 DAS of maize in calcareous Vertisol (Tables 48 and 49 and Fig.18 and 19).

Iron application methods had distinctly increased the chlorophyll content of maize. Application of F_1 treatment registered significant increased in total chlorophyll content by



F₀: Soil application of Fe, F₁: Soil plus foliar application of Fe, S₀: No iron (control),
 S₁: 50 kg FeSO₄ ha⁻¹, S₂: 100 kg FeSO₄ ha⁻¹, S₃: 25 kg pyrite ha⁻¹, S₄: 50 kg pyrite ha⁻¹

Fig. 18. Residual effect of iron management practices on total chlorophyll at different growth stages of maize



F₀: Soil application of Fe, F₁: Soil plus foliar application of Fe, S₀: No iron (control), S₁: 50 kg FeSO₄ ha⁻¹, S₂: 100 kg FeSO₄ ha⁻¹, S₃: 25 kg pyrite ha⁻¹, S₄: 50 kg pyrite ha⁻¹

Fig. 19. Residual effect of iron management practices on organic acid content at 60 days after sowing of maize

(13.9 and 17.9 %) over the treatment receiving soil application of iron only over a period of crop growth. It was significantly superior over F_0 .

Regarding to the residual effect of iron levels, application of S_4 treatment recorded significantly increased in chlorophyll content by (30.9 and 21.6 %) at 60 and 80 DAS over control (S_0) followed by S_2 (26.4 and 23.8 %), S_3 (23.1 and 18.7 %) and S_1 (12.7 and 11.7 %). The lowest chlorophyll content was obtained in the treatment receiving no iron (S_0). This might be due to various physiological characters in plants; one can exploit full genetic potential of a crop resulting increased chlorophyll synthesis by maize. This confirms the finding of Katyal and Sharma (1980) in rice and Romheld and Marschner (1990) in graminaceous plants.

With respect to the organic acids (citric acid and malic acid) content in maize leaves, the variation due to the residual effect of applied iron was significant at 60 DAS (Table 49 and Fig.19).

Soil plus foliar spray of iron had significant influence on citric acid and malic acid content at 60 DAS of groundnut. The F_1 treatment registered marked decrease in citric acid and malic acid content (9.0 %) and (9.1 %), respectively over no Fe foliar spray treatment. It was significantly lower than F_0 .

The accumulation of citric acid and malic acid decreased with increase iron levels, the significant decrease in citric acid (19.4 %) and malic acid content (16.9 %) was recorded in the treatment S_4 as compared to S_2 (14.6 and 12.4 %), S_3 (11.2 and 9.7 %) and S_1 (7.5 and 3.3 %) over no iron treatment (S_0), respectively. However, the highest citric acid and malic acid content was recorded in the treatment receiving no iron (control). The decreasing trend in citric acid and malic acid content with iron application might be due to the role of organic acids in iron translocation by plant. The results of the present investigation are in accordance with the finding of Decock and Morrison (1958) and Bergmann (1992).

5.3.5 Nutrient content and uptake by plants

5.3.5.1 Major nutrient content and uptake by groundnut

Nutrients play a major role in increasing growth and ultimately the yield. The data on nutrient content in whole plant (N, P and K) did not differ significantly due to application of iron at harvest stage of groundnut (Table 50).

Whereas, the data on nutrient uptake indicate that methods of iron application and iron levels significantly increased the uptake of nitrogen and potassium. However, phosphorous did not differ significantly at harvest stage of groundnut.

Application of iron as soil plus foliar spray had significantly increased nitrogen and potassium uptake by groundnut. The plots receiving F_1 treatment registered increase in nitrogen and potassium uptake by (2.5 %) over soil application of iron only (F_0). It was significantly superior over F_0 . This trend of greater uptake of nitrogen and potassium in the treatments receiving soil plus foliar application of iron could be due to increased iron availability in soil and the direct uptake of ferrous iron by leaves resulting in higher production of chlorophyll, dry matter and higher uptake of nitrogen and potassium by plants. These findings of Aiyer (1984) in bengalgram lend support this study.

In respect of iron levels, the highest nitrogen uptake and potassium uptake was recorded in plots applied with 50 kg pyrite per ha (S_4) and it was significantly superior over all other treatments. Application of S_4 treatment increased nitrogen uptake and potassium uptake by (27.7 %) and (27.6 %) over control (S_0), respectively. The lowest nitrogen uptake and potassium uptake was obtained in the treatment receiving no iron (control). This may be due to increased total dry matter production, yield and yield components viz. pod number per plant and 100-kernel weight of groundnut. These results observed in this study corroborate the findings of Bansal and Singh (1975) in cowpea and Singh *et al.* (1995).

5.3.5.2 Major nutrient content and uptake by maize

The data on nutrient content (N, P and K) in whole plant did not differ significantly due to the residual effect of iron application methods and iron levels at harvest stage of maize. Whereas, the data on nutrient uptake indicate that the residual effect of iron application methods and iron levels significantly increased the uptake of nitrogen. However, phosphorus, and potassium found to be non-significant at harvest stage of maize (Table 51).

The highest nitrogen uptake was noticed in plots receiving 50 kg pyrite per ha (S_4) and it was on par with S_2 and S_3 and significantly superior over rest of the treatments. Application of S_4 treatment increased nitrogen uptake by (21.1 %) over control (S_0)

followed by S₂ (17.9 %), S₃ (15.9 %) and S₁ (6.7 %). The lowest nitrogen uptake was obtained in the treatment receiving no iron (control). This may be due to increased total dry matter production, yield and yield components of maize.

5.3.5.3 Micronutrients content and uptake by groundnut

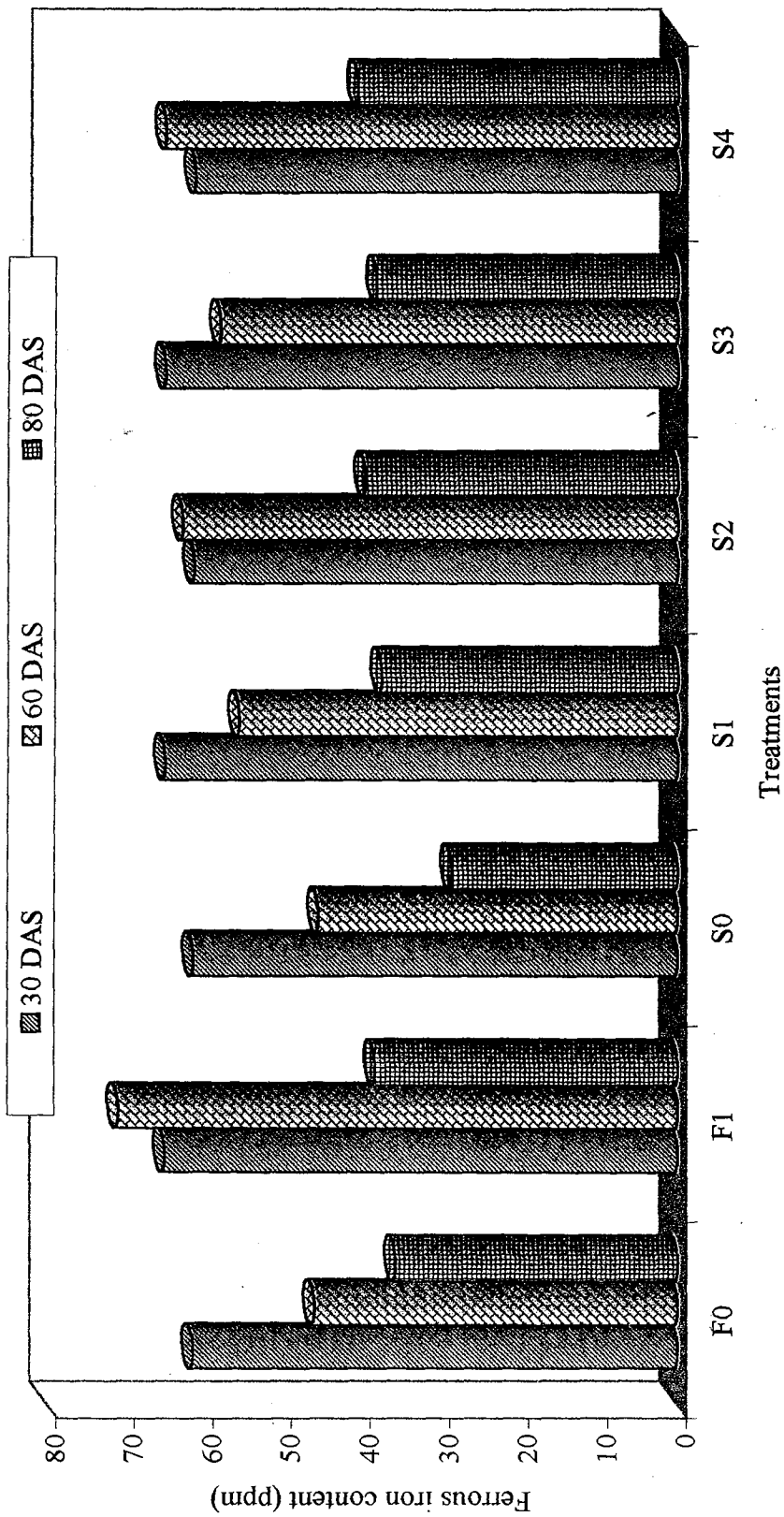
The data on micronutrients content in whole plant (Zn, Mn and Cu) did not differ significantly due to application of iron at groundnut harvest. However, total iron content and ferrous iron content found to be significant due to iron application methods and applied iron levels at different growth stages of groundnut in calcareous Vertisol.

Whereas, the data on micronutrients uptake indicate that the direct effect of iron application methods and iron levels significantly increased the uptake of manganese and copper at harvest stage of groundnut and iron at different growth stages of the crop. However, zinc did not differ significantly at harvest stage of groundnut crop

5.3.5.3.1 Ferrous iron (ppm)

Foliar spray distinctly increased ferrous iron content of groundnut. The plots receiving F₁ increased ferrous iron content by (54.3 and 7.3 %) over the treatment of soil application of iron (F₀) at 60 and 80 DAS, respectively. It was significantly superior over F₀. This trend of higher ferrous iron in the treatments receiving soil plus foliar application of iron could be due to increased iron availability in soil and the direct uptake of ferrous iron by leaves resulting in higher production of chlorophyll, dry matter and higher total iron content of plants. Rashid and Din (1992) in chickpea and Rashid *et al.* (1997) in groundnut recorded similar results (Table 52 and Fig.20).

Among iron levels, application of treatment S₄ registered increased in ferrous iron content by (43.0 and 42.0 %) as compare to S₂ (37.9 and 38.2 %), S₃ (27.6 and 33.3 %) and S₁ (22.1 and 30.9 %) over the treatment receiving no iron (S₀) at 60 and 80 DAS, respectively. It was on par with S₂ and significantly superior over rest of the treatments. This may be due to increased total dry matter production, yield and yield components of groundnut as result of increased iron availability in an inherently deficient soil by high acidulation effect of pyrite and the process of its absorption and translocation in the plant. Similar observations were made by Rao *et al.* (1987), Kulkarni *et al.* (1994) and Chandrashaker (2002).



F₀: Soil application of Fe, F₁: Soil plus foliar application of Fe, S₀: No iron (control),
 S₁: 50 kg FeSO₄ ha⁻¹, S₂: 100 kg FeSO₄ ha⁻¹, S₃: 25 kg pyrite ha⁻¹, S₄: 50 kg pyrite ha⁻¹

Fig. 20. Direct effect of iron management practices on ferrous iron content at different growth stages of groundnut

5.3.5.3.2 Total iron content (ppm)

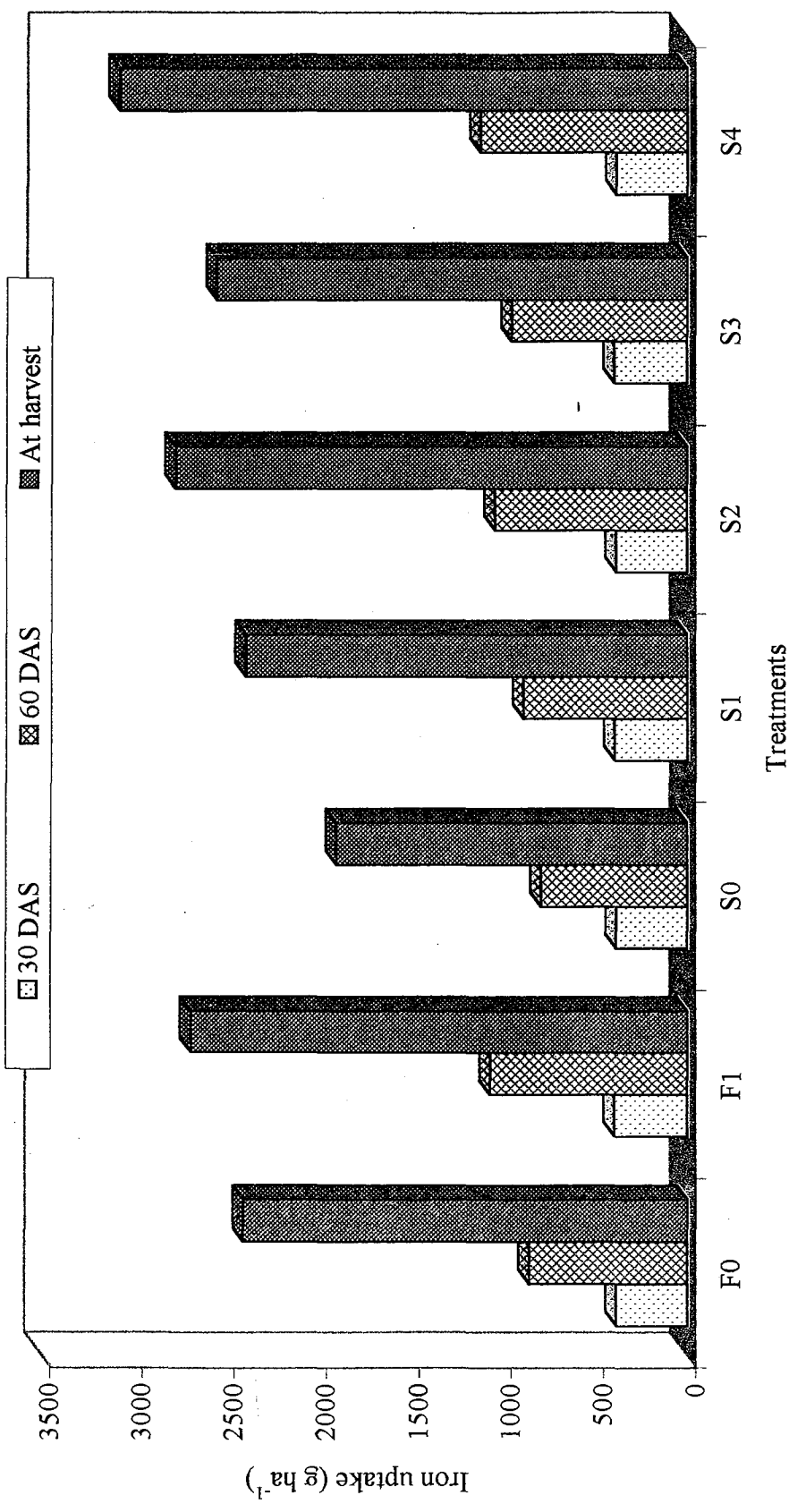
Application of iron as soil along with foliar spray significantly influence on total iron content of groundnut. The plots receiving F_1 registered markedly increased total iron content by (16.2 and 9.6 %) over soil application of iron at 60 DAS and harvest, respectively. This trend of higher total iron content in the treatments receiving soil plus foliar application of one per cent ferrous sulphate could be due to increased iron availability in soil and the direct uptake of ferrous iron by leaves resulting in higher production of chlorophyll, dry matter and higher total iron content of plants. The results of present investigation are in accordance with the reports of Basappa (1990) in groundnut and Djendo (1972) in sunflower (Table 53).

The total iron content increased significantly by (16.5 and 36.4 %) in the treatment S_4 as compare to S_2 (14.5 and 31.7 %), S_3 (11.6 and 26.4 %) and S_1 (9.0 and 22.0 %) over no iron treatment (S_0) at 60 DAS and harvest, respectively. The lowest total iron content obtained in the treatment receiving no iron. This may be due to increased total dry matter production, yield and yield components of groundnut as result of increased iron availability in an inherently deficient soil by high acidulation effect of pyrite and the process of its absorption and translocation in the plant.

5.3.5.3.3 Iron uptake

Methods of iron application significantly increased iron uptake by groundnut. The plots receiving F_1 treatment registered significantly higher iron uptake (25.4 and 12.0 %) over the treatments of soil application of iron only at 60 DAS and at harvest, respectively. This trend of higher uptake of iron in the treatments receiving iron as soil as well as foliar application of one per cent ferrous sulphate could be due to increased iron availability in soil and the direct uptake of ferrous iron by leaves resulting in higher production of chlorophyll, dry matter and higher uptake of iron by groundnut (Table 53 and Fig.21).

Among iron levels, addition of 50 kg pyrite per ha (S_4) recorded the highest per cent increase of iron uptake (42.5 and 62.3 %) as compared to T_3 (32.0 and 46.0 %), T_4 (20.4 and 34.4 %) and T_2 (12.4 and 25.8 %) over the iron uptake was obtained in the treatment receiving no iron (S_0) at 60 DAS and at harvest, respectively. This may be due to increased total dry matter production, yield and yield components viz. pod number per



F₀: Soil application of Fe, F₁: Soil plus foliar application of Fe, S₀: No iron (control),
 S₁: 50 kg FeSO₄ ha⁻¹, S₂: 100 kg FeSO₄ ha⁻¹, S₃: 25 kg pyrite ha⁻¹, S₄: 50 kg pyrite ha⁻¹

Fig. 21. Direct effect of iron management practices on iron uptake at different growth stages of groundnut

plant and 100-kernel weight of groundnut as result of increased iron availability in soil. Similar results were observed by Marschner and Romheld (1995) and Sarkar (2000).

5.3.5.3.4 Manganese and Copper uptake

Methods of iron application had significantly increased manganese and copper uptake by groundnut. The plots receiving F_1 treatment increased manganese and copper uptake by 2.5 and 2.2 per cent, respectively over soil application of iron only and it was significantly superior over F_0 . This trend of higher uptake of manganese and copper in the treatments receiving soil plus foliar application of one per cent ferrous sulphate could be due to acidulation effect of soil application of iron resulted in increasing manganese and copper availability in soil and uptake by plant resulting in higher production of chlorophyll and dry matter by plants. The results are in agreement with the finding of Biradar (1996) (Table 54).

The S_4 treatment recorded the highest manganese and copper uptake and it was markedly superior over S_2 , S_3 and S_1 and increased the uptake by (19.3 and 20.2 %), respectively. The lowest manganese and copper uptake obtained in the treatment receiving no iron (S_0). This may be due to increased total dry matter production, yield and yield components *viz.* pod number per plant and 100-kernel weight of groundnut as result of increased manganese and copper availability in soil due to acidulation effect of applied iron levels. Similar results were observed Mahendra Singh and Dahiya (1976) in oat plants.

5.3.5.4 Micronutrient content and uptake by maize

The data on micronutrients content (Zn, Mn and Cu) in whole plant did not differ significantly due to residual effect of iron application methods and applied iron levels at maize harvest. However, total iron content and ferrous iron content were found to be a significant at different growth stages of maize.

Whereas, the data on micronutrients uptake indicate that residual effect of iron application methods and applied iron levels significantly increased the uptake of iron uptake at different growth stages of maize. However, zinc, manganese and copper uptake were found to be non-significant at harvest stage of maize crop.

5.3.5.4.1 Ferrous iron (ppm)

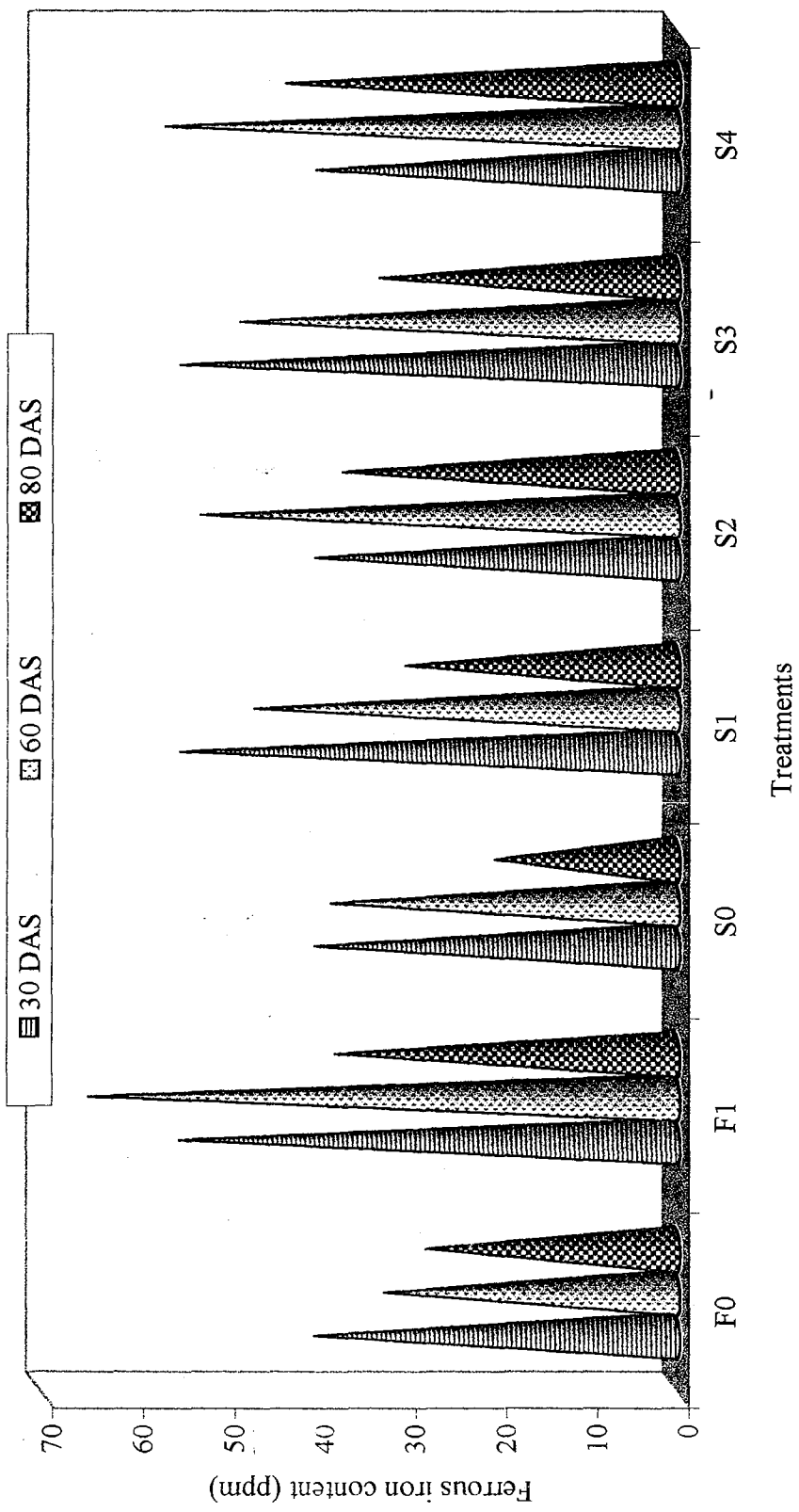
Methods of iron application distinctly increased ferrous iron of maize. The plots receiving F_1 treatment registered significantly higher increased of ferrous iron by (102.5 and 36.5 %) over soil application of iron treatments at 60 DAS and at harvest, respectively. This trend of higher ferrous iron content in the treatments receiving soil plus foliar application of iron could be due to increasing available iron in soil and the direct uptake of ferrous iron by leaves resulting in higher production of chlorophyll, dry matter and higher ferrous iron content of plants. This confirms the finding of Katyal and Sharma (1980) in rice plant and Ramaswami (1992) in maize (Table 55 and Fig. 22).

The highest per cent increased in ferrous iron (48.5 and 117.1 %) was observed in the treatment receiving the residual effect of 50 kg pyrite per ha (S_4) as compare to S_2 (38.3 and 84.4 %), S_3 (27.2 and 64.3 %) and S_1 (22.7 and 49.2 %) over the treatment receiving no iron (S_0) at 60 DAS and at harvest. It was markedly superior over all other treatments. The lowest ferrous iron obtained in the treatment receiving no iron (S_0). This may be due to increased total dry matter production, yield and yield components of maize as result of increased iron availability in an inherently deficient soil by high acidulation effect of pyrite and the process of its absorption and translocation in the plant. Similar results were reported by Sakal *et al.* (1982) in maize and Tupatkar and Sonar (1995) in rice.

5.3.5.4.2 Total iron content (ppm)

The effect of iron application methods significantly increased total iron content of maize. At 60 DAS, the plots receiving F_1 treatment registered increased of total iron by (37.2 %) over soil application of iron. It was significantly superior over F_0 . This trend of higher total iron content in the treatments receiving soil plus foliar application of iron could be due to increased iron availability and the direct uptake of iron by plant leaves resulting in higher production of chlorophyll, dry matter and higher total iron content of plants (Table 55).

With respect to the residual effect of applied iron levels, the highest per cent increase of total iron (14.5 %) was observed in the treatment S_4 over control followed by S_2 (10.1 %), S_3 (7.0 %) and S_1 (5.4 %). It was on par with S_2 and markedly superior rest of the



F₀: Soil application of Fe, F₁: Soil plus foliar application of Fe, S₀: No iron (control),
 S₁: 50 kg FeSO₄ ha⁻¹, S₂: 100 kg FeSO₄ ha⁻¹, S₃: 25 kg pyrite ha⁻¹, S₄: 50 kg pyrite ha⁻¹

Fig. 22. Residual effect of iron management practices on ferrous iron content at different growth stages of maize

treatments. The lowest total iron content obtained in the treatment receiving no iron (S_0). This may be due to increased total dry matter production, yield and yield components of maize as result of increased iron availability in an inherently deficient soil by high acidulation effect of pyrite and the process of its absorption and translocation in the plant. Similar results were made by Pareek *et al.* (1978) and Prasad (1981).

5.3.5.4.3 Iron uptake

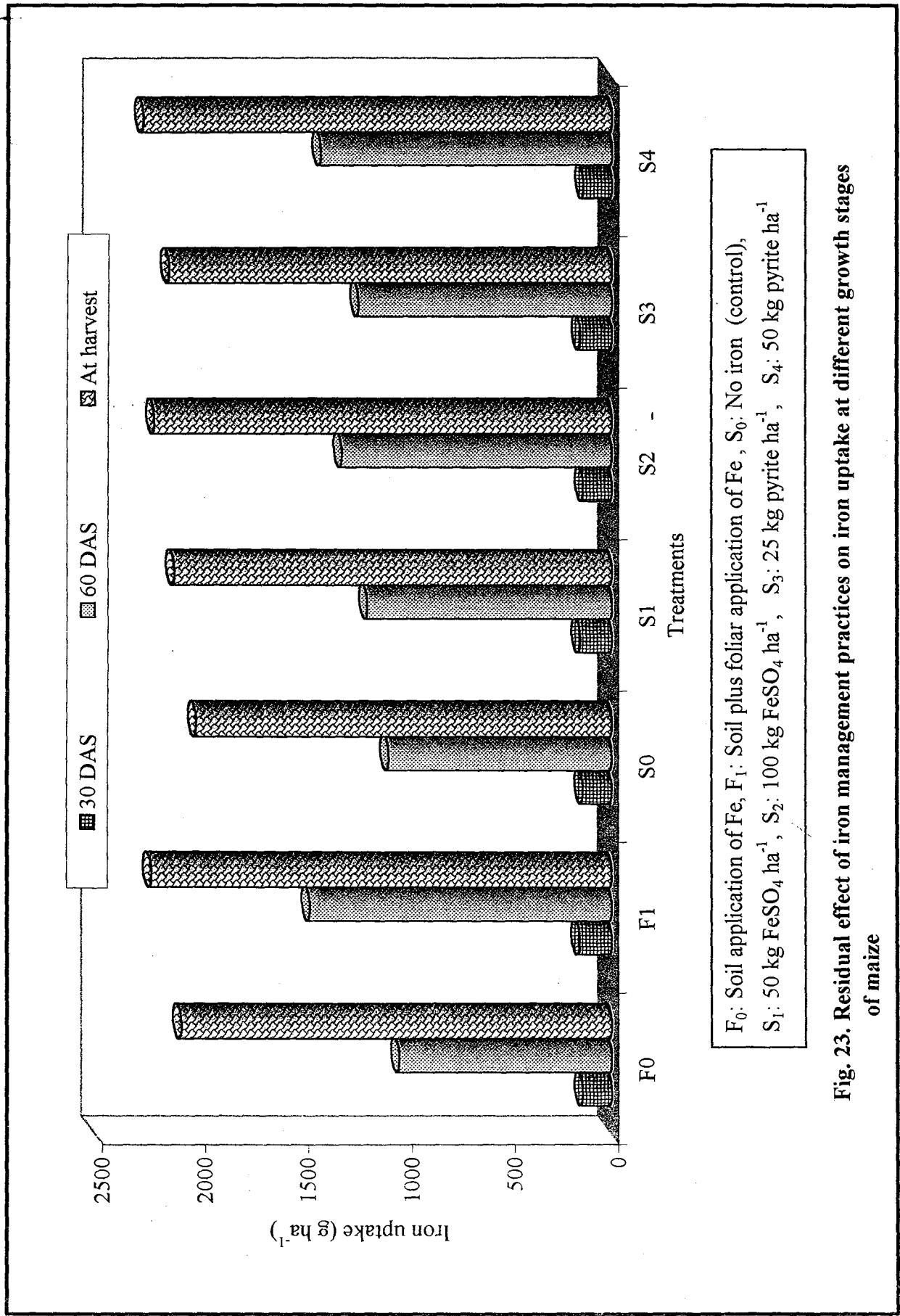
Iron application methods had profound influence on iron uptake by maize. The plots receiving F_1 treatment of soil plus foliar application of iron registered significantly higher iron uptake (42.1 and 7.0 %) over soil application of iron treatment (F_0) at 60 DAS and at harvest, respectively. It was significantly superior over F_0 . This trend of higher uptake of iron in the treatments receiving soil plus foliar application of iron could be due to increased iron availability in soil and the direct uptake of iron by leaves resulting in higher production of chlorophyll, dry matter and higher uptake of iron by plants (Table 56 and Fig 23).

The residual effect due to addition of S_4 treatment recorded significant increase in iron uptake by (31.3 and 13.0 %) at 60 DAS and at harvest, respectively over no iron applied (S_0) followed by S_2 (21.2 and 10.1 %), S_3 (13.9 and 6.7 %) and S_1 (9.7 and 5.3 %). This may be due to increased total dry matter production, yield and yield components *viz.* grain number per cob, grain weight per cob and test weight of maize as result of increased iron availability in soil by higher acidulation effect of pyrite. Similar observations were made by Pareek *et al.* (1978) in maize, Kalyan Singh *et al.* (1992) in wheat and Prasad and Rajkumar (1992) in rice.

5.3.6 Nutrient status of soil

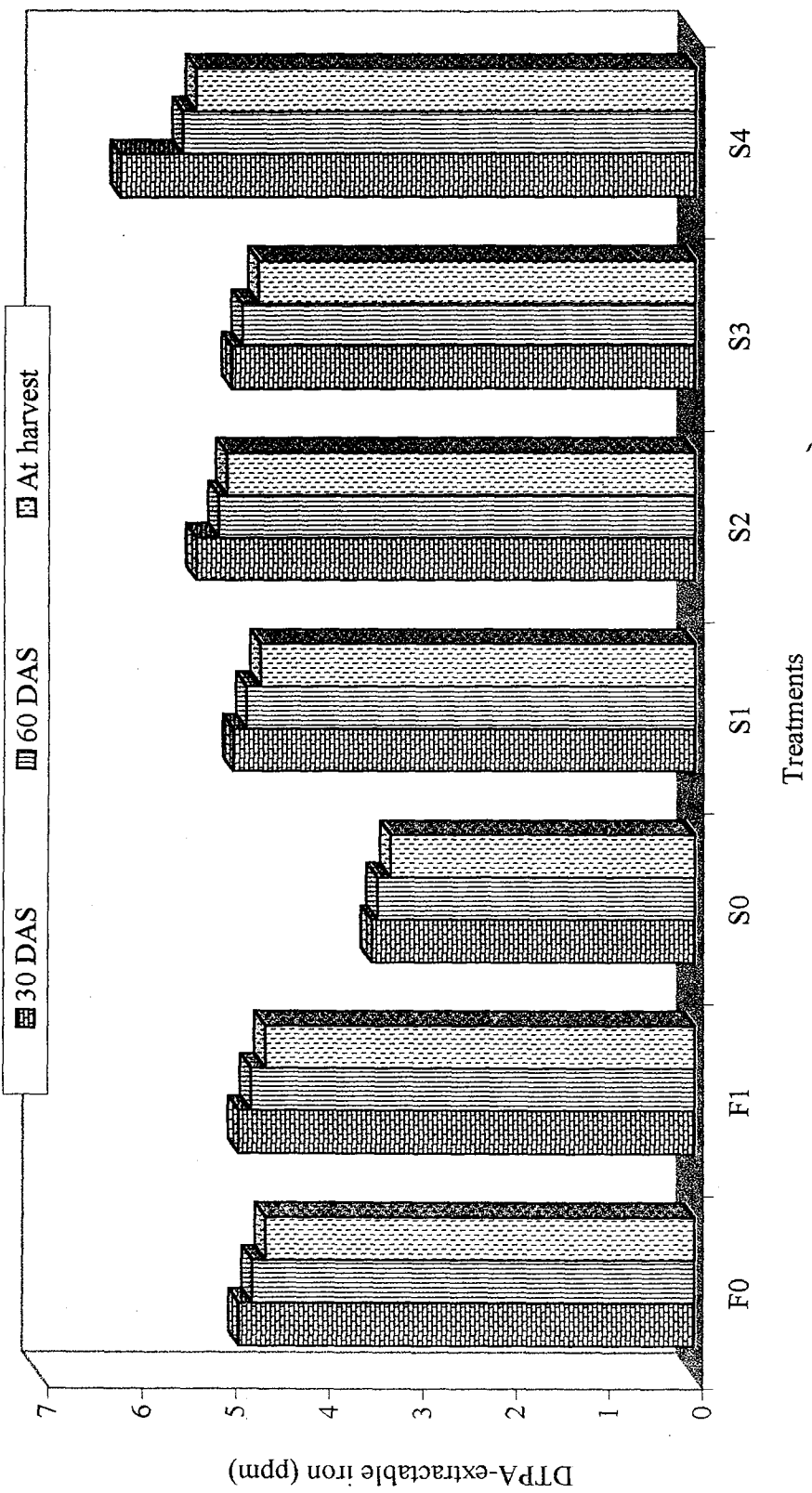
5.3.6.1 Available nutrient in soil at groundnut harvest

The data on available nutrient status in soil (N, P_2O_5 , K_2O , Zn, Mn and Cu) did not differ significantly due to methods of iron application and applied iron levels at groundnut harvest in calcareous Vertisol (Tables 58 and 61). Whereas, the data on DTPA-extractable iron indicate that levels of applied iron significantly increased the DTPA-extractable iron at different growth stages of groundnut (Table 60 and Fig. 24).



F₀: Soil application of Fe, F₁: Soil plus foliar application of Fe, S₀: No iron (control),
 S₁: 50 kg FeSO₄ ha⁻¹, S₂: 100 kg FeSO₄ ha⁻¹, S₃: 25 kg pyrite ha⁻¹, S₄: 50 kg pyrite ha⁻¹

Fig. 23. Residual effect of iron management practices on iron uptake at different growth stages of maize



F₀: Soil application of Fe, F₁: Soil plus foliar application of Fe, S₀: No iron (control),
 S₁: 50 kg FeSO₄ ha⁻¹, S₂: 100 kg FeSO₄ ha⁻¹, S₃: 25 kg pyrite ha⁻¹, S₄: 50 kg pyrite ha⁻¹

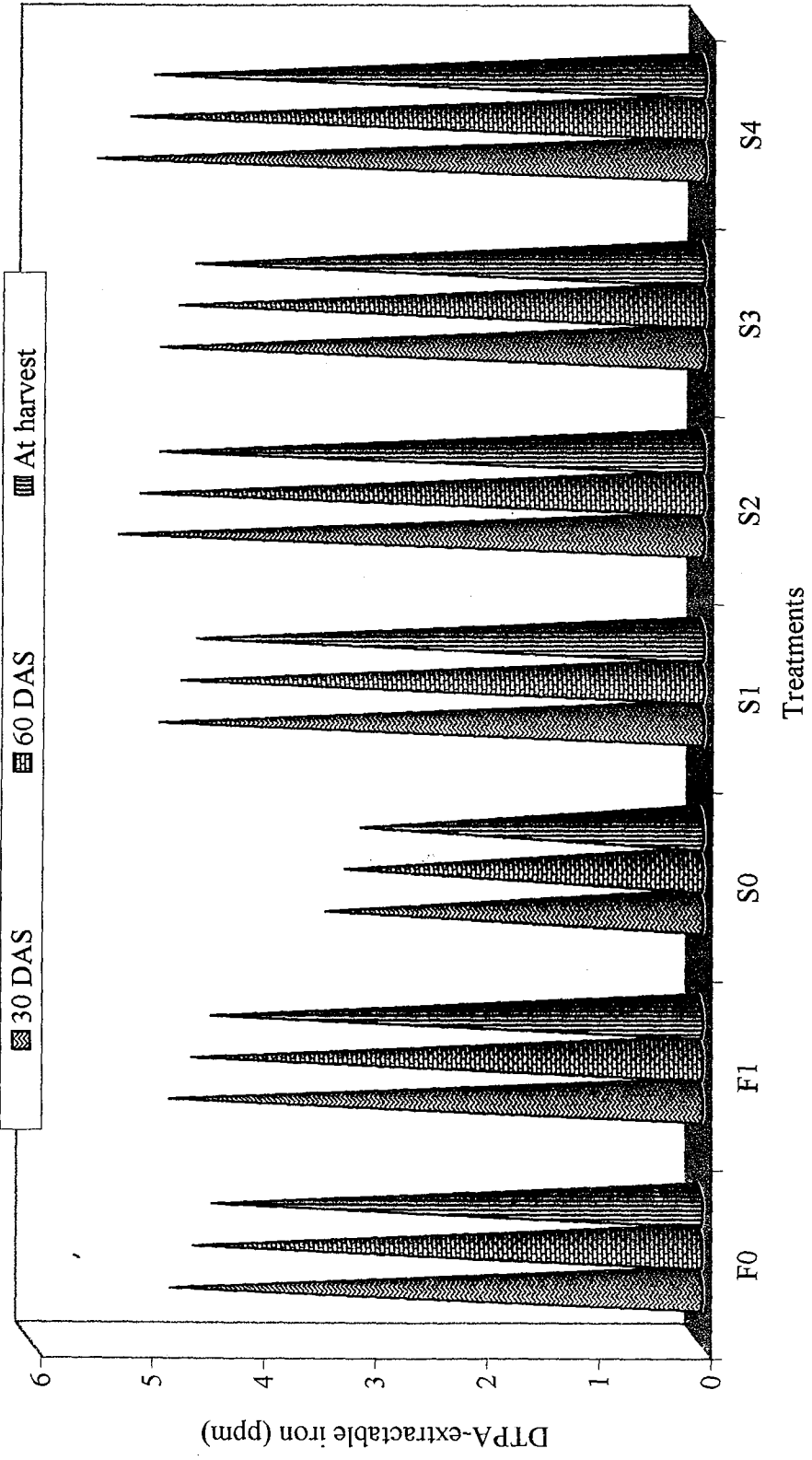
Fig. 24. Direct effect of iron management practices on DTPA-extractable iron at different growth stages of groundnut

With respect to DTPA-extractable iron, the treatment S₄ recorded the highest per cent increase in DTPA-extractable iron (61.4 and 64.5 %) as compared to S₂ (49.7 and 54.1 %), S₃ (42.7 and 43.7 %) and S₁ (40.9 and 42.8 %) over no Fe treatment (S₀) at 60 DAS and harvest. The lowest available iron obtained in the treatment receiving no iron (control). This could be due to more vegetative growth and root growth which release hydrogen ions, phenolic compounds and organic acids as well as acidulation effect of pyrite helped in increased availability and uptake of iron by groundnut plants. Similar observations were recorded by Tiwari *et al.* (1984), and Papastylianou (1989) Marschner and Romheld (1995).

5.3.6.2 Available nutrient in soil at maize harvest

The data on available nutrient status in soil (P₂O₅, K₂O, Zn, Mn and Cu) was found to be non-significant at harvest stage of maize due to the residual effect of applied iron (Tables 59 and 63). Whereas, the data indicate that the residual effect of applied iron levels significantly increased the available nitrogen at harvest and available iron in soil at different growth stages of maize (Tables 59 and 62 and Fig 25).

It was observed in the present study that, S₄ treatment recorded the highest increase DTPA-extractable iron (61.5 and 62.6 %) followed by S₂ (58.4 and 60.3 %), S₃ (47.6 and 50 %) and S₁ (46.7 and 49.3 %) over control at 60 DAS and at harvest. The lowest available iron was obtained in the treatment receiving no iron (S₀). This could be due to more vegetative growth and root growth, which release phytosiderophores as root exudates, acidulation effect of pyrite as well as role of FYM as natural chelating agent resulted in increased iron availability in soil. Sakal *et al.* (1982) studied the direct effect of iron carriers and compost on yield and Fe uptake by rice and their residual effect on winter maize and reported that the residual effect of FeSO₄ alone on maize yield was not so distinct while that of pyrite alone was about four times greater which may be due to acidulating action of pyrite and the residual response was magnified when these Fe carriers were applied in conjunction with organic manure. The results of the investigation are in consonance with the findings of Ramaswami (1992) and Marschner and Romheld (1995).



F₀: Soil application of Fe, F₁: Soil plus foliar application of Fe, S₀: No iron (control), S₁: 50 kg FeSO₄ ha⁻¹, S₂: 100 kg FeSO₄ ha⁻¹, S₃: 25 kg pyrite ha⁻¹, S₄: 50 kg pyrite ha⁻¹

Fig. 25. Residual effect of iron management practices on DTPA-extractable iron at different growth stages of maize

5.3.7 Iron fractions

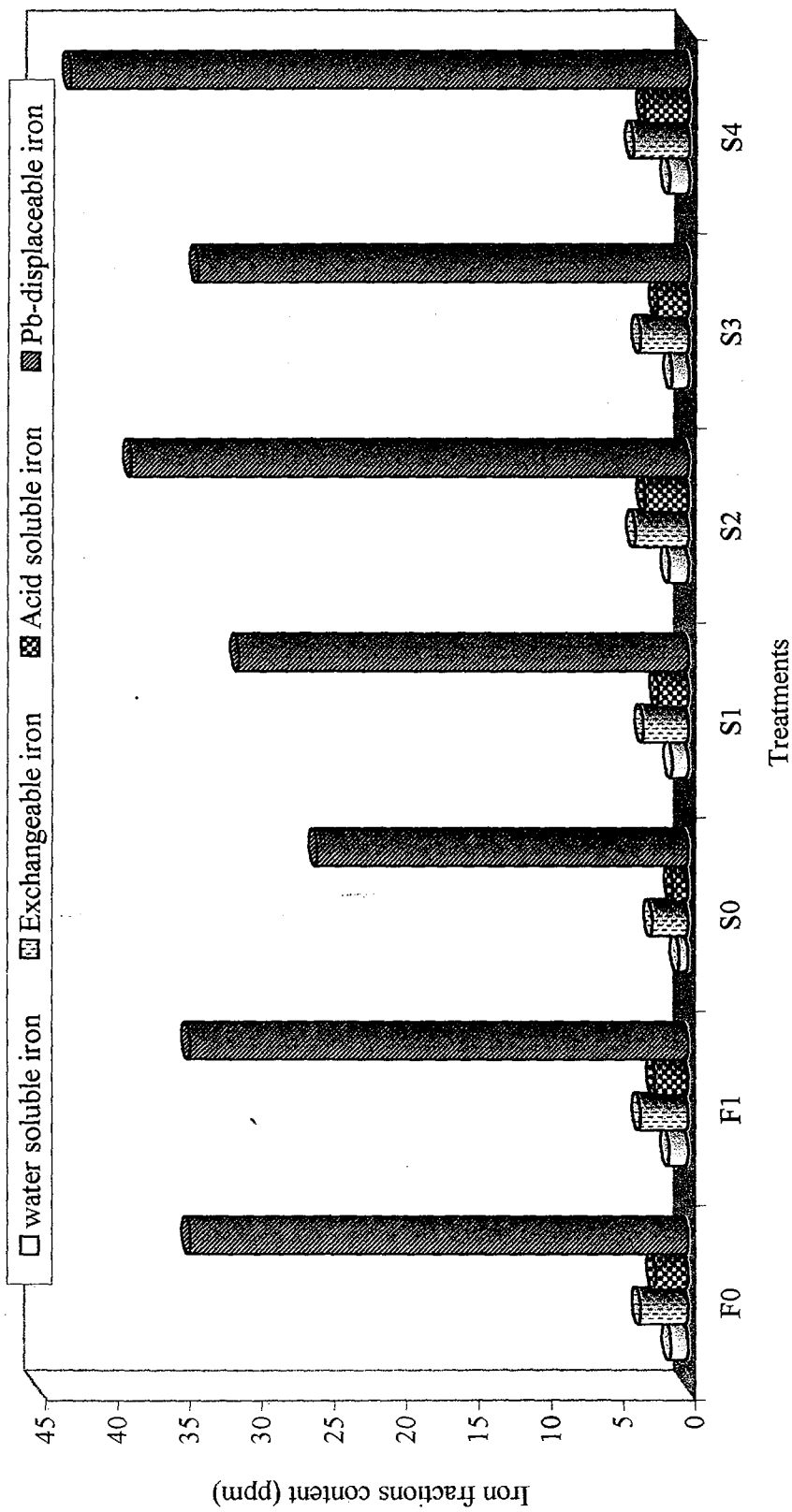
5.3.7.1 Iron fractions status at groundnut harvest

The solid phase plays an important role in determining the solubility of micronutrients in soils. The nutrients in soil solution are usually in equilibrium with the solid phase. Thus the solid phase tends to buffer the concentration of soluble nutrients in soils and iron is not an exception to this principle.

Several attempts have been made to fractionate the nutrients present in different forms in order to have a better understanding of their chemistry and availability in soils. Iron fractions existed in different distinct pools in the soils which apply to iron also, water soluble, exchangeable, Pb-displaceable, acid soluble, Mn oxide occluded, organically bound, amorphous Fe oxide occluded, iron held in secondary clay minerals and in metal oxides by occlusion, iron held within the primary minerals. Water soluble, exchangeable, and chelated iron are in reversible equilibrium with each other and the iron in these pools are readily available to plants (Viets and Jr 1962 and Miller *et al.* 1986).

The data on iron fractions (water soluble, acid soluble, exchangeable and Pb-displaceable) status in soil at groundnut harvest differed significantly due to the direct effect of applied iron levels. However, the iron fractions like, Mn oxide occluded, organically bound, amorphous Fe oxide occluded found to be not significant due to methods or levels of iron application in calcareous Vertisols (Tables 64-66 and Fig. 26).

The water soluble, exchangeable, acid soluble and Pb-displaceable increased by (117.2, 56.2, 186.2 and 66.9 %) in the treatment S₄ as compared to other treatments over control treatment (S₀). The lowest water soluble, exchangeable, acid soluble and Pb-displaceable obtained in the treatment receiving no iron (control). This may be due to increased total dry matter production, yield and yield components of groundnut as result of increased iron availability in calcareous soil due to high acidulation effect of pyrite and the process of its absorption and translocation in the plant. Thus, addition of soluble iron salt increased water soluble, acid soluble, exchangeable and pb-displaceable iron in soil. Similar observations were made by Mahendra Singh and Dahiya (1975), Tiwari *et al.* (1984) and Sposito (1984).



F₀: Soil application of Fe, F₁: Soil plus foliar application of Fe, S₀: No iron (control),
 S₁: 50 kg FeSO₄ ha⁻¹, S₂: 100 kg FeSO₄ ha⁻¹, S₃: 25 kg pyrite ha⁻¹, S₄: 50 kg pyrite ha⁻¹

Fig. 26. Direct effect of iron management practices on iron fractions content of soil at harvest stage of groundnut

5.3.7.2 Iron fractions status at harvest stage of maize

In the present investigation, it was found that the concentration of water soluble iron, acid soluble iron, exchangeable iron and Pb-displaceable iron in soil at maize harvest stage markedly differed due to the residual effect of iron levels. However, the iron fractions like, Mn oxide occluded, organically bound, amorphous Fe oxide occluded did not differ significantly (Tables 67-69 and Fig.27).

The water soluble iron, exchangeable iron, acid soluble iron and Pb-displaceable iron increased by (200.0, 54.1, 74.7 and 69.9 %) in S₄ treatment as compare to other treatments over S₀. The lowest water soluble iron, acid soluble iron, exchangeable iron and Pb-displaceable iron obtained in the treatment receiving no iron (S₀). This may be due to increased total dry matter production, yield and yield components of maize as result of increased iron availability in calcareous soil by high acidulation effect of pyrite. Thus, addition of soluble iron salt increased water soluble, acid soluble, exchangeable and pb-displaceable iron in soil. Similar observations were made by Sakal *et al.* (1982) and Yerriswamy *et al.* (1995).

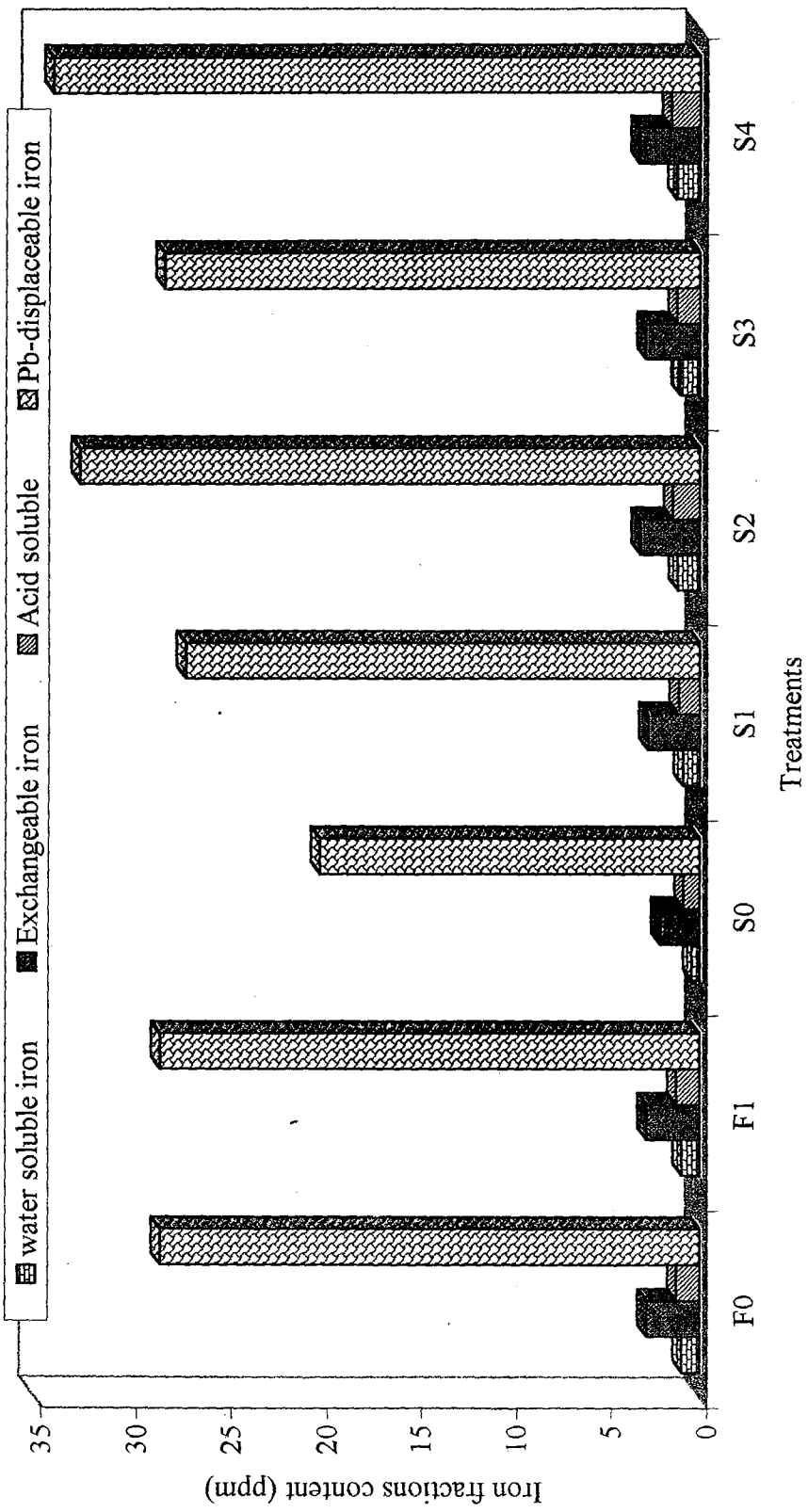
5.3.8 Path analysis study

5.3.8.1 Path analysis in groundnut

Positive and significant correlation of soil iron fractions (available iron, water soluble iron, acid soluble iron and exchangeable iron) and iron fractions in plant (Fe²⁺ at 30, 60 and 80 DAS and total iron) with pod yield was observed in groundnut. Similar results were obtained by Papastyianou (1989) and Srinivasaraao *et al.* (1993).

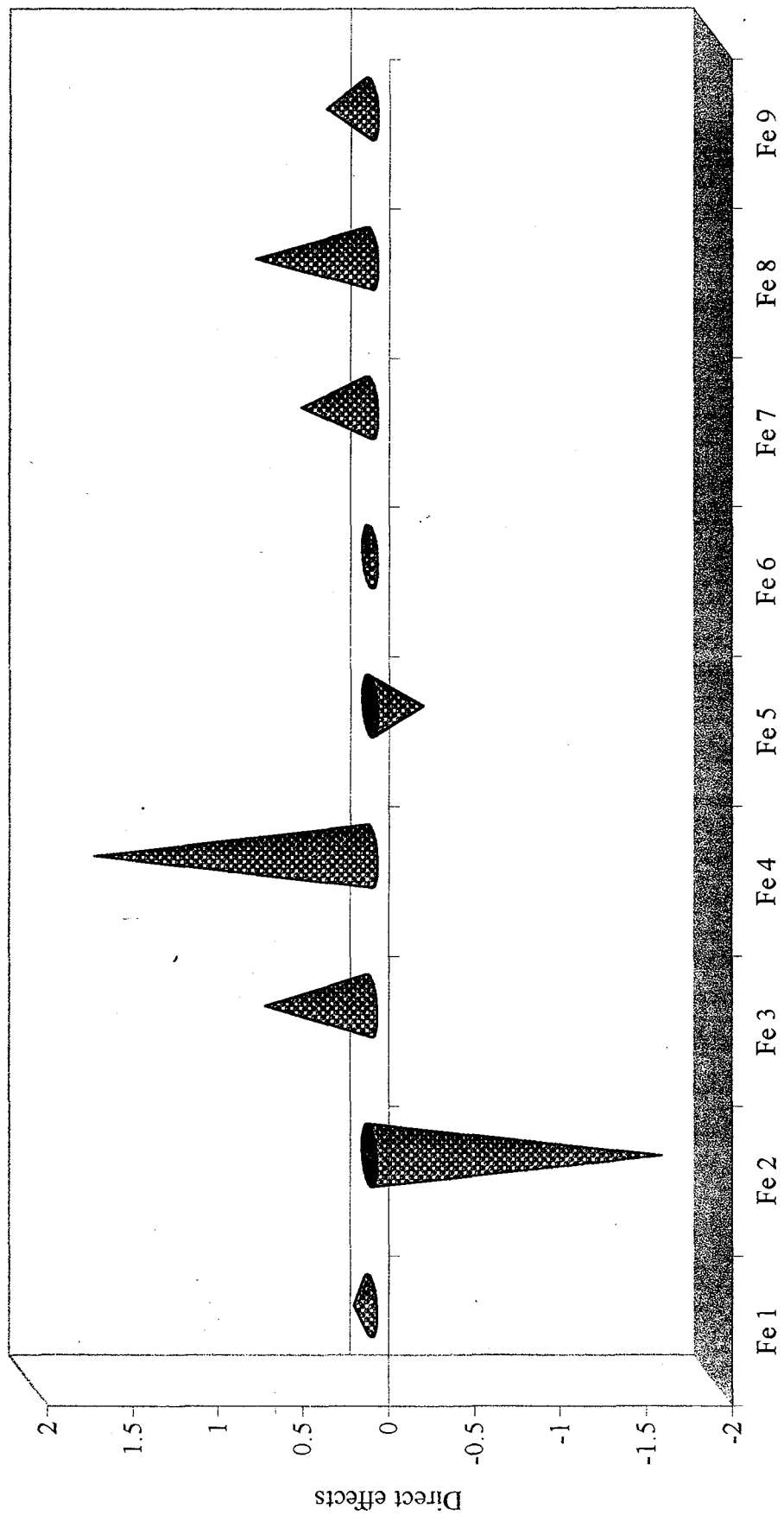
The results of path coefficient analysis indicate that the importance of exchangeable iron and acid soluble iron as important soil iron fractions for getting higher pod yield of groundnut. Both these in the order of importance showed very high direct effects in addition to the positive indirect effects of other fractions through them (Fig. 28).

Among the plant iron fractions, Fe²⁺ at 80 DAS was important since it showed high positive direct effect. However, a critical examination of the indirect effect indicate Fe²⁺ at 30 DAS and also at 60 DAS had very high positive indirect effect through Fe²⁺ at 80 DAS.



F₀: Soil application of Fe, F₁: Soil plus foliar application of Fe, S₀: No iron (control),
 S₁: 50 kg FeSO₄ ha⁻¹, S₂: 100 kg FeSO₄ ha⁻¹, S₃: 25 kg pyrite ha⁻¹, S₄: 50 kg pyrite ha⁻¹

Fig. 27. Residual effect of iron management practices on iron fractions content of soil at harvest stage of maize



Fe 1: Available iron, Fe 2: Water Soluble iron, Fe 3: Acid soluble iron, Fe 4: Exchangeable iron, Fe 5: Pb-displaceable iron, Fe 6: Fe²⁺ at 30 DAS, Fe 7: Fe²⁺ at 60 DAS, Fe 8: Fe²⁺ at 80 DAS, Fe 9: Total iron in plant

Fig. 28. Direct effects of soil and plant iron fractions on pod yield of groundnut

Therefore, the absorption of iron by groundnut at the early stages 30 and 60 DAS have shown their impact at 80 DAS. Further Fe^{2+} at 60 DAS had high positive direct effect also.

5.3.8.2 Path analysis in maize

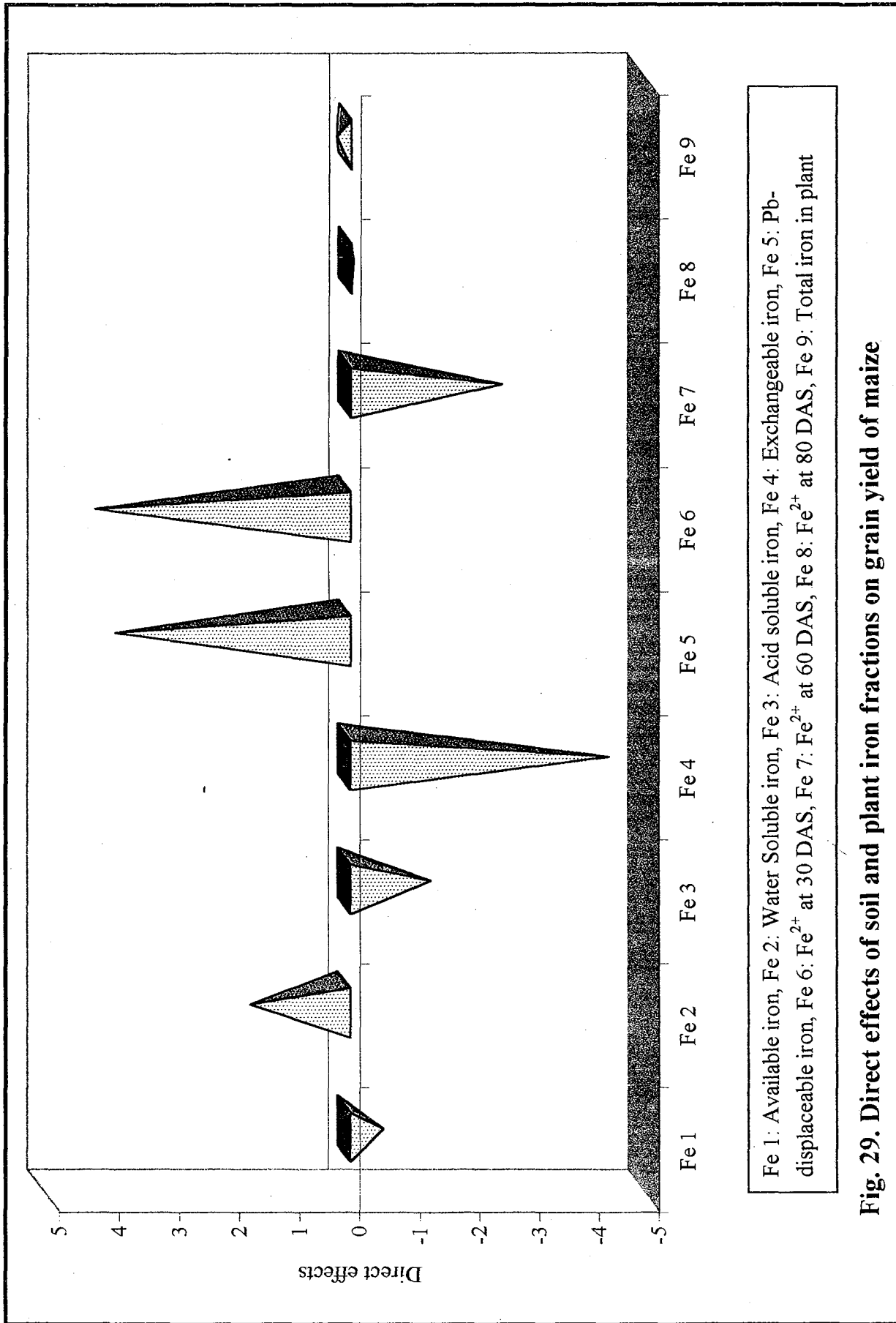
Contrary to the effect of types of iron fractions, which had influenced in case of groundnut, the iron fractions having impact on subsequent crop that is maize are altogether different. The acid soluble and exchangeable iron had the positive impact on groundnut indicating that their release and availability is quick and immediate to the crop to which it is applied (Fig. 29). However, as far as the available iron from the iron fractions is concerned it appears that Pb-displaceable iron and water soluble iron were more important. This probably indicates that these two fractions are made available to the crop with some time gap. Similarly, the stage at which iron is available is likely at later stage of crop growth, for the immediate use of the crop while it is at the early stage to the subsequent crop.

Results from the present study indicate that when iron is applied at the time of sowing to the groundnut crop, the availability and the impact of iron is visible only on 60 and 80 DAS. If the impact of iron is to be the early stage itself since as a precursor, it is necessary for chlorophyll development (Amberger, 1974) and organic acid formation (Pich and Scholl, 1992). It is perhaps required that iron may be applied little in advance to the date of sowing.

Further, it may be worthwhile to experiment individually with different crop species, which generally respond to iron application to decide the time at which iron is to be applied. This necessity arises because of the fact that there could be species differences in their response to applied iron (Marschner and Romheld, 1995).

5.3.9 Economics

In respect of the economics of groundnut, among iron application to soil, the higher net returns and Benefit: cost ratio was observed in the treatment receiving F_0S_4 (50 kg pyrite per ha) as compared to other treatments. The lowest net returns and Benefit: cost ratio were registered in control treatment (F_0S_0).



Fe 1: Available iron, Fe 2: Water Soluble iron, Fe 3: Acid soluble iron, Fe 4: Exchangeable iron, Fe 5: Pb-displaceable iron, Fe 6: Fe²⁺ at 30 DAS, Fe 7: Fe²⁺ at 60 DAS, Fe 8: Fe²⁺ at 80 DAS, Fe 9: Total iron in plant

Fig. 29. Direct effects of soil and plant iron fractions on grain yield of maize

Application of iron to soil and foliar spray together gave increased net returns and Benefit: cost ratio of groundnut crop. The plots receiving F_1S_4 treatment (50 kg pyrite per ha + foliar) registered the highest net returns, Benefit: cost ratio as compared to other treatments. This suggests that application of F_1S_4 treatment can help to get more net returns per ha over control (Appendix II). This might be due to increased iron availability and uptake by plants, which might have resulted in, increased the growth and yield component and improved the quality parameters of groundnut.

Whereas, in case of the economic analysis of maize crop, among iron application to soil (residual effect), the higher net returns and Benefit: cost ratio was observed in the F_0S_4 (50 kg pyrite per ha) as compared to control.

The residual effect of iron application to soil and foliar spray together gave increased gross returns, net returns and Benefit: cost ratio of maize crop. The plots receiving F_1S_4 (50 kg pyrite per ha + foliar) treatment registered the highest net returns, Benefit: cost ratio as compared to other treatments. This suggests that the residual effect of application of F_1S_4 treatment can help to get more net returns of Rs. 17036/- per ha over control (Appendix III). It could be due to increase in ferrous iron uptake and increased in grain number per cob, grain weight per cob, grain and stover yield and enhanced protein content of maize grains.

5.4 RESULTS OF PRACTICAL UTILITY

The present investigation generated the following results of practical utility.

1. Profile studies and soil properties, of different locations served as data base for occurrence of wide variations in iron availability at varying levels of calcareousness.
2. Based on this data, causes for iron chlorosis in calcareous Vertisol were identified and suitable iron management practices were adopted so that yield and quality of crops improved.
3. Studies on iron uptake at different growth stages gives hint for time and quantity of iron to be applied to get maximum efficiency of iron fertilizer for the cropping sequence.

4. Not only the use of pyrite in agriculture can find the way for its safe disposal but also helps in improving soil properties and obtaining higher yield of crops in calcareous Vertisol.
5. The use of pyrite in agriculture gives greater residual value in terms of yield levels and nutrient status of soil to succeeding crops.
6. Among different iron management practices, application of pyrite @ 50 kg per ha along with foliar spray of one per cent iron sulphate is best suited for getting higher yield and net returns of the crops. While application of FeSO_4 @ 100 kg per ha plus foliar spray of iron is suitable for those localities where pyrite is not easily available.

5.5 FUTURE LINE OF WORK

1. The results observed in field trial are encouraging and hence repetitive experiments of similar nature can be laid out in localities representing varying agro-climatic regions and also during different parts of the year.
2. In the present investigation, only the iron application as soil or soil plus foliar was tried. Hence, it would be worthwhile to try the interaction effects of other micronutrients along with iron in other cropping system.
3. Delineation of other iron deficient areas on a systematic and phased manner and identifying benchmark areas for future investigation.
4. Soil applications of iron along with foliar spray are gaining importance in groundnut-maize cropping sequences. Hence, trials using this cropping system as a test crop for this purpose can be explored especially in areas where micronutrients are deficient.
5. Detailed investigations are needed to characterize response of different species to iron application with regard to the time of application so as to get the required response at the right stage of crop growth.

SUMMARY

VI. SUMMARY

The present investigations were carried out to study the effect of iron management practices for groundnut–maize cropping sequences in calcareous Vertisol. For characterization and incubation study soil sample were collected from Dharwad, Belavatagi, Durgadevigudi, Bijapur and Amminabhavi. A field experiment was conducted at farmers field, Durgadevigudi near Dharwad city during *Kharif* season of 2002-03 and *rabi* season of 2003 and 2003-04 under irrigated condition to study the direct and residual effect of applied iron on growth, yield, certain quality and biochemical parameters, nutrient uptake and iron fractions in of groundnut (main crop) – maize (succeeding crop) cropping system. The results obtained during the course of the investigations are summarized hereunder.

- Total iron content varied from 2.71 to 3.76 per cent in different soil profiles and found more in subsurface layers than in surface layers.
- DTPA-extractable iron varied from 2.28 to 4.76 ppm in soil profiles. The distribution of DTPA-extractable iron was found to be associated with clay content, organic carbon, soil pH and calcium carbonate.
- Studies on the fractionation of soil iron revealed that water soluble, Mn-oxide occluded and organically bound iron decreased with depth, whereas exchangeable, acid soluble, Pb-displaceable, amorphous iron-oxide occluded and residual Fe increased with depth.
- The percentage contribution of soil iron fractions to total iron were in following order: Residual iron > amorphous Fe-oxide occluded iron > organically bound iron > Mn-oxide occluded iron > Pb-displaceable iron > exchangeable iron > acid soluble > water soluble iron. The amount of iron in labile pools was very low and this could be the reason for the frequent appearance of iron chlorosis in calcareous Vertisols of Karnataka.
- The gradual increase in different iron fractions due to ferrous sulphate application was observed up to 30 days of incubation period. However, it started declining from the 45 days onwards.

- The effect of varying level of FeSO_4 was significant with respect to water soluble iron, acid soluble iron, exchangeable iron and Pb-displaceable iron in soil. Whereas, the effect of applied iron on Mn oxide occluded iron, organically bound iron and amorphous iron oxide occluded found to be non-significant. However, increase in CaCO_3 levels in soil significantly decreased all iron fractions in soil at varying days after incubation period.
- The direct effects of applied iron as soil along with foliar spray resulted in significant differences over soil application of iron only with regard to growth parameters (plant height, number of green leaves and total dry matter production) and yield parameters (pod number per plant, 100-kernel weight pod yield and haulm yield) of groundnut. Application of 50 kg pyrite per ha recorded the highest growth and yield parameters and the lowest value was recorded in the treatment receiving no iron (control).
- Oil, protein and chlorophyll content of groundnut increased significantly in the treatment receiving soil plus foliar application of iron over soil application of iron only. Application of 50 kg pyrite per ha recorded the highest oil, protein and chlorophyll content and it was on par with 100 kg FeSO_4 per ha and significantly superior over rest of the treatments and the lowest value was registered in control treatment. However, citric acid and malic acid of groundnut decreased significantly due to iron application. Addition of 50 kg pyrite per ha recorded the lowest value and the highest was obtained in control.
- Significant differences among the treatments were noticed with respect to total iron and ferrous iron content of groundnut due to iron application. Application of 50 kg pyrite per ha recorded the highest total iron and ferrous iron content and it was on par with 100 kg FeSO_4 per ha and significantly superior over rest of the treatments and the lowest value were obtained in control.
- In post-harvest soil, the highest available iron of groundnut was recorded in the treatment receiving 50 kg pyrite per ha and it was on par with 100 kg FeSO_4 per ha and significantly superior over rest of the treatments. The lowest value registered in control.

- With respect to iron fractions status in soil of groundnut, significant differences among the treatments were noticed regarding to water soluble iron, acid soluble iron, exchangeable iron, Pb- displaceable iron due to applied iron levels. Application of 50 kg pyrite per ha recorded the highest iron fractions in soil and it was on par with 100 kg FeSO_4 per ha and significantly superior over rest of the treatments and the lowest value was registered in control.
- Economic analysis of groundnut influenced by iron management practices indicate that, the maximum net returns was registered in the treatment receiving 50 kg pyrite per ha + foliar spray of iron, this practice can help to obtain higher profit over conventional application of recommended dose of fertilizers to the crop.
- The residual effect of soil-applied iron along with foliar spray had significant effect on growth parameters (plant height and total dry matter production) and yield parameters (grain number per cob, grain weight per cob, test weight, grain yield and stover yield) of maize over soil-applied iron only. Addition of 50 kg pyrite per ha recorded the highest growth and yield parameters and the lowest values were recorded in control.
- Protein content and chlorophyll content of maize increased significantly in the treatment receiving soil plus foliar application of iron as compared to soil application of iron only. Addition of 50 kg pyrite per ha markedly increased protein and chlorophyll content and it was on par with 100 kg FeSO_4 per ha and significantly superior over rest of the treatments and the lowest value was recorded in control. However, addition of 50 kg pyrite per ha recorded the lowest citric acid and malic acid content and the highest values were obtained in control.
- Significant differences among the treatments were noticed with respect to total iron and ferrous iron content of maize due to soil plus foliar application of iron over soil application of iron only. The residual effect of addition of 50 kg pyrite per ha recorded the highest total iron content and ferrous iron content and the lowest value was registered in control.
- In post harvest soil after maize, the highest available iron was recorded in the treatment receiving 50 kg pyrite per ha and it was on par with 100 kg FeSO_4 per ha and

significantly superior over rest of the treatments. The lowest value was registered in the control.

- With respect to iron fractions in post harvest soil after maize, significant differences among the treatments were noticed with regard to water soluble iron, acid soluble iron, exchangeable iron, Pb- displaceable iron due to residual effect of applied iron levels. Application of 50 kg pyrite per ha recorded the highest of these iron fractions and it was on par with 100 kg FeSO_4 per ha and significantly superior over rest of the treatments.
- Economic analysis of maize influenced by iron management practices indicate that, the highest net returns was registered in the treatment receiving 50 kg pyrite per ha + Fe foliar spray of iron. This practice can help to obtain higher profit over conventional application of recommended dose of fertilizers to the crop.
- Path analysis study indicated that, the iron fractions, which were important for groundnut (acid soluble, ferrous iron at 60 and 80 DAS) and those, which were important for maize (water soluble, Pb-displaceable and ferrous at 30 DAS) are different to attain higher yield.

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* Originals not seen

APPENDICES

APPENDICES

Appendix I. Prices of inputs and returns

Sl. No.	Particulars	Prices (Rs.)
I.	INPUTS	
1.	Seed cost	
a.	Groundnut pods	20.00 kg
b.	Maize grains	56.00 kg
2.	Fertilizers	
a.	Urea	4.45 kg ⁻¹
b.	Diammonium phosphate	8.95 kg ⁻¹
c.	Muriate of potash	4.25 kg ⁻¹
d.	Farmyard manure (FYM)	50.00 t ⁻¹
e.	Ferrous sulphate	25.00 kg ⁻¹
f.	Iron pyrite	125.00 kg ⁻¹
3.	Plant protection chemicals	
a.	Captan	300.00 kg ⁻¹
b.	Dithane-M-45	200.00 kg ⁻¹
c.	Bavistin	420.00 kg ⁻¹
d.	Endosulfan 35 EC	325.00 lit ⁻¹
e.	Knapsack sprayer	50.00 day ⁻¹
4.	Labour charges	
a.	Men	50.00 day ⁻¹
b.	Women	30.00 day ⁻¹
c.	Bullock pair with men	200.00 day ⁻¹
5.	Miscellaneous	
a.	Marketing	10.00 q ⁻¹
b.	Land rent	500.00 season ⁻¹
II.	RETURNS	
a.	Groundnut pods	1200 q ⁻¹
b.	Maize grains	510 q ⁻¹

Appendix II: Economics of groundnut as influenced by iron management practices

Treatments	Pod yield (kg ha ⁻¹)	Total cost invested (Rs. ha ⁻¹)	Gross returns (Rs. ha ⁻¹)	Net returns (Rs. ha ⁻¹)	Benefit: cost ratio
F ₀ S ₀	2077	10837	24924	14087	2.30
F ₀ S ₁	2188	11125	26256	15131	2.36
F ₀ S ₂	2382	11763	28584	16821	2.43
F ₀ S ₃	2258	11337	27096	15759	2.39
F ₀ S ₄	2413	11819	28956	17137	2.45
F ₁ S ₀	2124	10892	25488	14596	2.34
F ₁ S ₁	2332	11612	27984	16372	2.41
F ₁ S ₂	2552	12348	30624	18276	2.48
F ₁ S ₃	2423	11868	29076	17208	2.45
F ₁ S ₄	2602	12390	31224	18834	2.52

F₀S₀ : No Fe soil or foliar (control)

F₀S₂ : 100 kg FeSO₄ ha⁻¹ soil application

F₀S₄ : 50 kg pyrite ha⁻¹ soil application

F₁S₁ : 50 kg FeSO₄ ha⁻¹ soil + Fe foliar

F₁S₃ : 25 kg Pyrite ha⁻¹ soil + Fe foliar

F₀S₁ : 50 kg FeSO₄ ha⁻¹ soil application

F₀S₃ : 25 kg Pyrite ha⁻¹ soil application

F₁S₀ : No soil application + Fe foliar

F₁S₂ : 100 kg FeSO₄ ha⁻¹ soil + Fe foliar

F₁S₄ : 50 kg Pyrite ha⁻¹ soil + Fe foliar

Appendix III. Economics of maize as influenced by iron management practices

Treatments	Grain yield (q ha ⁻¹)	Total cost invested (Rs. ha ⁻¹)	Gross returns (Rs. ha ⁻¹)	Net returns (Rs. ha ⁻¹)	Benefit: cost ratio
F ₀ S ₀	44.84	10686.17	22868.40	12182.23	2.14
F ₀ S ₁	46.61	10756.15	23771.10	13014.85	2.21
F ₀ S ₂	49.88	10965.00	25438.80	14473.80	2.32
F ₀ S ₃	47.87	10802.52	24413.70	13611.18	2.26
F ₀ S ₄	51.93	11081.29	26484.30	15403.01	2.39
F ₁ S ₀	46.95	10883.86	23944.50	13060.64	2.20
F ₁ S ₁	49.44	11256.43	25214.40	13957.97	2.24
F ₁ S ₂	54.59	11504.50	27840.90	16336.40	2.42
F ₁ S ₃	52.24	11434.51	26642.40	15207.89	2.33
F ₁ S ₄	56.13	11589.60	28626.30	17036.70	2.47

F₀S₀ : No Fe soil or foliar (control)F₀S₂ : 100 kg FeSO₄ ha⁻¹ soil applicationF₀S₄ : 50 kg pyrite ha⁻¹ soil applicationF₁S₁ : 50 kg FeSO₄ ha⁻¹ soil + Fe foliarF₁S₃ : 25 kg Pyrite ha⁻¹ soil + Fe foliarF₀S₁ : 50 kg FeSO₄ ha⁻¹ soil applicationF₀S₃ : 25 kg Pyrite ha⁻¹ soil applicationF₁S₀ : No soil application + Fe foliarF₁S₂ : 100 kg FeSO₄ ha⁻¹ soil + Fe foliarF₁S₄ : 50 kg Pyrite ha⁻¹ soil + Fe foliar

IRON MANAGEMENT PRACTICES FOR GROUNDNUT-MAIZE CROPPING SEQUENCES IN CALCAREOUS VERTISOL

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2004

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ABSTRACT

For characterization and incubation study soil sample were collected from Dharwad, Belavatagi, Durgadevigudi, Bijapur and Amminabhavi. A field experiment was conducted at farmer's field, Durgadevigudi near Dharwad city to study the direct and residual effect of iron management practices for groundnut-maize cropping sequence in calcareous Vertisol during during *Kharif* season of 2002-03 and *rabi* season of 2003 and 2003-04.

The characterization study revealed that, the distribution of available iron was found to be associated with clay content, organic carbon, soil pH and calcium carbonate and the percentage contribution of soil iron fractions to total iron were in following order: Residual iron > amorphous Fe-oxide occluded iron > organically bound iron > Mn-oxide occluded iron > Pb-displaceable iron > exchangeable iron > acid soluble > water soluble iron.

The incubation study indicated that, the effect of varying levels of FeSO_4 was significant with respect to water soluble iron, acid soluble iron, exchangeable iron and Pb-displaceable iron in soil. However, increase in CaCO_3 levels in soil significantly decreased all iron fractions in soil at varying days after incubation period.

The field experiment revealed that, direct and residual effects of pyrite application @ 50 kg per ha was superior in terms of growth, yield, quality and biochemical parameters and nutrient uptake by groundnut and maize and it was on par with 100 kg FeSO_4 per ha and significantly superior over rest of the treatments.

The iron fractions (water soluble iron, acid soluble iron, exchangeable iron, Pb- displaceable iron) was higher due to direct and residual effect of pyrite application @ 50 kg per ha and it was on par with 100 kg FeSO_4 per ha and significantly superior over rest of the treatments.

Path analysis indicated that, soil and plant iron fractions, which were important for groundnut (acid soluble, ferrous iron at 60 and 80 DAS) and those, which were important for maize (water soluble, Pb-displaceable and ferrous iron at 30 DAS) are different to attain higher yield.