SOLUTION CHEMISTRY AND AVAILABILITY OF IRON TO GROUNDNUT CROP (*Arachis hypogaea* L.) IN CALCAREOUS SOILS

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CERTIFICATE

This is to certify that the thesis entitled **"SOLUTION CHEMISTRY AND AVAILABILITY OF IRON TO GROUNDNUT CROP (*Arachis hypogaea* L.) IN CALCAREOUS SOILS"** submitted by **Miss. RESHMI SARKAR** for the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **SOIL SCIENCE AND AGRICULTURAL CHEMISTRY**, to the University of Agricultural Sciences, Dharwad, is a record of research work done by her during the period of her 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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Affectionately dedicated

To

My Beloved Parents

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INTRODUCTION

I. INTRODUCTION

Iron is the fourth most abundant element in the earth's crust, after oxygen, silicon and aluminium, where it's concentration is 4.7 per cent (by weight). The iron content, expressed as percentage of Fe_2O_3, make 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 in various rocks (Bear, 1964). Iron is subjected to increase in concentration through soil development processes, as reflected by contents of 10 to 15 per cent in many soil colloids. In Latosols and Laterites, the Fe_2O_3 content is frequently 20 to 80 per cent. Soils containing higher percentages of iron oxides are approaching towards low grade iron ore.

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 inter-veinal 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.

Plants are prone to iron deficiency in alkaline, calcareous soils, compacted fields, coarse-textured soils, soils low in organic matter, eroded soils, in cold weathered area and flooded rice fields being an exception. Some crops sensitive to iron deficiency are citrus, field bean, grapes, groundnut, sorghum, soybean, vegetables and ornamentals (Tandon,1998).

According to Scholtz (1983), the concentration of iron in soils, may range from 0.5 to 3.6 per cent. A concentration which in comparison with other plant nutrients such as N and P is extraordinary high. Despite this large amount of soil Fe, plants may suffer from Fe deficiency especially when grown on calcareous soils which cover 30 per cent of the earth's land surface (Chen and Barak, 1982). This is not surprising if one considers the strong dependence of iron solubility on pH so much so that one unit increase in pH can reduce the solubility of iron by as much as 1000 times. If it is in aqueous media, the concentration of iron in soil solution can never reach anywhere close to the level needed by plants. But the majority of plants (which are normally green) get hold of the needed iron, while others, grown under the same conditions, may suffer from Fe chlorosis. It appears that plants have developed mechanisms (usually referred to in the literature on Fe stress responses) by which they may mobilize Fe by their roots. So, as a whole, factors causing Fe-deficiency include the factors like the genetic susceptibility to Fe-deficiency, virus infection, root pruning by nematodes, insects and fungus diseases and other than the soil and environmental factors.

Iron deficiency seems to be one fourth as extensive as that of Zn, amongst the micronutrients. It is an important problem in Haryana and to a lesser extent in Tamil Nadu and Punjab. In Karnataka state, the results reported by the research institutions and the state Department of Agriculture, indicate that 39 per cent soil samples to be deficient in iron.

Iron chlorosis is emerging as a problem in groundnut growing area of Andhra Pradesh and in several crops including sugarcane on black clay soils in Maharastra and also in clayey soils of southern Rajasthan. Though research data are few, iron chlorosis in fruit plants and ornamentals is also quite common. Importance of iron deficiency can not be doubted in vast areas of alkaline calcareous soils. Iron deficiency was very high (46%) in the shallow and deep black soils of Madhya Pradesh but not so in medium black soils there. Iron deficiency is an important problem in Karnataka and Tamil Nadu, as well. Karnataka is one of the four states where 70 per cent of the area and 75 per cent of the production of groundnut are concentrated while, India occupies the first position, both in regard to the area and the production of groundnut in the world.

About 7.5 million hectares is put under groundnut annually and the production is about 6 million tonnes. The total out put increased within eight economic years was by 16.83 per cent (out put in 1990-91 was 75.15 lack M. T and in 1998-1999, 87.80 lack M. T). Groundnut is one of the most important oil seeds and food crop, not only that, among the oil seed crops, groundnut has first place in India due to various reasons as follows :

1. It can withstand drought and is suitable for dry land farming.

2. It is a soil erosion resistant crop and being a legume crop, it can fix the atmospheric nitrogen with the help of nodule bacteria and there by improves the soil fertility.

3. Its shell, skin, haulm and hay can be used as fodder.
4. Groundnut cake is chief oil cake feed to animals and it is also used as manure.
5. The plant stalks are feed to cattle in the form of green, dried and silage.
6. It is an important cash crop and is useful as a rotational crop.
7. Moreover, groundnut is a chief source of protein.

A popular bunch type variety, JL-24, recorded lowest leaf chlorophyll content in absence of iron amongst five varieties of groundnut (Tandon, 1998). An investigation on chemistry of iron in soil solution and lime induced iron chlorosis to groundnut crop (JL-24) was carried out under following objectives :

1. Characterisation of iron oxides in calcareous vertisols.

2. Solution chemistry with respect to iron and calcium.

3. Iron availability to plants under varied $CaCO_3$ and moisture level.

REVIEW OF LITERATURE

II. REVIEW OF LITERATURE

Iron makes up about 5 per cent by weight of the earth's crust and is invariably present in all soils. The greatest part of soil iron usually occurs in the crystal lattices of numerous minerals. The primary minerals in which Fe is present include the ferromagnesian silicates (eg. olivine, augite, hornblende and biotite). The oxides and hydroxides of iron found in lithosphere are as follows:

Hematite (α-Fe_2O_3), the abundant form of iron oxide which gives pink to bright red colour to soils, is coarsely crystalline and found in sand and silt fraction. Martite is another oxide form of iron having same molecular formula as of hematite.

Goethite (α-FeOOH), the hydroxide form of iron endows brown and dark reddish brown colour. Finely divided goethite particles are known as limonite which is more hydrous than goethite.

Magnetite (Fe_3O_4) is the form of oxides of iron which shows magnetic properties, whereas, maghemite (γ-Fe_2O_3) is the more oxidised form of magnetite.

Though iron containing minerals are so abundant in earth crust, it's availability to plant is limited in alkaline and/or in calcareous soils. This incidence of Fe unavailability in soil influenced by several factors which may be indigenous, environmental, nutritional or microbial.

Literature on forms, distribution and availability of iron with specific reference to calcareous Vertisols is presented in the following headings:

i) Characterisation and distribution of different form of iron in soil.

ii) Iron in solution and it's interaction with different ions.

iii) Factors influencing iron availability to plant.

2.1 Characterisation and distribution of different forms of iron in soil

Cooling of magma formed igneous rock and a sequence of rocks, bearing characteristic mineral species, containing iron as an element. From solid and residual magmas it came into soil as the process of weathering follows and in soil it is found in crystal lattices of primary and secondary minerals. The tendency of elements to replace one another in crystal lattices depending on charge and ionic radius predicts about the distribution of elements in a mineral. In which, higher charge is preferred and for iron of the same co-ordination number, the smaller ion is preferentially selected (Goldschmidt,1954). Ringwood (1955) introduced the added factor of electronegativity. The less electronegative a cation, the greater the tendency to enter into ionic crystal lattice such as that of the silicate minerals. For examples, iron bearing ferromagnesian primary minerals (olivine, hornblende, biotite) and secondary clay mineral (nontronite) where aluminium is substituted by iron at octahedral position.

2.1.1 Characterisation of iron in soil

2.1.1.1 Fe in secondary minerals

Mineralogy of Vertisols and Mollisols, associated in a hydrotoposequence in the plateau of Morocco was studied by Badraoui and Bloom (1990) using X-ray diffraction, interlayer swelling with alkylammonium cations, chemical analysis and infrared spectroscopy. After calculating the structural formula, they found that the clays are beidellite in nature having high charge density and may contain Fe. Infrared spectroscopy demonstrated that these beidellite contain substantial amount of Fe^{3+} in the octahedral sheet.

Bigham *et al.* (1991) have analysed the origin of contrasting soil colour of two soils formed from sedimentary rocks which were similar in clay content (50 to 65%)and mineralogy (smectite). The colours were dark reddish brown (2.5 YR 3/4) vs olive (5Y 5/3).

X-ray diffraction study of Fe-oxide-enriched specimen obtained through high gradient magnetic separations of the soil clays showed goethite to be the only detectable Fe-oxide in the pedon formed from olive (5Y 5/3) shale. Red pigmentation in the companion soil was due to the presence of lithogenic hematite associated with varying amounts of goethite and lepidocrocite. Ratios of dithionite extractable to total iron indicated that goethite had formed primarily by pedogenic weathering of silicate minerals in the profile developed from olive shale. In contrast, sufficient Fe was apparently mobilized by dissolution of lithogenic hematite in the red soil to suppress the release of iron from silicates and to exceed the solubility product of goethite and lepidocrocite on at least a seasonal basis.

2.1.1.2 Sedimented iron oxide

Barral Silva and Guitian Ojea (1991) have classified ferruginous sedimentation (mainly goethite), on the basis of morphological and analytical characteristics.

Class-I : Hard laminar crusts of goethite cemented sand are thought to have been formed in some cases by chemical diffusion of dissolved Fe^{2+} to the capillary fringe of a former water table and in other cases by oxidation and precipitation of iron oxides at the interface between sediment layers with different texture and aeration condition. During formation, continuous deposition would maintain the dissolved iron concentration gradient and hence give rise to a sink effect ensuring the continuance of the diffusion and gradual thickening of the precipitates.

Class II: Globular accumulation consist of an indurated coat of goethite surrounding blackish, acid reduced material containing iron sulphides namely pyrite and sulphate metanterite ($FeSO_4$. $7H_2O$) ; presence of carboniferrous organic matter in the sediments produce gases that may form bubbles which under water-logged conditions, may deform the texture of the deposit and mobilize large amounts of ferrous iron (Siuta and Motowicka, 1969). In this case the globular concretions can be seen. On exposure to better aerated environment the ferrous iron would be oxidised and hydrolysed to produce goethite as a hard coating, protecting the inner materials from oxidation.

Class III: Tubular goethite precipitates are most striking features which is due to the redistribution of iron as the combined result of channeled horizontal flow and the diffusion of dissolved iron towards the unsaturated zone where it would be oxidized and precipitated.

2.1.1.3 Precipitated form of iron oxide

Iron oxide coating from ped surfaces and pores of three rice paddy soils and one non paddy soil from Beaumont, Texax, provided samples for studying iron oxides, mineralogy and the relationship of extractable Fe to extractable Al, Si and P. Chemical analysis of iron oxides, sonication, centrifugation and magnetic separation by Wang *et al.* (1993) showed that these iron oxide coatings cement clay minerals and quartz particles together. Iron oxide coatings in all soils contained lepidocrocite and smaller amounts of goethite. An improved differential X-ray diffraction (DXRD) method *in situ* DXRD on a non reflecting quartz plate allowed the identification of ferrihydrite which is otherwise difficult to identify because of its poor crystallinity and low concentration. The DXRD and chemical data indicate that the paddy soils have more ferrihydrite in relation to total iron oxides than the non-paddy soil. The P to Fe ratio decreased with each AOD treatment (ammonium oxalate, pH 3, in the Dark) step for all soils, their study suggested that physical separation and *in situ* AOD treatment can be used with the DXRD method to identify ferrihydrite, lepidocrocite and goethite in soil clays containing extractable iron concentrations as low as 10 to 44 g/kg.

White and Dixon (1996) in their two sequential studies, showed the distribution of iron as well as manganese distribution in nodules from a young Texas Vertisol and described different types of banding of Fe and Mn in spherical nodules. Whereas, Golden *et al.* (1997) at Texas described the precipitated form of iron oxides. They collected precipitation of iron oxides on ped surfaces, desiccation cracks, pores of clay soil and also the Fe-oxides on the roots of rice plants grown in flooded soil. They characterised two types of iron oxides based on crystallinity :

1. The red precipitation found on the freshly exposed desiccated cracks and on surface of pores of clay soil, which are poorly crystalline iron oxides. These iron oxides precipitate directly from the bulk solution also contain Si and P as these anions are soluble in the reduced medium.

2. The forms found in oxidising condition precipitated near the rice-root surface (Green and Etherington, 1977) contains abundant, well-crystallized lepidocrocite that is free of P and Si.

2.1.2 Distribution of iron in soil

The distribution of iron is a function of the oxidation potential of the soil environment. In soil, divalent form of Fe is less strongly held by soil surfaces 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.

In India, while studying distribution, iron deficiency has been reported in the soils of Punjab (Kanwar *et al.*, 1962), Uttar Pradesh (Agarwala and Mehrotra, 1963), Madhya Pradesh (Rai, *et al.*, 1972) and in South India (Shankarasubramoney *et al.*, 1955).

2.1.2.1 Iron diagnosed by different extractants

To study the distribution of different forms of iron in soils of Uttar Pradesh, Misra and Pande (1975) have 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 is free Fe> 0.1 N, 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.

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 decrease with depth, it was probably due to precipitation of soluble iron at lower depth by adsorption on clays and uncharged oxides as pointed out by Dubey (1982). Iron contents were high when extracted through selective dissolution of 1N HCl, 0.2M oxalate, citrate-bicarbonate-dithionite and 0.5 N NaOH (boiling). 1N HCl extracted more iron might be due to increased solubility of iron compound in acid. For both the soils, the amount extracted by dithionite exceeded the amount that extracted by oxalate. The lower values were obtained with respect to amorphous free iron in Typic Chromustert suggested that most of the free iron was crystalline in the form of goethite as pointed out by McKeague *et al.* (1971). Crystallization of released iron oxides may have been encouraged by low organic matter content and their ageing speeded up by relatively high pH (Blume and Schwertmann, 1969 ; Singer, 1977). The value with respect to 0.5 N NaOH (boiling) extractable Fe_2O_3 showed an increasing trend with depth in both the soils. Similar findings were also reported by Dubey (1982).

A very small quantity of Fe^{2+} was found in these soils than Fe^{3+} which might be due to its transformation into ferric forms (Thakur *et al.*, 1995). The higher values in lower layers and reduction to ferrous iron from the higher total iron was observed in Typic Pellustert due to its basaltic origin as found in soils of Narmada valley.

2.1.2.2 Fractionation of iron

Fractionation of iron revealed that water soluble, Mn-oxide occluded and organically found iron decreased whereas, exchangeable, acid-soluble, Pb-displaceable, amorphous iron oxide-occluded and residual iron increased with depth as found by Yerriswamy *et al.* (1995) in five typical Vertisol series of Karnataka. The percentage contribution of different fractions to the total Fe was in the following order: residual > amorphous Fe-oxide occluded > organically bound> Mn-oxide occluded > Pb-displaceable > exchangeable > acid soluble > water soluble iron. According to their study, 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.

2.1.2.3 Influence of soil properties on distribution of iron

To find out the cause for iron deficiency in the Vertisols (Typic Chromusterts) in Maharashtra, Yelvikar *et al.* (1996) have analysed several soil samples and found significant influence of pH, $CaCO_3$, organic carbon and clay to different fraction of iron. The fractions of iron tested were DTPA-extractable Fe, exchangeable, reducible, dilute acid soluble and water soluble iron.

Zhang *et al.* (1997) reported the sorption and downward transport of trace metals and phosphate in soils are dependent, in part on the distribution of various forms of Fe, Al and Mn. The objectives of this study were to investigate

i) 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

ii] The distribution of these elements in different depth 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.

2.2 Iron in solution and its interaction with different ions

As weathering proceeds, Fe originally present in the easily weatherable ferromagnesian primary minerals appears in illitic clay minerals and ultimately in soil solution. The inorganic iron species in solutions are Fe^{3+}, $Fe\,(OH)^{2+}$, $Fe\,(OH)_3^0$, $Fe(OH)^-_4$ and Fe^{2+}. The content of soluble Fe in soils is extremely low in comparison with the total Fe content. In well aerated soils, however Fe^{2+} contributes little to the total soluble inorganic Fe except under low soil pH conditions. Iron solubility is largely controlled by the solubility of hydrous Ferric oxides. These give rise to Fe^{3+} and its hydrolysis species (Lindsay, 1972):

$$Fe^{3+} + 3(0H)^- = Fe\,(OH)_3\text{ (solid)}$$

The equilibrium is very much in favour of $Fe(OH)_3$ precipitation and is highly pH dependent, the activity of Fe^{3+} falling with increasing pH. At higher pH levels Fe^{3+} activity in solution decreases 1000 fold for rise in each pH unit. In this high pH range (7 to 9), $Fe\,(OH)^{2+}$, $Fe\,(OH)_3$ and $Fe\,(OH)^-_4$ are formed.

2.2.1 Iron in solution

According to Wada and Higashi (1976), the addition of fresh organic matter to soils known to increase the water-soluble iron in soil solution. While solubility level reaches a minimum in the pH range between 7.4 to 8.5 (Lindsay and Schwab, 1982). Acid soils are thus relatively high in soluble inorganic Fe than calcareous soils where levels can be extremely low. This may be the reason for Fe deficiency in crops growing on these soils. According to Chen and Barak (1982) the solubility of Fe oxides/hydroxides decreases in the following sequence: Fe $(OH)_3$ amorphous> Fe $(OH)_3$ in soils > maghaemite (γ-Fe_2O_3) > lepidocrocite (γ-FeOOH) > heamatite (α-Fe_2O_3) > goethite (α-FeOOH).

When soils are water logged a reduction of Fe^{3+} to Fe^{2+} takes place accompanied by an increase in Fe solubility. Reduction is brought about by anaerobic bacteria which use Fe oxides as electron acceptors in respiration (Munch and Ottow, 1983). A close contact between the bacteria and the Fe oxides is required for this process. In soils subjected to anaerobic conditions the ratio of activities of Fe^{3+}/Fe^{2+} can be an important parameter in relation to crop growth. This is assessed by measurement of the redox potential under anaerobic soil conditions. But the differences in redox potential can often be observed in the same profile. In the deeper soil layers which are less well aerated, Fe^{2+} is frequently higher than in the upper horizons. The observations of Wiklander and Hallgren (1949) showed that at a depth of 2m, over 90% of the soluble Fe was present as Fe^{2+}. The redox potential thus generally falls from the upper to the lower horizons.

El-Demerdashe *et al.* (1993) worked on status of iron in a calcareous soil of north-western coast of Egypt. Total iron range was between 2,500 to 55,250 ppm. They extracted available Fe with different extractants and efficiency of different extractants to keep available iron in solution was in the order: HCl > NH_4HC0_3 + DTPA > EDTA > NH_4OAC > DTPA > H_20.

2.2.2 Concentration of bicarbonate in soil solution to induce iron chlorosis

With regard to the exact cause of lime-induced chlorosis, however, there is much diversity of opinion. It is a well-known fact, that plant species vary in their susceptibility to lime-induced chlorosis. Besides the inability of the plant to take up iron from the soil, iron deficiency may also be due to inactivation of the iron within the plant. Wallace and Lunt stressed on the following causal factors:

a) Low iron availability as a result of high pH,

b) high soil moisture content and poor aeration,

c) high bicarbonate content in the soil,

d) extreme temperatures,

e) high phosphate, and

f) incorporation of organic matter.

The multiplicity of factors makes it difficult to evaluate each one for its contribution to lime-induced chlorosis. Pot experiments and field trials were conducted by Boxma (1972), to determine the direct cause of lime-induced chlorosis in Netherlands.The findings were as follows:

1) High bicarbonate content in the soil was the main cause of lime-induced chlorosis.

2) There was a significant correlation between lime-induced chlorosis and the bicarbonate content of the soil in the spring under field conditions.

Coulombe *et al.* (1984) also studied on bicarbonate induced iron chlorosis. Four soybean (*Glycine max* (L.) Merr.) cultivars differing in susceptibility to iron (Fe) chlorosis in wet calcareous soils were grown in nutrient solutions to characterise the effects of phosphate (P) and bicarbonate (HCO^-_3) in inducing chlorosis. $NaHCO_3$ (O or 10 μM), P (10 or 400 μM) as NaH_2PO_4 and NH^+_4 (0 or 300 μM) as $(NH_4)_2SO_4$ were factorial treatments in a nutrient solution. Low Fe availability was maintained by supplying 5μM

Fe + 10 μM EDDHA and excess $CaCO_3$ (pH 7.5). With no HCO^-_3 added, 'T 203' (extremely chlorosis susceptible) was green at 10μM P, but severely chlorotic at 400 μM P; 'Wayne' (chlorosis susceptible) was green at both P levels. Addition of HCO^-_3 caused chlorosis in T203 and wayne at 10 or 400μM P. Chlorosis resistant 'AP9' and 'Hawkeye' remained green with added P on HCO_3. Low Fe concentrations in young leaves corresponded with high chlorosis ratings. Phosphorus concentration in young leaves did not change with HCO_3^- at 10 μM P, but decreased with HCO_3^- at 400μM P. In the absence of HCO_3^- 'Wayne' was not chlorotic at either concentration of solution P, although this cultivar is known to be highly susceptible to chlorosis in the field. Bicarbonate induced chlorosis in wayne was not the result of increased solubility on plant uptake of P. Thus, HCO_3^- was a direct factor in causing soybean chlorosis and likely is also a cause in soils.

2.2.3 Iron availability as influenced by other ions in presence of HCO^-_3

Four pot experiments were performed by Inskeep and Bloom (1986), with five calcareous soils from western Minnesota to determine the effects of soil moisture on Fe chlorosis in soybean (*Glycine max* (L.) Merr.). The soil to CO_2 contents measured from gas wells in pots increased from 0.16 to 16.4 c mol mol^{-1} as a result of decreased gas diffusion when the air-filled porosity decreased. With increasing soil moisture, HCO_3^- concentrations in soil solution attained values as high as 10 μM. Total chlorophyll contents of Anoka soybeans decreased as soil moisture, soil pCO_2 and soil solution HCO_3^- increased. The same response was not observed in all calcareous soils. Calcareous soils with lower amounts of clay sized $CaCO_3$, lower soil solution Mg^{2+} and/or lower bicarbonate extractable P did not produce severe chlorosis with increased moisture. This suggests that clay sized $CaCO_3$, Mg or P may be additional stress factors associated with HCO_3^- induced chlorosis.

Watanbe and Matsumoto (1994) studied effect of monosilicate, phosphate and carbonate on iron dissolution by mugeneic acid. They chose ferrihydrite as a mineral of Fe used to study dissolution rate by the phytosiderophore mugeneic acid (MA) suspended in NaCl (aqueous, pH 4-9) containing orthophosphate, monosilicate and carbonate at a range of concentration. The results showed inhibited Fe dissolution 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 all the tested pH values.

2.3 Factors influencing iron availability to plant

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 in not as a consequence of too low availability of Fe in the soil, but is rather a physiological disorder. Despite physiological disorder some specific cultivar may not face iron chlorosis. So, it can be expressed that there are other factors which are related to iron chlorosis.

In 1975, Venkata Subrahmanyam and Mehta at Anand, Gujarat, studied on availability of iron in presence of different levels of Zn, Fe and moisture in calcareous soil. They found antagonistic effect of Zn towards Fe availability. Maximum available Fe was present under flooding, least under field capacity and intermediate under saturation.

Singh and Dahiya (1975) in Hissar, Haryana conducted experiment to findout the effect of added $CaCO_3$ and iron on the transformation of iron in a light textured soil in laboratory. Exchangeable, available and reducible iron decreased with the increase in added $CaCO_3$. Increase in time of incubation also caused significant decrease in all forms of iron irrespective of addition of $CaCO_3$. Addition of soluble iron salt resulted in immediate increase in all forms of iron which also decreased with incubation time.

Morris *et al.* (1990) have classified the factors influencing iron availability in to four heads.

i) Indigenous soil

ii) Environmental

iii) Nutritional and

iv) Microbial

The indigenous soil factors are those parameters that remain relatively constant and are not readily altered by environmental condition on management practices. The major indigenous soil factors implicated include concentration, mineralogy and crystalline nature of soil Fe (Loeppert and Hallmark, 1985; Vempati and Loeppert, 1988) and concentration, particle size distribution, reactivity and composition of soil carbonate phase (Yaalon, 1957 ; Inskeep and Bloom, 1987) ; soil organic matter (Chen and Barak [1982]), exchangeable Mg and exchangeable Na concentrations (Inskeep and Bloom, 1984) ; Loeppert and Hallmark, 1985) and soil solution composition, especially HCO_3^- concentration (Brown *et al.*, 1959 ; Bloom and Inskeep, 1986).

Environmental factors that have been manifested in Fe availability include soil-water content, soil gas phase composition and rooting volume.

Nutritional factors as it recognised to be responsible for iron availability include P concentration, NH_4/NO_3 balance, K-fertilization and Mn / Fe balance.

Microbial factors implicable to micro-organism population that either increases or decreases the concentration on available Fe, mobilizing the labile Fe including O_2 balance in soil atmosphere. Available Fe in calcareous soils extracted by DTPA-$CaCl_2$ (pH 7.3) DTPA-$CaCl_2$ (pH 8.0), EDTA $(NH_4)_2CO_3$ (pH 8.6), DTPA-NH_4HCO_3 (pH 7.6) and

EDTA-NH_4OAC (pH 7.0) showed significant correlation negatively with pH, free $CaCO_3$ and active $CaCO_3$, whereas positively with organic carbon. Clay content showed a tendency of positive correlation with extractable total Fe in the experiment conducted by Prasad and Sakal (1991) at Pusa, Samastipur, Bihar.

A pot experiment was conducted with calcareous vertic ustochrept in Junagarh, Gujarat by Suthar and Patel (1992). They studied the effect of lime (0, 10 or 20%) and soil water (saturation, 20 and 80% of soil water) on groundnut. Lime application decreased pod yield, soil available iron and plant Fe, Mn and K contents and increased plant P content. Pod yield was highest with 80% available soil water that with 20% ; no pods formed with soil saturation. With increase in soil water content, plant P and K contents decreased and plant Fe, Mn and Zn contents increased.

Campillo and Torrent (1992) chose chickpea and sunflower as test crops and grew in a growth chamber on 25 calcareous soils from Andalusia representing Xeroflurents, Xerorthents, Xerochrepts, Haploxeralfs, Rodoxeralfs, 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 of soil.

Rao *et al.* (1993) observed iron chlorosis of groundnut and studied on plant nutrient content and soil factors on samples collected at different stages of the crop (groundnut) and their yield in chlorotic and nonchlorotic plots. They mentioned significant negative correlation between phosphorus content and ferrous iron in calcareous soil of Andhra Pradesh which showed high P content in plant ; actually the reason behind lesser iron absorption by plants, due to immobilization of Fe.

Jagtap and Mohite (1994) came to know, 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 and Fe and decrease in soil pH was found with addition of organic matter (20 t/ha), and the application of finer (>100 mesh) particles of pyrites during incubation. The soil pH decreased initially in pyrites treated soil up to 7 days and thereafter increased slightly.

Khorsandi (1994) studied the effect of sulphuric acid on the availability of Fe and P in two calcareous soils in green house experiment conducted with sorghum (*Sorghum bicolor*). Addition of sulphuric acid increased soil acidity, salinity, DTPA-Fe, available P ($NaHCO_3^{-}$extractable) and crop yield. The change in soil pH was the key to the increased nutrient availability and subsequent crop yield. Leaching after acid application was beneficial in decreasing salinity during the germination and the seedling stages and this directly affected the yield. The beneficial effect was maintained over two greenhouse cropping seasons.

MATERIAL AND METHODS

III. MATERIAL AND METHODS

To study the distribution of different forms of iron and calcium in calcareous black soils in relation to presence of different concentration of iron in soil solution, soils were collected from Dharwad and Hebballi (from $15^{\circ}19'$ N to $15^{\circ}41'$ N and from $74^{\circ}43'$ E to $75^{\circ}15'$ E) and Hebsur ($15^{\circ}11'$ to $15^{\circ}31'$ N, $75^{\circ}01'$-$75^{\circ}28'$ E) in North Karnataka. Pot culture experiment was carried out to know the influence of moisture and free $CaCO_3$ on iron availability to groundnut crop in a calcareous black soil. The material used and methods followed for the study, mentioned above, are given below.

3.1 Characterisation of calcareous vertisols for form and distribution of iron and calcium

3.1.1 Collection of soil samples

Samples at depth of 0 to 15 cm, 15 to 30 cm, 30 to 60 cm and 60 cm to 1 m of a profile and fourteen surface samples surrounding the profile were collected from each of the selected sites in Dharwad (main research station), Hebballi (Agricultural Research Station) and Hebsur (farmer's field). Collected soil samples represented vertisols and were calcareous in nature. The soil samples were air dried in shade, mixed and powdered with wooden pestle and mortar. After passing through 2 mm sized sieve the powdered soil samples were preserved in plastic bags for further analysis.

3.1.2 Basic characterisation of soils

3.1.2.1 Soil reaction

Soil pH was determined in 1:2.5 (soil:water) suspension using a pH meter (Jackson, 1967).

3.1.2.2 Electrical conductivity (dSm^{-1})

Electrical conductivity was determined in the supernatant solution of 1:2.5 (soil:water) extract using a conductivity meter (Jackson, 1967).

3.1.2.3 Organic carbon

Organic carbon was estimated by Wakley and Black wet oxidation method by oxidising the organic matter in finely ground soil with chromic acid using sulphuric acid as source of heat through heat of dilution of it. The procedure followed was described by Jackson (1967).

3.1.3 Alkaline earth carbonate (free calcium carbonate)

Free calcium carbonate content of soil was determined by acid dilution method as described by Piper, (1966).

3.1. Different forms of iron oxides

3.1.4.1 Free iron oxide

Citrate bicarbonate dithionite (CBD) method was followed to extract free iron oxide from soil samples. Soil sample was heated at 70^0C with citrate-bicarbonate buffer (1:5 to soil : buffer) . At soil suspension temperature of 75^0 C, 1g of sodium dithionite was added once and stirred intermittantly. The suspension was cooled, centrifuged and supernatant was collected. The residue was washed with citrate-bicarbonate and NaCl (twice) and the supernatant was collected. Iron in the washings which was made to a known volume was estimated using atomic absorption spectro photometer (Mehra and Jackson, 1960).

3.1.4.2 Amorphous iron oxide-occluded iron

One part of soil and 40 part of oxalate reagent (ammounium oxalate + oxalic acid) was stirred and kept in darkness for 4 hours. Later centrifuged (30 r.p.m.)and iron in the supernanant was measured in a atomic absorption spectrophotometer (Miller *et al.*, 1986).

3.1.5 Estimation of iron calcium, carbonate and bicarbonate in soil solution

3.1.5.1 Water soluble iron

Soil was extracted with double distilled water maintaining soil to water ratio of 1: 40 and by shaking for 16 hours. Iron in the extract was determined by AAS (Miller *et al.*, 1986).

3.1.5.2 Water soluble calcium

Soil was extracted with double distilled water by maintaining soil to water ratio of 1:1. Calcium in the extract was determined by versenate titration (Black, 1965).

3.1.5.3 Carbonate and bicarbonate

1:2.5 (soil:water) extract was used for determination of carbonate and bicarbonate ion. 0.05 N sulphuric acid was used in presence of phenolphthalein indicator to neutralize carbonate ion. At this stage, another suitable indicator methyl orange was added and further titrated against sulphuric acid to get the neutralization point which indicate the presence of bicarbonate ion (Jackson, 1967).

3.1.6 Estimation of available forms of iron and calcium in soils

3.1.6.1 DTPA extractable form of iron

The method found to be useful for seperating soils into deficient and non deficient categories for micro nutrients, developed by Lindsay and Norvell (1978) was followed for estimation of available iron. DTPA (Diethylene triamine penta acetic acid) was used as extractant and atomic absorption spectrophotometer was used for estimation as described by Tandon (1998).

3.1.6.2 Exchangeable calcium

KCl-TEA(Tri-ethanol amine) buffer solution (pH 8.2) was used to extract exchangeable form of calcium instead of using ammonium acetate to prevent overestimation of calcium especially in case of calcareous soil. The extracted solution was titrated against versene (disodium dihydrogen ethylene diamine tetra acetic acid) using murexide as indicator (Jackson, 1967).

3.2 Pot culture experiment

3.2.1 Collection and preparation of soil sample for pot culture

Surface soil samples (0-15 cm) were collected from a site in MRS Dharwad which represented calcareous vertisol (Typic Haplustert). Collected soil sample was dried, powdered, passed through 2 mm sieve and included in pot culture study.

3.2.2 Experimental details

Different levels of calcium carbonate were chosen for pot culture experiment to get five treatments. The levels chosen were 5, 7, 10, 15 and 20 per cent which represented the wide variation of calcium carbonate in calcareous vertisol of North Karnataka. These treatments were combined with three different moisture levels (75, 150 and 200% of field capacity of soil) to get a combination of 15 treatments.

Required amount of $CaCO_3$ (L. R grade) was mixed with 6 Kg of soil which was filled in cleaned porcelain pots and these pots were transferred to green house, where the added $CaCO_3$ was allowed to equilibrate with soil for 2 months by keeping the soil at moisture level of F. C.

Groundnut (*Arachis hypogaea* L.), variety JL-24 (Phule Pragati) was used as test crop. Five seeds were dibbled in each pot and three healthy seedlings were retained. The crop was grown till the stage of harvest, following all of the cultural practices except adding gypsum.

The details of the experiment are given in Table 1.

3.2.3 Maintenance of moisture level

Using pressure plate apparatus, the field capacity of the soil was determined. Depending upon the treatment, pot received different quantities of water at two pre determined stages, viz., the flowering and pegging stage of the crop. While maintaining the three moisture levels, three seperate pots with 500 gm soil were kept in same environmental condition (in greenhouse) and reduction in weight due to evaporation was measured and moisture was maintained in different treatments in accord with that.

Table 1. DETAILS OF THE EXPERIMENT

Sl. No	Particulars	
1	Crop variety	JL-24
2	Design	2 factor Completely Randomised Design
3	Treatments	T_1- Moisture level at 75% of F.C+5% of $CaCO_3$ (M_1C_1) T_2- Moisture level at 75% of F.C+7% of $CaCO_3$ (M_1C_2) T_3- Moisture level at 75% of F.C+10% of $CaCO_3$ (M_1C_3) T_4- Moisture level at 75% of F.C+15% of $CaCO_3$ (M_1C_4) T_5- Moisture level at 75% of F.C+20% of $CaCO_3$ (M_1C_5) T_6- Moisture level at 150% of F.C+5% of $CaCO_3$ (M_2C_1) T_7- Moisture level at 150% of F.C+7% of $CaCO_3$ (M_2C_2) T_8- Moisture level at 150% of F.C+10% of $CaCO_3$ (M_2C_3) T_9- Moisture level at 150% of F.C+15% of $CaCO_3$ (M_2C_4) T_{10}- Moisture level at 150% of F.C+20% of $CaCO_3$ (M_2C_5) T_{11}- Moisture level at 200% of F.C+5% of $CaCO_3$ (M_3C_1) T_{12}- Moisture level at 200% of F.C+7% of $CaCO_3$ (M_3C_2) T_{13}- Moisture level at 200% of F.C+10% of $CaCO_3$ (M_3C_3) T_{14}- Moisture level at 200% of F.C+15% of $CaCO_3$ (M_3C_4) T_{15}- Moisture level at 200% of F.C+20% of $CaCO_3$ (M_3C_5)
4	Replication	Three
5	Date of sowing	31.12.1999
6	Date of harvest	18:04.2000

3.2.4 Soil analysis

3.2.4.1 Iron and calcium content after harvest

After harvest soil samples were collected and analysed for different forms of iron, calcium and bicarbonate ion. [procedure as mentioned in section 3.1(3.4.5.6)].

3.2.5 Dry matter yield and plant analysis

3.2.5.1 Dry matter yield

As soon as the crop growth period was over, plant sample was collected, washed with water followed by 0.1 N HCl and distilled water and kept for air drying. Air dried haulm samples were oven dried at 70°C for overnight. The weight of oven dried haulm and air dried pod samples were recorded.

3.2.5.2 Preparation of plant samples

Dried samples were powdered in a grinder and pressured in paper bags for further analysis.

3.2.5.3 Estimation of iron and calcium in plant samples

Plant samples were digested in diacid mixture (Nitric acid : Perchloric acid in proportion of 9:4) and filtered extract was used for estimation of iron by AAS and calcium by versenate titration method (Tandon, 1998).

3.3 Statistical analysis

Completely randomised design (2 factor) was followed for pot culture experiment and correlation study was made to analyse distribution of iron and calcium in soil samples collected from three different places. Computed data was interpreted with critical difference level at 5 per cent and 1 per cent.

EXPERIMENTAL RESULTS

IV. EXPERIMENTAL RESULTS

Surface and profile soil samples, representing calcareous black soil (Typic Haplustert) were collected from M.R.S., Dharwad (D-Block), Hebballi (Agricultural Research Station) and Hebsur (Farmer's field). A pot culture experiment was conducted with groundnut (JL-24) as test crop in the winter season of 1999-2000 and soil samples were analysed for different forms of iron, calcium and bicarbonate and plant samples for total iron and calcium. The results of the survey work and pot culture experiment are presented as follows:

4.1 Results of soil survey

4.1.1 Basic characterization of soils

4.1.1.1 Soil reaction

Surface soil samples (0-15cm) of Dharwad were neutral in pH, ranging from pH 6.50 to pH 7.16. In Hebballi, surface soils were having the pH range of 7.56 to 8.36, indicating neutral to slightly alkaline soil reaction. Surface soil samples from Hebsur were alkaline in pH ranged from 8.24 to 8.96.

pH of profile samples (table 2) did not follow any specific distribution pattern in Dharwad and Hebballi and the range were 6.70 to 7.69 and 7.01 to 7.87 respectively. Whereas, profile samples in Hebsur showed pH in decreasing order as the depth increased (pH 8.96 to pH 8.78).

4.1.1.2 Soluble salts

Electrical conductivity of surface soils of Dharwad, Hebballi and Hebsur ranged from 0.43 to 0.64 dSm^{-1}, 0.29 to 0.77 dSm^{-1} and 0.57 to 0.68 dSm^{-1} respectively, revealing the wider range of E.C. values in the surface soils of Hebballi.

Table 2. BASIC CHARACTERISATION OF SOILS OF THREE DIFFERENT PLACES

Profile samples	DHARWAD			HEBBALLI			HEBSUR		
Depth(cm)	**pH**	**E. C (dSm^{-1})**	**O. C (%)**	**pH**	**E. C (dSm^{-1})**	**O. C (%)**	**pH**	**E. C (dSm^{-1})**	**O. C (%)**
0-15	6.70	0.43	0.60	7.72	0.56	0.60	8.96	0.68	0.60
15-30	7.19	0.54	0.51	7.87	0.50	0.57	8.96	0.65	0.54
30-60	7.69	0.62	0.48	7.83	0.68	0.51	8.84	0.66	0.48
60-100	7.33	0.55	0.36	7.01	0.72	0.45	8.78	0.66	0.39
Surface samples Depth (0-15 cm)									
1	6.50	0.51	0.57	7.80	0.60	0.60	8.48	0.61	0.57
2	6.55	0.54	0.63	7.69	0.34	0.60	8.79	0.58	0.60
3	6.54	0.59	0.66	8.00	0.77	0.57	8.83	0.59	0.57
4	6.66	0.48	0.72	8.09	0.62	0.57	8.81	0.61	0.39
5	6.67	0.56	0.69	8.07	0.71	0.54	8.67	0.60	0.42
6	7.05	0.63	0.60	8.20	0.72	0.54	8.56	0.58	0.63
7	6.73	0.64	0.48	8.31	0.59	0.63	8.68	0.61	0.54
8	6.57	0.61	0.63	8.14	0.55	0.54	8.71	0.63	0.39
9	7.35	0.61	0.69	8.36	0.42	0.54	8.80	0.67	0.42
10	7.16	0.63	0.72	8.09	0.49	0.57	8.81	0.64	0.60
11	6.59	0.60	0.51	8.06	0.40	0.57	8.72	0.64	0.57
12	6.55	0.58	0.63	8.31	0.34	0.54	8.67	0.63	0.57
13	6.91	0.58	0.66	8.31	0.30	0.54	8.55	0.62	0.42
14	6.55	0.59	0.57	7.56	0.29	0.54	8.24	0.57	0.54

Profile samples of all the three places was recorded E.C. values which did not follow any definite pattern with depth. Soil samples from Dharwad recorded E.C. values which were in the range of 0.43 to 0.62 dSm^{-1}. E.C.values of Hebballi soils ranged from 0.50 to 0.72 dSm^{-1} and E.C. of Hebsur soils were in the range of 0.65 to 0.68 dSm^{-1} (Table 2). It can be concluded from the results that soluble salt content in all the soils were quite less and soils of all of the three places were non-saline.

4.1.1.3 Organic carbon

Surface soils samples of Dharwad was recorded the lowest value of 0.48 per cent and the highest value of 0.72 per cent organic carbon content and in Hebballi soil it ranged from 0.54 to 0.63 per cent. In Hebsur soil the values ranged from 0.39 to 0.63 per cent (Table.2).

Organic carbon content in profile samples of all of the three places decreased with depth. The range of organic carbon in profile of Dharwad was 0.60 to 0.36 per cent, in Hebballi it was 0.60 to 0.45 per cent and in Hebsur it was 0.60 to 0.39 per cent.

In all the three places, the distribution of organic carbon was medium.

4.1.2 Distribution of water soluble iron, calcium and bicarbonate in soil solution

Water soluble iron, calcium and bicarbonate in soil solution were estimated in the soil samples collected from different places. The results (Table 3) are as follows.

4.1.2.1 Water soluble iron

Surface soil samples of Dharwad was recorded water soluble iron from 0.28 to 0.76 ppm and it was in the range of 0.26 to 0.48 ppm in Hebballi. Whereas, Hebsur soils showed a lowest value of 0.22 ppm and highest of 0.32 ppm.

Table 3. IRON, CALCIUM AND BICARBONATE CONCENTRATION (ppm) IN SOILS OF THREE DIFFERENT LOCATIONS

	D H A R W A D			H E B B A L L I			H E B S U R		
Profile samples Depth(cm)	**Water soluble iron (ppm)**	**Water soluble calcium (ppm)**	**Bicarbonate in solution (ppm)**	**Water soluble iron(ppm)**	**Water soluble calcium (ppm)**	**Bicarbonate in solution (ppm)**	**Water soluble iron(ppm)**	**Water soluble calcium (ppm)**	**Bicarbonate in solution (ppm)**
0-15	0.76	226.70	152.50	0.48	70.00	457.50	0.36	90.00	305.00
15-30	0.68	266.70	305.00	0.44	40.00	610.00	0.22	50.00	762.50
30-60	0.68	260.00	305.00	0.46	60.00	610.00	0.26	40.00	762.50
60-100	0.44	400.00	305.00	0.46	150.00	762.50	0.24	120.00	610.00
Surface samples									
1	0.28	250.00	305.00	0.38	50.00	457.50	0.34	50.00	457.50
2	0.38	220.00	457.50	0.26	60.00	457.50	0.36	40.00	457.50
3	0.42	333.30	457.50	0.48	70.00	610.00	0.38	60.00	610.00
4	0.46	230.00	457.50	0.26	70.00	457.50	0.36	120.00	457.50
5	0.40	250.00	305.00	0.48	70.00	610.00	0.34	40.00	610.00
6	0.28	270.00	457.50	0.38	70.00	762.50	0.36	50.00	762.50
7	0.28	230.00	305.00	0.40	80.00	457.50	0.36	60.00	305.00
8	0.38	260.00	152.50	0.40	60.00	762.50	0.38	50.00	915.00
9	0.44	280.00	305.00	0.36	20.00	762.50	0.34	40.00	915.00
10	0.54	290.00	305.00	0.46	80.00	762.50	0.32	40.00	762.50
11	0.54	260.00	305.00	0.44	80.00	762.50	0.32	60.00	762.50
12	0.48	240.00	152.50	0.42	130.00	610.00	0.36	40.00	457.50
13	0.42	270.00	305.00	0.44	60.00	762.50	0.34	50.00	610.00
14	0.68	300.00	457.50	0.46	40.00	762.50	0.32	60.00	610.00

Water soluble iron of profile soil samples of Dharwad decreased with increasing depth, ranging from 0.76 to 0.44 ppm. In profile samples of Hebballi and Hebsur, water soluble iron did not follow any definite trend and the values were in the range of 0.48 to 0.44 ppm and 0.36 to 0.22 ppm respectively.

4.1.2.2 Water soluble calcium

Surface samples of Dharwad was recorded water soluble Ca which was in the range of 220.0 to 333.3 ppm. In Hebballi, it was in the range of 20.0 to 130.0 ppm. Whereas, it was 40.0 to 120.0 ppm in Hebsur (Table.3).

Distribution of water soluble calcium in profile samples did not follow any definite trend in all of the three places and the values were in the ranges of 226.7 to 400.0 ppm, 40.0 to 150.0 ppm and 40.0 to 120.0 ppm in Dharwad, Hebballi and Hebsur respectively.

4.1.2.3 Bicarbonate

The bicarbonate concentration in surface soils of Dharwad were in the range of 152.5 to 457.5 ppm. A range of 457.5 to 762.5 ppm of bicarbonate iron concentration was observed in soils of Hebballi and in Hebsur it was in the range of 305.0 to 915.0 ppm.

The profile soil samples of Dharwad did not follow any definite trend in the distribution of bicarbonate iron but the concentration was more in all other depths except surface. The values of bicarbonate ions concentration were in the range of 152.50 to 305.00 ppm (Table.2). Bicarbonate concentration in profile of Hebballi increased with increasing depth and the values were in a range of 457.5 to 762.5 ppm. The profile samples of Hebsur did not show any definite trend in bicarbonate concentration and the values ranged from 305.0 to 762.5 ppm (Table.3).

4.1.3 Distribution of different forms of iron and calcium

Amorphous iron oxide-occluded iron, free iron oxide, free calcium carbonate, exchangeable calcium and DTPA-extractable iron content in profile and surface soil samples are presented in Table 4 and the results are described as under:

4.1.3.1 Amorphous iron oxide-occluded iron

Amorphous Fe oxide-occluded iron was in the range of 1043.6 to 1264.4 ppm surface soils of Dharwad (Table 4). It ranged from 1066.0 to 1466.0 ppm in Hebballi. Whereas, it was in range of 445.0 to 1103.2 ppm in Hebsur.

Amorphous iron oxide-occluded iron content increased as the depth increased in profile samples at all the three places which ranged from 1095.80 to 1434.0 ppm of soil, 798.8 to 1072.8 ppm and 479.6 to 1222.0 ppm in Dharwad Hebballi and Hebsur respectively.

Average value of amorphous Fe oxide-occluded iron was more in Dharwad soil and was less in Hebsur.

4.1.3.2 Free iron oxide

Free iron oxide content in surface samples of Dharwad was in a range of 175.6 ppm to 416 ppm. The surface soils of Hebballi recorded a range of 100 to 350 ppm. It was 89.9 to 210 ppm in the surface soils of Hebsur.

Free iron oxide content in profile samples of Dharwad showed positive relation with depth, ranging from 175.6 to 210.6 ppm (Table 4). Whereas, Hebballi and Hebsur did not recorded any definite pattern in distribution of free iron in profile samples and the values ranged from 153.6 to 319.0 ppm and 76.1 to 112.7 ppm respectively.

Table 4. CHARACTERISATION OF IRON AND CALCIUM IN SOILS OF THREE DIFFERENT LOCATIONS

Place	DHARWAD					HEBBALLI					HEBSUR				
Depth	Amorphous Fe oxide-occluded Fe(ppm)	Free Fe oxide(ppm)	Free CaCO3(%)	Exchangeable Ca(c.mol/kg)	DTPA-Fe(ppm)	Amorphous Fe oxide-occluded Fe(ppm)	Free Fe oxide(ppm)	Free CaCO3(%)	Exchangeable Ca(c.mol/kg)	DTPA-Fe(ppm)	Amorphous Fe oxide-occinded Fe(ppm)	Free Fe oxide(ppm)	Free CaCO3(%)	Exchangeable Ca(c.mol/kg)	DTPA-Fe(ppm)
0-15	1095.80	175.60	4.00	24.60	5.20	798.80	191.80	2.00	39.00	1.64	479.60	99.70	16.50	28.20	2.35
15-30	1157.80	177.00	2.00	27.00	2.67	907.00	153.60	3.00	39.00	1.06	344.20	76.10	13.50	26.60	0.45
30-60	1188.20	179.40	2.00	27.60	1.75	914.80	209.20	3.50	39.20	1.03	678.40	98.30	13.00	30.60	0.49
60-100	1434.00	210.60	9.00	28.40	2.12	1072.80	319.00	5.50	45.80	0.30	1222.00	112.70	17.50	42.60	1.02
Surface samples Depth (0-15 cm)															
1	1162.40	210.30	4.50	27.20	5.33	1052.80	186.90	2.50	39.20	1.72	757.40	192.90	12.50	33.20	1.85
2	1043.80	235.60	4.00	24.80	4.33	1071.00	193.40	1.50	41.20	1.81	498.60	177.30	18.50	30.60	2.20
3	1229.40	325.40	6.00	36.40	2.80	1024.20	207.50	3.50	31.60	1.36	598.80	189.90	10.00	31.40	1.95
4	1123.40	223.50	6.50	25.40	2.77	1064.00	180.00	2.50	43.00	1.05	721.20	142.10	12.50	36.80	0.40
5	1161.80	209.70	7.00	27.20	3.01	1079.00	193.30	3.50	44.00	0.90	512.80	210.10	8.00	30.00	1.07
6	1043.60	178.40	8.00	30.60	1.79	1415.80	178.70	6.00	43.20	0.83	787.00	195.60	14.00	32.40	2.62
7	1096.40	236.00	4.00	26.20	4.74	1197.20	350.70	3.50	45.00	1.69	494.60	91.40	10.50	31.40	1.53
8	1190.40	247.00	1.50	27.80	6.97	1466.00	100.30	8.50	42.40	0.73	445.00	89.90	15.00	30.80	0.25
9	1140.80	190.20	2.50	32.20	4.99	1064.80	153.70	6.00	18.60	0.72	495.60	107.30	15.50	29.60	0.24
10	1087.20	210.50	2.50	34.80	5.03	1006.00	170.60	7.00	44.40	0.39	509.20	119.90	10.50	28.00	2.04
11	1157.40	278.60	3.50	27.20	5.20	1037.80	187.30	6.50	44.80	1.17	513.20	198.90	14.50	31.00	1.64
12	1155.40	279.70	4.00	26.00	8.35	1045.20	152.50	5.50	42.80	0.81	531.40	101.10	13.50	28.20	1.98
13	1264.40	380.10	4.00	28.00	5.13	1023.40	154.40	6.00	42.00	0.80	795.60	186.50	14.00	32.40	0.29
14	1242.60	416.60	6.00	36.80	2.77	1176.80	220.20	5.00	37.00	0.96	1103.20	101.60	17.50	31.40	1.31

4.1.3.3 Free calcium carbonate

Free calcium carbonate content ranged from 1.5 to 8.0 per cent in surface soils of Dharwad. In surface soils of Hebballi, it was from 1.5 to 8.5 per cent while in surface soils of Hebsur it was from 8.0 to 18.5 per cent (Table 4).

The distribution of free calcium carbonate in surface soil samples of Dharwad varied very narrowly whereas, the range was wide, in surface soils of Hebsur (8.0 to 18.5%).

Free calcium carbonate in profile samples of Dharwad did not follow any definite trend, and the values ranged from 2.0 to 9.0 per cent (Table 4). Distribution of free calcium carbonate in profile samples in Hebballi was in increasing order as the depth increased, ranging from 2.0 to 5.5 per cent. There was no definite trend followed in free calcium carbonate content in profile samples of Hebsur and it ranged from 13.0 to 17.5 per cent.

4.1.3.4 Exchangeable calcium

Exchangeable calcium in the surface soils of Dharwad ranged from 24.8 to 36.8 c.mol $(p^+)kg^{-1}$. It was 18.6 to 45.0 c.mol $(p^+)kg^{-1}$ in surface samples of Hebballi and 28.0 to 36.8 c.mol $(p^+)kg^{-1}$ in surface samples of Hebsur.

The data of exchangeable calcium as given in Table 3, showed positive relation with depth, in profiles of both Dharwad and Hebballi, where the values ranged from 24.6 to 28.4 c.mol $(p^+)kg^{-1}$ and 39.0 to 45.8 c.mol $(p^+)kg^{-1}$ respectively. Whereas, distribution of exchangeable calcium in profile of Hebsur did not follow any definite trend and it ranged from 26.6 to 42.6 c.mol $(p^+)kg^{-1}$ (Table 4).

Table 5. CORRELATION STUDY OF DIFFERENT PARAMETERS OF SURFACE SAMPLES

Sl. No.		**r-value**		
		Dharwad	**Hebballi**	**Hebsur**
1	Free calcium carbonate vs DTPA-Fe	-0.786**	-0.766**	---
2	Water soluble Ca vs DTPA-Fe	-0.307	-0.010	-0.153
3	Water soluble Ca vs water soluble Fe	0.039	0.177	0.158
4	Exchangeable Ca vs Free iron oxide	0.413	0.051	0.345
5	Exchangeable Ca vs Amorphous Fe oxide-occluded Fe	0.370	0.168	0.498
6	Exchangeable Ca vs water soluble Fe	0.098	0.024	0.142
7	Bicarbonate vs Free calcium carbonate	0.631*	0.889**	0.644*
8	Bicarbonate vs DTPA-Fe	-0.842**	-0.797**	-0.374

* Significant at 5% level.

** Significant at 1% level.

4.1.3.5 DTPA-extractable iron

DTPA-extractable iron in surface soils of Dharwad ranged from 1.79 to 8.35 ppm. Surface samples of Hebballi recorded 0.73 to 1.81 ppm of DTPA Fe and it was 0.23 to 2.62 ppm in surface samples of Hebsur (Table 4).

The distribution of DTPA-Fe did not follow any definite trend in profile samples of Dharwad, which ranged from 1.75 to 5.19 ppm. The DTPA-extractable iron content in profile of Hebballi decreased with depth and the values ranged from 0.30 to 1.64 ppm. There was no definite trend found in DTPA-Fe content in profile of Hebsur and it ranged from 0.44 to 2.34 ppm.

4.2 Pot culture study

Groundnut (JL-24, a bunch variety) was chosen as test crop and was grown in pot till maturity of the crop. Availability of iron and calcium to plant was studied by imposing different levels of moisture and $CaCO_3$ as different treatments to the soil. Moisture treatment was imposed at flowering (7 days) and pegging (7 days) stage during crop growth with seven days gap, while $CaCO_3$ treatment was imposed at the beginning of the experiment.

4.2.1 Basic characterisation of soil

Chemical and physical properties of soil and different forms of iron and calcium were analysed at the beginning of the experiment. The data is presented in Table 6.

4.2.2 Pod and haulm yield

Air-dry weight of pods (g/pot) and oven-dry weight of haulm (g/pot) are given in Table 7 and the details are as follows.

Table 6. BASIC CHARACTERISATION OF SOIL USED IN POT CULTURE STUDY

Treatments analysed	Values	Methodology
Physical properties		
Coarse sand	18.10 %	International pipette method (Piper, 1966)
Fine sand	26.00 %	
Silt	22.44 %	
Clay	30.0%	
Texture	clay loam	
Chemical properties		
pH	7.34	Jackson, 1967
Electrical conductivity	0.61 dSm^{-1}	Jackson, 1967
Organic carbon	0.63%	Jackson, 1967
Free calcium carbonate	5.00%	Piper, 1966
Amorphous Fe oxide- occluded iron	1064 ppm	Miller *et al.*, 1986
Free iron oxide	423.4 ppm	Mehra & Jackson,1960
DTPA-extractable iron	8.49 ppm	Lindsay & Norvell,1978
Water soluble iron	0.888 ppm	Miller *et al.*, 1986
Water soluble calcium	370.00 ppm	Tandon, 1998
Bicarbonate	537.25 ppm	Jackson , 1967
Exchangeable calcium	28.40 c. mol $(p^{+})kg^{-1}$	Black, 1965.

4.2.2.1 Yield of pod (g/pot)

Moisture level had positive and significant effect on pod yield. At moisture level of 75 per cent of F.C. pod yield was 11.25 g/pot. At moisture level of 150 per cent of F.C. it increased to a level of 13.92 g/pot. Whereas, at 200 per cent of F.C. (M_3) yield of pod increased further and it was 14.21g/pot.

Different $CaCO_3$ level also influenced significantly on yield of pod. At C_1 (5% of $CaCO_3$) yield was 14.37 g/pot and it increased to a level of 14.93 g/pot at C_2 (7% of $CaCO_3$). Whereas, C_3 i.e., at 10 per cent $CaCO_3$ content yield decreased, recording a value of 12.37 g /pot. Yield of pod at C_4 (15% of $CaCO_3$) showed positive effect over C_3 and yield increased to 12.60 g /pot. 20 per cent of $CaCO_3$ content (C_5) showed negative effect on pod yield (11.38 g /pot) (Table 7).

Interaction effect of moisture and $CaCO_3$ level showed more yield in T_6-M_2C_1 and T_7-M_2C_2 than in other treatments (19.40 g/pot in T_6 and 19.90 g /pot in T_7). Whereas, maximum pod yield was recorded in T_7, at moisture level of 150 per cent of F.C. in presence of 7 per cent of $CaCO_3$.

4.2.2.2 Yield of haulm

Significant increase in haulm yield was observed with increase in moisture level (22.35 to 23.73 g/pot). At M_1(75% of F.C.) yield of haulm was 22.35 g/pot which increased to 23.11 g/pot at M_2(150% of F.C.) and further increased to 23.73 g/pot at M_3 (200% of F.C.) (Table 7).

Significant influence was recorded in yield of haulm with increase in level of $CaCO_3$. At 5 per cent level of $CaCO_3$, yield was 24.29 g/pot and it decreased to 23.26 g/pot at C_2 (7% of $CaCO_3$). Further decrease in yield of haulm was observed at C_3 and it was 21.86 g/pot. The haulm yield further decreased (21.76 g/pot) at 15 per cent $CaCO_3$

Table 7. DRY MATTER YIELD OF GROUNDNUT (*Arachis hypogaea.* L.) AS INFLUENCED BY CALCIUM CARBONATE AND MOISTURE

	Oven Dry weight of Haulm (g/pot)			
	M_1	M_2	M_3	MEAN
C_1	22.17	26.90	23.80	24.29
C_2	21.50	26.07	22.20	23.26
C_3	22.67	19.13	23.77	21.86
C_4	22.47	19.63	23.17	21.76
C_5	22.93	23.80	25.73	24.16
MEAN	22.35	23.11	23.73	

Factor	Sem±	CD (0.05)
A	0.18	0.426
B	0.23	0.551
AxB	0.396	0.954

Factor A

M_1= Moisture level at 75% of F. C

M_2= Moisture level at 150% of F. C

M_3= Moisture level at 200% of F. C

	Air Dry weight of Pods(g/pot)			
	M_1	M_2	M_3	MEAN
C_1	6.10	19.40	17.60	14.37
C_2	9.00	19.90	15.90	14.93
C_3	11.70	10.63	14.77	12.37
C_4	14.57	10.50	12.73	12.60
C5	14.90	9.17	10.07	11.38
MEAN	11.25	13.92	14.21	

Factor	Sem±	CD (0.05)
A	0.03	0.076
B	0.04	0.098
AxB	0.071	0.17

Factor B

C_1= 5% of $CaCO_3$

C_2= 7% of CaCO3

C_3= 10% of CaCO3

C_4= 15% of CaCO3

C_5= 20% of CaCO3

content (C_4). Treatment with 20 per cent $CaCO_3$ (C_5) recorded exceptionally increased yield of haulm (24.16 g/pot).

Interaction effect indicated more yield at T_6-M_2C_1 and at T_7 -M_2C_2 (recording 26.90 g/pot at T_6 and 26.06 g/pot at T_7). Whereas, maximum yield amongst all the treatment was in the treatment of 150 per cent of F.C. + 5 per cent of $CaCO_3$ content (26.90 g/pot).

4.2.3 Concentration of different ions in soil solution

Different ions *viz.*, water soluble iron, water soluble calcium and bicarbonate were estimated after harvest in the soil samples which were treated with different level of moisture and $CaCO_3$ (Table 8).

4.2.3.1 Water soluble iron

Increased moisture level influenced significantly on water soluble iron content after harvest (Table 8). At 75 per cent F.C. (M_1) water soluble iron content was 0.62 ppm which increased up to a level of 0.98 ppm at 150 per cent and 75 per cent of FC, though further increase was not found at 200 per cent F.C. (0.98 ppm).

Negative but significant effect of $CaCO_3$ level was observed on concentration of water soluble iron. At C_1(5% of $CaCO_3$) it was 1.80 ppm and decreased to 1.37 ppm in C_2(7% of $CaCO_3$). Increase of $CaCO_3$ content to 10 per cent (C_3), decreased the concentration of water soluble iron to a level of 0.94 ppm. Further increase in $CaCO_3$ to 15 per cent (C_4), decreased the water soluble iron to 0.09 ppm, $CaCO_3$ over 15 per cent, did not show any influence on concentration of water soluble iron (0.09 ppm at 20% of $CaCO_3$).

Table 8. CHANGES IN IRON, CALCIUM AND BICARBONATE CONCENTRATION (ppm) IN SOIL SOLUTION AFTER THE HARVEST OF THE CROP

WATER SOLUBLE IRON (ppm)				
	M_1	M_2	M_3	Mean
C_1	1.54	2.06	1.80	1.80
C_2	1.29	1.54	1.29	1.37
C_3	0.26	1.29	1.29	0.94
C_4	ND	ND	0.26	0.09
C_5	ND	ND	0.26	0.09
Mean	0.62	0.98	0.98	

*ND Not detected

Factor	Sem±	CD (0.05)
A	0.09	0.21
B	0.12	0.28
AxB	0.20	NS

WATER SOLUBLE CALCIUM (ppm)				
	M_1	M_2	M_3	Mean
C_1	43.33	110.00	173.33	108.89
C_2	56.67	113.33	220.00	130.00
C_3	86.67	120.00	270.33	160.00
C_4	106.67	160.00	300.00	188.89
C_5	126.67	240.00	350.33	240.00
Mean	84.00	148.67	264.00	

Factor	Sem±	CD (0.05)
A	0.09	0.21
B	0.12	0.28
AxB	0.20	NS

BICARBONATE (ppm)				
	M_1	M_2	M_3	Mean
C_1	510.67	660.83	711.67	627.72
C_2	585.75	711.67	737.08	678.17
C_3	660.83	727.08	787.92	725.28
C_4	711.67	787.83	813.33	770.94
C_5	737.08	813.33	838.75	796.39
Mean	641.20	740.15	777.75	

Factor	Sem±	CD (0.05)
A	0.09	0.21
B	0.12	0.28
AxB	0.20	NS

Factor A

M_1= Moisture level at 75% of F. C
M_2 = Moisture level at 150% of F. C
M_3 = Moisture level at 200% of F. C

Factor B

C_1 = 5% LEVEL OF $CaCO_3$
C_2 = 7% LEVEL OF $CaCO_3$
C_3 = 10% LEVEL OF $CaCO_3$
C_4 = 15% LEVEL OF $CaCO_3$
C_5 = 20% LEVEL OF $CaCO_3$

Interaction effect showed presence of maximum concentration (1.80 ppm) of water soluble iron at moisture level of 200 per cent of F.C. (saturation) with 5 per cent of $CaCO_3$ (T_{11}-M_3C_1).

4.2.3.2 Water soluble calcium

Water soluble calcium was significantly and positively related to moisture level. M_1 (75% of F.C.) recorded the concentration of 84.00 ppm of water soluble calcium which increased to 148.67 ppm at M_2 (150% F.C.). Further increase was observed at M_3 (200% of F.C.) and it was 264.00 ppm (Table 8).

Calcium carbonate treatments showed positive and significant effect on water soluble calcium. In C_1 (5% of $CaCO_3$) it was 108.89 ppm which increased to 130.00 ppm in C_2 (7% of $CaCO_3$). 10 per cent of $CaCO_3$ (C_3) showed more increase in water soluble calcium (160.00 ppm). Further increase was recorded at C_4 (15% of $CaCO_3$) and the value was 188.89 ppm. Maximum value (240.00 ppm) of water soluble calcium was recorded at C_5 (20% of $CaCO_3$).

Interaction effect showed presence of maximum amount of water soluble calcium (353.33 ppm) at moisture level of 200 per cent F.C. + 20 per cent of $CaCO_3$ (T_{15}-M_3C_5).

4.2.3.3 Bicarbonate

Bicarbonate was positively and significantly related to moisture level. In M_1 (75% of F.C.) bicarbonate concentration was 641.20 ppm which increased to 740.15 ppm in M_2(150% of F.C.). A concentration of 777.75 ppm of bicarbonate was observed in M_3 (200% of F.C.) (Table 8).

Increased level of $CaCO_3$ increased the concentration of bicarbonate showing significant and positive effect. Under treatment of 5 per cent of $CaCO_3$ content bicarbonate recorded 627.72 ppm which increased to 678.17 ppm at C_2 (7% of C_aCO_3). Further increase in $CaCO_3$ level increased the bicarbonate level to 725.28 ppm in C_3 (10% of $CaCO_3$) and in C_4 (10% of $CaCO_3$), it was 770.94 ppm and 796.39 ppm in the treatment of 20 per cent of $CaCO_3$ (C_5).

Interaction showed presence of lowest amount of bicarbonate (510.67 ppm) at moisture level of 75 per cent of F.C. + 5per cent of $CaCO_3$ (T_1-M_1C_1). Maximum concentration of bicarbonate (838.75 ppm) was found at moisture level of 200 per cent of F.C. + 20 per cent of $CaCO_3$ (T_{15}-M_3C_5).

4.2.4 Iron oxide

Two forms of iron oxides *viz.*, free iron oxide and amorphous Fe oxide-occluded iron were analysed and data is presented in Table 9.

4.2.4.1 Free iron oxide

Moisture level influenced positively and significantly on free iron oxide content. In M_1 (75% of F.C.) free iron oxide content was 364.770 ppm and it increased to 370.060 ppm in M_2 (150% of F.C.). Further increase in moisture level resulted in 381.980 ppm of free iron oxide as in M_3 (200% of F.C.) (Table 9).

$CaCO_3$ level influenced negatively and significantly on free iron oxide content and it decreased from 395.060 ppm [C_1(10% $CaCO_3$)] to 378.260 ppm [C_2 (10% $CaCO_3$)]. Further increase in $CaCO_3$ content, decreased the free iron oxide content to 370.100 ppm and it lessened to 363.000 ppm as in 15 per cent of $CaCO_3$ (C_4). Whereas, further increase in $CaCO_3$ to 20 per cent(C_5), decreased the free iron oxide to 354.960 ppm.

Table 9. CHANGES IN DIFFERENT FORMS OF IRON OXIDES(ppm) IN SOIL AFTER THE HARVEST OF CROP

Free Iron Oxides				
	M_1	**M_2**	**M_3**	**Mean**
C_1	390.167 (7.85)	392.640 (7.26)	402.363 (4.97)	395.060
C_2	365.567 (13.66)	376.737 (11.02)	392.483 (7.30)	378.260
C_3	362.530 (14.38)	367.317 (13.25)	380.440 (10.15)	370.100
C_4	355.583 (16.02)	361.143 (14.71)	372.260 (12.08)	363.000
C_5	350.023 (17.33)	352.470 (16.75)	362.377 (14.41)	354.960
Mean	364.770	370.060	381.980	

Factor	Sem(+)	CD (0.05)
A	0.37	0.089
B	0.48	1.147
Interaction AxB	0.827	1.987

Amorphous Fe oxide-occluded iron				
	M_1	**M_2**	**M_3**	**Mean**
C_1	989.447 (7.01)	1024.187 (3.74)	1043.060 (1.97)	1 012.900
C_2	913.533 (14.15)	876.220 (17.65)	989.447 (7.01)	926.400
C_3	572.567 (46.19)	858.207 (19.34)	970.100 (8.83)	779.290
C_4	481.213 (54.77)	730.827 (31.37)	784.867 (26.23)	665.640
C_5	319.093 (17.01)	335.820 (68.44)	647.193 (39.17)	434.040
Mean	655.170	765.050	874.930	

Factor	Sem(+)	CD (0.05)
A	1.74	4.176
B	2.24	5.392
Interaction AxB	3.884	9.339

Factor A
M_1= Moisture level at 75% of F. C
M_2 = Moisture level at 150% of F. C
M_3 = Moisture level at 200% of F. C

Factor B
C_1 = 5% LEVEL OF $CaCO_3$
C_2 = 7% LEVEL OF $CaCO_3$
C_3 = 10% LEVEL OF $CaCO_3$
C_4 = 15% LEVEL OF $CaCO_3$
C_5 = 20% LEVEL OF $CaCO_3$

Values in parenthesis indicate percent decrease over initial concentration

Interaction effect indicated maximum content (402.363 ppm) of free iron oxide in soil at T_{11}-M_3C_1. Minimum amount of free iron oxide (350.023 ppm) was found at T_5-M_1C_5.

4.2.4.2 Amorphous Fe oxide-occluded iron

Amorphous Fe oxide-occluded iron was positively and significantly related to moisture content in soil. In M_1 (75% of F.C.) amorphous iron oxide-occluded iron was 655.17 ppm which increased to 765.05 ppm in M_2 (150% of F.C.) further in M_3 (200% of F.C.), it was 871.93 ppm. In 5 per cent $CaCO_3$ (C_1), amorphous Fe oxide-occluded iron was 1019.90 ppm which decreased to 926.40 ppm in C_2 (7% $CaCO_3$). In C_3 (10% $CaCO_3$), it was 779.29 ppm and further increase in level of $CaCO_3$ decreased the iron content and it was 665.64 ppm in C_4 (15% $CaCO_3$) and 434.04 ppm in C_5 (20% $CaCO_3$).

Interaction effect indicated highest amount of amorphous iron oxide-occluded iron (1043.06 ppm) in 5 per cent + 200 per cent of F.C. and was lowest (319.093 ppm) in T_5-M_1C_5 (75% of F.C.+ 20% $CaCO_3$).

4.2.5 Other forms of iron and calcium in soil after harvest

DTPA-extractable iron and exchangeable calcium were analysed and the results are presented in Table 10.

4.2.5.1 DTPA extractable iron

Moisture level influenced negatively on DTPA-Fe in soil. In 75 per cent of F.C. (M_1) DTPA-Fe content was 3.70 ppm and decreased to 3.35 ppm at 150 per cent of F.C. (M_2). Further decrease was observed at 200 per cent F.C. (M_3) where the value was 2.42 ppm of DTPA - Fe.

Table 10.CHANGES IN AVAILABLE IRON AND CALCIUM IN SOIL AFTER HARVEST OF THE CROP

	DTPA- extractable iron(ppm)					Exchangeable Calcium(c.mol(p^+) kg^{-1})			
	M_1	M_2	M_3	Mean		M_1	M_2	M_3	Mean
C_1	5.51	4.28	3.90	4.56	C_1	26.93	26.33	28.20	27.16
C_2	3.82	3.74	2.97	3.51	C_2	26.13	25.67	25.60	25.80
C_3	3.24	3.24	1.89	2.79	C_3	25.20	24.00	25.13	24.78
C_4	3.06	2.99	1.74	2.60	C_4	24.73	23.20	21.53	23.16
C_5	2.89	2.47	1.58	2.31	C_5	22.33	18.47	20.53	20.44
Mean	3.70	3.35	2.42		Mean	25.07	23.53	24.20	

Factor	Sem ±	CD(0.05)
A	0.01	0.03
B	0.02	0.04
AxB	0.03	0.06

Factor	Sem ±	CD(0.05)
A	0.05	0.13
B	0.07	0.17
AxB	0.12	0.29

Factor A

M_1= Moisture level at 75% of F. C
M_2 = Moisture level at 150% of F. C
M_3 = Moisture level at 200% of F. C

Factor B

C_1 = 5% LEVEL OF $CaCO_3$
C_2 = 7% LEVEL OF $CaCO_3$
C_3 = 10% LEVEL OF $CaCO_3$
C_4 = 15% LEVEL OF $CaCO_3$
C_5 = 20% LEVEL OF $CaCO_3$

$CaCO_3$ also showed negative and significant effect on concentration of DTPA-Fe in soil. In C_1 (5% $CaCO_3$), DTPA-Fe was found to be 4.56 ppm, which reduced to 3.51 ppm, 2.79 ppm and 2.60 ppm in the treatments C_2 (7% $CaCO_3$), C_3 (10% $CaCO_3$) and C_4 (15% $CaCO_3$) respectively. The lowest value was recorded in the 20 per cent $CaCO_3$ treatment (C_5), where the value was 2.31 ppm.

Interaction effect of moisture and $CaCO_3$ resulted in maximum level of DTPA-Fe (5.51 ppm) at moisture level of 75 per cent of F.C + 7 per cent $CaCO_3$. The lowest amount of DTPA-Fe (1.58 ppm) was found in presence of moisture of 200 per cent of F.C. + 20 per cent of $CaCO_3$ (T_{15}-M_3C_5).

4.2.5.2 Exchangeable calcium

Moisture had a significant influence on exchangeable Ca in soil. It was 25.07 c.mol (p^+) kg^{-1} at the moisture level of 75 per cent of F.C. (M_1). The Ca level decreased to 23.53 c.mol (p^+) kg^{-1} at 150 per cent of F.C. (M_2) and at 200 per cent of F.C. (M_3) the exchangeable Ca was 24.20 c.mol (p^+) kg^{-1}.

Significant and negative effect of $CaCO_3$ was observed on exchangeable Ca content in soil. Exchangeable Ca in C_1 (5% $CaCO_3$) was 27.16 c.mol (p^+) kg^{-1} and it reduced to 25.80 , 24.78 and 23.16 c.mol (p^+) kg^{-1}at C_2 (7% $CaCO_3$),C_3 (10% $CaCO_3$) and C_4 (15% $CaCO_3$) respectively. Further decline in exchangeable Ca was found in the 20 per cent $CaCO_3$ (C_5) treatment and the value was 20.44 c.mol (p^+) kg^{-1} (Table 10).

Interaction effect revealed, presence of highest amount of exchangeable Ca (28.20 c.mol (p^+) kg^{-1}) at 200 per cent of F.C. with 5 per cent of $CaCO_3$ content (T_{11}-M_3C_1). Lowest amount of exchangeable Ca (18.4 c.mol (p^+) kg^{-1}) was found in presence of moisture level of 150 per cent of F.C. with 20 per cent $CaCO_3$ (T_{10}-M_2C_5).

4.2.6 Calcium content in plant samples

Calcium content in kernel and haulm was analysed after harvest and data is given in Table 11.

4.2.6.1 Calcium in kernel

With increasing level of moisture, Ca content in kernel increased showing significant and positive relationship. At moisture level of 75 per cent of F.C. (M_1), Ca content in kernel was 0.88 per cent which increased to 0.93 per cent at 150 per cent of F.C. (M_2) and further increased to a level of 1.00 per cent at 200 per cent of F.C. (M_3).

Calcium carbonate content in soil increased the Ca content in kernel showing positive and significant effect. In 5 per cent of $CaCO_3$ treatment, Ca content in kernel was 0.71 per cent which increased to 0.81 per cent at 7 per cent $CaCO_3$ content (C_2). Further increase in $CaCO_3$ level in soil, raised the Ca content in kernel also [0.92% and 1.07% at C_3 (10% $CaCO_3$) and C_4 (15% $CaCO_3$) respectively]. Maximum Ca content (1.18%) in kernel was associated with 20 per cent $CaCO_3$ (C_5).

Interaction effect revealed presence of higher amount of Ca (1.23%) in kernel at moisture level of 200 per cent of F.C. with 20 per cent of $CaCO_3$ (T_{15}-M_3C_5). The lowest amount (0.65%) was found at moisture level of 75 per cent of F.C. and with 5 per cent of $CaCO_3$ (T_1-M_1C_1).

4.2.6.2 Calcium content in haulm

Calcium content in haulm increased significantly with the influence of moisture. In 75% F.C. treatment(M_1) Ca content in haulm was 1.10 per cent which increased to 1.54 per cent and 1.80 per cent at 150 per cent of F.C.(M_2) and 200 per cent of F.C. respectively.

Table 11. CONCENTRATION OF CALCIUM IN PLANT AS INFLUENCED BY MOISTURE AND CALCIUM CARBONATE

Calcium content (%) in kernel				
	M_1	M_2	M_3	MEAN
C_1	0.65	0.69	0.77	0.71
C_2	0.76	0.80	0.88	0.81
C_3	0.84	0.92	1.00	0.92
C_4	1.01	1.05	1.13	1.07
C_5	1.13	1.17	1.23	1.18
MEAN	0.88	0.93	1.00	

Calcium content (%) in haulm				
	M_1	M_2	M_3	MEAN
C_1	0.56	0.96	1.32	0.95
C_2	0.72	1.33	1.57	1.21
C_3	1.04	1.51	1.76	1.44
C_4	1.40	1.84	2.04	1.76
C_5	1.76	2.08	2.32	2.05
MEAN	1.10	1.54	1.80	

Factor	Sem±	CD (0.05)
A	0.01	0.02
B	0.01	0.03
(AxB)	0.02	NS

Factor	Sem±	CD (0.05)
A	0.01	0.03
B	0.02	0.04
(AxB)	0.03	0.08

Factor A

M_1= Moisture level at 75% of F. C

M_2= Moisture level at 150% of F. C

M_3= Moisture level at 200% of F. C

Factor B

C_1= 5% of $CaCO_3$

C_2= 7% of CaCO3

C_3= 10% of CaCO3

C_4= 15% of CaCO3

C_5= 20% of CaCO3

In C_1 (5% $CaCO_3$), Ca content in haulm was 0.95 per cent which raised to 1.21 per cent to 1.44 per cent at 7 per cent of $CaCO_3$ (C_2) and 10 per cent of $CaCO_3$ (C_3) content in soil respectively. Further increase in $CaCO_3$ content to 15% per cent (C_4) and 20 per cent (C_5), increased the Ca content in haulm to 1.76 per cent and 2.05 per cent respectively.

Interaction effect showed, presence of the highest amount of Ca (2.32%) in T_{15}-M_3C_5 [moisture level of 200% of F.C. (saturation)] and lowest Ca (0.56%) was noticed at T_1-M_1C_1 (75% of F.C. and 5% of $CaCO_3$).

4.2.7 Iron content in plant

Total iron was analysed both in kernel and haulm after harvest and is presented in Table 12.

4.2.7.1 Iron in kernel

A significant positive effect was found between iron content in kernel and moisture level in soil. In M_1(75% of F.C.), Fe content in kernel was 192.49 ppm which raised to 195.44 ppm in M_2(150% of F.C.) and further increase in moisture level at 200 per cent of F.C. (M_3) resulted in increased Fe concentration (199.95 ppm) in kernel.

$CaCO_3$ content in soil also showed positive and significant effect on Fe content in kernel. In 5 per cent $CaCO_3$ treatment Fe content in kernel was 183.99 ppm which increased to 189.78 ppm and 196.65 ppm in C_2 (7% $CaCO_3$) and in C_3 (10% $CaCO_3$) respectively. Further increase in Fe content was also observed [202.2 ppm at C_4 (15% $CaCO_3$) and 207.15 ppm at C_5 (20% $CaCO_3$)] as the level of $CaCO_3$ content increased in soil.

Table 12. CONCENTRATION OF IRON IN PLANT AS INFLUENCED BY CALCIUM CARBONATE AND MOISTURE.

Iron (ppm) in kernel				
	M_1	M_2	M_3	Mean
C_1	180.78	184.64	186.57	183.99
C_2	184.64	189.78	194.93	189.78
C_3	193.64	195.57	200.72	196.65
C_4	199.43	201.36	205.87	202.22
C_5	203.94	205.87	211.66	207.15
Mean	192.49	195.44	199.95	

Factor	Sem ±	CD(0.05)
A	0.320	0.778
B	0.420	1.004
AxB	0.720	1.740

Iron (ppm) in haulm				
	M_1	M_2	M_3	Mean
C_1	528.82	532.68	536.54	532.68
C_2	589.29	622.75	603.45	605.16
C_3	666.78	744.98	698.66	703.81
C_4	681.29	952.78	862.07	832.04
C_5	703.16	980.44	1025.47	903.03
Mean	634.07	766.72	745.24	

Factor	Sem ±	CD(0.05)
A	0.64	1.55
B	0.83	1.99
AxB	1.44	3.46

Factor A

M_1= Moisture level at 75% of F. C
M_2= Moisture level at 150% of F. C
M_3= Moisture level at 200% of F. C

Factor B

C_1= 5% of $CaCO_3$
C_2= 7% of CaCO3
C_3= 10% of CaCO3
C_4= 15% of CaCO3
C_5= 20% of CaCO3

Study of interaction effect indicated, presence of highest amount of iron (211.66 ppm) in T_{15}-M_3C_5 (moisture level of 20% of F.C. + 20% of $CaCO_3$). Lowest amount of total iron content (180.78 ppm) in kernel was recorded in T_1-M_1C_1 i.e., at moisture level of 75 per cent of F.C. with 5 per cent of $CaCO_3$.

4.2.7.2 Iron in haulm

Moisture influenced significantly on iron content in haulm. 634.07 ppm of Fe was found in M_1 (75% of F.C.) and 766.62 ppm in M_2 (150% of F.C.). Further increase in moisture level in M_3 (200% of F.C.) decreased the Fe content in haulm to the level of 745.24 ppm.

Increased $CaCO_3$ level, increased the Fe content in haulm showing significant and positive relation. At 5 per cent of $CaCO_3$ (C_1), Fe content in haulm was 532.68 ppm which increased to 605.16 ppm in C_2 (7% $CaCO_3$). Further increase in level of $CaCO_3$, increased Fe content in haulm to 703.81 ppm [in C_3(10% $CaCO_3$)]and to 832.04 ppm [in C_4(15% $CaCO_3$)]. At 20 per cent of $CaCO_3$ in soil, further increase in Fe content was noticed in haulm (903.03 ppm).

Interaction effect showed presence of highest amount of total iron (1025.47 ppm) at T_{15} (moisture level of 200% of F.C. with 20% of $CaCO_3$). Lowest amount of total iron (528.82 ppm) in haulm was found at T_1-M_1C_1 (moisture level of 75% of F.C. in presence of 5% of $CaCO_3$ content).

4.3 Observation of visual symptom on groundnut

During the first imposition of moisture levels at flowering stage (48 DAS) prominent chlorotic symptoms in younger leaves was observed. With increasing moisture level the more prominent yellowness was noticed (Plate 3). At 20 per cent of $CaCO_3$ content and at moisture level 75 per cent of F.C. plants did not appear chlorotic

Plate 1. Effect of different levels of calcium carbonate at same moisture level (Saturation)

Sl. No.	Treatment
1.	T_{11} (M_3C_1) = Moisture content of 200 per cent of F.C. + 5 per cent $CaCO_3$
2.	T_{12} (M_3C_2) = Moisture content of 200 per cent of F.C. + 7 per cent $CaCO_3$
3.	T_{13} (M_3C_3) = Moisture content of 200 per cent of F.C. + 10 per cent $CaCO_3$
4.	T_{14} (M_3C_4) = Moisture content of 200 per cent of F.C.. + 15 per cent $CaCO_3$
5.	T_{15} (M_3C_5) = Moisture content of 200 per cent of F.C. + 20 per cent $CaCO_3$

Plate 2. Influence of different levels of moisture 75, 150 and 200 per cent of F. C. at 20 per cent of $CaCO_3$

Sl. No.	Moisture level	$CaCO_3$ content (%)
1.	200 per cent of F.C.	20
2.	150 per cent of F.C.	20
3.	75 per cent of F.C.	20

Plate 3. A general view of the symptoms appeared under different treatments with three replication

Sl. No.	$CaCO_3$ content (%)	Moisture content
1.	5, 7, 10, 15 and 20	200 per cent of F.C.
2.	5, 7, 10, 15 and 20	150 per cent of F.C.
3.	5, 7, 10, 15 and 20	75 per cent of F.C.

Plate 1. Effect of different levels of $CaCO_3$ at same moisture level (saturation)

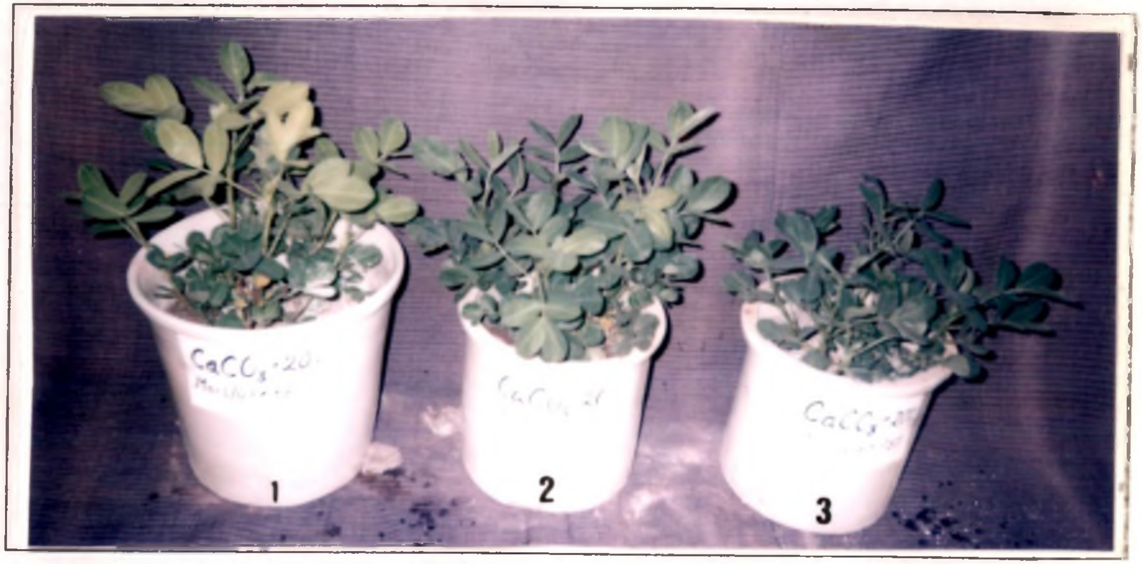

Plate 2. Influence of different levels of moisture (75, 150 and 200 per cent of F.C.) at 20 per cent of $CaCO_3$

Plate 3. A general view of the symptoms appeared under different treatments with three replications

whereas, plants at moisture level of 150 per cent of F.C. and 200 per cent of F.C. (saturation) showed chlorotic symptoms (Plate 1). Degree of yellowness increased with increasing moisture level. In case of moisture level of 200 per cent of F.C. with 20 per cent $CaCO_3$ (T_{15}-M_3C_5) lamina of younger leaves was completely yellow whereas at moisture level of 150 per cent of F.C. with 20 per cent $CaCO_3$ (T_{10}-M_2C_5), only veins were yellow but lamina appeared still greenish (Plate 1).

On the other hand at saturation level [M_3(200% of F.C.)] yellowness was more prominent with increasing level of $CaCO_3$. In T_{11}-M_3C_1 (5% $CaCO_3$) symptom was not prominent, in T_{12} -M_3C_2 (7% $CaCO_3$) two or three leaves in each branch showed chlorotic symptom, in T_{13}-M_3C_3 (10% $CaCO_3$) maximum of four leaflets in a twig were chlorotic showing yellow veins, in T_{14}-M_3C_4 (15% $CaCO_3$) one or two leaflets in a twig appeared totally yellow whereas, at maximum concentration of $CaCO_3$ [T_{15}-M_3C_5(20% $CaCO_3$)] all the leaflets in every younger twigs were chlorotic showing yellow appearance of leaf lamina (Plate 2). But second time, when moisture levels were imposed at pegging stage (61 DAS) after a interval of 7 days, plants did not show any such chlorotic appearance, even at the end of the moisture imposition period of 7 days.

DISCUSSION

V. DISCUSSION

The results of ionic composition of soils with respect to iron, calcium and bicarbonate at selected places of Dharwad, Hebballi and Hebsur and results of pot culture experiment conducted in different levels of moisture and calcium carbonate are discussed under the following headings.

5.1 Characterization of iron and calcium in soils of three locations in Dharwad district

5.1.1 Initial properties of soils

5.1.2 Water soluble ions (iron, calcium and bicarbonate) in soil

5.1.3 Content and distribution of different forms of iron and calcium in profiles and surface of Dharwad, Hebballi and Hebsur

5.2 Pot culture study

5.2.1 Dry matter yield of groundnut

5.2.2 Ionic composition of soil solution with respect to iron, calcium and bicarbonate after the harvest of the crop

5.2.3 Changes of different forms of iron and calcium in soil after harvest

5.2.4 Uptake and concentration of calcium and iron in plant in different treatments

5.2.5 Symptoms of lime induced iron chlorosis

5.1 Characterization of iron and calcium in soils of three locations in Dharwad district

5.1.1 Initial properties of soils

Soil of Dharwad was neutral, that of Hebballi was neutral to slightly alkaline, while the soil of Hebsur was slightly alkaline to alkaline in pH (Table 2). It is evident from result, pH increased due to increase in bicarbonate concentration (152.5 to 457.5 , 457.5 to 762.5 and 305.0 to 915.0 ppm respectively in Dharwad, Hebballi and in Hebsur) and may be associated with high concentration of sodium.

All the soil samples (profile and surface) were found to be non-saline (EC range was 0.29 to 0.77 dSm^{-1}).

Organic carbon content in profile and at surface were medium in range in all the three soils. Organic carbon content decreased with increasing depth of profiles in all the three places. Presence of higher organic matter at surface than in sub surface soil could be expected as a result of addition of organic matter through the decomposition of plant and animal tissues which was confined to upper horizon only.

5.1.2 Water soluble ions (iron, calcium and bicarbonate) in soil solution

5.1.2.1 Water soluble calcium

Although the profile samples did not show any definite pattern in distribution of water soluble calcium, the deepest layer (60 cm to 1m) contained highest amount of water soluble Ca. Comparing surface soils of the three soils, the calcium concentration (226.7 to 400.0 ppm) in Dharwad soil was very high. It might be due to difference in particle size distribution of $CaCO_3$, substantiated by the work of Nandi and Dasog (1992).

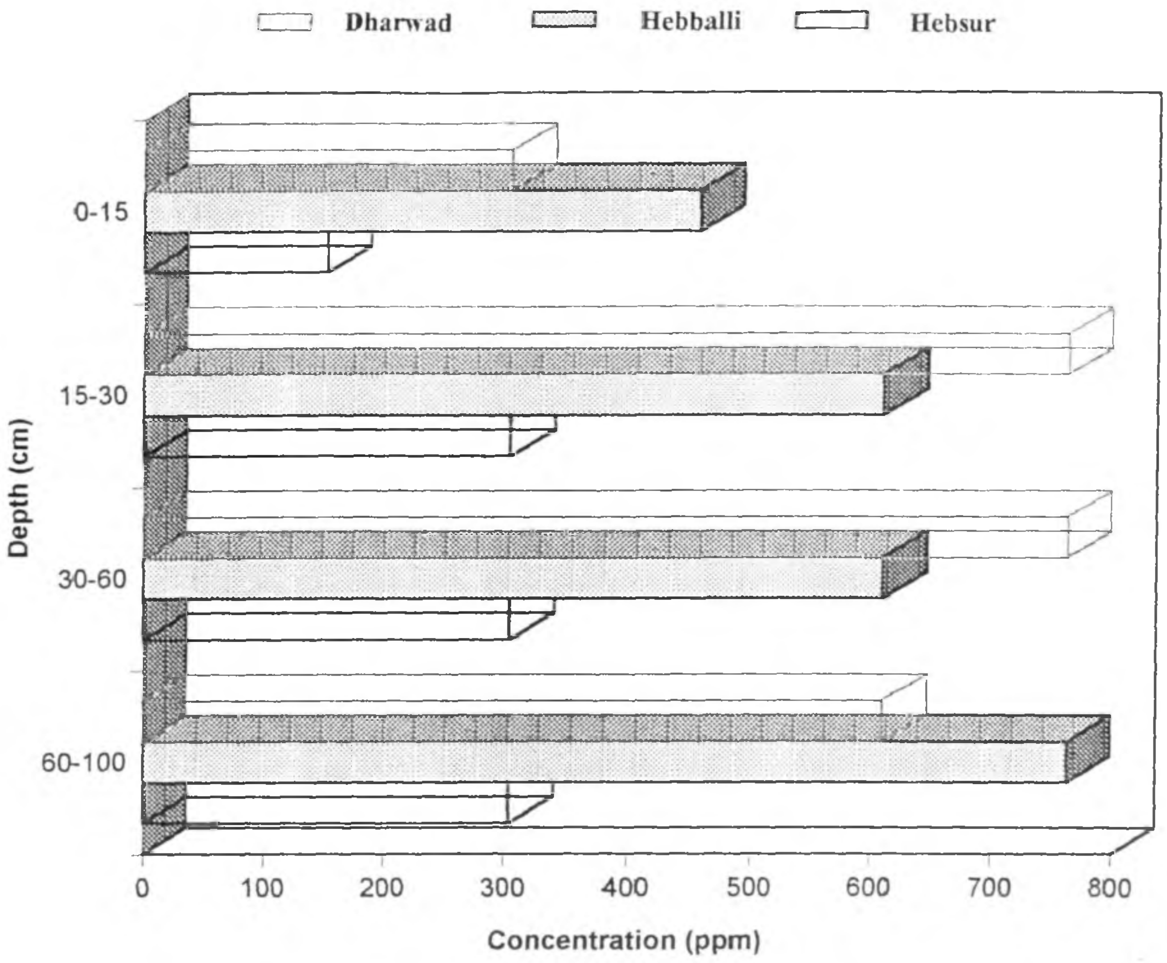

Fig. 1 Distribution of Bicarbonate ion in profile samples of three locations

5.1.2.2 Bicarbonate

Subsurface soils contained more amount of bicarbonate than surface soils in all the three profiles (Fig.1). Moisture might have contributed to higher bicarbonate concentration in Dharwad.

Rao *et al.* (1993) found positive correlation ($r = 0.96$) of soil water with HCO^-_3 in soil solution. Once the profile is wet, higher moisture remains for a long period in the lower depth and thus favours HCO^-_3 formation which is one of the products of hydrolysis of $CaCO_3$ ($CaCO_3 + CO_2 + H_20 = Ca^{2+} + 2HCO^-_3$).

5.1.2.3 Water soluble iron

Distribution of water soluble iron in profile samples (Fig.2) revealed less amount of water soluble iron in subsurface layers (15-30 cm, 30-60 cm and 60 cm to 1 m) than in surface (0-15cm). More clay content and less amount of organic matter in subsurface layers could be the reason of this type of distribution. Yerriswamy *et al.* (1995) also found negative relation of clay ($r = -0.792^{**}$) and positive relation of organic matter ($r = 0.703^{**}$) with water soluble iron.

Comparison of data of surface samples at the three places indicated the presence of highest amount of water soluble iron in Dharwad (0.68 ppm). It might be due to relatively less soil pH. According to Lindsay and Schwab (1982) each unit increase in pH, decreases the solubility of iron as much as 1000 times.

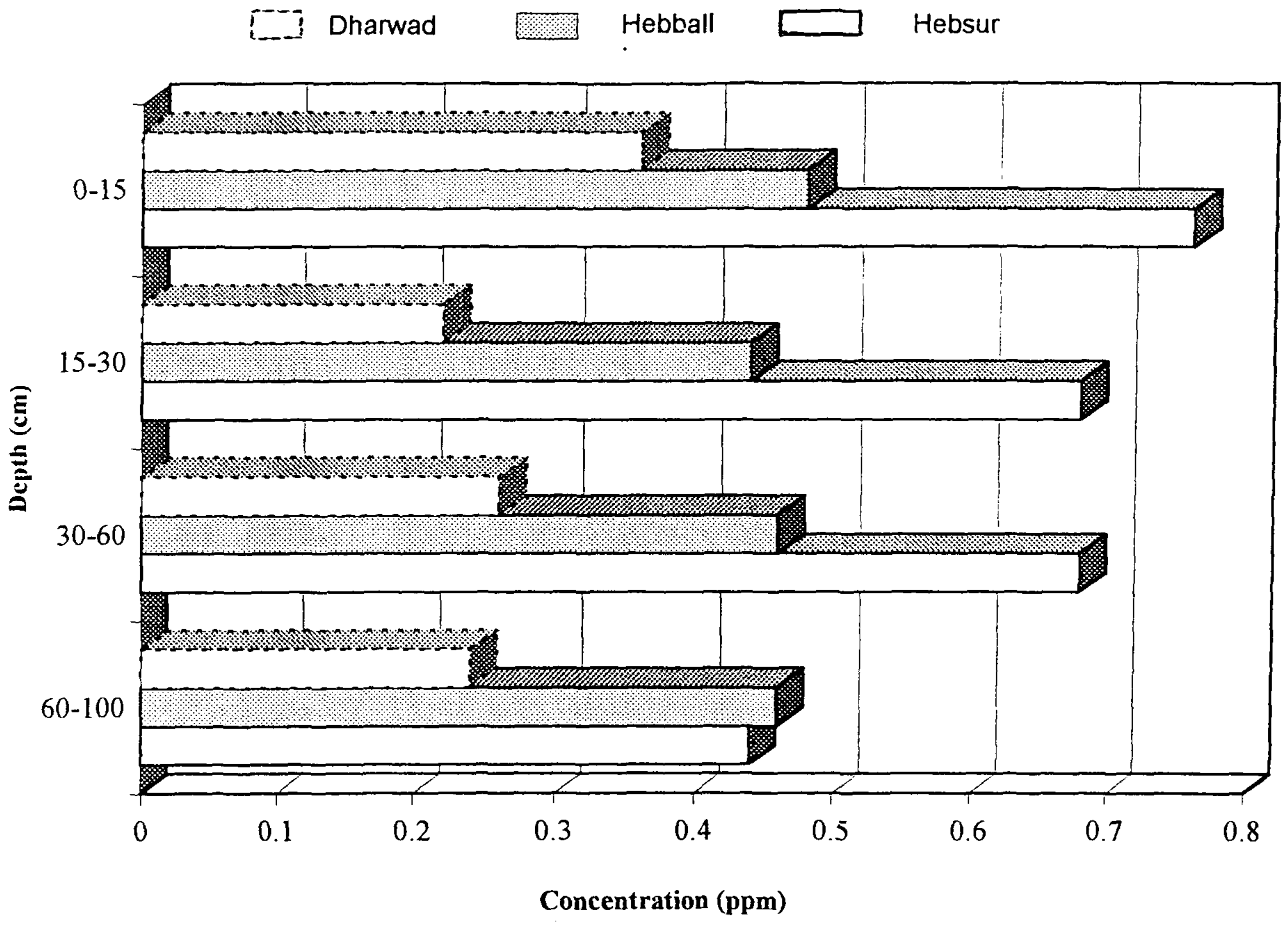

Fig. 2 Distribution of water soluble iron in profile samples of three different locations

5.1.3 Distribution of different forms of iron and calcium

5.1.3.1 Amorphous iron oxide-occluded iron

It can be noted from the data presented in Table 4 that amorphous iron oxide-occluded iron increased with depth of profile samples at all the three places. Yerriswamy *et al.*(1995) noticed positive correlation of clay (r = 0.65**) with distribution of amorphous iron oxide-occluded iron in profile samples.

The concentration of amorphous iron oxide-occluded iron was less in surface samples of Hebsur (445.0 to 1103.2 ppm) than in those from Dharwad (1043.6 to 1264.4 ppm). This is evident from the higher of concentration of free iron oxides (76.1 to 112.7 ppm and 175.6 to 210.6 ppm in Hebsur and in Dharwad respectively) since the trend of distribution of amorphous iron oxide-occluded iron follows the trend of distribution of free iron oxide. Hawkes and Webb (1962) are of the opinion that amorphous iron oxide-occluded iron remain sorbed on the surface or in interlayer spaces of free iron oxides.

5.1.3.2 Free iron oxide

Perusal of the data (Table 4) revealed that concentration of free iron oxide increased with depth and maximum amount was found at the depth of 60 cm to 1 m (2106 , 319.0 and 112.7 ppm in Dharwad, Hebballi and Hebsur respectively). This might be due to more accumulation of precipitated iron oxide at this depth (60 cm to 1m) which later crystallized to free iron oxide. The results are in confirmity with the findings of Thakur *et al.*(1995) who found differences in amount of precipitated iron in subsurface layers which influenced crystallization and ultimately indicated the age of soil.

5.1.3.3 Free calcium carbonate

Results (Table 4) indicated that no definite trend was followed in distribution of free calcium carbonate in profile samples of Dharwad (2.0 to 9.0%) and Hebsur (13.0 to 17.5%). Amount of free calcium carbonate increased with increase in depth in the profile of Hebballi (2.0 to 5.5 %). Generally concentration of calcium carbonate was high at 1 m depth (Fig.3) at all the three places which might be due to leaching of calcium from surface horizons and precipitation as $CaCO_3$. This might also be due to higher concentration of exchangeable calcium and solution calcium at lower depth.

5.1.3.4 Exchangeable calcium

Exchangeable calcium in profile did not follow any definite pattern of distribution (Fig.4) but maximum level of exchangeable calcium was noticed at lower depth. This could be related to higher clay content at that particular layer (Appendix II).

Surface soils of Hebballi was found to have more exchangeable calcium content [18.6 to 45.0 c. mol (p^+) kg^{-1}] than those or other two places. This might be due to higher clay in Hebballi soils. Mengel and Kirkby (1987) were of the opinion that exchangeable calcium mostly remained adsorbed to inorganic soil colloids.

5.1.3.5 DTPA-extractable iron

No definite trend in the distribution pattern of DTPA-extractable iron was observed in profiles of Dharwad and Hebsur soils (Fig.5). DTPA-Fe concentration was found to decrease with increasing depth at Hebballi (0.30 to 1.64 ppm). The concentration was found to be higher at surface than in sub-surface of all the profiles. It might be due to higher organic matter content at surface than in sub-surface. Katyal and Sharma (1991) also observed positive relation of DTPA-Fe with content of organic matter in soil in different climatic zones of India.

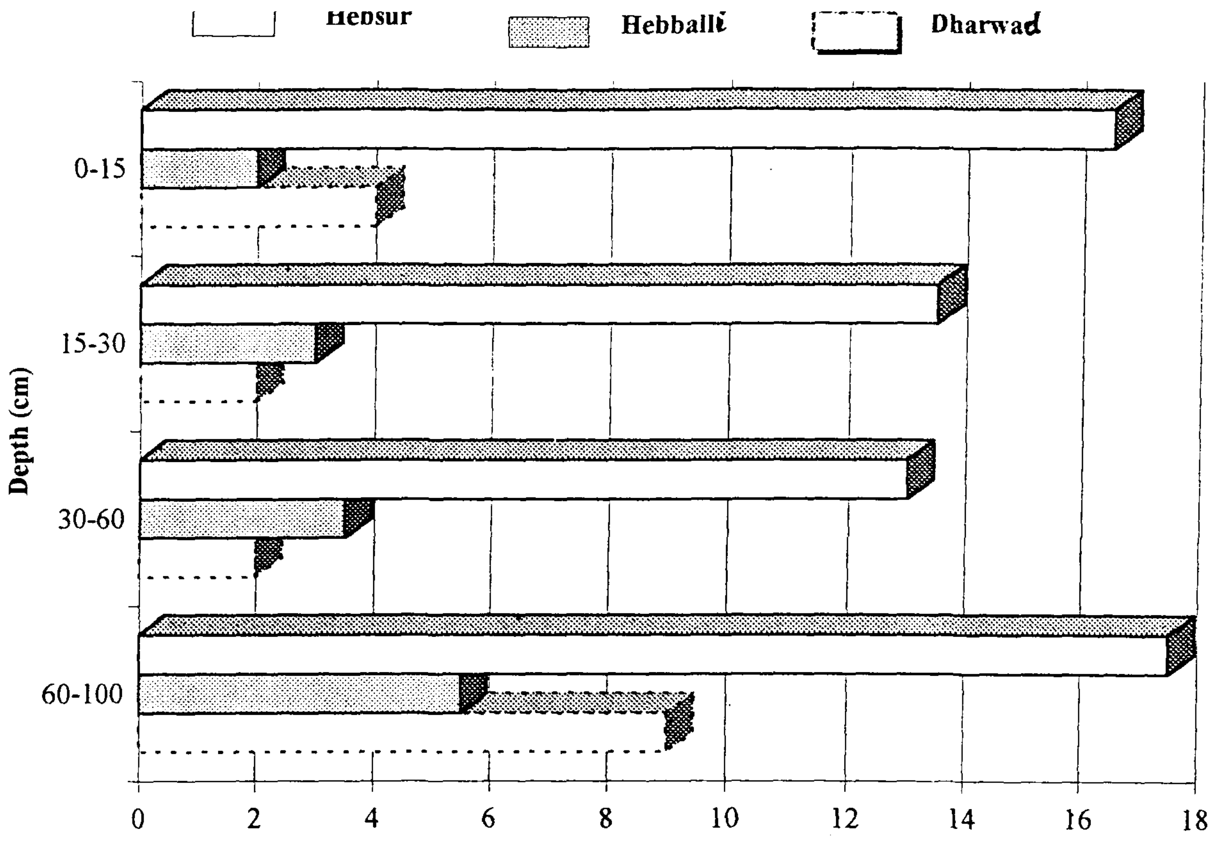

Fig. 3 Distribution of free calcium carbonate content (%) in profile samples of three different locations

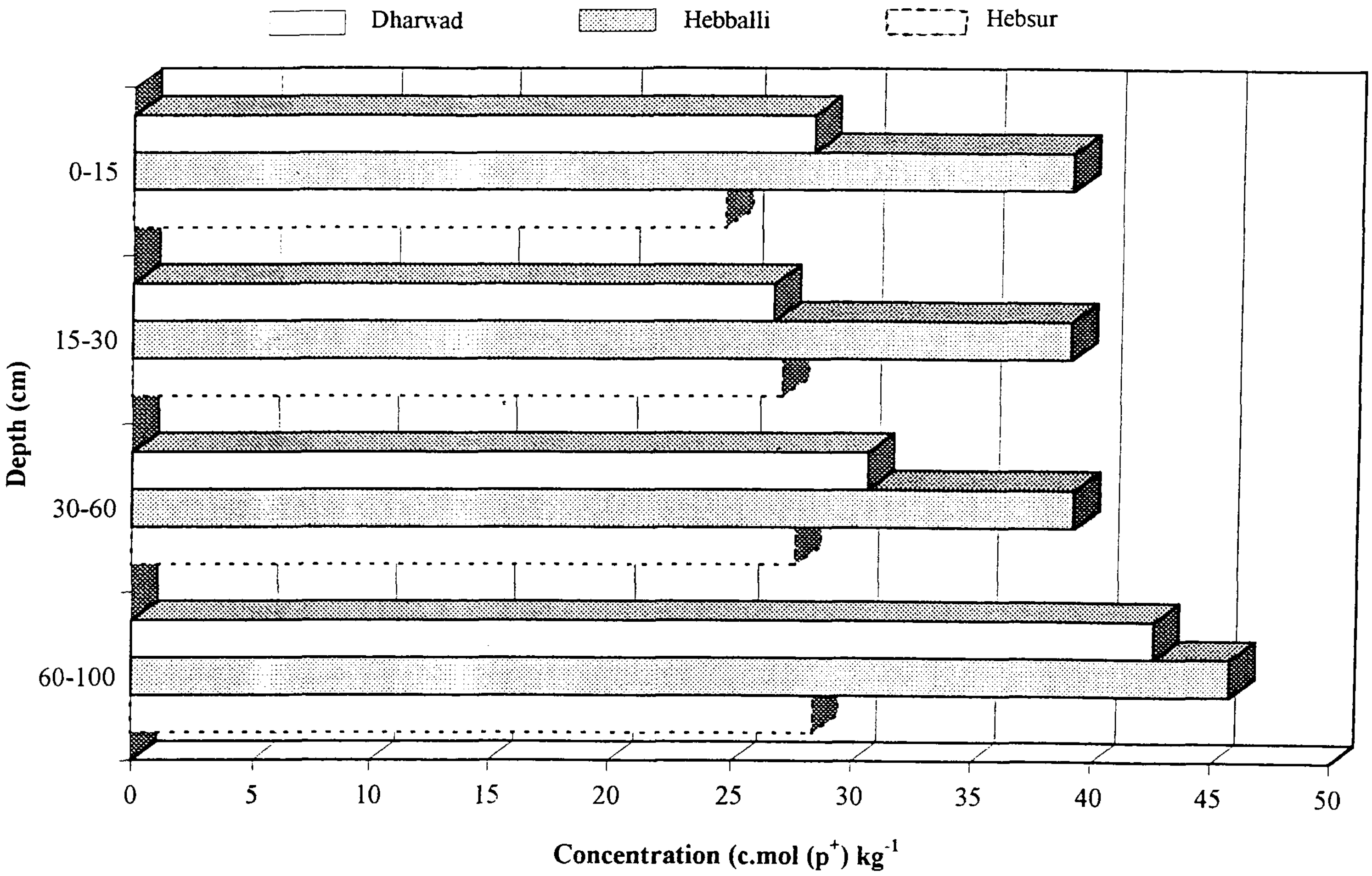

Fig. 4 Distribution of exchangeable Ca in profile samples of three locations

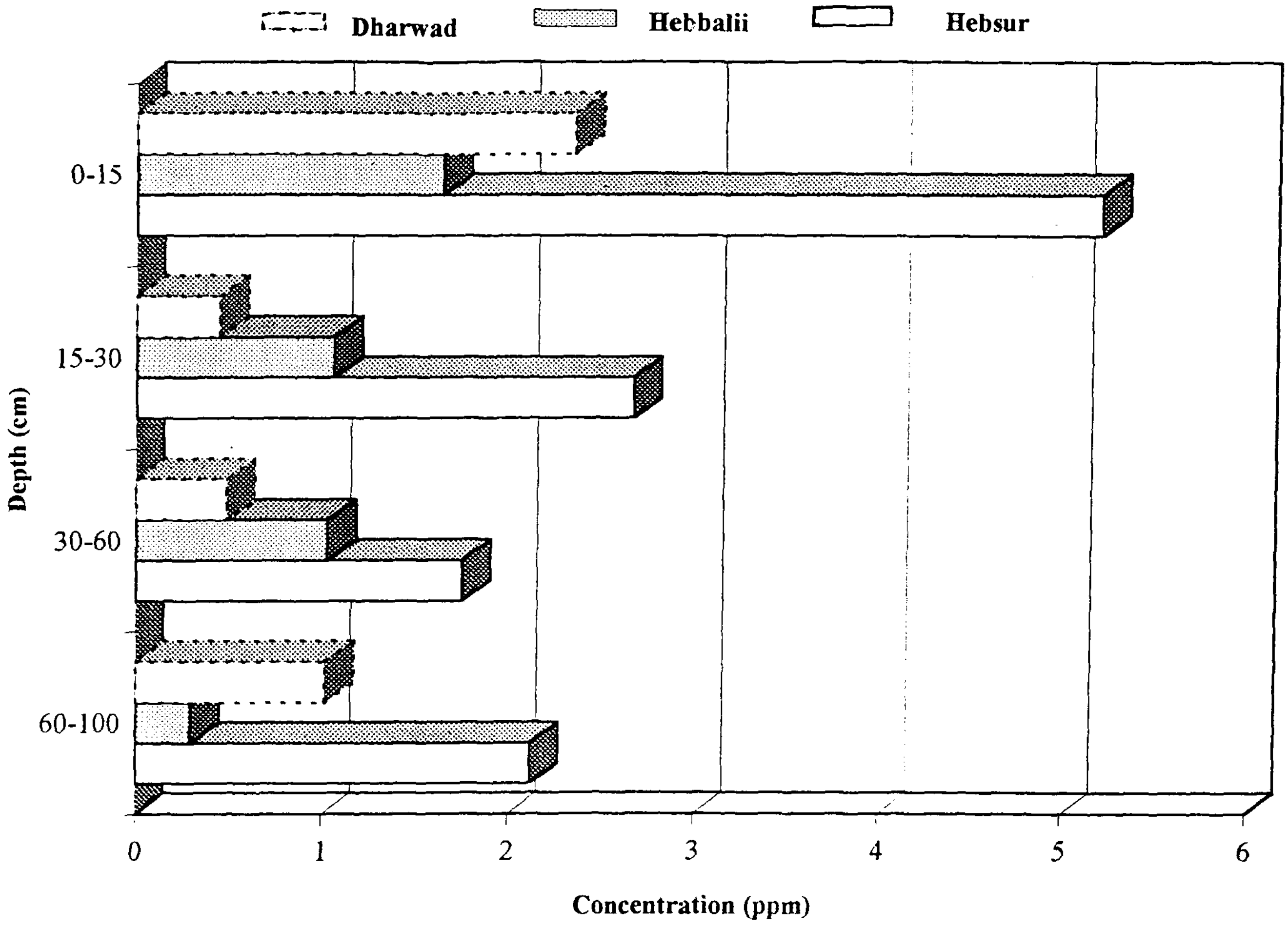

Fig. 5 Distribution of DTPA extractable *iron in profile samples of three different locations*

Surface soil samples of Dharwad contained maximum amount (1.79 to 8.35 ppm) of DTPA- Fe than the surface soils of Hebballi and Hebsur (Table 4). This might be associated with the concentration of bicarbonate ions, since, it was noticed that bicarbonate concentration was lower at surface of Dharwad (152.5 to 457.5 ppm) than at Hebsur (305.0 to 915.0 ppm) and Hebballi (457.5 to 762.5 ppm). This result is in confirmity with the results obtained by Rao *et al.* (1993) who noticed significant negative relation of DTPA-Fe with bicarbonate concentration in calcareous soil of Andhra Pradesh.

5.2 Pot culture study

5.2.1 Dry matter yield of groundnut

Pod and haulm yield were recorded (Table 7) and the influence of different treatments on these parameters are discussed as under.

5.2.1.1 Pod yield

Decreased pod yield was noticed (14.37 at C_1 to 11.38 g/pot at C_5) with increase in $CaCO_3$ level which might be due to lesser iron uptake (ranged from 0.66 at C_1 to 0.59 mg/plant at C_5) as mentioned in Table 14. At 75 per cent of F.C, pod yield increased with increasing $CaCO_3$ (6.10 at C_1 to 14.90 g/pot at C_5) since, pod formation is known to be influenced by Ca content in soil. According to Hartmond *et al.* (1994) computation of soil Ca content needed to satisfy pod calcium requirement, higher concentrations were needed mostly for the bunch cultivars than for runners. They suggested higher dose of Ca to increase radius of pod and yield of pod.

In a study, Singh and Singh (1996) found higher the Ca content, higher will be the groundnut yield. So, it is evident that higher concentration of soluble calcium at higher moisture level is the reason for more yield of pod in 150 and 200 per cent F.C. than in

75 per cent F.C. (yield of pod was 11.25, 13.92 &14.21 g/ha respectively in M_1, M_2 and in M_3).

Amongst all the treatments, the highest yield (1043.6 to 1264.4 ppm) was noticed where moisture content was 150 per cent of F.C. and $CaCO_3$ content was 7 per cent (T_7-M_2C_2) had greater effect on pod yield. Suther and Patel (1992) also found more yield of groundnut in calcareous soil when moisture content was near 80 percent of available soil water i.e 160 per cent of F.C.

5.2.1.2 Dry matter yield of haulm

No definite trend was found in haulm yield with increase in $CaCO_3$ level. Increase in moisture level increased the haulm yield (22.35 to 23.73 g/pot) . It might be due to more Ca uptake at moisture level of 150 and 200 per cent of F.C.than in 75 per cent F.C. . More water content might have resulted in more calcium in solution which was ultimately reflected in more uptake of Ca to produce more haulm yield.

Amongst all the treatments, the interaction effect of moisture and $CaCO_3$ showed maximum dry matter yield of haulm at 150 per cent of F.C. with 5 per cent of $CaCO_3$ content (T6-M_3C_1). It might be due to balanced uptake of Fe and Ca (4.779 mg/plant of Fe and 86.070 mg/plant of Ca) in an ideal condition with respect to water and oxygen supply resulting in better growth and haulm yield. Patel and Patel (1985) also observed more yield when ideal ecological condition was provided with respect to water and oxygen.

5.2.2 Ionic composition of soil solution with respect to iron, calcium and bicarbonate after harvest of the crop

5.2.2.1 Water soluble iron

Lesser concentration of water soluble iron was found at higher level of $CaCO_3$ and the values varied from 1.80 to 0.09 ppm. High concentration of bicarbonate (627.72 to 796.39), might be the reason to decrease the concentration of water soluble iron (Fig.6). Since, bicarbonate ions are known to induce higher pH which reduces the solubility of iron as pointed out by Thakur *et al.* (1995).

Increase in water soluble iron was noticed with increase in moisture level at any given $CaCO_3$ level in soil. This indicated the fact that free calcium and moisture together were responsible for higher concentration of bicarbonate in soil solution, which in turn reduced iron availability (as indicated by lower water soluble iron). On the other hand, moisture alone tends to increase water soluble iron due to more reduced environment as moisture changed from 75 per cent F.C. to 200 per cent F.C .

5.2.2.2 Water soluble calcium

Both the levels of $CaCO_3$ and moisture increased the concentration of water soluble calcium. It is a fact that if Ca^{2+} in exchange site is more, more will be in solution. So also as the content of $CaCO_3$ increased, Ca^{2+} in soil solution increased. Further, presence of CO_2 in soil environment induced more dissolution of Ca. When the moisture content was 150 or 200 percent of F.C, it led to anaerobic situation where CO_2 predominated due to root respiration and microbial activity and caused dissolution of lime material in more amount.

Interaction effect also showed highest amount of water soluble Ca (353.33 ppm) in treatment with 20 per cent $CaCO_3$ + moisture level of 200 percent of F.C (T_{15}-M_3C_5).

5.2.2.3 Bicarbonate

Bicarbonate concentration increased with increase in moisture and $CaCO_3$ level (Table 8). It might be due to formation of calcium bicarbonate in presence of CO_2 at high moisture level which led to increase in concentration of bicarbonate in soil solution.

$$Ca(HCO_3) \overset{H_2O}{=} Ca^{2+} + 2HCO_3^-$$

Rao *et al.*(1993) pointed out positive correlation of soil moisture to bicarbonate ($r = 0.96$). Interaction effect showed, at moisture level of 200 per cent of F.C. (saturation, M_3) with 20 per cent of $CaCO_3$ level induced the presence of maximum amount of HCO_3^- (838.75 ppm). Correlation study also revealed positive relation of bicarbonate with free $CaCO_3$($r = 0.889^{**}$) as found in Hebballi (Table 5).

5.2.3 Changes in different forms of iron and calcium in soil after harvest

5.2.3.1 Different forms of iron oxides

According to the data shown in Table 9, both the forms of iron oxides decreased as the level of $CaCO_3$ increased . Moreover, increase in moisture level from 75 per cent of F.C. to 200 per cent of F.C. also resulted in presence of higher free and amorphous Fe oxide-occluded iron content after harvest.

Initial free iron oxide content (423.4 ppm) was itself lesser than the initial content of amorphous Fe oxide-occluded iron (1064 ppm).This supports the views of Yerriswamy *et al.* (1995) who found the form of iron oxides mentioned later comprises about 4 to 6 per cent of the total iron which was just next to residual iron. Since, free iron oxide, the form extracted by CBD was mostly crystalline (in the form of goethite) as pointed out by Mckeague *et al.* (1971), was less soluble than amorphous form of Fe oxides.

LEGEND

$T_1(M_1C_1)$	Moisture level at 75% of F. C +5% of $CaCO_3$
$T_2(M_1C2)$	Moisture level at 75% of F. C +7% of $CaCO_3$
$T_3(M_1C_3)$	Moisture level at 75% of F. C +10% of $CaCO_3$
$T_4(M_1C_4)$	Moisture level at 75% of F. C +15% of $CaCO_3$
$T_5(M_1C_5)$	Moisture level at 75% of F. C +20% of $CaCO_3$
$T_6(M_2C_1)$	Moisture level at 150% of F. C +5% of $CaCO_3$
$T_7(M_2C_2)$	Moisture level at 150% of F. C +7% of $CaCO_3$
$T_8(M_2C_3)$	Moisture level at 150% of F. C +10% of $CaCO_3$
$T_9(M_2C_4)$	Moisture level at 150% of F. C +15% of $CaCO_3$
$T_{10}(M_2C_5)$	Moisture level at 150% of F. C +20% of $CaCO_3$
$T_{11}(M_3C_1)$	Moisture level at 200% of F. C +5% of $CaCO_3$
$T_{12}(M_3C_2)$	Moisture level at 200% of F. C +7% of $CaCO_3$
$T_{13}(M_3C_3)$	Moisture level at 200% of F. C +10% of $CaCO_3$
$T_{14}(M_3C_4)$	Moisture level at 200% of F. C +15% of $CaCO_3$
$T_{15}(M_3C_5)$	Moisture level at 200% of F. C +20% of $CaCO_3$

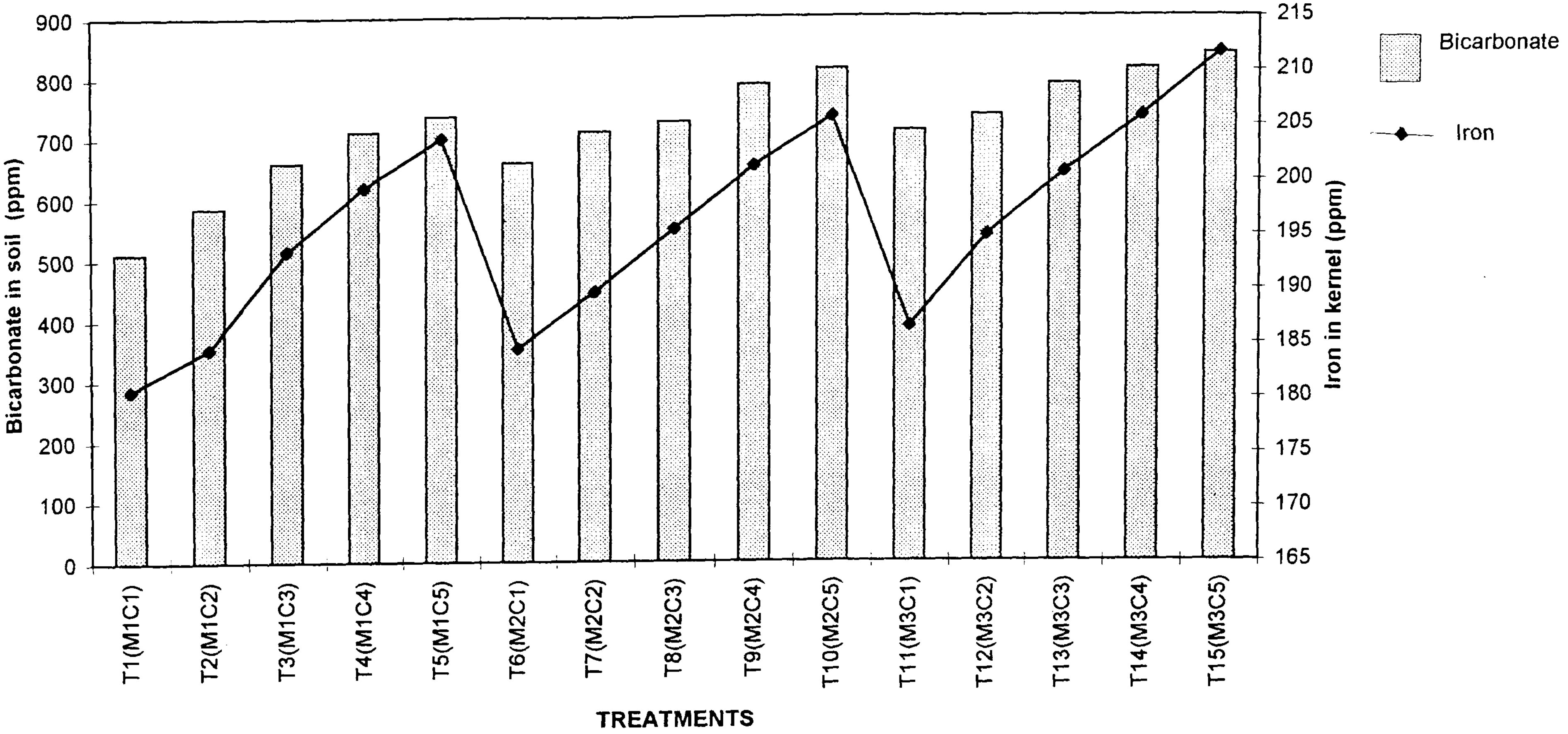

Fig.6 Concentration of bicarbonate ions in soil and concentration of iron in groundnut kernel

Interaction effect showed significant effect of moisture and $CaCO_3$ level to decrease both of the iron oxides, but lesser availability of free iron oxide (only 17 per cent) to plant than amorphous iron (70 %) in T_5-M_1C_5 was observed. Since, amorphous form of oxides or hydroxides were most soluble than crystalline (free iron oxide) form (Chen and Barak, 1982). Despite least amount of $CaCO_3$ content in treatment T_{11}-M_1C_1 (with 5% of $CaCO_3$) the content of iron oxides both occluded and free iron were found to be maximum after harvest (1043.06 and 402.363 ppm respectively). This might be due to presence of more concentration of bicarbonate at 200 percent F.C (777.75 ppm) which related to lesser uptake of Fe by plant system. Similarly Rutland (1971) also noticed lesser availability, uptake and translocation of iron to plant (*Azalea)* system when concentration of HCO^-_3 was more. Same observation was made by Rutland and Bukovac (1971) in chrysanthemum.

5.2.3.2 Exchangeable calcium

Concentration of exchangeable Ca was found to decrease with increasing level of $CaCO_3$ (27.16 to 20.14 c.mol (p^+) kg^{-1}). Exchangeable Ca, the major form which is available to plant, that might be the reason behind presence of lesser amount of exchangeable Ca in treatment with more level Ca. Isermann (1970) and Drew and Biddulph (1971) were of the opinion that both uptake and transport of Ca is associated with presence of exchangeable Ca in soil.

Interaction effect revealed presence of lowest amount (18.47 c.mol (p+) kg $^{-1}$) in T_{10}-M_2C_5 after harvest where plants were provided with ideal ecological condition with respect to water and oxygen supply which affects growth and uptake, as indicated by Patel and Patel (1985), who did not find formation of pod of groundnut at extremely high and low moisture level maintained throughout the crop growth period and mentioned about ideal ecological condition at 160 per cent F.C. where yield was also observed to be highest.

On the other hand presence of minimum amount of exchangeable Ca (18.47 c.mol (p^+) kg^{-1}) was found in treatment with 150 percent F.C + 20 per cent of $CaCO_3$. So it was evident that more Ca was taken up by plant in T_5- M_1C_5 than in T_{15} -M_3C_5 at same level of $CaCO_3$. Inskeep and Bloom (1986) were of the opinion that abnormally high or low water content in the soil has ill effects on the growth and physiological process of plant which in turn affected the nutrient absorption by plant.

5.2.3.3 DTPA - extractable iron

Decrease in concentration of DTPA- Fe (Fig.7) was observed with increase in moisture [DTPA -Fe decreased from 3.7 (M_1) to 2.42 ppm (M_3)] and $CaCO_3$ (DTPA-Fe decreased from 4.56 at C_1 to 2.31 ppm at C_5). This might be due to more concentration of HCO^-_3 ion at higher moisture and $CaCO_3$ level (Table 8). Bicarbonate was found to be negatively correlated with DTPA -Fe (r = - 0.892**, r=-0.777** in Dharwad and Hebballi as given in Table 5). The result was in confirmity with the results found by Rao *et al* (1992). In a similar type of experiment they observed negative correlation (r – - 0.94) of DTPA -Fe to HCO^-_3 ion.

As a consequence of this, interaction effect showed presence of highest amount of DTPA -Fe (5.51 ppm) in moisture level of 75 per cent F.C + 5 per cent $CaCO_3$ and lowest amount of DTPA - Fe (1.58 ppm) was noticed in moisture level of 200 percent of F.C + 20 per cent of $CaCO_3$.

5.2.4 Uptake and concentration of calcium and iron

5.2.4.1 Influence of calcium in soil on calcium content and uptake of plant

Calcium content in plant samples (Table 11) increased with increase in level of $CaCO_3$ and moisture. Maximum concentration of Ca (1.23%) in kernel and in haulm (2.32%) were noticed in T_{15} - M_3 C_5 (200 %of F.C + 20% $CaCO_3$), Ca uptake by plant

Table13. UPTAKE OF CALCIUM IN PLANT AS INFLUENCED BY CALCIUM CARBONATE AND MOISTURE

Calcium uptake (mg/plant) by kernel				
	M_1	M_2	M_3	Mean
C_1	9.97	33.65	34.05	25.89
C_2	17.10	39.81	34.99	30.63
C_3	24.58	24.47	36.93	28.66
C_4	36.92	27.67	36.12	33.57
C_5	42.23	27.23	30.91	33.46
Mean	26.16	30.56	34.60	

Calcium uptake (mg/plant) by haulm				
	M_1	M_2	M_3	Mean
C_1	41.37	86.07	104.72	77.38
C_2	51.61	115.86	116.41	94.63
C_3	78.57	96.11	139.44	104.71
C_4	104.83	120.41	157.38	127.54
C_5	134.55	165.03	199.01	166.20
Mean	82.19	116.70	143.39	

Factor	Sem ±	CD(0.05)
A	0.28	0.67
B	0.36	0.86
AxB	0.62	1.50

Factor	Sem ±	CD(0.05)
A	1.42	3.41
B	1.83	4.40
AxB	3.17	7.63

Factor A

M_1= Moisture level at 75% of F. C
M_2= Moisture level at 150% of F. C
M_3= Moisture level at 200% of F. C

Factor B

C_1= 5% of $CaCO_3$
C_2= 7% of CaCO3
C_3= 10% of CaCO3
C_4= 15% of CaCO3
C_5= 20% of CaCO3

* Significant at 1% level

LEGEND

$T_1(M_1C_1)$	Moisture level at 75% of F. C +5% of $CaCO_3$
$T_2(M_1C2)$	Moisture level at 75% of F. C +7% of $CaCO_3$
$T_3(M_1C_3)$	Moisture level at 75% of F. C +10% of $CaCO_3$
$T_4(M_1C_4)$	Moisture level at 75% of F. C +15% of $CaCO_3$
$T_5(M_1C_5)$	Moisture level at 75% of F. C +20% of $CaCO_3$
$T_6(M_2C_1)$	Moisture level at 150% of F. C +5% of $CaCO_3$
$T_7(M_2C_2)$	Moisture level at 150% of F. C +7% of $CaCO_3$
$T_8(M_2C_3)$	Moisture level at 150% of F. C +10% of $CaCO_3$
$T_9(M_2C_4)$	Moisture level at 150% of F. C +15% of $CaCO_3$
$T_{10}(M_2C_5)$	Moisture level at 150% of F. C +20% of $CaCO_3$
$T_{11}(M_3C_1)$	Moisture level at 200% of F. C +5% of $CaCO_3$
$T_{12}(M_3C_2)$	Moisture level at 200% of F. C +7% of $CaCO_3$
$T_{13}(M_3C_3)$	Moisture level at 200% of F. C +10% of $CaCO_3$
$T_{14}(M_3C_4)$	Moisture level at 200% of F. C +15% of $CaCO_3$
$T_{15}(M_3C_5)$	Moisture level at 200% of F. C +20% of $CaCO_3$

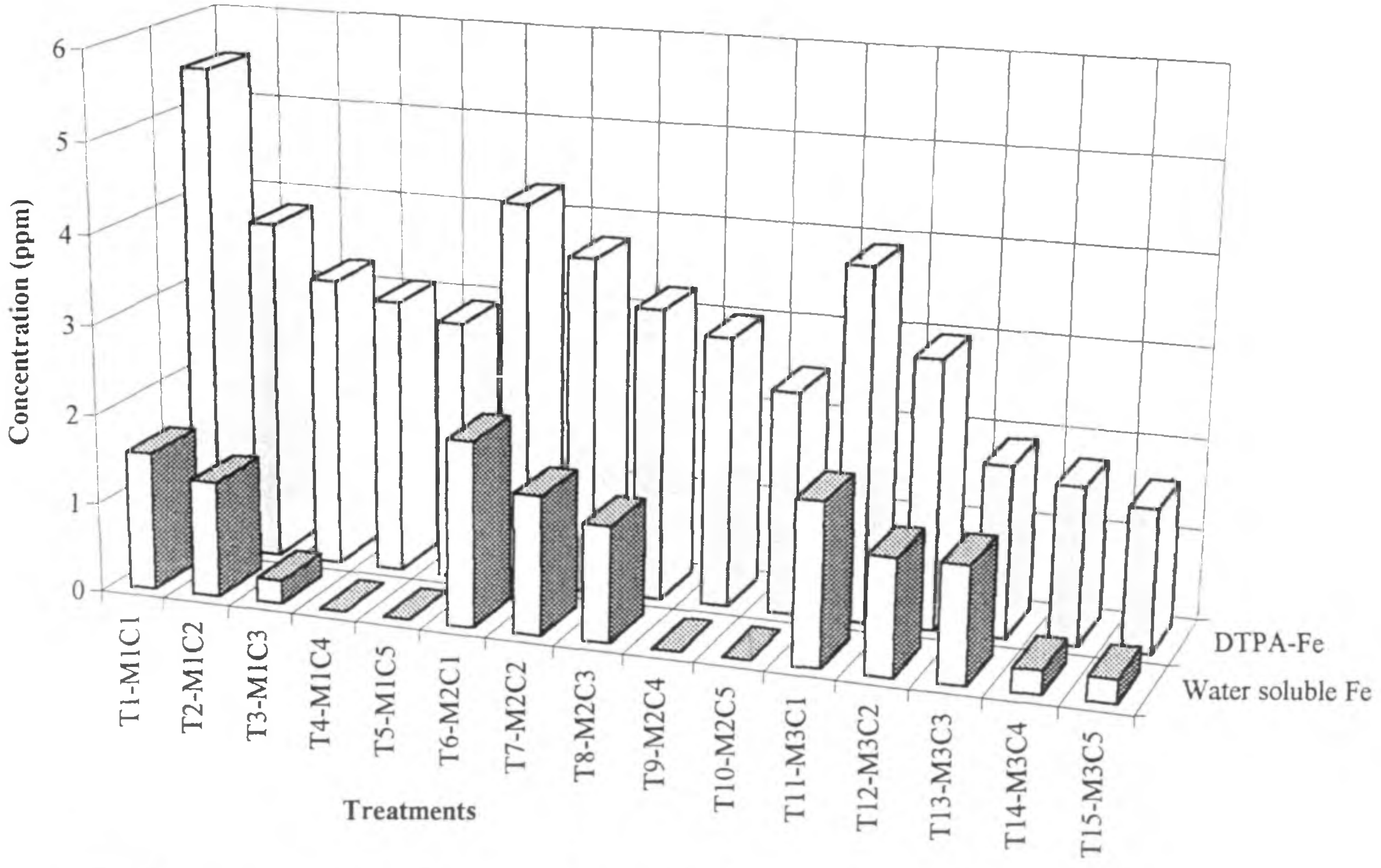

Fig. 7 Concentration of available forms of iron as influenced by different levels of $CaCO_3$ and moisture

samples also followed same trend as that of Ca content. It is evident from Table 13 that uptake of Ca by kernel was more in T_7 - M_2 C_2 (39.81 mg/plant). It might be due to high concentration of Ca in soil solution (both in the form of water soluble and exchangeable) which was adequate to meet the crop demand resulting in more uptake of Ca by plant (Fig.8) and more pod yield (19.90 g/pot) as indicated by Mengel and Kirkby (1996).

5.2.4.2 Influence of different levels of moisture and $CaCO_3$ on uptake and concentration of Fe in plant

It is quite clear (Fig.9), that pod yield increased with increase in iron uptake and decreased with decrease in iron uptake. Iron uptake was influenced by both $CaCO_3$ and moisture but the effect was opposite at 75 per cent of F.C.where increased uptake of iron was noticed with increased $CaCO_3$ level. However, with increase in moisture level (150 per cent and 200 per cent F.C) and $CaCO_3$, iron uptake was decreased .

If we consider the concentration of iron, it increased with increasing level of $CaCO_3$ and moisture, the concentration of Fe in plant was found highest at T_{15} -M_3 C_5 (Fig.10), though symptoms of chlorosis was more prominent in same treatment. Chen and Barak (1982) were of the view that Fe deficiency can not be determined by plant analysis since chlorotic leaves may contain even more Fe than healthy leaves. The high concentration of Fe in chlorotic plants occurs in the vein and in the apoplast but it can not be translocated across the plasma membrane in to the inter costal cells if HCO^-_3 ion exists in apoplast (Mengel and Bubl, 1983; Rutland, 1971). So, we have evidence to express that the chlorosis is not due to Fe unavailability (less DTPA-Fe in soil solution) but because of a physiological disorder (The ineffective translocation of Fe towards the younger leaves) which is induced by excess bicarbonate ion concentration (Mengel and Kirkby., 1996). It is supposed, that abundant HCO^-_3 ion in the root medium results in Fe immobilization in the plant. Therefore, we can conclude, though the value of iron content in plant revealed

Table 14. UPTAKE OF IRON IN PLANT AS INFLUENCED BY CALCIUM CARBONATE AND MOISTURE

Iron uptake (mg/plant) by kernel				
	M_1	M_2	M_3	**Mean**
C_1	0.275	0.896	0.820	0.660
C_1	0.414	0.946	0.775	0.710
C_2	0.568	0.520	0.742	0.610
C_3	0.726	0.528	0.656	0.640
C_4	0.757	0.473	0.532	0.590
C_5	0.550	0.670	0.710	

Iron uptake (mg/plant) by haulm				
	M_1	M_2	M_3	**Mean**
C_1	3.909	4.779	4.255	4.310
C_2	4.226	5.407	4.464	4.700
C_3	5.070	4.752	5.536	5.120
C_4	5.100	6.194	6.660	5.980
C_5	5.377	7.775	8.798	7.320
Mean	4.740	5.780	5.940	

Factor	Sem ±	CD(0.05)
A	0.0016	0.004
B	0.0021	0.003
AxB	0.0036	0.009

Factor	Sem ±	CD(0.05)
A	0.05	0.12
B	0.06	0.15
AxB	0.108	0.26

Factor A

M_1= Moisture level at 75% of F. C
M_2= Moisture level at 150% of F. C
M_3= Moisture level at 200% of F. C

Factor B

C_1= 5% of $CaCO_3$
C_2= 7% of CaCO3
C_3= 10% of CaCO3
C_4= 15% of CaCO3
C_5= 20% of CaCO3

LEGEND

$T_1(M_1C_1)$	Moisture level at 75% of F. C +5% of $CaCO_3$
$T_2(M_1C2)$	Moisture level at 75% of F. C +7% of $CaCO_3$
$T_3(M_1C_3)$	Moisture level at 75% of F. C +10% of $CaCO_3$
$T_4(M_1C_4)$	Moisture level at 75% of F. C +15% of $CaCO_3$
$T_5(M_1C_5)$	Moisture level at 75% of F. C +20% of $CaCO_3$
$T_6(M_2C_1)$	Moisture level at 150% of F. C +5% of $CaCO_3$
$T_7(M_2C_2)$	Moisture level at 150% of F. C +7% of $CaCO_3$
$T_8(M_2C_3)$	Moisture level at 150% of F. C +10% of $CaCO_3$
$T_9(M_2C_4)$	Moisture level at 150% of F. C +15% of $CaCO_3$
$T_{10}(M_2C_5)$	Moisture level at 150% of F. C +20% of $CaCO_3$
$T_{11}(M_3C_1)$	Moisture level at 200% of F. C +5% of $CaCO_3$
$T_{12}(M_3C_2)$	Moisture level at 200% of F. C +7% of $CaCO_3$
$T_{13}(M_3C_3)$	Moisture level at 200% of F. C +10% of $CaCO_3$
$T_{14}(M_3C_4)$	Moisture level at 200% of F. C +15% of $CaCO_3$
$T_{15}(M_3C_5)$	Moisture level at 200% of F. C +20% of $CaCO_3$

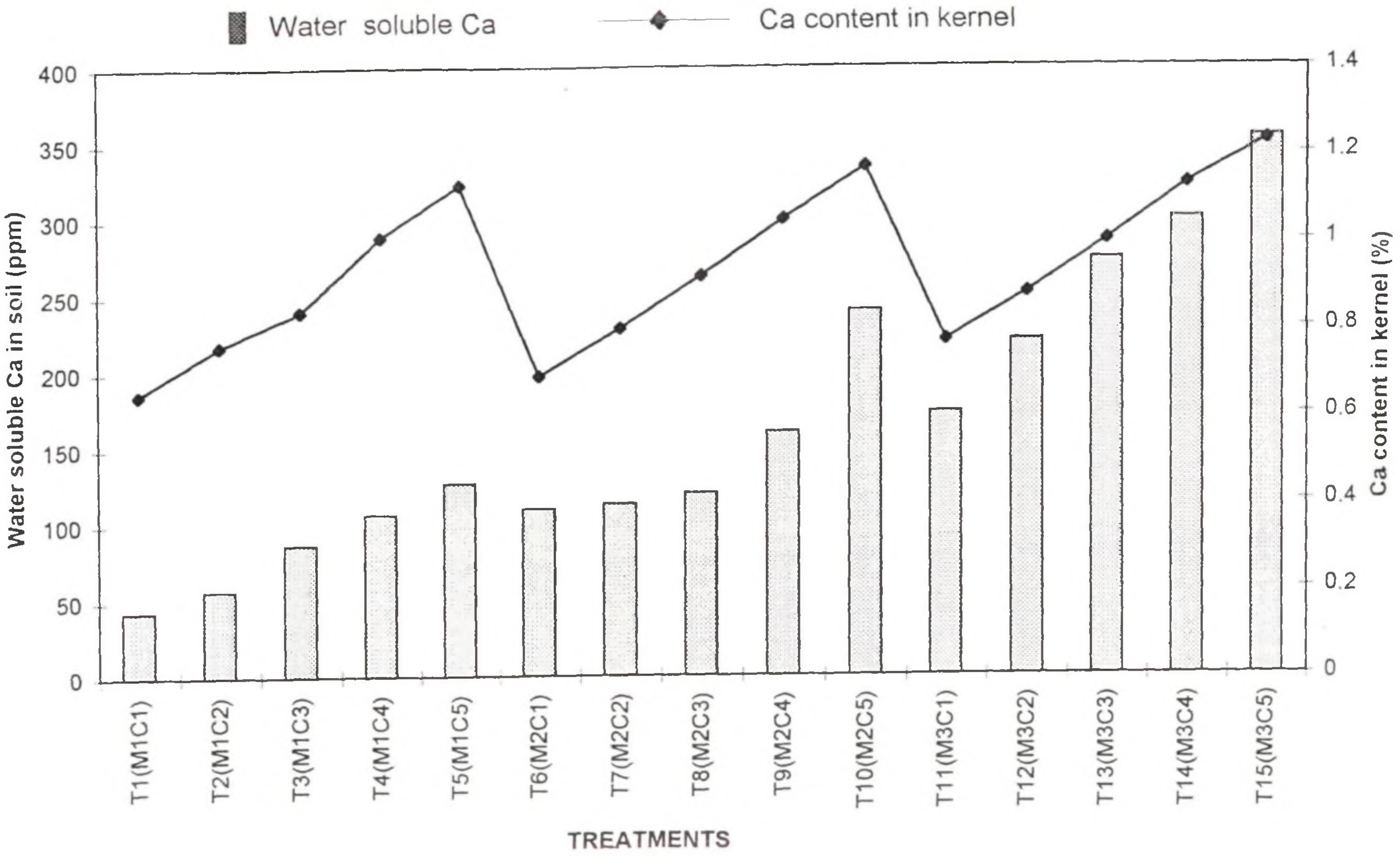

Fig. 8 Influence of water soluble Ca in soil on Ca content of kernel under different levels of CaCO3 and moisture.

LEGEND

$T_1(M_1C_1)$	Moisture level at 75% of F. C +5% of $CaCO_3$
$T_2(M_1C2)$	Moisture level at 75% of F. C +7% of $CaCO_3$
$T_3(M_1C_3)$	Moisture level at 75% of F. C +10% of $CaCO_3$
$T_4(M_1C_4)$	Moisture level at 75% of F. C +15% of $CaCO_3$
$T_5(M_1C_5)$	Moisture level at 75% of F. C +20% of $CaCO_3$
$T_6(M_2C_1)$	Moisture level at 150% of F. C +5% of $CaCO_3$
$T_7(M_2C_2)$	Moisture level at 150% of F. C +7% of $CaCO_3$
$T_8(M_2C_3)$	Moisture level at 150% of F. C +10% of $CaCO_3$
$T_9(M_2C_4)$	Moisture level at 150% of F. C +15% of $CaCO_3$
$T_{10}(M_2C_5)$	Moisture level at 150% of F. C +20% of $CaCO_3$
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$T_{14}(M_3C_4)$	Moisture level at 200% of F. C +15% of $CaCO_3$
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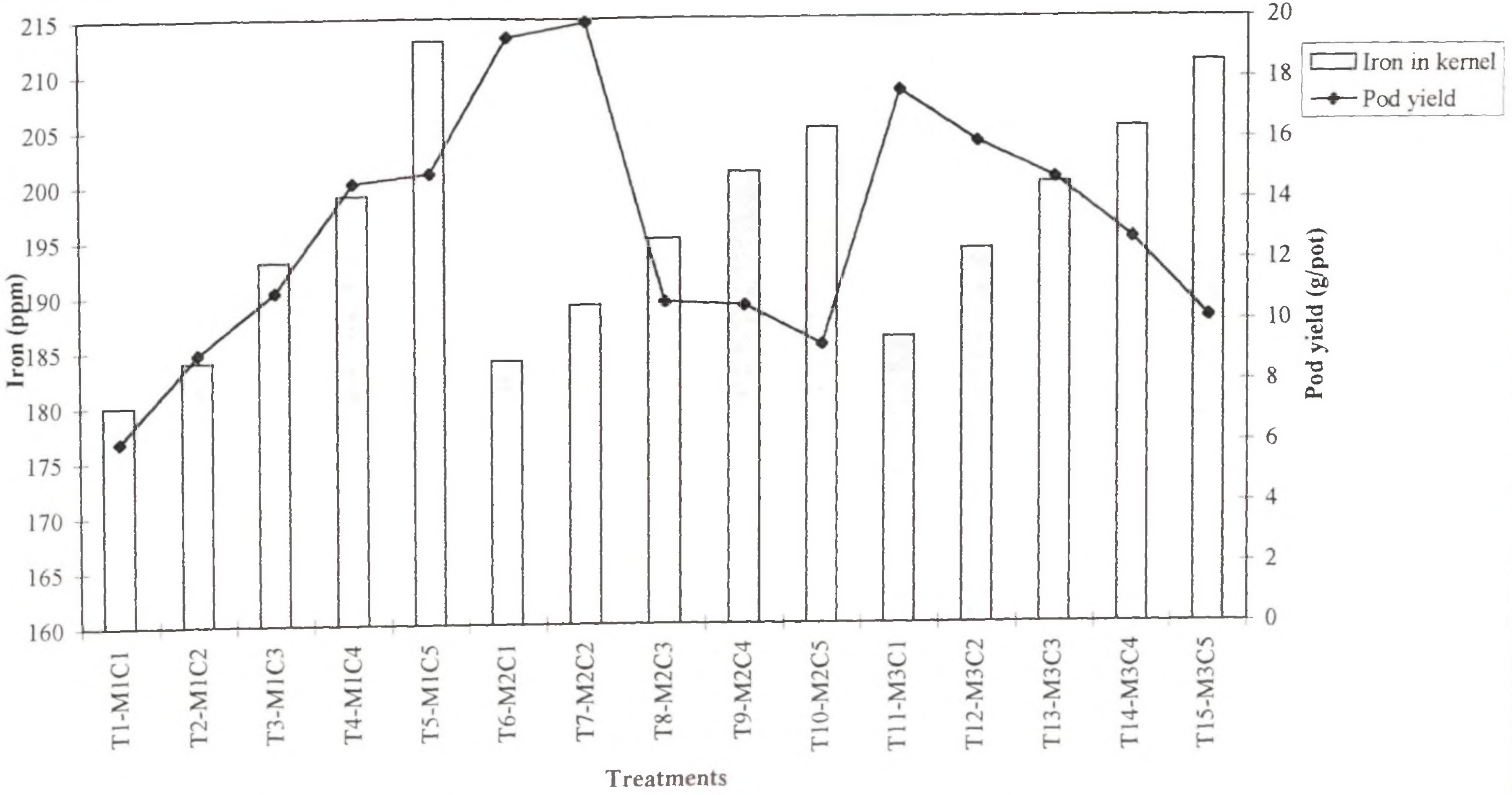

Fig 9. Influence of concentration of iron in kernel on pod yield

LEGEND

$T_1(M_1C_1)$	Moisture level at 75% of F. C +5% of $CaCO_3$
$T_2(M_1C2)$	Moisture level at 75% of F. C +7% of $CaCO_3$
$T_3(M_1C_3)$	Moisture level at 75% of F. C +10% of $CaCO_3$
$T_4(M_1C_4)$	Moisture level at 75% of F. C +15% of $CaCO_3$
$T_5(M_1C_5)$	Moisture level at 75% of F. C +20% of $CaCO_3$
$T_6(M_2C_1)$	Moisture level at 150% of F. C +5% of $CaCO_3$
$T_7(M_2C_2)$	Moisture level at 150% of F. C +7% of $CaCO_3$
$T_8(M_2C_3)$	Moisture level at 150% of F. C +10% of $CaCO_3$
$T_9(M_2C_4)$	Moisture level at 150% of F. C +15% of $CaCO_3$
$T_{10}(M_2C_5)$	Moisture level at 150% of F. C +20% of $CaCO_3$
$T_{11}(M_3C_1)$	Moisture level at 200% of F. C +5% of $CaCO_3$
$T_{12}(M_3C_2)$	Moisture level at 200% of F. C +7% of $CaCO_3$
$T_{13}(M_3C_3)$	Moisture level at 200% of F. C +10% of $CaCO_3$
$T_{14}(M_3C_4)$	Moisture level at 200% of F. C +15% of $CaCO_3$
$T_{15}(M_3C_5)$	Moisture level at 200% of F. C +20% of $CaCO_3$

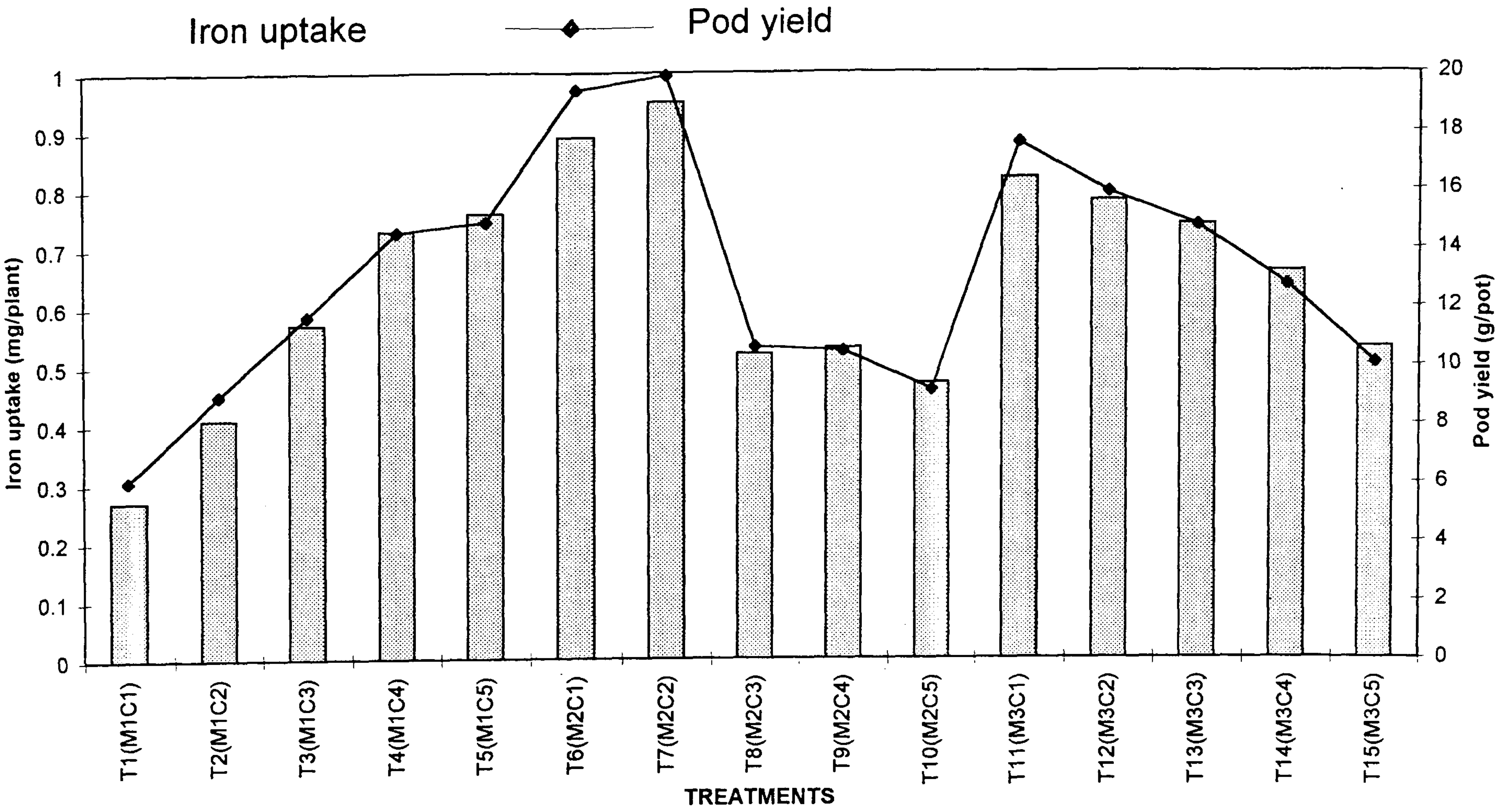

Fig.10 Yield of pod and Fe uptake by kernel as influenced by different levels of moisture and $CaCO_3$

more concentration of Fe both in haulm and kernel, plant failed to assimilate Fe in system which was reflected in yield.

5.2.5 Symptoms of lime induced iron chlorosis

During flowering stage, when moisture treatment was imposed plant exhibited chlorotic symptoms. But when moisture treatment was imposed for the second time plants did not express chlorotic symptoms. The reason for plant showing no symptom during second time might be due to sudden increase in temperature.

At flowering stage, average temperature (Appendix I) was 32.64 ^{0}C (max) and 14.71 ^{0}C (min) and in pegging stage (2nd period of moisture control) temperature was 34.26 ^{0}C (max) and 17.21 ^{0}C (min) which might have increased the mobility of Fe in soil and better translocation to upward position of plant parts. Similar results were found by Benett *et al.* (1992) and Shii *et al.* (1980). The study revealed, in relation to iron stress there was response of plant to elevated temperature in nutrient assimilation. It is also found that after an adaptation period, the terminal leaves to be regreened and growth was also resumed whereas temperature tolerant parent genotypes did not develop chlorosis in same condition.

SUMMARY

VI. SUMMARY

Distribution of different forms of iron and calcium in presence of bicarbonate ion in calcareous black soils of Dharwad, Hebballi and Hebsur was studied. A pot culture experiment was conducted to know the uptake of iron and calcium by groundnut crop (*Arachis hypogaea* L.) (JL-24) using calcareous black soil collected from M. R. S., Dharwad and which received three moisture level (M_1=75% of F. C., M_2=150% of F. C. and M_3=200% of F. C) and five level of $CaCO_3$ (C_1=5%, C_2=7%, C_3=10%, C_4=15% and C_5=20%). Possible iron deficiency to plant in moist calcareous soil (lime induced chlorosis) was investigated. After the harvest of the crop characterisation of iron oxides, solution chemistry with respect to Fe and Ca and iron availability to plant through uptake were studied under treatment of different moisture level and $CaCO_3$ content . The summary of the investigation is described as follows.

- Free calcium carbonate content was more in surface soils of Hebsur (8.0 to 18.5 %) than that of Dharwad (1.5 to 8.0 %) and Hebballi (1.5 to 8.5 %). The profile samples of Dharwad and Hebsur did not follow any definite pattern of distribution,whereas free calcium carbonate percentage increased with increase in depth at Hebballi.

- Amorphous iron oxide-occluded iron and free iron oxides increased in profiles of Dharwad, Hebballi and Hebsur, with increase in depth. However, the distribution of free iron oxide in Hebsur profile did not follow any definite pattern.

- Exchangeable Ca increased with depth in profiles of Dharwad and Hebballi but distribution did not follow any definite pattern in profile sample of Hebsur.

- Amongst the different soluble ions, Fe, Ca and HCO^{-}_3 were analysed. Water soluble iron in a range of 0.22 to 0.76 ppm in surface soil. No definite pattern was followed in distribution of profiles.

High water soluble calcium was noticed in soils of Dharwad (220.0 to 333.3 ppm) than at Hebballi and Hebsur.

The concentration of bicarbonate ions in surface was found to be high in Hebballi (457.5 to 762.5 ppm) and Hebsur (305.0 to 915.0 ppm) than in Dharwad (152.5 to 457.5 ppm). In profiles there was no definite trend as it followed with respect to distribution of bicarbonate ions although lower depths recorded higher concentration of biocarbonate.

- DTPA extractable iron was found high in Dharwad (1.79 to 8.35 ppm) than in Hebballi (0.73 to 1.81 ppm) and Hebsur (0.24 to 2.62 ppm).

The distribution of DTPA-Fe did not follow any definite trend in profile of Dharwad and Hebsur. The concentration of DTPA-Fe decreased as the depth increased in profile of Hebballi (1.64 to 0.30 ppm).

- After the harvest of groundnut crop, grown in pots, both of the forms of iron oxides in soil decreased significantly with increase in $CaCO_3$ level and moisture level. Minimum concentration of amorphous iron oxide-occluded iron (350.02 ppm) and free iron oxide (319.09 ppm) were noted in treatment with moisture level of 75 per cent F.C + 20 per cent $CaCO_3$ indicating higher utilization of iron oxides by the plants.

Amongst water soluble ions, water soluble Ca and bicarbonate increased significantly with increase in both $CaCO_3$ and moisture level in soil after the harvest of crop. Interaction effect showed highest concentration of water soluble Ca and HCO_3^- (350.33 ppm of water soluble Ca and 838.75 ppm of HCO^{-}_3) in treatment with moisture level of 200 per cent F.C and 20 per cent $CaCO_3$. Concentration of water soluble iron decreased with increase in $CaCO_3$ level whereas, water soluble iron (0.62 ppm to 0.98 ppm) increased with increase in level of moisture.

The concentration of exchangeable calcium decreased after the harvest of the crop as influenced by the levels of $CaCO_3$ (27.16 c.mol (p+) kg^{-1} in 5% CaCO3 to 20.44 c.mol (p^+) kg^{-1}in 20% CaCO3), whereas, no definite pattern was observed in the change of exchangeable Ca concentration with increased moisture level.

DTPA-extractable iron decreased significantly with increase in level of moisture and $CaCO_3$ in the treatments. Highest (5.51 ppm) and lowest (1.58 ppm) concentration of DTPA-Fe was noticed in treatment with 75 per cent F.C + 5 per cent $CaCO_3$ and 200 per cent F.C + 20 per cent $CaCO_3$ respectively.

- Calcium concentration in plant samples (haulm and kernel) and Ca uptake in haulm increased significantly with increase in both $CaCO_3$ and moisture level. But more uptake of Ca by kernel (39.81 mg/plant) was noticed in treatment with 150 per cent F.C + 7 per cent $CaCO_3$ only.

Iron concentration in plant samples (haulm and kernel) and Fe uptake by haulm was significantly increased with increased level of moisture and $CaCO_3$ in treatments. But maximum Fe uptake by kernel was noticed in treatment with moisture level of 150 per cent F.C with 7 per cent $CaCO_3$ (0.946 mg/plant).Results also indicated about ill effects of higher concentration of Ca and Fe in treatment with higher level of $CaCO_3$ and 200 per cent F.C moisture.

- Maximum yield of pod (26.07 g/pot) was observed in treatment with moisture level of 150 per cent F.C + 7 per cent $CaCO_3$. Haulm yield did not follow any definite pattern with changing pattern of $CaCO_3$ level and moisture level.

It is evident from the study that though available iron (DTPA-Fe + water soluble iron) was found less in treatment with more $CaCO_3$ and moisture, it did not show any influence in Fe concentration in plant samples. However, balanced uptake of Fe (0.946 mg/plant) and Ca (39.81 mg/plant) as found in treatment with 150 per cent F.C + 7 per cent $CaCO_3$ resulted in highest yield of pod (19.90 g/pot).

REFERENCES

VII. REFERENCES

AGARWAL, S.C. AND MEHROTRA, N.K., 1963, Studies on mineral nutritional disorders of plants in Uttar Pradesh. *Journal of Indian Society of Soil Science*, **11** : 51-55.

BADRAOUI, M. AND BLOOM, P.R., 1990, Iron-rich light-charge beidellite in vertisols and mollisoils of the high chaonia region of Morocco. *Journal of American Society and Soil Science*, **54** : 267.

BARRAL SILVA, M.T. AND GUITIAN OJEA, F., 1991, Iron oxide accumulation in tertiary sediments of the Roupar Basin, Galicia, New Spain. *Catena*, **18** : 31-34.

BEAR, F.E., 1964, *Chemistry of the soil*, Oxford and IBM Publlishlng Company Private Ltd.

BENNETT, J.H., CHATTERTON, N.J., WYSE, R.E., HARTUNG, W. AND MOK, D.W.S., 1992, High temperature stress in *Phaseolus vulgaris* seedlings genotype iron stress response interaction. *Plant Physiolology and Biochemistry*, **30** : 11-18.

BIGHAM, J.M., HECKENDRON, S.E., JAYANES, W.F. AND SMECK, N.E., 1991, Stability of iron oxides in two soil with contrasting colours. *Journal of American Society of Soil Science*, **55** : 1485-1492.

BLACK, C.A., 1965, *Methods of soil Analysis*, Part II. *Agronomy Monograph*, 9 : American Society of Agronomy, Madison, Wisconsin, U. S. A.

BLUME, H.P. AND SCHWERTMANN, U., 1969, Genetic evaluation of profile distribution of aluminium, iron and manganese oxides. *Proceedings of American Society of Soil Science*, **33** : 438-444.

BOXMA, R., 1972, Bicarbonate as the most important soil fraction in lime-induced chlorosis in the Netherlands. *Plant and Soil*, **37** : 233-243.

BROWN, J.C., HOLMES, R.S. AND TIFFIN, L.D., 1959, A comparative study of soil solution chemistry associated with chlorotic and non-chlorotic soybeans in Western Minnesota. *Journal of Plant Nutrition,* **7** : 513-531.

CAMPILLO, M.C.D. AND TORRENT, J., 1992, Predicting the incidence of iron chlorosis in calcareous soils of southern Spain. *Soil Science and Plant Analysis*, **23** : 399-416.

CHEN, Y. AND BARAK, P., 1982, Iron nutrition of plants in calcareous soils. *Advances in Agronomy*, **35** : 217-240.

COULOMBE, B.A., CHANEY, R.L. AND WIEBOLD, W.J., 1984, Bicarbonate directly induces iron chlorosis in susceptible soybean cultivars. *Journal of American Society of Soil Science,* **48** : 1297-1301.

DREW, M.C. AND BIDDULPH, O., 1971, Effect of metabolic inhibitors and temperature on uptake and translocation of ^{45}Ca and ^{45}K by intact bean plants. *Plant Physiology,* **48** : 426-432.

DUBEY, D.D., 1982, Genesis and Characterisation of salinity and alkalinity hazards of medium black soils of Indore region. *Ph. D. Thesis,* Devi Ahilya Vishwa Vidyalaya, Indore (M.P.).

EL-DEMERDASHE, S., ABDEL.- HAMID, E.A., ABED, F.M.A. AND EL-KASSAS, H.I., 1993, Iron status and its relation to some soil variables in calcareous soils of Egypt. *Egyptian Journal of Soil Science*, **31** (3) : 357-372.

GOLDEN, D.C., TURNER, F.T., SITTER-BHATKAR, H. AND DIXON, J.B., 1997, Seasonally precipitated iron oxides in a vertisol of southeast Texas. *Journal of American Society of Soil Science,* **61** : 958-964.

GOLDSCHMIDT, V.M., 1954, *Geochemistry.* Oxford University Press, London and New York.

GREEN, M.S. AND ETHERINGTON, J.R., 1977, Oxidation of ferrous iron by rice (*Oryza sativa* L.) roots it mechanism for rates logging tolerance. *Journal of Experimental Botany,* **28** : 678-690.

HARTMOND, U., WILLIAM, J.H. AND LENZ, F., 1994, The influence of plant growth habit on calcium nutrition of groundnut pods. *Plant and Soil,* **16** (1) : 113-118.

HAWKES, H.E. AND WEBB, J., 1962, *Geochemistry of mineral exploration*, Harper and Row, New York.

INSKEEP, W.P. AND BLOOM, P.R., 1984, A comparative study of soil solution chemistry associated with chlorotic and non-chlorotic soybeans in western Minnesota. *Journal of Plant Nutrition*, 7 : 513-531.

INSKEEP, W.P. AND BLOOM, P.R.,1986, Effects of soil moisture on soil pCO_2, soil solution bicarbonate and iron chlorosis in soybean. *Journal of American Society of Soil Science,* **50** : 946-952.

INSKEEP, W.P. AND BLOOM, P.R., 1987, Soil chemical factors associated with the incidence of soybean chlorosis in calciaquolls of Western Minnesota. *Agronomy Journal,* **79** : 779-786.

ISERMANN, K., 1970, The effect of adsorption process in the xylem on the calcium distribution in higher plants. *Zenti Planzenernaahr Bodenk,* **126** : 191-203.

JACKSON, M.L., 1967, *Soil Chemical Analysis.* Prentice Hall of India Pvt Ltd.

JAGTAP, P.B. AND MOHITE, A.V.,1994, Release of sulphur and iron from pyrites in saline sodic calcareous soil and soil reaction. *Journal of Maharashtra Agriculture University,* **58** : 120-122.

KANWAR, J.S., RANDHAWA, N.S. AND GREWAL, J.S., 1962, Distribution of micronutrients in the Punjab soils and their effect on crops for the years 1958-1962. *Annual Progress Report.*

KATYAL, J.C. AND SHARMA. B.D., 1991, DTPA-extractable and total Zn, Cu, Mn and Fe in Indian soils and their association with some soil properties. *Geoderma,* **49** : 165-179.

KHORSANDI, F., 1994, Sulphuric acid effects on iron and phosphorus availability in two calcareous soils. *Journal of Plant Nutrition*, **17** (9) : 1611-1623.

LINDSAY, W.L., 1972, Role of chelation in micro nutrient availability. *The Plant Root and Its Environment*. Edited by Larson, E.W., University Press of Virginia.

LINDSAY, W.L. AND NORVELL, W.A., 1978, Development of a DTPA soil test for Zn, Fe, Mn and Cu. *Journal of American Society of Soil Science,* **42** : 421-428.

LINDSAY, W.L. AND SCHWAB, A.P., 1982, The chemistry of iron in soils and its availability to plants. *Journal of Plant Nutrition,* **5** : 821-840.

LOEPPERT, R.H. AND HALLMARK, C.T., 1985, Indigenous soil properties influencing the availability of iron in calcareous soils. *Journal of American Society of Soil Science,* **49** : 597-603.

McKEAGUE , J.A., BRYDON, J.E. AND MITES, N.M., 1971, Differentiation of forms of extractable iron and aluminium in soils. *Proceedings of American Society of Soil Science*, **35** : 33-38.

MEHRA, O.P. AND JACKSON, M.L., 1960, Iron oxide removal from soils and clays by a dithionite-citrate-system buffered with sodium bicarbonate. *Clays and Clay Minerals*, **7** : 317-327.

MENGEL, K. AND BUBL, W., 1983, Distribution of iron in vine leaves with HCO^-_3 induced chlorosis. *Zenti Pflanzenernahr Bodenk*, **146** : 650-671.

MENGEL, K AND KIRKBY, E.A., 1996, *Principles of Plant Nutrition*. Fourth edition. Panima Publishing Corporation.

MILLER, W.P., MARTENS, D.C. AND ZELAZNY, L.W., 1986, Effect of sequence in extraction of trace metals from soils. *Journal of American Society of Soil Science,* **50** : 598-601.

MISRA, S.G. AND PANDE, P., 1975, Distribution of different forms of iron in soils of Uttar Pradesh. *Journal of Indian Society of Soil Science*, **23** (2) : 242-246.

MORRIS, D.R., LOEPPERT, R.H. AND MOORE, T.J., 1990, Indigenous soil factors influencing iron chlorosis of soybean in calcareous soils. *Journal of American Society of Soil Science,* **54** : 1336-1339.

MUNCH, J.C. AND OTTOW, J.C.G., 1983, Bacterial reduction of amorphous and crystalline iron oxides. *Science du Sol - Bolletin de I'A.F.E.S.* **3** : 205-215.

NANDI, S. AND DASOG, G.S., 1992, Properties, origin and distribution of carbonate nodules in some vertisols. *Journal of Indian Society of Soil Science.* **40** : 329-334.

PATEL, J.J. AND PATEL, M.S., 1985, Effect of different levels of lime, sulphur, iron and moisture on yield and nutrient absorption by groundnut. *Indian Journal of Agricultural Research,* **19** : 124.

PIPER, C.S., 1966, *Soil and Plant Analysis.* Hani Publishers, Bombay.

PRASAD, R. AND SAKAL, R., 1991, Availability of iron in calcareous soils in relation to soil properties. *Journal of Indian Society of Soil Science,* **39** : 658-661.

RAI, M.M., PAL, A.R. AND CHIMANIA, B.P., 1972, Available micronutrients status of shallow black soils of Madhya Pradesh. *Journal of Indian Society of Soil Science,* **20** : 129-132.

RAO, N.S., RAMAVATHARAM, N., RAO, M.S. AND REDDY, K.S., 1993, Lime induced iron chlorosis in groundnut. *Journal of Indian Society of Soil Science,* **41**(2) : 393-395

RINGWOOD, A.E., 1955, *Geochemistry Cosmochemistry* Acta, **7** : 189-202.

RUTLAND , R.B., 1971, Radioisotopic evidence of immobilization of iron in *Azalea* by excess calcium bicarbonate. *Journal of American Society of Horticultural Science*, **96** (5) : 653-655.

RUTLAND, R.B. AND BUKOVAC, M.J., 1971, The effect of calcium bicarbonate on iron absorption and distribution by *Chrysanthemum morifolium* (Ram). *Plant and Soil* , **35** : 225-236.

SHANKARASUBRAMONEY, H., MEHROTRA, N.K. AND SHARMA, K.R., 1955, Distribution of different forms of iron in calcareous soils. *Journal of Soil Science*, **6** : 257-262.

SHII, C.T., MOK, M.C., TEMMPLE, S.R. AND MOK. D.W.S., 1980, Expression of development abnormalities in hybrids of *Phaseolus vulgaris* L. *Journal of Heredity,* **71** : 218-222.

SINGER, A., 1977, Extractable sesquioxides in six mediterranean soils developed on basalt. *Journal of Soil Science,* **28** : 125-135.

SINGH, M. AND DAHIYA, S.S., 1975, Effect of $CaCO_3$ and iron on the availability of iron in a light textured soil. *Journal of Indian Society Soil Science,* **23**(2) : 247-252.

SINGH, S. AND SINGH, K.P., 1996, Effect of gypsum on yield, oil content and uptake of Ca and S by groundnut on an acid alfisol of Ranchi. *Journal of Indian Society of Soil Science,* **44**(4) : 695-697.

SIUTA, J. AND MOTOWICKA-TERELAK, T., 1969, The origin and systematic of ferruginous precipitates in quaternary formation and in present-day soils, *Bulletein of Periglacyalry,* **18** : 257.

SUTHAR, D.M. AND PATEL, M.S., 1992, Yield and nutrient absorption by groundnut and iron availability in soil as influenced by lime and soil water. *Journal of Indian Society of Soil Science*, **40** : 594-596.

TANDON, H.L.S., 1998, *Methods of analysis of soils, plants, waters and fertilizers.* Fertilizer Development and Consultation Organization.

THAKUR, D.S., DUBEY, D.D., SHARMA, O. P. AND SHARMA, R. A., 1995, Physico-chemical properties and forms of iron in two usterts of central peninsular India. *Crop Research*, **9**(2) : 252-257.

VEMPATI, R.K. AND LOEPPERT, R.H., 1988, Chemistry and mineralogy of Fe-containing oxides and layer silicates in relation to plant available Fe. *Journal of Plant Nutrition,* **11** : 1557-1574.

VENKATA SUBBRAHMANYAM, A. AND MEHTA, B.V., 1975, Effect of Zn Fe and moisture on the availability of En, Fe and Mn in soil. *Journal of Indian Society of Soil Science,* **28** (2) : 236-241.

WADA, K. AND HIGASHI, T., 1976, The categories of aluminum and iron-humus complexes in Ando soils determined by selective dissolution. *Journal of Soil Science,* **27** : 357-368.

WALLACE, A. AND LUNT, O.R.,1960,Iron chlorosis in horticultural plants. *Proceedings of American Society of Horticultural Science*, **75** : 819-841.

WANG, H.D., WHITE, G.N., TURNER, F.T. AND DIXON, J.B., 1993, Ferrihydrite, lepidocrocite and goethite in coatings from East Texas vertic soils. *Journal of American Society of Soil Science,* **57** : 1381-1386.

WATANBE, S. AND MATSUMOTO, S., 1994, Effect of monosilicate, phosphate and carbonate on iron dissolution by mugineic acid. *Soil Science and Plant Nutrition,* **40** : 9-17.

WHITE, G.N. AND DIXON, J.B.,1996, Iron and manganese distribution in nodules from a young Texas vertisol. *Journal of American Society of Soil Science,* **60**(4) : 1254-1259.

WIKLANDER, L. AND HALLGREN, G., 1949, Studies on Gyttja soils. *Kunglai Antbrukshogok Annomous* , **16** : 811-827.

YAALON, D.H., 1957, Problems of soil testing on calcareous soils. *Plant and Soil,* **8** : 275-288.

YELVIKAR, N.V., ISMAIL, S., SIDDIQUI, M., MALEWAR, G.U. AND TAJUDDIN, 1996, Distribution of different forms of iron in vertic soils and their relation with soil properties. *Journal of Indian Society of Soil Science,* **44**(4) : 781-783.

YERRISWAMY, R.M., VASUKI, N., MANJUNATHAIAH, H.M. AND SATYANARAYANA, T., 1995, Forms of iron and their distribution in some vertisols of Karnataka. *Journal of Indian Society of Soil Science*, **43**(3) : 371-374.

ZHANG, M., AIVA, A.K., LI, Y.C. AND CALVERT, D.V.,1997, Fractionation of iron, manganese, aluminium and phosphorus in selected sandy soils under citrus production. *Journal of American Society of Soil Science,* **61** : 794-801.

APPENDICES

APPENDIX I : Maximum and Minimum temperature of Jan, Feb, Mar, April (2000)

Date	January		February		March		April	
	Max(^{0}C)	Min(^{0}C)	Max(^{0}C)	Min(^{0}C)	Max(^{0}C)	Min(^{0}C)	Max(^{0}C)	Min(^{0}C)
1	28.3	12.2	32.1	13.3	32.1	16.2	37.1	20.1
2	27.3	13.0	33.6	17.4	**33.5**	**16.0**	37.3	21.0
3	27.4	12.3	33.0	14.8	**24.9**	**18.1**	36.3	21.6
4	27.3	12.3	32.2	16.0	**33.9**	**18.7**	36.6	23.2
5	27.9	13.8	33.4	17.2	**34.7**	**18.1**	36.8	23.0
6	27.9	11.1	33.2	14.3	**35.0**	**17.4**	37.2	22.8
7	28.0	11.1	32.0	13.6	**35.0**	**16.3**	37.7	21.2
8	28.6	11.5	30.7	14.2	**33.0**	**15.9**	37.1	20.0
9	29.0	12.9	31.7	11.5	33.8	16.7	35.9	22.0
10	30.5	15.2	31.2	15.9	32.8	17.5	38.7	22.0
11	30.6	16.1	32.3	16.1	33.0	15.9	39.1	21.3
12	31.5	15.9	27.7	15.9	32.8	16.3	39.4	21.2
13	31.2	18.8	29.9	16.0	33.8	17.0	37.8	20.8
14	31.2	18.0	32.3	16.5	23.6	16.5	37.5	20.7
15	31.6	20.0	32.5	18.1	34.9	16.4	37.6	20.9
16	32.4	19.6	32.9	17.6	35.0	20.9	37.1	21.6
17	32.0	19.0	**33.5**	**18.1**	35.6	18.5	36.8	22.5
18	33.3	14.8	**33.9**	**16.5**	36.5	18.1	36.6	22.0
19	31.7	14.3	**34.0**	**14.0**	37.7	18.2	37.2	18.0
20	30.1	16.0	**33.9**	**12.7**	37.7	18.1	33.8	21.5
21	32.5	17.0	**28.6**	**11.5**	36.9	18.1	35.9	21.5
22	34.1	17.2	**30.6**	**15.9**	36.6	21.0	35.6	20.8
23	33.9	14.8	**32.7**	**19.6**	36.6	20.3	36.6	21.0
24	34.1	13.3	23.1	17.6	36.6	20.2	37.2	22.6
25	32.2	14.8	34.1	18.1	36.0	23.5	37.3	23.2
26	31.6	15.5	31.7	18.8	36.2	21.0	36.8	20.3
27	30.1	16.6	30.8	16.9	36.9	19.8	38.8	21.1
28	30.4	14.7	31.9	18.1	36.3	21.0	38.6	21.8
29	29.3	14.5	32.0	17.5	36.2	20.7	39.2	20.9
30	30.4	15.0			36.0	21.0	38.0	20.1
31	31.1	14.6			36.6	21.0		

Average temperature				
17th Feb to 23rd Feb			2nd Mar to 8th Mar	
Max(^{0}C)	Min(^{0}C)		Max(^{0}C)	Min(^{0}C)
32.64	14.71		34.26	17.21

Appendix II. Data of mechanical analysis of soils of Hebballi and Hebsur

Place	Depth (cm)	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Textural class
Hebballi	0-25	11.4	3.9	15.7	69.1	Clay
	25-55	9.6	5.7	13.6	71.1	Clay
	55-100	8.3	4.3	12.2	75.2	Clay
Hebsur	0-15	12.6	3.8	15.6	66.1	Clay
	15-52	9.8	4.9	16.2	68.2	Clay
	52-140	8.7	8.6	11.7	70.0	Clay

SOLUTION CHEMISTRY AND AVAILABILITY OF IRON TO GROUNDNUT CROP (*Arachis hypoguea* L.) IN CALCAREOUS SOILS

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ABSTRACT

Distribution of different forms of iron and calcium in presence of bicarbonate ion in calcareous soils of Dharwad, Hebballi and Hebsur was studied. A pot culture experiment (imposing three moisture and five $CaCO_3$ levels) was conducted at M.R.S., Dharwad to know the uptake of iron and calcium by groundnut crop in calcareous soils.

Free calcium carbonate was more in soils of Hebsur while exchangeable Ca was found more in Hebballi. Amorphous iron oxide-occluded iron and free iron oxides increased with increase in depth. No definite pattern was followed in distribution of water soluble iron, whereas, high water soluble calcium was noticed in soils of Dharwad. The concentration of bicarbonate ions in surface soils was found least in Dharwad and did not follow any trend in profiles. DTPA-Fe was found high in Dharwad.

After harvest of the crop, both forms of iron oxides in soil was found to decrease significantly with increased level of $CaCO_3$ and moisture. Water soluble Ca and HCO^-_3 increased significantly with increase in both $CaCO_3$ and moisture level. With increasing level of $CaCO_3$, concentration of water soluble Fe decreased. Decrease in concentration of exchangeable Ca and DTPA-Fe was observed with increasing level of $CaCO_3$ and with increasing level of both of the factors respectively.

Uptake and concentration of Fe and Ca in plant samples (haulm and kernel) increased significantly with increasing level of moisture and $CaCO_3$.

Balanced uptake of Fe and Ca resulted in maximum yield of pod in treatment with moisture of 150 per cent of F.C. + 7 per cent $CaCO_3$.