STUDIES ON THE DYNAMICS OF FORMS OF SOIL IRON IN THE ACID SOILS OF KERALA DURING SUBMERGENCE

BY

K. P. HARIKUMAR

THESIS

Submitted in partial fulfilment of
the requirement for the degree
MASTER OF SCIENCE IN AGRICULTURE
Faculty of Agriculture
Kerala Agricultural University

DEPARTMENT OF SOIL SCIENCE & AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE
VELLAYANI, TRIVANDRUM

1989

DECLARATION

I hereby declare that this thesis entitled STUDIES ON THE DYNAMICS OF FORMS OF SOIL IRON IN THE ACID SOILS OF KERALA DURING SUBMERGENCE is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title at any other University or Society.

Harikumar

K.P. HARIKUMAR

Vellayani,
20.12.89.

CERTIFICATE

Certified that this thesis, entitled STUDIES ON THE DYNAMICS OF FORMS OF SOIL IRON IN THE ACID SOILS OF KERALA DURING SUBMERGENCE is a record of research work done independently by Sri. K.P. Harikumar under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

Dr. P.R. Ramasubramonian
Chairman
Advisory Committee
Professor of Soil Science NARP(SR)
Department of Soil Science &
Agricultural Chemistry
College of Agriculture
Vellayani

Vellayani,
20/12/89

APPROVED BY:

CHAIRMAN

Dr. P.R. Ramasubramonian
5/5/90

Members:

1. Dr. R.S. Aiyer 5/5/90

2. Dr.(Mrs.) Alice Abraham Alice Abraham 5/5/90

3. Sri. M. Subramonia Iyer M. Subramoni 5/5/90

4. Dr. (Mrs.) P. Saraswathy Saraswathy P 5/5/90

Examiner: 5/5/90

ACKNOWLEDGEMENT

I wish to place on record my deep sense of gratitude and heartfelt thanks to:

Dr. P.R. Ramasubramonian, Professor of Soil Science & Agricultural Chemistry and Chairman of the Advisory Committee for suggesting the problem, for his valuable guidance in the planning and execution of this work, for the expert advice, creative criticism and sustained efforts given throughout the period of investigation and preparation of the thesis.

Dr. R.S. Aiyer, Professor & Head of the Department of Soil Science & Agricultural Chemistry and member of the Advisory Committee for the valuable guidelines and constant encouragement at every stage of the work and for the several creative suggestions.

Dr. (Mrs.) Alice Abraham, Professor of Soil Science & Agricultural Chemistry and member of the Advisory Committee for the kind inspiration and encouragement at every stage of the work, critically going through the manuscript and offering valuable suggestions.

Sri. M. Subramonia Iyer, Associate Professor of Soil Science & Agricultural Chemistry and member of the Advisory Committee for the sincere efforts and guidence given during the description of the profiles and at every stage of the work and preparation of the thesis.

Dr. (Mrs.) P. Saraswathy, Associate Professor of Agricultural Statistics and member of the Advisory Committee for the valuable help in the statistical analysis and interpretation of the data.

Dr. N. Saifudeen, Associate Professor of Soil Science & Agricultural Chemistry for the valuable assistance in the analytical works.

All my friends, teaching and non-teaching staff of the Department of Soil Science & Agricultural Chemistry for their assistance and kind co-operation.

Government of Kerala for kindly allowing deputation and

My parents for their constant help and encouragement throughout the period of my studies.

K.P. HARIKUMAR

Vellayani,

LIST OF TABLES

LIST OF ILLUSTRATIONS

INTRODUCTION

INTRODUCTION

Among the micronutrients considered essential for the normal growth and nutrition of crop plants, iron occupies a key position. The availability of this element in the soil for crops is governed by soil reaction, moisture content, drainage, organic matter status, redox potential, cation exchange capacity, duration of soil anaerobicity and the management practices followed. In acid soils, however, the unavailability of this element is not considered as a constraint in crop production, though it is so in alkaline soils due to its possible precipitation. Most of the acidic paddy soils in Kerala have been derived from furruginous parent materials and in these soils particularly under submergence or low land situation, in which rice is cultivated, reducing condition sets in, rendering the conversion of insoluble Fe^{3+} in to soluble Fe^{2+} often reaching concentrations toxic enough for the crop. The special ways of management of the paddy soils, by practices of levelling the land, puddling, continuous retention of minimum 5 cm standing water and subsequent draining and drying of the land to hasten maturity can bring about a series of physical, chemical and biological reactions in these soils, which are distinctly different from those of the upland soils.

The reduction of iron and its increased solubilisation are the consequences of anaerobic metabolism and appears to be due to chemical reduction of Fe^{3+} by bacterial metabolites, although direct reduction coupled with respiration may also be involved (Tanaka and Yoshida, 1970). Close relationships between fall in redox potential and increases in soluble and exchangeable iron have been noticed by many workers.

In Kerala, the submerged soils include mainly those of the kari, karappadom and kayal soils of Kuttanad, the kole soils of Trichur, the saline soils of pokkali and Kaipad lands and the brown hydromorphic soils in the depressions of mid land and mid upland lateritic belt, where iron toxicity is likely to be manifested in varying degrees. The nature and magnitude of transformation of iron resulting in the changes in its availability in soil under submerged conditions depend on the different forms as well as the other soil chemical characteristics and the presence or absence of other cations such as K^{+}, Ca^{2+}, Mg^{2+}, Zn^{2+}, Mn^{2+} etc. Studies on the chemical transformation of iron are thus helpful in ascertaining their influence on the availability of many other elements to rice.

The relationship between the forms of iron has often been studied from the estimations using different extractants. The amounts of iron extractable by these extractants often give nearly reliable indications of their availability to plants. Thus, while normal ammonium acetate of pH 7.0 extracts exchangeable and water soluble iron, the same extractant buffered at pH 4.8 gives indications of available iron. Again, ammonium acetate at pH 3.0 extracts reducible and exchangeable iron together. Various other extractants such as 0.5 *M* EDTA, 0.05 *M* DTPA and 0.1 N HCl have also been successfully attempted. Eventhough the dilute acid extractable iron is more important in the nutrition of the crop plants, the free or active (iron oxides) iron can be extracted with sodium dithionite + EDTA (Asami and Kumada, 1959) which constitutes largely the total iron in the soil. Though other forms such as crystalline, amorphous organic (Pyrophosphate extractable) and inorganic iron are also known, their influence in improving the predictability regarding available content is negligible and as such, they have more of relevance to pedology rather than to edaphology.

Major forms of iron in soils are the sparingly soluble ferric oxides which occur as coatings of aggregates or as separate constituents of the clay fraction. The very slow solubility of these compounds mean that the iron concentrations in soil solutions are also very low.

The pattern of distribution and the dynamics of different forms of soil iron under the submerged conditions and the relationship between these forms and the soil properties in the acid rice soils of Kerala have not been investigated in detail earlier. The study was therefore undertaken with a view to obtain a better understanding of these aspects, by carrying out laboratory as well as incubation experiments with the following specific objectives;

1. To study the distribution pattern of the various forms of soil iron in the major acid rice soils of Kerala

2. To study the dynamics of soil iron under the conditions of submergence

3. To study the relationship between the physico-chemical properties of rice soils and the different forms of soil iron and

4. To study the significance of soil treatment with lime and organic matter in changing the pattern of dynamics of soil iron during submergence.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Submergence of the soil sets in motion, a series of physical, chemical and biological processes that profoundly influence the quality of soil as a medium for plant growth. In the acid soils, problems such as toxicity of iron, hydrogen sulphide and carbon dioxide and deficiency of phosphorus and some micro nutrients (Coulter, 1973; Ponnamperuma et al., 1973) arise due to submergence. The transformation of iron in submerged acid soils and the availability of excessive amounts of this element to plant are of great practical interest. The present study relates to the influence of period of submergence and different management practices on the dynamics of different forms of iron in the major rice growing acid soils of Kerala.

The most conspicuous chemical change that occurs when a soil is flooded is the reduction of Fe(III) to Fe(II). The oxidation-reduction reaction undergone by soil iron and its resultant solubility changes under submergence, play an important role in the absorption and accumulation of iron by the rice plant. The nature and magnitude of transformation of this element under water logged condition depend on their different forms in soil as well as the soil physico-chemical properties like Eh, pH, electrical conductivity, organic carbon content, clay content etc. A review of earlier work done on the role of iron in plant nutrition, its distribution in the soil and the changes brought about by submergence, inter-relationship between the forms of iron and the soil physico-chemical properties and changes due to the soil management practices like liming and addition of organic matter are furnished below:

I Iron as a plant nutrient

The importance of iron and its essentiality in plant nutrition has been reported by several scientists as early as in 1844. This element is involved in various metabolic activities in plants, mainly as an activator in many enzymes. It is a constituent of porphyrin compounds - cytochromes, peroxidase, catalase, haem and non-haem enzymes and other functional metallo-proteins like ferrodoxins and haemoglobin. Apart from its physiological functions in respiration, photosynthesis, nitrogen fixation by micro organisms etc., it has also a role in chlorophyll synthesis in plants.

The plant requirement of iron varies according to the species, contents of other macro and micro nutrients in the soil and the soil conditions. Kapp (1936) observed that the iron requirement of rice under submerged condition is greater than that of upland soils and suggested 1-25 ppm for improved green colour and root growth. Olsen (1965) reported 2 ppm content of iron as the critical deficiency limit in plants. In rice plant, the presence of 70 ppm or below of iron in leaf blade at active tillering stage would indicate possible deficiency of iron under submerged condition (Tanaka and Yoshida, 1970).

According to Tanaka and Yoshida (1970) and Van Breemen and Moorman (1978) the wide range in critical concentration investigated by different workers might be due to differences in criteria used for toxicity, varieties, forms of applied iron, concentration of other dissolved substances, the nutrient status of plants, susceptibility of the rice plants at different growth stages and environmental factors (temperature and solar radiation).

Agarwala and Sharma (1976) after a series of pot culture studies with different crops has worked out, in general, the limit for deficiency of iron as 0.05 to 2 ppm and the requirement of iron for optimum growth as 5 to 10 ppm for crops.

Lindsay (1984) observed that the major cause of iron deficiency in plants is the insolubility of Fe(III) oxides in soils which occurs in the pH range 7.4 to 8.5 and indicated the critical level of soluble iron for plants as approximately 10^{-8} M.

The effect of increasing iron concentrations on the rice yield in alkaline soils has been investigated by many workers. Pathak et al. (1979) reported that grain and straw yield in rice increased with increasing iron concentration upto 18 ppm.

Tandon and Saxena (1987) reported that the rate of photosynthesis was increased by increasing rates of Fe and P. The contents of total sugars, non-reducing sugars and ascorbic acid in all plant parts also increased by increasing rates of iron.

The deficiency of iron in most crop plants and fruit trees is manifested by the symptoms of chlorosis starting from the basal part of the leaf and spreading to the anterior margin, with or without reddish brown necrotic lesions along leaf margin away from the base.

Localised chlorosis in sorghum or soyabean in variable extents of severity commonly referred to as hot spot, has been reported in patches within the field as due to iron deficiency by Loeppert et al. (1984).

Sharma and Sharma (1987) found that deficiency of iron caused an increase in water potential, transpiration rate and water loss.

Although iron is essential for the normal growth of plants, the presence of excess soluble iron in the soil has been proved detrimental particularly to rice crop. The iron toxicity arises mostly in wet land acid soils, where rice is cropped under submerged condition. The available literature on this aspect pertains mainly to toxicity of iron in relation to the growth and yield of cereal crops particularly of low land rice.

Excessive quantities of iron absorbed by the rice plant is manifested by bronzing symptoms usually seen in humid tropics and sub-tropics. In the soils of Kuttanad where rice is cropped under submerged condition, Subramoney and Kurup (1960 and 1961) have indicated a possible relation of the reddish brown scum seen in acidic paddy fields to excess soluble iron. When the soluble iron content exceeds the threshold level of toxicity, growth retardation and browning of roots are the other possible consequences. Tanaka and Navasero (1966) and Tanaka and Yoshida (1970) reported that the critical concentration of iron in culture solution for bronzing to occur was 100 ppm at pH 3.7, but it was frequently over 500 ppm. They also noted that rice leaves containing 300 ppm iron often exhibited bronzing symptoms. Young plants were most susceptible to iron toxicity.

Agarwala and Sharma (1976) had worked out the threshold of toxicity limit as 30 ppm.

However, these limits differ among species and even between varieties depending on soil conditions. When soils are supplied with other nutrients, iron toxicity to rice may occur only when dissolved iron in the rooting medium is in the 300-500 ppm range (Ponnamperuma, 1955; IRRI, 1964), but in soil with low nutrient levels (K and P) or in presence of respiration inhibitors like H_2S, the soluble iron concentration as low as 30 ppm might prove toxic (Van Breemen and Moorman, 1978).

Lopes (1987) reported the orange discolouration of rice leaves might be due to toxicity of iron or deficiency of other nutrients resulting from the hindered absorption caused by the layer of iron on the roots. Fageria (1988) observed that the uptake of all nutrients were reduced with increasing iron concentration in the rooting medium.

II Forms and distribution of iron in the soil

Iron in the soil can be mainly divided into (i) iron present in the primary mineral, the nature of which will depend on the type of parent material undergoing weathering and (ii) iron present in the secondary minerals.

Iri et al. (1958) reported that in rice fields under flooded conditions, ferrous iron was lowest in the 'A' horizon but increased towards 'B' horizon and was maximum in the lowest layers. In poorly drained soils in the field, the ferrous iron content in all the horizons was higher.

Oades (1963) classified the free iron oxides in soils under (i) iron concentrations, (ii) illuvial deposits in lower 'B' horizon of podzolic soils, (iii) lateritic crusts and (iv) iron oxides of agricultural soils and brown earths.

In a model described by Harmsen and Van Breemen (1975), the distribution of dissolved ferrous iron was shown as a function of time and depth in a flooded soil profile.

Singh and Patiram (1975) noticed high contents of total iron in soils of high clay content and the free iron ranged from 0.24 to 1.45 per cent while Takkar (1978) found that the content of total iron was generally high in hill and acid soils.

Karamova (1978) classified the total iron in the soil as non-silicate iron and silicate iron. Non-silicate part was further classified into crystalline and amorphous forms, the amorphous iron further comprising of amorphous organic and amorphous inorganic fractions.

Shavrova (1984) in a study of podzolic and sodpodzolic soils observed that elluvial horizon of all soils are iron poor. Silicate forms of iron predominate which shows weak weathering over non-silicate iron. The sod process (humus accumulation) leads to an increase in total content of non-silicate iron especially the crystallised form.

Savant and McClellan (1987) suggested that iron would occur in forms ranging from very finely divided amorphous to crystalline poly morphic particles mainly in the clay fraction, coatings on external and/or internal surfaces of clay minerals or concretions. They had also indicated the possible pathways of major transformations of iron oxides in soils under wet land rice based cropping system.

Ramasubramonian (1989) noticed decrease in the total iron content and increases in the contents of water soluble, exchangeable and active iron with depth in the major paddy soils of Kerala.

From study of total iron content in several soils, Biswas (1953), Kanwar and Randhawa (1974), Takkar and Randhawa (1978) reported that in divergent soils the total iron content ranged from 0.27 per cent to 19.1 per cent.

Several Scientists had studied the content and distribution of water soluble, exchangeable and available forms of iron, as these three are the major forms absorbed by plants.

Olsen and Carlson (1949) suggested that the iron extracted with N. NH_4OAc of pH 4.8 would give a better indication of its availability to plants as the acidic extractant would bring more iron into solution, while Olsen (1965) and Jackson (1973) maintained that N. NH_4OAc of pH 7 used as the extractant would give the exchangeable iron content. Jackson (1973) suggested that N. NH_4OAc with pH 3.0 would give the content of reducible iron.

Pisharody (1965) studied the major forms of iron and their distribution in six soil profiles from Kerala and indicated that the variation in the contents of water soluble, exchangeable and reducible iron were 9.0 to 45.11, 6.2 to 58.6 and 5.0 to 100.8 ppm respectively.

Rajagopal et al. (1977) from results of analysis of a large number of soils from different parts of Kerala concluded that the contents of available iron ranged from 1.6 ppm to 5066 ppm.

Kamala Devi et al. (1974) reported that the concentration of iron in Kerala soils was highest in reclaimed marshy lands, followed by laterite, alluvial, red sandy loam and coastal sandy, which registered the least content.

High amounts of available iron were reported by Aiyer et al. (1975) in the acid rice soils of Kerala, particularly in the kari (peat) soils of Kuttanad suggesting the possibility of iron toxicity to rice.

Kabeerathumma (1975) noticed that the exchangeable iron content of kayal, kari, karappadom, pokkali and kole soils of Kerala was 22, 32, 13, 13 and 8 ppm respectively.

Singh and Patiram (1975) in a study of the distribution of iron in the paddy soils of eastern Uttar Pradesh observed that available iron content varied from 4.8 to 234.0 ppm.

Dubey et al. (1983) in a study of salt affected black soils of western part of Madhya Pradesh concluded that water soluble iron decreased with increase in depth. This might be due to the precipitation of soluble iron at lower depth, by adsorption on clays and charged oxides or possibly by an increase in pH.

Patel and Dangarwala (1983) in a study of rice soils of Gujarat, indicated that the available and reducible forms of iron were related and the reducible form was a potential source of available iron in a study of rice soils of Gujarat.

Yu Tian-ren (1980) referring to the water soluble, exchangeable, complexed with organic matter of the solid phase and precipitated forms of iron reported that the water soluble iron increased with decrease in pH at the expense of the precipitated iron.

Jugsujinda et al. (1987) reported that microbially reducible iron which consisted of water soluble and exchangeable forms represented 20 per cent of the chemically reducible iron. The amount of iron reduced by micro-organism increased for about ten days to two weeks following flooding and thereafter remained constant.

Asami and Kumada (1959) observed that the water soluble, exchangeable and easily reducible which is freshly precipitated Fe_2O_3, together constitute 'active iron'. They have recommended a method for estimating active iron in soils.

Kabeerathumma (1975) in a study of kayal, kari, karappadom, pokkali and kole soils of Kerala, reported that the active iron content varies from 2.7, 0.75, 0.78, 1.0 and 3.28 per cent respectively.

In a study of free oxide (dithionite extractable) amorphous forms (oxalate extractable) of iron Mckeague and Day (1966), Mckeague (1967) and Mckeague et al. (1971) observed that selective extraction would permit an approximate differentiation among the organic complexed iron extractable by 0.1 M sodium pyrophosphate and total amorphous iron extractable by acid ammonium oxalate. The difference between oxalate and pyrophosphate extractable forms of iron would give amorphous inorganic form, while the difference between dithionite and oxalate would give more or less the crystalline iron oxides. The usefulness in the differentiation between the free oxides formed as product of recent weathering and those inherited from the parent material were also emphasised by them. They also recommended dithionite method to determine free iron and oxalate method for amorphous products of recent weathering.

Fresneda et al. (1979) also reported that dithionite extractable iron included both crystalline and amorphous forms.

Udo (1980) reported low contents of free oxides forming nearly nine per cent of the total iron in poorly drained soils while, the well drained soils had highest content, frequently above 61 per cent of the total iron.

Mitra and Mandal (1983) noticed that the free iron constituting the iron oxides, iron salts and iron associated with organic matter formed an average of 30-40 per cent of the total iron.

Dolui et al. (1988) from a study of the Terai and Teesta alluvial soils of West Bengal concluded that the content of exchangeable iron varied from 26 to 405 ppm, dithionite extractable iron from 1666 to 3666 ppm, ammonium oxalate extractable iron from 583 to 2850 and pyrophosphate extractable iron from 125 to 1487 ppm.

III Dynamics of iron in soils under submergence

Islam and Elahi (1954), Ponnamperuma (1955), Mandal (1961), Mahapatra (1968) and Olomu et al. (1973) have highlighted the process of reduction of iron and iron solubilisation under waterlogged conditions in acid soils.

Mandal (1961), Motomura (1962), Thenabadu (1966), Savant and Kibe (1971), Jayaram and Nayar (1972) and several others have noticed that lateritic soils on submergence released large amounts of ferrous iron, toxic enough for rice growth.

Ponnamperuma (1972) observed that within a few weeks after flooding, water soluble iron increased from 0.1 to 600 ppm.

Munch et al. (1978) in a study of soil under submerged condition reported that iron reduction reached maximum after 15-16 days of submergence while Socorro and Bolomou (1981) observed that ferrous iron content increased after 12 days of flooding and then decreased to a minimum on 33rd day.

Sharma and Banerjee (1983) noticed that the formation of ferrous iron at 50 per cent water holding capacity of the acid soils of West Bengal increased with duration of incubation, but at a very slow rate, while under waterlogged condition the rate of ferrous iron formation was very high, the maximum being in alluvial soil containing a higher content of free iron oxides.

The exchangeable iron content also increased due to submergence. Kabeerathumma (1975), Ghosh et al. (1976), Bandyopadhyay and Bandyopadhyay (1984), Patra and Mohanty (1989) noticed an increase in exchangeable iron content upto 30 days and thereafter a gradual decrease.

Mandal and Mitra (1982) reported that the contents of soluble and exchangeable iron were more in continuously waterlogged soils than in alternately waterlogged and saturated soils.

Katyal and Deb (1982) observed that the build up of ferrous iron in rice soils was determined by the quantity of active iron or reducible iron.

The status of iron with reference to free iron oxides, crystalline, amorphous forms and organo-complexed form was reported by Munch et al. (1978) in an inoculation study with iron reducing nitrogen fixing clostridia. They observed that in all the soils the total amount of Fe_d as well as crystalline Fe, (Fe_d - Fe_o) decreased immediately on submergence significantly, while Fe (II) in solution increased sigmoidally and was inversely proportional to changes in pH. Fe_o remained relatively constant.

Munch and Ottow (1980) in a study of the above mentioned forms of iron concluded that in a soil with high Fe_o: Fe_d which is the activity ratio, there was a rapid decrease in the content of Fe_d and Fe_o during incubation and Fe_{d-o} and Fe_o:Fe_d remained relatively constant throughout the entire period of reduction. This behaviour is suggestive of the preferential reduction of non-crystalline iron by bacterial action rather than their crystalline counter parts. In soils with low Fe_o:Fe_d ratio there was transitory increase in Fe_o and at the same time Fe_d and Fe_{d-o} decreased rapidly, while Fe_o:Fe_d ratio increased. Under such conditions crystalline iron oxide is first subjected to bacterial activity. In soils with very low degree of activity (ie, $Fe_o:Fe_d = 0.10$), Fe_o fraction is lowered during the first day of incubation only, with subsequent significant increase. The Fe_d and Fe_{d-o} decreased showing preferential action of crystalline iron oxides by bacteria.

Willett and Higgins (1980) observed an increase in amorphous iron content of the soil due to submergence, while He-Qun and Xu Zu-yi (1980) reported increase in the content of both amorphous and pyrophosphate extractable iron due to submergence.

Patra and Mohanty (1989) reported an increase in pyrophosphate extractable iron upto 30 days of submergence after which it decreased continuously upto 90 days.

IV Relationship of iron and soil physico-chemical properties under submergence

Submergence of soil brings about a series of physico-chemical changes that are different from those of an upland aerobic soil. The major physico-chemical changes that are affected by submergence of a soil having relevance to soluble iron are given below.

Soil reaction

Ponnamperuma (1955) suggested that submergence of an acid soil leads to a gradual increase in pH, the magnitude of which depends on the initial pH, the organic matter content and duration of submergence. The increase in pH on submergence was ascribed to the precipitation of $Fe_3(OH)_8$.

Jeffery (1961) reported that $Fe^{3+} - Fe^{2+}$ systems might be responsible for pH and Eh changes in submerged soil.

Motomura (1962), Ponnamperuma and Castro (1964), Redman and Patrick Jr. (1965), Mahapatra (1968), Chakraverty and Kar (1970), Savant and Kibe (1971), Kabeerathumma and Patnaik (1982) have all reported that the overall effect of submergence is to increase the pH of acid soils to a fairly stable value of 6.7 - 7.2 and to depress the pH of sodic and calcareous soil to neutrality.

According to Patrick Jr. (1964) an increase in pH was always accompanied by a decrease in redox potential and that at low redox potential, ferric hydroxide was reduced to ferrous hydroxide according to the equation

$$Fe(OH)_3 + \bar{e} \rightarrow Fe(OH)_2 + OH^-$$

Reports from IRRI (1964) indicated that the increase in pH of waterlogged soils was increased by the likely conversion of ferric hydroxide to ferrous state.

According to Bao et al. (1964) the pH of the medium plays a dominant role in the transformation of iron and in determining the relative proportions among the various form of iron.

Ponnamperuma et al. (1967) reported that the availability of iron under submerged condition can be predicted by the physico-chemical relations in flooded soils and the formulation of iron reactions with pE and pH as variables.

Ponnamperuma (1972) indicated that all the reduction reactions which occur based on the predictions of thermodynamic sequences involve consumption of H^+ ions, thereby resulting in a decrease in acidity or increase in net OH^- ion concentration. Since most soil contain Fe(III)oxides, the increase in pH of acid soils is largely due to the reduction of iron.

With regard to the effect of pH on different forms of iron, Takkar (1969) found that the high content of free iron and low pH resulted in higher amount of extractable iron in acid soils. Gotoh and Patrick Jr. (1974) reported that water soluble and exchangeable iron were favoured by a decrease in both redox potential and pH. In a relative study of pH and Eh, they had also reported that critical redox potential for iron reduction and its consequent dissolution was between +300 mV and +100 mV at pH 6 and 7 and -100 mV at pH 8, while at pH 5 appreciable reduction occurs at +300 mV.

Singh and Patiram (1975) in a study of the paddy soils of eastern Uttar Pradesh observed that free iron and available iron showed significant negative correlation with pH.

De and Banerjee (1977) and Sakal et al. (1988) reported that available iron was significantly negatively correlated with pH of soil and pH appeared to be the dominant factor in controlling the availability of iron.

Sims and Patrick Jr. (1978) found the highest amount of exchangeable and pyrophosphate extractable iron at low pH and Eh.

Jones et al. (1980) reported that while Eh regulates the mobilisation of insoluble iron to soluble form, the pH controls its concentration in soil solution.

Kaurichev et al. (1981) observed that flooding resulted in the reduction of iron at Eh values between +270 and +14 mV at pH 5.0 - 6.8.

Patrick Jr. and Henderson (1981) reported that iron reduction and reoxidation were more sensitive to redox potential especially at pH 5 and 6. At pH 4, iron remained in solution at all Eh values and at pH 7 and 8 little iron was present in the soluble form when Eh was decreased.

Electrical conductivity

When a soil is submerged the specific conductance increases in the early phase of submergence, reaches a maximum and then decreases to a fairly stable value which varies with soil (Ponnamperuma, 1976; Verma and Neue, 1988).

Ponnamperuma (1977) has attributed the increase in Ec during the first few weeks of submergence to mobilisation of Fe^{2+}, accumulation of NH_4^+, HCO_3^- and $RCOO^-$ and displacement of cations from soil colloids by Fe^{2+}, Mn^{2+} and NH_4^+.

Bandyopadhyay and Bandyopadhyay (1984) noticed that submergence of coastal saline soil (EC=13.6 mmhos/cm^3) resulted in a sharp fall in Eh and caused considerable increase in soluble and exchangeable Fe^{2+} and Mn^{2+} fractions.

Sadana and Takkar (1985) in a pot experiment to study the effect of salt on iron equilibria found that Fe^{2+} concentration increased at all stages of submergence.

Clay content of the soil

Several studies have revealed that iron content is more in soils having higher amount of clay.

Singh (1964) observed that soil texture significantly influenced the fate of applied water soluble iron. Fine textured soils may retain a major part of the applied iron in a form in which it is not readily available. This could be the reason for the higher amount of ferrous iron in light textured soils.

Singh and Patiram (1975) and Kanwar et al. (1986) observed a positive correlation between total iron and clay content of the soil.

However, Ghosh and Banerjee (1979) in a study of the soils of West Bengal reported that exchangeable, available and reducible forms of iron showed a negative correlation with clay content. The same observation was made by Patel and Dangarwala (1983) in a study of rice soils of Gujarat.

Dolui et al. (1988) in a study of Terai and Teesta alluvial soils of West Bengal, observed that the concentration of the different forms of iron such as exchangeable, pyrophosphate, extractable, ammonium oxalate extractable, EDTA extractable etc.,were governed by clay content, in addition to pH and organic carbon.

V Influence of soil management practices on the iron solubilisation

1. Organic matter

Islam and Elahi (1954) observed that addition of oxidizable materials especially organic matter promoted the reduction of iron during submergence.

Mandal (1961) reported that in presence of organic matter reduction of iron from ferric to ferrous form was more intense under waterlogged condition.

Pisharody (1965) in a study of water soluble, exchangeable, reducible and active forms of iron, in the major rice soils of Kerala observed that these forms were greatly influenced by organic matter.

Patnaik and Bhadrachalam (1965) have found that addition of organic manures or green manure may aggravate soil reduction in addition to the accumulation of toxic decomposable products. Takkar (1969) observed that the presence of organic matter in acid soils under waterlogged condition increased the content of extractable iron several times.

Ponnamperuma (1972), Jaggi and Russel (1973), Bandyopadhyay and Bandyopadhyay (1984) reported that high levels of readily decomposable organic matter hastened fall in Eh and thus favoured a build up of Fe^{2+}.

Mohanty and Patnaik (1973) suggested flooding the soil for considerable length of time preferably with addition of organic matter to hasten iron reduction before puddling or transplatning. This would result in the reprecipitation of released iron thus decreasing its concentration in the soil solution.

Ottow (1980) observed that the higher the content of easily decomposable organic matter and the lower the amount of nitrate as well as Mn (IV) compounds the more intensive is the accumulation of Fe^{2+}.

Yu-Tian-ren (1980) reported that a linear correlation between the amount of complexed iron (iron associated with solid phase of the soil organic matter) and organic matter existed in soil.

Patel and Dangarwala (1983) reported a positive correlation between exchangeable, available, reducible form of iron and organic matter content.

Sah and Mikkelson (1986) in a study of the effect of anaerobic decomposition of organic matter on the amorphous iron content in soils used for flooded rice upland crop rotations observed a significant increase in the transformation of crystalline iron into amorphous form.

Thind and Chahal (1986) reported that all forms of iron except active form increased due to submergence and green manuring.

2. Liming

Allaway (1957), Vaculik (1963), Mandal and Sinha (1964), Sahu (1968), Wang (1971) and Kabeerathumma and Chitharanjan (1973) have observed that toxic effects of iron and aluminium could be corrected by lime.

Subramony and Kurup (1961) reported that iron solubilisation could be fairly suppressed by treatment with calcium oxide or calcium carbonate.

Ponnamperuma (1965) suggested that the activities of water soluble $AlOH^{2+}$ and Fe^{2+} decrease a hundred fold per unit increase in pH, hence raising the pH of the soil appeared to be a promising method for decreasing the toxicity of these in soils.

Singh and Patiram (1975) reported a negative correlation between available iron and calcium carbonate content.

Mahendra Singh and Dahiya (1975) observed a decrease in exchangeable iron by the addition of increasing levels of calcium carbonate. This according to them might be due to substitution of Ca for Fe on the exchange complex resulting from the release of calcium from the hydrolysis of calcium carbonate. Decrease in available and reducible iron resulting from the addition of calcium carbonate might be due to oxidation of soluble, native, and added iron through direct reaction with calcium carbonate.

Kabeerathumma (1975) reported a marked decrease in exchangeable iron by liming kari, kayal, karappadom, kole and pokkali soils of Kerala.

Arulandoo (1981) obtained substantial increase in rice yields by lime application at 2.5 MT/ha to acid sulphate soil of Malaysia where rice frequently showed iron toxicity symptoms.

Verma and Tripathy (1984) in a study of pot trials with acid soils (pH 5.2) found that flooding reduced grain and straw yields when no calcium carbonate was applied, because of increased iron content. Liming increased yield and decreased iron content with submergence.

Silveira et al. (1987) reported that although iron availability increased with submergence, it decreased with quantity of lime.

Bertic et al. (1988) reported a drastic decrease in plant available iron with the application of lime.

Patra and Mohanty (1989) noticed that liming along with NPK decreased the different fractions of iron to the highest extent followed by K and NPK and that iron and manganese toxicity could be minimised by liming.

MATERIALS AND METHODS

MATERIALS AND METHODS

The materials for the experiments included in this work consisted of six rice growing acid soils of Kerala, representing lateritic alluvium (brown hydromorphic) from Vellayani kayal land, kari and kole (acid sulphate) soils from Kuttanad and Kattukampal respectively, kayal soil (reclaimed lake bed) from Mathi kayal and Pulinkunnu, karappadom soil (lateritic alluvium-hydromorphic) from RRS, Moncompu and pokkali (acid saline) from RRS, Vytilla where iron toxicity to rice has been reported.

The first experiment consisted of a study of the soil profile for which pits were dug during March-April 1988 when the field was fallow at the above mentioned six sites, upto a depth of ground water level which varied in different sites (Table 1). Profile descriptions were made on the basis of methods suggested by FAO (1978). The Munsell soil colour chart was used to describe the soil colour. The profiles are described in Appendix I.

The second experiment was the study of physico-chemical properties of soils collected from different horizons of the six soil profiles and surface samples from a depth of 0-20 cm collected from these locations. Total, water soluble, exchangeable, active, free oxides, total amorphous, crystalline, amorphous organic and amorphous inorganic forms of iron were also determined in the surface soil samples.

The third experiment consisted of a series of incubation studies in which the effect of submergence alone and with lime and organic matter, on the release of different forms of iron were traced in typical submerged rice soils from lateritic alluvium, kari, kayal, karappadom, kole and pokkali sites.

1. Description of the soil profile

The detailed description of each profile made as per the guidelines suggested by FAO (1978).

2. Physico-chemical properties of the soils from soil profiles

Soil samples were taken from four horizons in lateritic alluvium, kayal, karappadom, kole and pokkali soil profiles and five horizons from kari soil profile. The moist soils were packed in polythene bags and transferred to the laboratory as such. The soils were air dried, powdered, sieved and stored in labelled bottles for mechanical analysis and the determination of general physico-chemical characteristics.

i) Mechnical analysis

The mechanical composition of the soil was determined by the International Pipette method as described by Piper (1966).

ii) Moisture

10 g soil was dried in an air oven at 100°-$105^{\circ}C$ to constant weight and the loss in weight was expressed as percentage of moisture on oven-dry basis. The moisture percentage was determined for computing the various components of the analysis of soil on moisture free basis.

iii) Soil reaction (pH)

The pH was determined in a 1:2.5 soil water suspension using a Perkin-Elmer pH meter and glass electrode.

iv) Electrical conductivity (EC)

The electrical conductivity was determined in the 1:2 water extract using Elico Solubridge.

v) Organic carbon

Organic carbon was estimated by the Walkley and Black's rapid titration method using diphenylamine as indicator as given by Jackson (1973).

vi) Cation exchange capacity (CEC)

The cation exchange capacity of the soil samples was determined by the neutral N ammonium acetate method as described by Jackson (1973).

vii) Preparation of soil extract

20 g of soil was boiled with 200 ml of constant boiling hydrochloric acid for six hours, filtered using No.42 grade Whatman filter paper, washed free of chloride and made upto one litre (Piper, 1966). The acid extract thus obtained was used for the following estimations.

a) Total iron

Total iron was estimated in an aliquot of the HCl extract by thiocyanate method (Snell and Snell, 1949). Using Klett Summerson Photoelectric Colorimeter with a green filter (480-520 µ) and expressed as percentage.

b) Total aluminium

Total aluminium was estimated using Atomic Absorption Spectrophotometer (Perkin Elmer, Model 3030) and expressed as percentage.

B. Physico-chemical properties of surface samples of soils

The surface samples collected from the six locations were air dried and subjected to the following physico-chemical analytical studies.

a) Single value constants

Apparent specific gravity, absolute specific gravity, pore space, water holding capacity and volume expansion on wetting were determined by the Keen - Raczkowski brass cup method (Piper, 1966).

b) Total nitrogen

Total nitrogen in the soil was determined by the modified Kjeldahl's method (Jackson, 1973).

c) Total phosphorus

Total phosphorus was read in Spectronic 2000, from the HCl extract of the soil (Jackson, 1973).

d) Total potassium, calcium, manganese

The total contents of potassium, calcium and manganese were determined from the HCl extract using Perkin-Elmer Model 3030 Atomic Absorption Spectrophotometer.

e) Lime requirement (LR)

Lime requirement of the surface soil was determined by Schoemaker's method using extractant buffer with pH 7.5 (Schoemaker et al., 1961).

f) Water soluble iron

10 g of the air dry soil sample was wetted with 50 ml ~~of~~ distilled water and shaken well in an end over end shaker for five minutes. Filtered and determined the water soluble iron in an aliquot of the extract using thiocyanate method (Jackson, 1973).

g) Exchangeable iron

To the soil left after the extraction of the water soluble iron, was added 150 ml of neutral N ammonium acetate solution. The suspension was shaken vigorously for 20 seconds and filtered quickly through a Whatman No.5 filter paper fitted to a Buchner funnel under suction. The extraction was repeated twice with 50 ml portions of ammonium acetate. The filtrate was evaporated to dryness over a sand bath until all the ammonium acetate was eliminated. The last traces of organic matter were removed by treatment with a few drops of aqua regia and evaporation. Aqua regia treatment was repeated till all organic matter were oxidised as evidenced by the greyish white colour of the residue.

The residue was taken up with a few drops of N HCl, made upto a convenient volume and the exchangeable iron was determined by the thiocyanate method. (Jackson (1973))

h) Active iron

Active iron was estimated by the method suggested by Asami and Kumada (1959). One gram soil was weighed into a 250 ml Erlenmeyer flask and treated with 3 g sodium dithionite and 100 ml of 0.02 M-EDTA. The reaction mixture was placed in a water bath maintained at 75°C for 15 minutes with occasional shaking. The supernatent liquid was filtered into a 250 ml volumetric flask and the residue washed down with 10 per cent sodium chloride solution thrice and made upto volume. Iron was determined in an aliquot by thiocyanate method.

i) Free oxides of iron (Dithionite extractable form of iron)

To 5 g of soil and 5 g of sodium dithionite in a shaking bottle 250 ml of distilled water was added and shaken well for 16 hours in a mechanical shaker. Adjusted the pH 3.5 to 4.0 with 1 N HCl and made upto 250 ml. To 50 ml of aliquot 15 ml of H_2O_2 was added and boiled. Addition of H_2O_2 and boiling was repeated twice to ensure removal of sulphur. Filtered and made upto 100 ml. Iron was determined in suitable aliquot by thiocyante method.

j) Total amorphous iron (Ammonium oxalate extractable)

Five gram of soil with 100 ml 0.2 M ammonium oxalate (pH 3.0) was kept over night in dark after shaking for four hours. Filtered and made upto 100 ml. Iron was estimated in suitable aliquot by the thiocyanate method (Jackson, 1973).

k) Crystalline iron

It was determined by the difference between dithionite extractable and oxalate extractable iron.

l) Amorphous organic iron (Pyrophosphate extractable)

Five gram of soil was wetted with 100 ml 0.1 M sodium pyrophosphate. The mixture was shaken well for four hours, filtered and made upto 100 ml. Iron was estimated in a suitable aliquot by thiocyanate method (Jackson, 1973).

m) Amorphous inorganic iron

It was estimated by taking the difference between total amorphous and amorphous organic forms.

3. Incubation studies

The influence of submergence on the pH and on the release of water soluble, exchangeable, active, free oxide, amorphous, crystalline, amorphous organic and amorphous inorganic forms of iron at intervals upto 90 days was studied in the surface soils of typical lateritic alluvium, kari, kayal, karappadom, kole and pokkali soils under incubation. The effect of liming and organic matter addition to these soils under submergence on the release of water soluble, exchangeable and active forms of iron were also investigated.

The major physico-chemical properties of the samples used for the incubation studies are given in Tables 2 and 3. Each soil type under study was uniformly mixed by hand and a quantity of 2.5 kg of the representative soil samples were placed in small plastic buckets of three litre capacity and flooded with double distilled water to maintain a standing water level of 5 cm over the surface of the soil throughout the period of study. The experiment was programmed as an incubation study and laid out in factorial CRD with five treatments replicated twice for each soil. The treatments used were:

T_1 - Control (The control was also used for the study of the effect of submergence alone on the release of different forms of iron)

T_2 - Lime at full lime requirement level (LR) (vide, Table 3)

T_3 - Lime at half lime requirement level ($\frac{1}{2}$LR)
T_4 - Organic matter at 5 t/ha
T_5 - Organic matter at 2.5 t/ha

The treatments were given to soils just before submergence. The samples were drawn at an interval of 0, 5, 10, 20, 30, 60 and 90th days of submergence and the content of different forms of iron was determined. The pH of soil solution was also recorded during these intervals. The soil samples from pots were taken by the funnel method as described by Abichandani and Patnaik (1957). The wet soil weights were adjusted based on the percentage of moisture in each soil.

Statistical analysis

The data obtained were statistically analysed. The following analysis were made for the interpretation of results.

a) Analysis variance of each form of iron
b) Correlation analysis of each form of iron and soil properties

RESULT AND DISCUSSION

RESULT AND DISCUSSION

The results of observations and analysis recorded during the course of study of distribution of different forms of iron in soils, its relationship with various physico-chemical properties of soil and the effect of submergence alone and in presence of organic matter and lime on these forms are discussed in this chapter.

I.a Description of the soil profile

The description of the soil profiles collected from various locations are furnished in Appendix I.

b) Physico-chemical properties of soil

(i) Profile

The results of the mechanical analysis of soil from different horizons of the profiles along with the major physico-chemical characteristics (Table 1) are discussed below.

1. Lateritic alluvium

The coarse sand and fine sand content varied from 26.9 to 31.4 per cent and 21.7 and 29.2 per cent respectively within a depth of 122 cm (Table 1.a). Their contents decreased upto the II layer (18-55 cm) of the profile and then increased with further depth, while the contents of silt and clay increased upto the II layer and then decreased with depth and ranged between 16.3 to 18.3 per cent and 22.8 to 32.4 per cent respectively. The dominance of silt and clay in the surface soil can be ascribed to the continuous ploughing during cultivating seasons annually resulting in the cumulative deposition of these finer fractions. In view of the hydromorphic nature of the profile and due to its location in the low land valley surrounded by the sloppy terrain of the adjoining areas, the transportation of finer fractions of the soil from adjacent slopes might also have contributed towards the higher contents of silt and clay on the surface. The lower contents of clay and silt in the subsurface layers are due to their restricted movements under the influence of plough pans resulting from continuous paddy cultivation.

The pH remained almost unchanged except for the slight increases in the middle layers of the profile. The pH values varied from 5.0 to 5.4.

The electrical conductivity increased significantly upto II layer and thereafter showed a decreasing trend with depth, the values ranging from 0.10 to 0.22 dSm^{-1}. The Vellayani lake is a fresh water lake where salinity is never felt as a constraint in cultivation. The conductivity values reported ranged between 0.10 and 0.22 dSm^{-1} which is well within the safe limits of salinity to rice crop.

The organic carbon content increased from 1.20 per cent in the first layer to 2.30 per cent in the III layer, but decreased to 1.20 per cent in the bottom layer of the profile. The relatively higher contents of organic carbon in the subsoil horizons is due to the submerged and marshy nature of kayal soil and the resultant accumulation of organic matter.

The cation exchange capacity increased from 10.6 to 11.7 C mol(+)kg^{-1} upto II layer in the profile, then decreased to 9.3 C mol(+)kg^{-1} with further depth. The increase in the clay content in the second horizon followed by progressive decreases in the lower layers is reflected in the corresponding changes in CEC implicating the low buffer capacity of the soil.

The total iron and aluminium contents showed a progressive decrease with depth of the profile from 4.26 to 1.06 per cent and 4.22 to 1.99 per cent respectively. This decreases can be ascribed to lower contents of clay minerals in these layers. Venugopal (1980), Venugopal and Koshy (1982) have also reported similar findings.

Table 1.a Physico-chemical properties of Lateritic alluvium (Vellayani soil) profile

Horizon	Depth (cm)	Mechanical Analysis				pH	EC (dSm^{-1})	Organic carbon (%)	CEC (C mol (+)kg^{-1})	Total Fe (%)	Total Al (%)
		Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)						
I	0-18	29.8	24.2	16.4	28.1	5.0	0.10	1.20	10.6	4.26	4.22
II	18-55	26.9	21.7	18.3	32.4	5.4	0.22	1.80	11.7	3.91	3.73
III	55-91	31.2	27.3	17.8	23.2	5.3	0.20	2.30	10.3	1.20	2.83
IV	91-122	31.4	29.2	16.3	22.8	5.1	0.19	1.20	9.3	1.06	1.99

2. Kari soil

The coarse sand content increased with depth from 8.2 to 14.6 per cent while the silt content decreased from 21.8 to 18.1 per cent. A slight decrease in fine sand from 10.9 to 9.5 per cent was observed upto the third layer of the profile, followed by a substantial increase to 16.8 per cent with depth. The surface clay content of 58.6 per cent almost remained steady till the IV layer of the profile and then reduced to 49 per cent at the bottom layer (Table 1.b). The increase in the contents of coarse fractions of the soil with depth is attributed to estuarine influences over the years.

The pH of the soil showed a slight decrease with depth and ranged between 3.6 and 3.2. The lower pH of the kari soil is due to the acid sulphate nature of the soil and the presence of undecomposed organic matter in the form of wood fossils. Subramony and Kurup (1961), Kabeerathumma (1975) have also reported similar observations.

The almost steady values of the electrical conductivity of the soil upto a depth of the III layer slightly reduced beyond the III layer. High electrical conductivity of the soil is due to the seawater inundation leading to salt contamination.

Table 1.b Physico-chemical properties of Kari soil profile

		Mechanical Analysis									
Horizon	Depth (cm)	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	pH	EC (dSm^{-1})	Organic carbon (%)	CEC (C mol (+) kg^{-1})	Total Fe (%)	Total Al (%)
I	0-9	8.2	10.9	21.8	58.6	3.6	4.40	6.00	24.0	5.34	5.56
II	9-37	9.3	10.1	20.3	59.4	3.4	4.50	7.20	25.1	5.19	4.74
III	37-59	10.4	9.5	20.2	59.2	3.4	4.60	8.60	24.2	4.97	4.13
IV	59-85	12.4	11.6	18.4	57.3	3.3	4.30	9.20	22.2	3.78	3.63
V	85-116	14.6	16.8	18.1	49.0	3.2	4.00	10.50	19.6	1.49	1.47

The organic carbon content showed progressive increases with depth from 6.0 per cent in the surface layer to 10.5 per cent in the V layer of the profile. The large amounts of food fossils and undecomposed organic matter in the lower layers of the profile may be the reason for high content of organic carbon in lower layers.

The cation exchange capacity of the soil which was 24.0 C mol(+)kg^{-1} on the surface progressively decreased with depth to 19.6 C mol(+)kg^{-1} in the V layer. The decreased CEC values of the soil with depth is supported by the lower contents of clay in these layers. However, the presence of organic matter has helped in the maintenance of fairly high values of CEC in the soil.

The content of total iron and aluminium varied from 5.34 to 1.49 per cent and 5.56 to 1.47 per cent respectively from top layer to the bottom thereby showing a decrease with depth.

3. Kayal soil

The coarse sand and silt fractions of the profile progressively increased with depth from 15.9 to 18.1 per cent and 22.4 to 26.2 per cent respectively, while the clay content decreased from 39.8 to 32.3 per cent.

Increase in fine sand was also noticed with depth (Table 1.c). The textural variations noticed in the kayal soil with depth are not much different from those of the kari soil. This is likely in view of the proximity of these two soil types to Vembanad lake.

The pH of the soil decreased from 3.8 on the surface to 3.3 in the lowest layer except for a slight increase to 4.1 in the II layer.

The electrical conductivity of the soil profile increased from 1.89 on the surface to 3.5 dSm^{-1} in the lowest layer. The increase in electrical conductivity in the subsoils of the kayal profile is the result of salt accumulation due to sea water inundation during the non-cropping seasons and washing effect by rain water which removes only the surface salt, leaving the lower layers with salt residues.

The organic carbon content of the soil increased from 3.8 to 4.3 per cent upto III layer and then got decreased in the next lower layer.

Much variation in the cation exchange capacity of the soil could not be noticed in the different layers of the profile. The value gradually decreased upto the III layer after which an increase was noted in the lowest layer.

Table 1.c Physico-chemical properties of Kayal soil profile

Horizon	Depth (cm)	Mechanical Analysis				pH	EC (dSm^{-1})	Organic carbon (%)	CEC ($C\ mol(+)kg^{-1}$)	Total Fe (%)	Total Al (%)
		Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)						
I	0-13	15.9	21.3	22.4	39.8	3.8	1.89	3.80	13.0	3.93	6.71
II	13-28	16.8	20.4	24.3	38.3	4.1	1.95	3.90	12.8	3.51	5.39
III	28-48	17.3	22.6	25.6	34.2	3.5	3.40	4.30	12.1	2.31	3.58
IV	48-62	18.1	23.3	26.2	32.3	3.3	3.50	3.60	15.5	3.22	4.34

The total iron and aluminium contents decreased with depth upto the III layer and then showed increasing trends.

4. Karappadom soil

The variation in the content of coarse sand had a decreasing pattern from 11.8 to 10.4 per cent with depth. The fine sand and silt fractions however remained almost steady down the profile except for a small increase in the II layer. The clay content also remained the same throughout the profile except for a small decrease in the II layer (Table 1.d). Much variation in the contents of soil separate was not noticeable in the different depths of the profile.

Progressive but slight decreases in the pH of the soil with depth were noticed. The value ranged from 4.1 to 3.3. Slight decrease in pH noted in the lower layers is accompanied by increased contents of organic matter. The organic acids formed by the decomposition of organic matter might have contributed towards the lower pH. This is in agreement with the observations of Ramasubramonian (1989).

The decrease in electrical conductivity with depth was noticed only upto the III layer, beyond which the value increased. Lower electrical conductivity

Table 1.d Physico-chemical properties of Karappadom soil profile

Horizon	Depth (cm)	Mechanical Analysis				pH	EC (dSm^{-1})	Organic carbon (%)	CEC (C mol (+) kg^{-1})	Total Fe (%)	Total Al (%)
		Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)						
I	0-10	11.8	20.8	23.2	43.4	4.1	1.54	2.17	18.7	3.03	4.73
II	10-30	11.2	22.1	26.4	39.8	4.0	1.25	2.90	14.4	3.32	4.72
III	30-74	10.8	21.6	24.3	44.1	3.5	1.05	3.20	14.3	3.98	4.73
IV	74-103	10.4	20.3	24.2	44.8	3.3	2.52	3.30	14.1	3.19	4.71

values noted on the surface layers is attributed to the washing of salt by rain and flooded rivers. Karappadom soils are situated on the banks of the major rivers which are likely to get flooded during monsoon seasons annually. Subsurface accumulation of salt has caused an increase in conductivity.

Organic carbon content has increased with depth from 2.17 to 3.30 per cent. The increase is ascribed to higher organic matter in the lower layers of the karappadom soils.

There was decrease in cation exchange capacity with depth from 18.7 to 14.1 C mol(+)kg^{-1}.

The total iron showed slight increasing trends from 3.03 to 3.98 per cent with depth upto the III layer. However, in the lowest layer its content decreased to 3.19 per cent. The total aluminium content remained almost steady throughout the profile (4.71 to 4.73 per cent).

5. Kole soil

The coarse sand content which was 28.6 per cent on the surface did not show much variation in the IV layer. However, the intervening layers registered lower contents. Fine sand fraction on the other hand registered higher contents in the middle layer, though in the surface layer and in the lowest layer its content remained without change. Decrease in the clay content with depth from 32.3 per cent to 29.3 per cent could be noticed (Table 1.e). Except for the slight decreases in the silt and clay contents in the sub soil layers there was in general no appreciable change in the contents of the other fractions in the profile.

The pH remained more or less unchanged throughout the profile except in the II layer, where a slight increase was observed. The electrical conductivity of the soil showed steady values with depth. However, in the lowest layer a decrease was noted. The organic carbon content decreased from 5.9 to 4.40 per cent down the profile. Progressive decrease in the cation exchange capacity of the soil was noticed with depth in the profile. The lower CEC values recorded in the sub soil layers of the profile might be due to the variations in the organic matter and clay contents.

Total iron and aluminium contents recorded a decreasing trend with depth though the variation is slight. The decrease in the total iron and aluminium contents down the profile is explained as due to lower contents of clay minerals resulting from clay and silt.

Table 1.e Physico-chemical properties of Kole soil profile

Horizon	Depth (cm)	Mechanical Analysis Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	pH	EC (dSm^{-1})	Organic carbon (%)	CEC ($C\ mol(+)kg^{-1}$)	Total Fe (%)	Total Al (%)
I	0-10	28.6	19.2	19.4	32.3	4.8	1.42	5.90	19.6	6.11	6.03
II	10-27	21.1	26.2	20.7	31.4	5.1	1.40	4.40	16.4	5.93	5.85
III	27-42	25.4	23.2	21.4	29.7	4.8	1.40	4.20	12.4	5.31	5.78
IV	42-56	29.0	18.2	13.5	29.3	4.8	1.32	4.40	11.6	5.25	5.61

6. Pokkali soil

The coarse and fine sand contents of the soil remained almost steady throughout the profile. Considerable decrease in the clay content was observed with depth. The clay content which was 53.4 per cent on the surface reduced to 41.3 per cent in the lowest layer. Silt content increased from 22.3 to 32.1 per cent upto III layer and then slightly decreased to 30.0 per cent in the lowest layer (Table 1.f).

The pH and electrical conductivity values remained almost steady in the different horizons.

The EC values have registered very high values throughout the profile. Such high values can be expected since salt water ingression into paddy fields occur due to the tidal influences of adjoining sea. The high salt content makes the soil unsuitable for paddy crop. In fact paddy cultivation is attempted in these locations using salt resistant varieties and by adopting special methods.

The organic carbon increased from 2.8 per cent in the surface layer to 3.5 per cent in the III layer. In the lowest layer, however a rapid decrease to 3.2 per cent was observed. Slight increase in organic carbon is seen in the lower layers may be due to the marshy nature of the soil.

Table 1.f Physico-chemical properties of Pokkali soil profile

Horizon	Depth (cm)	Mechanical Analysis: Coarse sand (%)	Mechanical Analysis: Fine sand (%)	Mechanical Analysis: Silt (%)	Mechanical Analysis: Clay (%)	pH	EC (dSm^{-1})	Organic carbon (%)	CEC (C mol (+) kg^{-1})	Total Fe (%)	Total Al (%)
I	0-10	10.1	12.3	23.3	53.4	4.6	5.40	2.80	19.5	3.57	4.91
II	10-31	12.2	12.4	29.2	45.1	4.9	5.40	2.85	16.5	3.53	3.38
III	31-62	8.3	13.6	32.1	44.2	4.3	5.90	3.50	14.6	3.19	3.32
IV	62-95	11.9	14.7	30.0	41.3	4.3	5.40	3.20	13.3	3.06	3.27

A progressive decrease in cation exchange capacity of the soil from 19.5 to 12.3 C mol(+)kg^{-1} with depth could be noticed. Low CEC values noticed in the lower layers are accompanied by the similar decreases in the clay content. Total iron and aluminium contents also showed a decreasing trend with depth. The decreased contents of iron and aluminium in the lower layers result from lower clay contents with depth. Singh and Patiram (1975) have reported nonsignificant positive correlation between clay and total iron in soils.

(ii) Surface soil

a) Physico-chemical properties of the surface soil

The major physico-chemical characteristics of the lateritic alluvium, kari, kayal, karappadom, kole and pokkali soils are given in Table 2 and 3.

1. Coarse sand

The coarse sand content varied from 5.3 to 32.6 per cent in the six soil types studied. Its content was highest in the lateritic alluvium and was least in kari soil. The content increased in the order kari < karappadom < kayal < kole < pokkali < lateritic alluvium. The coarse fractions dominate in the lateritic alluvium as a result of erosion from the surrounding uplands of sloppy terrain. The site of sample collection of lateritic alluvium was the Vellayani lake where hydromorphic situation exists.

2. Fine sand

The fine sand content of the lateritic alluvium, kari, kayal, karappadom, kole and pokkali soils were 22.2, 10.9, 19.6, 9.4, 14.6 and 17.3 per cent respectively. The highest content was observed in the lateritic alluvium while the karappadom soil registered the lowest content.

3. Silt

The karappadom soil indicated the highest content of 22.6 per cent silt followed by pokkali, kole, kari and kayal. Lateritic alluvium recorded the lowest silt content of 15.1 per cent. The highest content of silt in karappadom soil is the result of sedimentation of transported soil material by flooded rivers.

4. Clay

The clay content varied from 29.6 per cent in the lateritic alluvium to 62.7 per cent in the kari soil. The kayal, karappadom, kole and pokkali soils registered a clay content of 43.6, 38.1, 42.5 and 33.4 per cent respectively. Highest content of clay is associated with humus.

5. Bulk density

Bulk density was highest (1.27 g/cc) in the lateritic alluvium and the lowest (1.04 g/cc) in the kari soil. In other soils the values ranged between 1.08 and 1.18 g/cc.

6. Absolute specific gravity

The values of absolute specific gravity ranged from 2.13 in kayal soil to a maximum of 2.58 in the lateritic alluvium.

7. Maximum waterholding capacity

The water holding capacity was highest in pokkali soil (59.6%) while the least value was seen in the lateritic alluvium (45.5%).

8. Per cent pore space

Kari soil registered the highest pore space and lateritic alluvium the least. The values ranged between 50-54 per cent in the six different soils studied.

9. Volume expansion

The maximum volume expansion of the soil was seen in the kari soil, while the lateritic alluvium registered the minimum volume expansion.

Table 2 Physical properties of surface soil

Soil	Mechanical Analysis				Texture	Bulk density	Absolute specific gravity	Maximum water holding capacity	Pore space	Volume expansion
	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)		(gcm^{-3})		(%)	(%)	(%)
1. Lateritic alluvium	32.6	22.2	15.1	29.6	Sandy-clay loam	1.27	2.58	45.5	50.7	2.68
2. Kari	5.3	10.9	20.8	62.7	Clay	1.04	2.21	55.1	53.2	6.96
3. Kayal	12.0	19.6	20.1	43.6	Clay loam	1.08	2.13	54.9	50.1	5.32
4. Karappadom	11.8	9.4	22.6	38.1	Clay loam	1.14	2.28	49.4	52.0	4.68
5. Kole	19.6	14.6	21.3	42.5	Clay loam	1.18	2.45	49.9	52.8	4.75
6. Pokkali	23.1	17.3	22.3	33.4	Clay loam	1.13	2.34	59.6	52.7	5.14

10. Soil reaction (pH)

Kari soil was the most acidic with pH 3.6. Kayal, karappadom, kole and pokkali soils had almost similar pH values. Least acidity was observed in the lateritic alluvium (pH 5.1). The highest acidity noticed in kari soil is associated with low base status, high content of organic matter and sulphur containing minerals which have undergone chemical and bacterial oxidation resulting in the formation of acid sulphate soils. Acid sulphate soils or 'cat clays' are extremely acid clays with a high content of sulphate. They have a pH of less than 3.5 in some layer in the upper 50 cm of the profile. The acidity is due to the presence of sulphuric acid and iron and aluminium sulphates. These soils are derived from marine sediments high in sulphide but poor in bases. When submerged and anaerobic they are mud clays, nearly neutral. But when the water recedes the pyrites are oxidised to sulphuric acid and soils become extremely acid. The existence of sulphur bacterial cycle in kari soils has been proved earlier (Subramoney, 1960). The distribution of different forms of sulphur in the surface and subsurface soils as well as in the wood fossils were studied earlier.

11. Electrical conductivity

The pokkali soils are acid saline in nature and as can be expected of such soils, the highest value of electrical conductivity (5.4 dSm^{-1}) was recorded in this soil. The electrical conductivity values showed variations in different soils with the lateritic alluvium registering the least value of 0.40 dSm^{-1}. High electrical conductivity recorded in pokkali as well as in kari, kayal and karappadom soils indicates salt contamination due to the proximity to sea. Aiyer et al. (1975), Kabeerathumma (1975), Ramasubramonian (1989) have also obtained high values of electrical conductivity in these soils.

12. Organic carbon

The organic carbon content which was lowest in lateritic alluvium increased in the order lateritic alluvium < kayal < pokkali < karappadom < kole < kari soils. Kari soil registered a maximum of 7.4 per cent organic carbon followed by kole soil which had 6.8 per cent. The high organic carbon content in the kari soil is ascribed to the presence of undecomposed organic matter in the surface as well as in the lower layers.

13. Cation exchange capacity

The CEC values of soils ranged between 8.3 and 21.7 C mol(+)kg^{-1}. The highest value was noticed in the kari soil followed by kole (19.1), pokkali (16.7), karappadom (16.6), kayal (13.6) soils and lateritic alluvium with the lowest CEC of 8.3 C mol(+)kg^{-1}. High CEC values in kari soil is ascribed to considerable quantity of humus in surface as well as in the lower layers. Though the acid soils studied mainly contain kaolinite type of clay mineral, high CEC is probably due to high organic matter content.

14. Total nitrogen

Kari soil recorded the maximum content of 0.21 per cent total nitrogen, while the lateritic alluvium indicated the lowest content of 0.02 per cent.

15. Total phosphorus

Highest content of 840 ppm was observed in the kari soil, while the lateritic alluvium registered the minimum of 240 ppm.

16. Total potassium

All the six soils had relatively high contents of total potassium. Among the soils, kari soil had the highest content of 2535 ppm, while the lateritic alluvium had the least content of 827 ppm.

Table 3 Chemical properties of surface soil

Soil	Organic carbon (%)	pH	EC (dSm^{-1})	CEC ($C\ mol(+)kg^{-1}$)	Total N (%)	Total P (ppm)	Total K (ppm)	Total Ca (ppm)	Total Mg (ppm)	Lime requirement (t/acre)
1. Lateritic alluvium	1.3	5.1	0.40	8.3	0.02	240	827	292	403	7.7
2. Kari	7.4	3.6	4.40	21.7	0.21	840	2535	194	718	16.1
3. Kayal	2.4	4.3	2.42	13.6	0.09	720	2250	826	688	11.1
4. Karappadom	3.8	4.2	1.89	16.6	0.07	750	1935	761	709	8.6
5. Kole	6.8	4.2	1.54	19.1	0.16	360	1088	479	600	8.2
6. Pokkali	2.8	4.4	5.40	16.7	0.08	480	1790	818	746	8.2

17. Total calcium

The kayal and pokkali soils had the maximum content of calcium while kari soil had the lowest content.

18. Total magnesium

The six soils studied had fairly higher contents of magnesium ranging from 403 ppm in the lateritic alluvium to 746 ppm in pokkali soil.

b) Forms of iron

1. Water soluble iron

Kari soil recorded the highest content of 32.0 ppm water soluble iron. The other five soils had almost similar contents ranging from 24.0 to 27.0 ppm (Table 4). High acidity of the kari soil might have contributed towards the high content of this form of iron. The results of correlation study of this form of iron and soil chemical properties, furnished in Table 5, indicate its negative correlation with pH ($r = -0.8746^*$). Ponnamperuma (1972, 1978, 1980) has reported that the pH of the soil affects the concentration of Fe^{2+} ions through the involvement of H^+ ions in chemical equilibria. The pH-Fe relationship derived by Ponnamperuma (1984) would indicate that a pH increase by one unit should decrease the concentration of Fe^{2+} ions 100 times.

Similar observations have been reported by Nhung and Ponnamperuma (1966), Ponnamperuma et al. (1973), Misra and Pande (1975), Sukla et al. (1975), IRRI (1977), Rajagopal et al. (1977), Patrick Jr. and Henderson (1981), Patel and Dangarwala (1983), Sakal et. al. (1988) and Ramasubramanian (1989).

Correlation studies (Table 5) have also shown positive relationships between clay ($r = 0.9317^{**}$) organic matter ($r = 0.9052^{*}$) and CEC ($r = 0.8763^{*}$) with the water soluble iron content. The high clay content enables higher adsorption of Fe^{2+} which in turn might result in the greater solubilisation under conditions of low pH. Similar observations between water soluble iron with clay and CEC have also been reported by Mandal (1961), Chakravorty and Kar (1970) and Dubey et al. (1983). Positive significant correlation between water soluble iron and organic matter is possible due to the production of more organic acids which can solubilise more iron. This observation is in agreement with the findings of Singh and Patiram (1975), Rajagopal et al. (1977) and Patel and Dangarwala (1983).

2. Exchangeable iron

Exchangeable iron in the lateritic alluvium, kari, kayal, karappadom, kole and pokkali soils were 78.0, 129.0, 107.0, 74.0, 82.0 and 79.0 ppm respectively. The kari soil recorded the maximum content while the contents in the other five soils did not vary appreciably.

The content of exchangeable iron was highest in kari soil which can be attributed to high CEC and high clay content of the soil. Bao et al. (1964) in his experiments with acid sandy paddy soils found that increase in CEC resulted in increased contents of exchangeable iron and total ferrous iron.

A significant positive correlation between exchangeable iron and clay content ($r = 0.8254^{*}$) and also with CEC ($r = 0.8613^{*}$) (Table 5) is observed. This confirms the reason for high exchangeable iron content in clay rich kari soil. Similar correlation is also observed between exchangeable iron and organic carbon (0.8224^{*}). A negative significant correlation was observed between exchangeable iron and pH (-0.8769^{**}). Pisharody (1965), Gotoh and Patrick Jr. (1974), Kamala Devi et al. (1974), Kabeerathumma (1975), Ghosh and Banerjee (1979), Mandal and Mitra (1982) have also reported similar observations.

A. Active iron

Among the six soils the active iron content of the kari soil was highest (1.72 per cent). This was followed by kole, kayal, lateritic alluvium and karappadom soils. Pokkali soil registered the lowest content of 0.82 per cent active iron.

The highest content of active iron in kari and kole soils are due to high organic carbon content. Correlation matrix given in Table 5 indicated a significant positive correlation between organic carbon and active iron ($r = 0.8147^{*}$) contents of the soil. Similar positive significant correlation have also been reported by Pisharody (1965), Misra and Pande (1975), Mitra and Mandal (1983) and Ramasubramonian (1989). Similar a positive non-significant correlation is observed between active iron content and electrical conductivity ($r = 0.7959$).

4. Free iron oxides (Dithionite extractable)

Kari soil had the highest content of 0.69 per cent free oxides followed by kole with 0.66 per cent, lateritic alluvium with 0.58 per cent, kayal with 0.56 per cent, karappadom with 0.49 per cent and pokkali with 0.47 per cent.

The results indicated that no correlation existed between the free iron oxide content and any of the chemical characteristics of the soil except the clay content where a non significant positive correlation (0.6951) could be noted (Table 5).

5. Total amorphous iron (Oxalate extractable)

The highest content of 0.45 per cent total amorphous iron was observed in the kari soil while the pokkali soil registered the minimum of 0.27 per cent. The content increased in the order pokkali < lateritic alluvium < karappadom < kayal < kole < kari soils. Highest content of total amorphous iron in the kari soil may be attributed to the high level of organic matter in that soil and its complexing action on iron. A positive correlation (Table 5) could be observed between total amorphous and organic carbon ($r = 0.8135^{*}$).

6. Amorphous organic iron (Pyrophosphate extractable)

The content of amorphous organic iron ranged from 0.12 per cent in the lateritic alluvium to 0.28 per cent in kari soil. The content decreased in the order kari > kole > karappadom > kayal > pokkali > lateritic alluvium. A significant positive correlation (Table 5) between amorphous organic iron and organic carbon could be observed ($r = 0.8681^{*}$). This may be the reason for the high content of this form in kari soil and the least in lateritic alluvium.

7. Amorphous inorganic iron

The highest content of 0.17 per cent amorphous inorganic iron was observed in kari and kole soil. The

Table 4 Mean content of different forms of iron in surface soil

Soil	Water soluble (ppm)	Exchangeable (ppm)	Active (%)	Free oxide (%)	Total amorphous (%)	Amorphous organic (%)	Amorphous inorganic (%)	Crystalline (%)	Total (%)
1. Lateritic alluvium	24	78	1.27	0.58	0.28	0.12	0.16	0.30	3.94
2. Kari	32	129	1.72	0.69	0.45	0.28	0.17	0.24	4.21
3. Kayal	27	107	1.54	0.56	0.35	0.19	0.16	0.21	2.58
4. Karappadom	25	74	0.91	0.49	0.34	0.20	0.14	0.15	2.45
5. Kole	24	82	1.68	0.66	0.38	0.21	0.17	0.28	6.38
6. Pokkali	27	79	0.82	0.47	0.27	0.13	0.11	0.20	2.66

Table 5 Correlation matrix - Physico-chemical properties and forms of iron

(n=6)

Forms of iron	Clay	pH	Organic carbon	CEC	EC
1. Water soluble	0.9317**	-0.8746*	0.9052*	0.8763*	0.7218
2. Exchangeable	0.8254*	-0.8769*	0.8224*	0.8613*	0.4767
3. Active	0.1450	-0.4287	0.8147*	0.5312	0.7959
4. Free oxide	0.6951	-0.4699	0.5637	0.4411	0.5878
5. Total amorphous	0.6587	-0.3763	0.8135*	0.1357	0.1915
6. Amorphous organic	0.5700	-0.5817	0.8681*	0.4709	0.2781
7. Amorphous inorganic	0.6173	-0.4130	0.5132	0.1387	0.3671
8. Crystalline	0.6313	-0.6099	0.5935	0.4651	0.5433

* Significant at 5% level

** Significant at 1% level

n=Sample size

lateritic alluvium and kayal soil had equal contents of 0.16 per cent, while the pokkali soil recorded the least content of 0.11 per cent. The karappadom soil had 0.14 per cent of this form of iron. The highest content in kari soil is probably due to the complexing action of organic matter on the inorganic constituent minerals such as iron pyrites in this soil.

8. Crystalline iron

The lateritic alluvium indicated the highest content of 0.30 per cent crystalline iron followed by kole, kari, kayal, pokkali, karappadom with the contents of 0.28, 0.24, 0.21, 0.20 and 0.15 per cent respectively.

9. Total iron

The highest content of 6.38 per cent total iron was observed in the kole soil followed by 4.21 per cent in the karisoil, 3.94 per cent in the lateritic alluvium, 2.66 per cent in pokkali soil, 2.58 per cent in kayal soil and the least content of 2.45 per cent in karappadom soil.

II Incubation studies

Soil submergence brings about anaerobic conditions resulting in, among others, reduction of iron and its solubilisation, often leading to concentrations toxic enough for the rice crop. The result of the study on the dynamics of the forms of iron in soils under the influence of submergence alone and in the presence of added ameliorants such as lime and organic matter and to assess the extent of such iron solubilisation are discussed below.

a) Influence of submergence on soil reaction and dynamics of forms of iron

The data on the influence of period of submergence on soil reaction and dynamics of forms of iron are discussed below.

1. Soil reaction (pH)

All the soils under study had initially lower pH values indicating their acidic nature (Table 6 and Fig.1). On submergence the pH of all the soils gradually increased with time to reach maximum value after a few days. However, with kari soil, which recorded an initial pH of 3.5, showed a continuous but slow increase till the pH was 5.0 on the 90th day of submergence, lateritic alluvium having a pH of 5.5 showed increases upto a maximum value of 6.4 on the 20th day of submergence after which the pH did not show variation. In karappadom soil, the initial pH of 4.9 increased due to submergence and reached the peak values of 5.6 on 30th day and thereafter remained steady upto

60th day and then declined to 5.2 on the 90th day. The kayal, kole and pokkali soils which had initial pH values of 4.5, 4.5 and 4.4 showed gradual increases upto 60 days to reach the peak values of 5.5, 6.0 and 5.6 respectively after which much variation is not observed upto the 90th day.

The increase in pH of the waterlogged acid soils with period of submergence is attributed to the reduction reaction of iron and manganese, involving consumption of H^+ ions according to the reaction.

$$Fe(OH)_3 + 3H^+ + \bar{e} \longrightarrow Fe^{2+} + 3H_2O \quad \text{and}$$

$$1/2\ MnO_2 + 2H^+ + \bar{e} \longrightarrow 1/2\ Mn^{2+} + H_2O$$

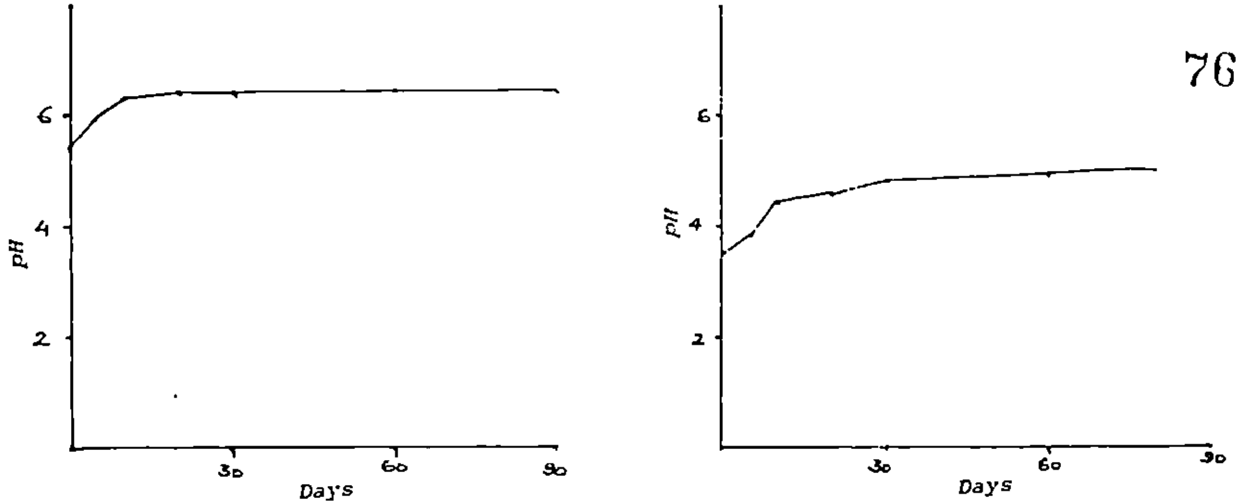
(Ponnamperuma, 1972)

A series of reduction reactions occur in submerged soils as predicted by thermodynamic sequence of chemical reaction and all these reactions involve utilisation of H^+ ions leading to the formation of reduced products. Consequently, the OH^- ions in soil solution increases, resulting in an increased pH with submergence. A fairly stable pH is attained when the sequential reductions are completed.

The increased pH is also regulated by the partial pressure of CO_2 developed from the decomposition of organic matter by anaerobes. Partial pressure of CO_2 which is good measure of CO_2 accumulation in soils, gradually increases

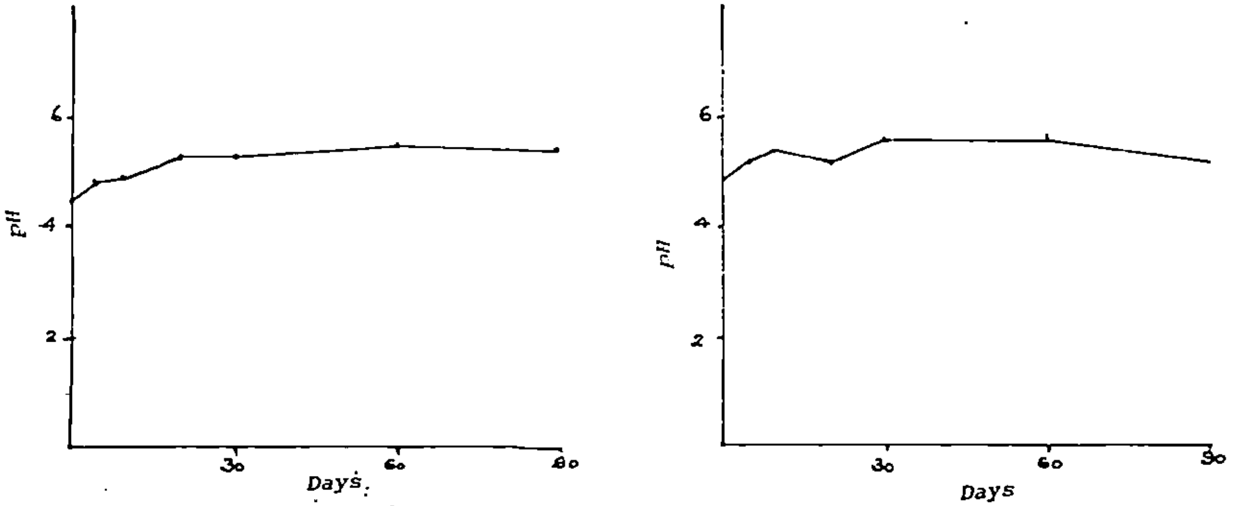
Table 6 Effect of submergence on the pH of the soil

Soil	Days of submergence						
	0	5	10	20	30	60	90
1. Lateritic alluvium	5.5	5.9	6.3	6.4	6.4	6.4	6.4
2. Kari	3.5	3.8	4.4	4.6	4.8	4.9	5.0
3. Kayal	4.5	4.8	4.9	5.3	5.3	5.5	5.5
4. Karappadom	4.9	5.2	5.4	5.2	5.6	5.6	5.2
5. Kole	4.5	4.6	5.1	5.6	5.7	6.0	6.0
6. Pokkali	4.4	4.6	5.0	5.2	5.4	5.6	5.4



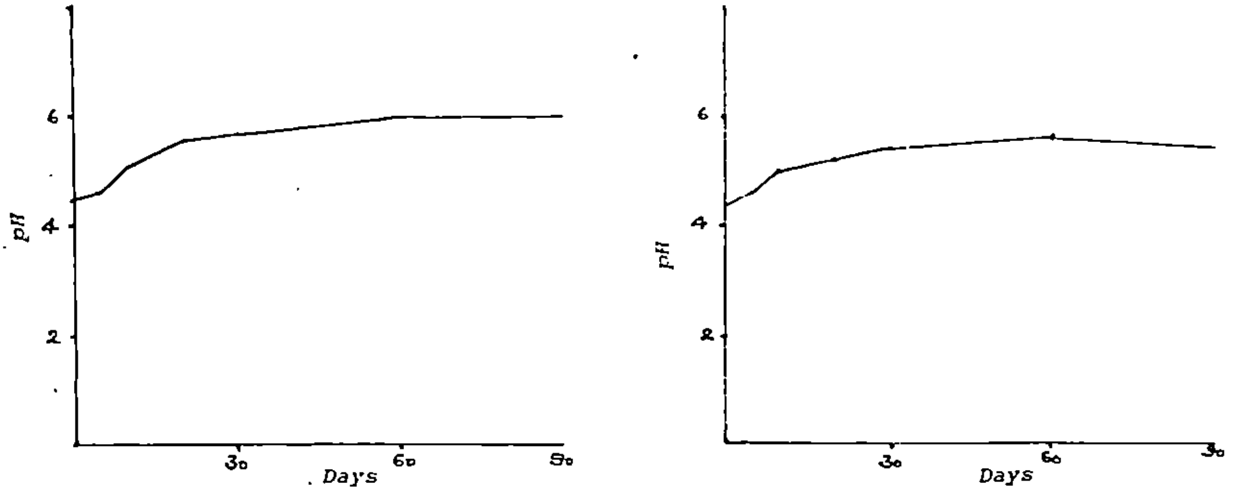
Lateritic alluvium

Kari soil



Kayal soil

Karappadom soil



Kole soil

Pokkali soil

Fig.1 *Effect of submergence on the pH of soil* on flooding and reaches peak value in a few days after submergence and later declines to a fairly stable value (Ponnamperuma, 1972). Acid soils high in organic matter show a rapid increase in PCO_2. Progressive increases in PCO_2 result in increased suppression of soil pH, ultimately resulting in steady values of pH corresponding to the maximum influence exerted by peak values of PCO_2 a few weeks after submergence according to the relationship.

$$pH = 6.1 - 0.58 \log PCO_2$$

(Ponnamperuma, 1972)

The failure to attain a stable pH in kari soil is probably because these soils are potentially acid sulphate soils containing pyrite, which on oxidation and hydrolysis give rise to H_2SO_4. Very high organic matter content and high buffering capacity of this soil type also contribute to the non-attainment of stable pH values on submergence.

With progressive increase in duration of submergence, there was more increase in soil pH and at the end of 90 days of submergence all the soils attained a pH between 5-6. This narrowing of difference between the values after a period of submergence agree with earlier findings of Nhung and Ponnamperuma (1966), Ponnamperuma (1965), Mohanty and Patnaik (1973) and Verma and Neue (1988).

2. Water soluble iron

Table 7 and Fig.2 gives the content of water soluble iron during the different periods of submergence. When the lateritic alluvium was submerged, the mean water soluble iron content of soil, which was initially 22.5 ppm increased upto a maximum of 37.5 ppm on the 20th day and decreased gradually to 27·0 ppm on 90th day.

In kari soil, the content of 30·0 ppm water soluble iron estimated on the day of submergence rose to a maximum of 45·0 ppm on 20th day and decreased slightly to lower values on further incubation upto 90th day.

The kayal soil which had an initial content of 28.0 ppm water soluble iron immediately after submergence, increased upto 20th day of submergence when the peak value of 43.0 ppm was attained. The content thereafter decreased with further periods of submergence.

The karappadom soil having an initial water soluble iron content of 27.0 ppm on the day of submergence increased with period of submergence and reached 33.5 ppm on the 20th day. However, further periods of submergence did not have makred influence in reducing the soluble iron concentration.

The mean content of this form increased upto 20th day in kole and pokkali soils from the initial content of 26.0 and 25.0 ppm to 38.0 and 36.0 ppm respectively. After reaching the peak values, the water soluble iron contents in these soils decreased to 31.5 and 29.5 ppm respectively on the 90th day of submergence.

The analysis of variance indicated release of water soluble iron 20 days after submergence in all the soils. Later soluble iron gradually dropped to lower values with continued submergence upto 90 days.

Iron which normally exists in the ferric form in aerobic soils, is reduced to ferrous form in submerged soils under anaerobic conditions. Ponnamperuma (1967, 1972) have reviewed the chemistry of iron reduction in submerged paddy soils according to which the solubility of iron in submerged soils is controlled by three redox reactions viz., $Fe(OH)_3 - Fe^{2+}$; $Fe_3(OH)_8 - Fe^{2+}$ and $Fe(OH)_3 - Fe_3(OH)_8$ systems; according to the following reactions.

$$Fe(OH)_3 + 3H^+ + \bar{e} = Fe^{2+} + 3H_2O$$

$$3Fe(OH)_3 + H^+ + \bar{e} = Fe_3(OH)_8 + H_2O$$

$$Fe_3(OH)_8 + 8H^+ + 2\bar{e} = 3Fe^{2+} + 8H_2O$$

Of these three systems in equilibria, the $Fe(OH)_3$ - Fe^{2+} system would alone operate throughout the period of submergence, while $Fe(OH)_8$ - Fe^{2+} and $Fe_3(OH)_8$ - $Fe(OH)_3$ would operate at the beginning of the peak of water soluble iron, when $Fe_3(OH)_8$ would get precipitated.

The decrease after the peak concentration can be ascribed to the precipitation of iron as $Fe_3(OH)_8$. This precipitation results from an increase in pH following a decline in PCO_2. The decline in PCO_2 is probably due to the escape of CH_4 produced in the later stages of anaerobic organic matter decomposition, bacterial reduction of CO_2 or leaching losses or removal of CO_2 as insoluble carbonates. The role of iron hydroxide systems in the control of pH has also been explained by Tejinder Singh and Pasricha (1978). Takkar (1969) has attributed the formation of Fe^{2+} in all the water logged soils to the reducing compounds and CO_2 produced in the course of anaerobic decomposition or fermentation of added organic matter. The findings are in agreement with those of Islam and Elahi (1954), Mandal (1961, 1962) and Motomura (1962).

The pH is found to play an active role in controlling the release of water soluble iron from the soils. It was found that the release of iron was maximum in kari soil which has recorded the lowest initial pH of 3.5. A maximum of 45 ppm water soluble iron was found released from this soil on the 20th day of submergence.

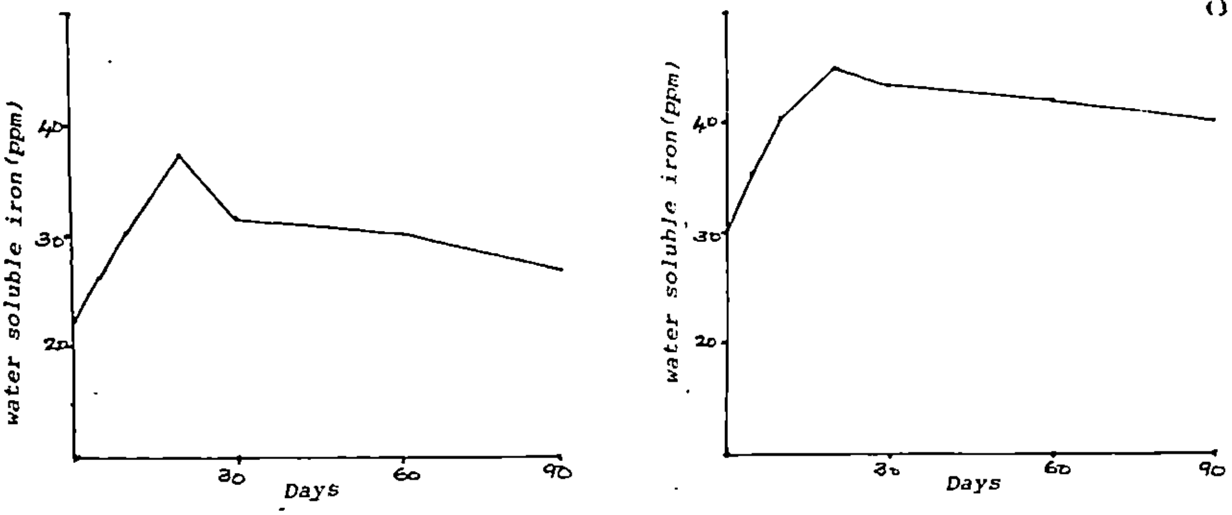
The conductance of soil solution increases during the first few weeks of flooding and then decline sharply in striking similarity to the kinetics of water soluble iron. Infact the increase in conductance is due to the release of Fe^{2+} and Mn^{2+} forms from insoluble Fe(III) and Mn(IV) oxides, hydrates (Sadana and Takkar, 1985). They also reported that the increase in electrical conductivity in the soil brings about an increase in pH. The P^E of soil solution might decrease in view of the relationship Eh = 0.43-0.059 pH which in turn may result in an increased iron concentrations at all stages of submergence. Kari soil where the electrical conductivity is fairly high, along with high PCO_2 other than low pH, therefore, released more water soluble iron as compared to other soils. Due to the same reason, kayal soils where saline contamination due to sea water incursion is likely, closely followed kari soil with regard to maximum release of soluble iron. In kole and pokkali soils though salinity status is higher, much increase in the iron release could not be seen, probably due to the higher pH condition of these soils.

Table 7 Effect of interaction - Soil and submergence on the mean content of water soluble iron (ppm)

Soil	Days of submergence						
	0	5	10	20	30	60	90
1. Lateritic alluvium	22.5	26.5	30.5	37.5	31.5	30.5	27.0
2. Kari	30.0	35.5	40.5	45.0	43.5	42.0	40.0
3. Kayal	28.0	31.5	39.5	43.0	40.5	38.5	37.5
4. Karappadom	27.0	28.5	31.5	33.5	33.0	32.5	32.0
5. Kole	26.0	29.5	33.0	38.0	35.0	33.0	31.5
6. Pokkali	25.0	30.0	32.0	36.0	32.5	30.0	29.5

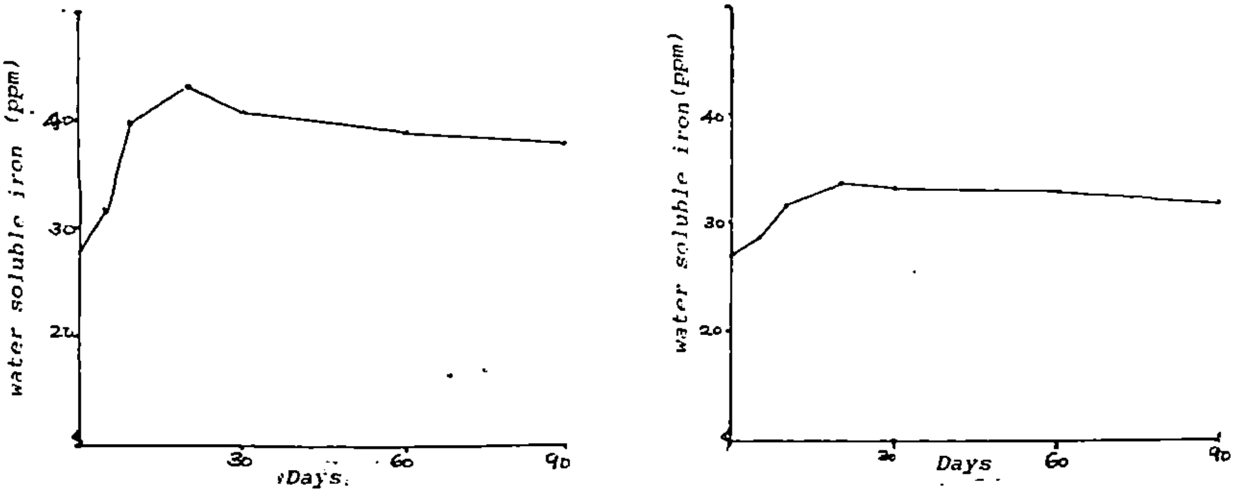
$F_{(30,36)} = 8.10^{**}$

CD = 1.50



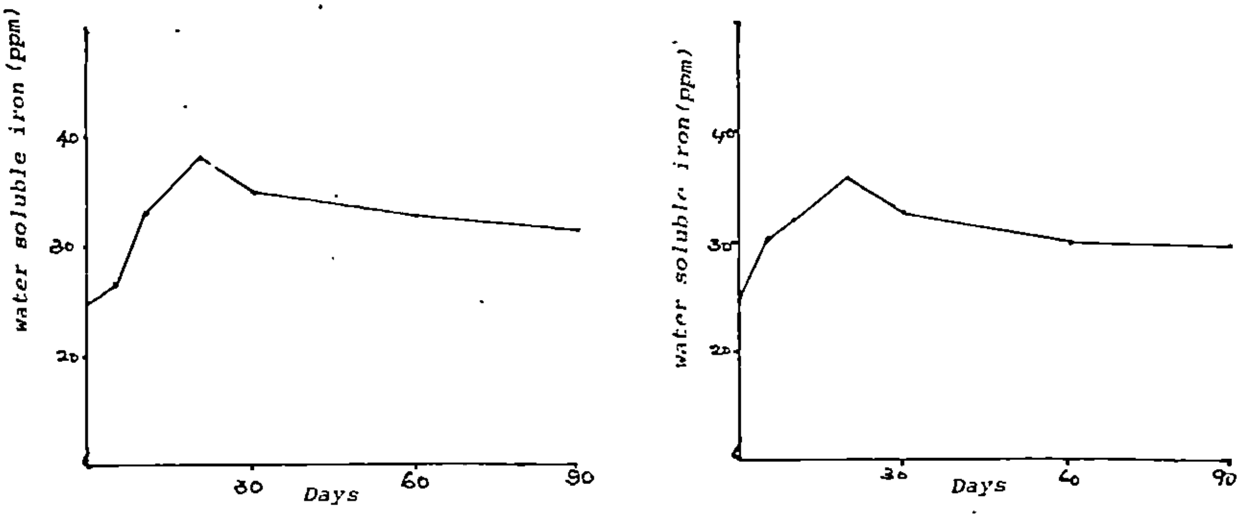
Lateritic alluvium

Kari soil



Kayal soil

Karappadom soil



Kole soil

Pokkali soil.

Fig.2 Effect of submergence on the mean content of water soluble iron in soil

Correlation studies (Table 15) with this form of iron has revealed a positive significant relationship with exchangeable iron ($r = 0.8003^{**}$), free iron oxide ($r = 0.3129^{**}$), total amorphous iron ($r = 0.3659^{**}$) and amorphous organic iron ($r = 0.7627^{**}$).

3. Exchangeable iron

The content of exchangeable iron increased significantly under the influence of length of submergence (Table 8 and Fig.3). The change in concentration of exchangeable iron in the lateritic alluvium, kole and pokkali soils under submergence followed more or less similar trends. While lateritic alluvium recorded an increase in exchangeable iron content from 97 ppm to a maximum of 184 ppm, kole soil recorded an increase from 107 to 255 ppm and pokkali soil indicated a rise from 81 to 172 ppm during 30 days of submergence. Further periods of submergence upto 90 days resulted in decreased contents of exchangeable iron in these three soils to 159, 245 and 148 ppm respectively.

The exchangeable iron content in kari and kayal soils registered increases from 146 and 77 ppm on the day of submergence to 317 and 240 ppm respectively on the 60th day after which kari soil showed steady values while kayal soil showed a slight decrease to 200 ppm on the 90th day.

The karappadom soil exhibited steady increase in exchangeable iron content from 71 ppm to 157 ppm throughout the period of submergence.

In all the soils studied, the content of exchangeable iron in general, increased two or three fold due to submergence.

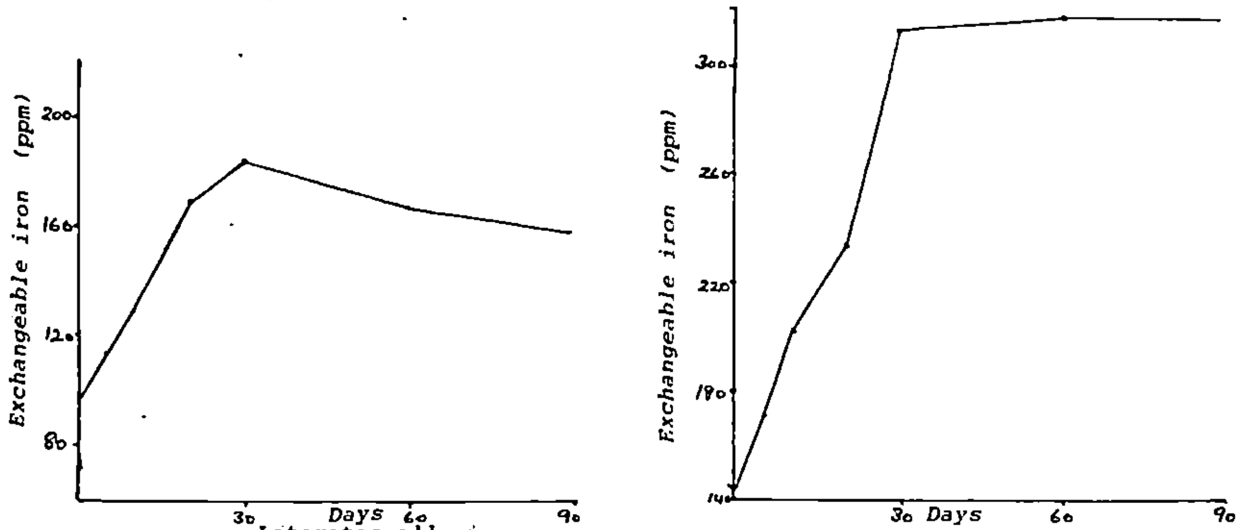
This increase in exchangeable iron content with period of submergence is attributed to the direct result of massive reduction of oxides of iron that has taken place with the onset of anoxic conditions (Takkar, 1969). In addition to the effect of increased pH of the soil during submergence, the decreased bonding energy resulting from soil submergence can also lead to the removal of Fe^{2+} from exchange sites. The reduction in the exchangeable iron content after the peak value might be due to the reoxidation of ferrous iron at the interface of water and atmosphere and consequent precipitation (Singh and Patiram, 1977). The results indicated that while lateritic alluvium, kole and pokkali registered increases in exchangeable iron upto the 30th day of submergence, kari and kayal soils showed increases upto 60th day. The more prolonged releases of exchangeable iron in the kari, kayal and karappadom soils may be due to the high buffer capacity and higher CEC value of these soils. Similar increases

Table 8 Effect of interaction - Soil and submergence on the mean content of exchangeable iron (ppm)

Soil	Days of submergence						
	0	5	10	20	30	60	90
1. Lateritic alluvium	97	113	128	169	184	167	159
2. Kari	146	172	203	234	313	317	317
3. Kayal	77	119	135	167	218	240	200
4. Karappadom	71	113	120	123	136	152	157
5. Kole	107	160	215	237	255	250	245
6. Pokkali	81	94	138	156	172	163	148

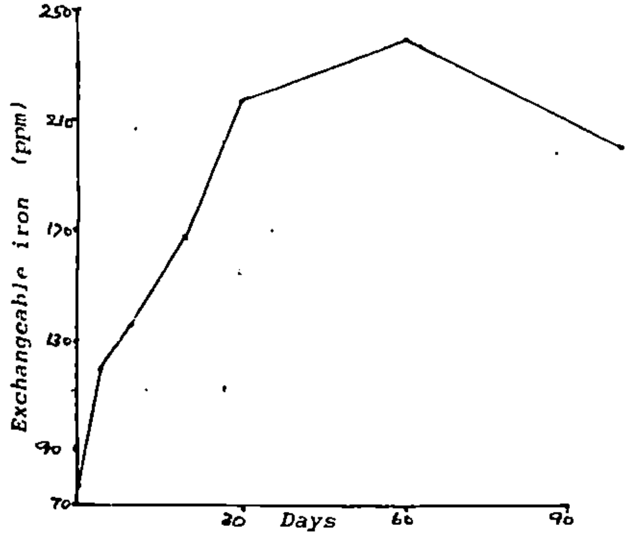
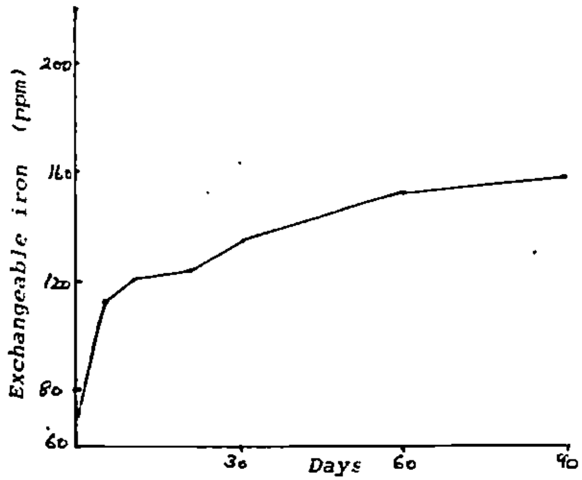
$F_{(30,36)} = 36.70^{**}$

CD = 8.14



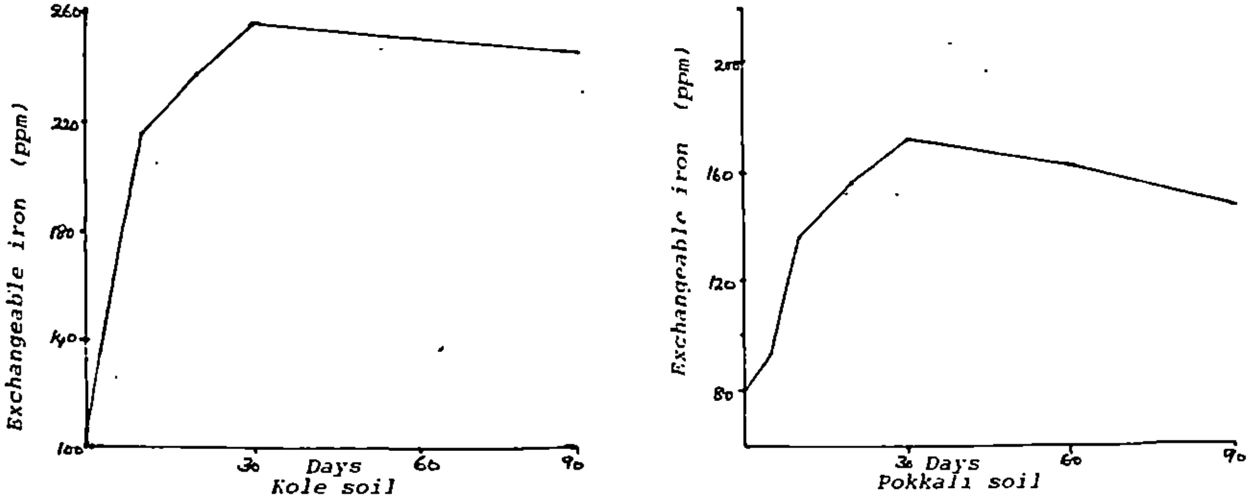
Lateritic alluvium

Kari soil

Kayal soil

Karappadom soil



Kole soil

Pokkali soil

Fig.3 Effect of submergence on the mean content of exchangeable iron in soil in exchangeable iron content in soils of Kerala under the influence of submergence have also been reported by Kabeerathumma (1975), Ghosh et al. (1976) and Najeeb (1989).

Correlation studies (Table 15) indicated a significant positive correlation with water soluble iron ($r = 0.8003^{**}$), free iron oxide ($r = 0.4785^{**}$), total amorphous iron ($r = 0.5871^{**}$) and amorphous organic iron ($r = 0.8192^{**}$) content of the soil.

4. Active iron

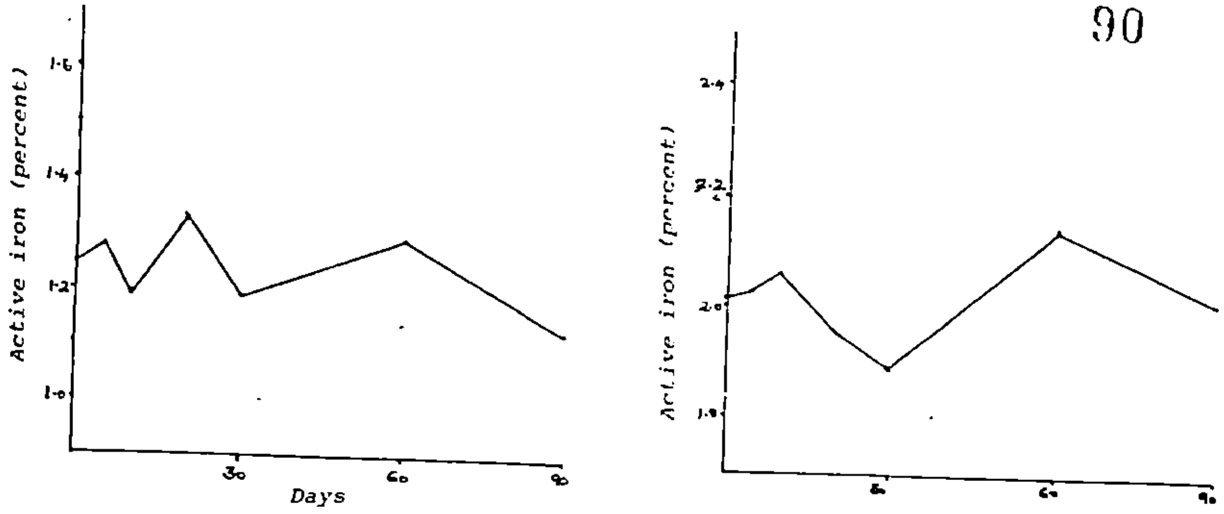
The content of active iron varied significantly between soils ranging from 2.02 per cent in the kari soil to 0.72 per cent in the pokkali soil (Table 9 and Fig.4). However, submergence caused no significant change in the content of this form. The variation in content of this form among the soils can be ascribed to the high content of easily reducible part of total Fe_2O_3 in the soils, which forms a major constituent of the active form. Depending on the relative contents of different iron oxide minerals in the six soils studied, variation in the content of active iron can be noticed. The nearly steady content of active iron in the soils under the influences of submergence substantiate the above reason as total Fe_2O_3 is not affected by submergence.

Table 9 Effect of interaction - Soil and submergence on the mean content of active iron (per cent)

Soil	Days of submergence						
	0	5	10	20	30	60	90
1. Lateritic alluvium	1.25	1.28	1.19	1.33	1.19	1.29	1.13
2. Kari	2.02	2.03	2.06	1.96	1.89	2.15	2.02
3. Kayal	1.54	1.52	1.56	1.49	1.40	1.60	1.47
4. Karappadom	1.08	1.05	1.03	1.08	0.98	0.99	1.07
5. Kole	1.78	1.73	1.76	1.66	1.80	1.75	1.67
6. Pokkali	0.72	0.81	0.72	0.73	0.74	0.85	0.61

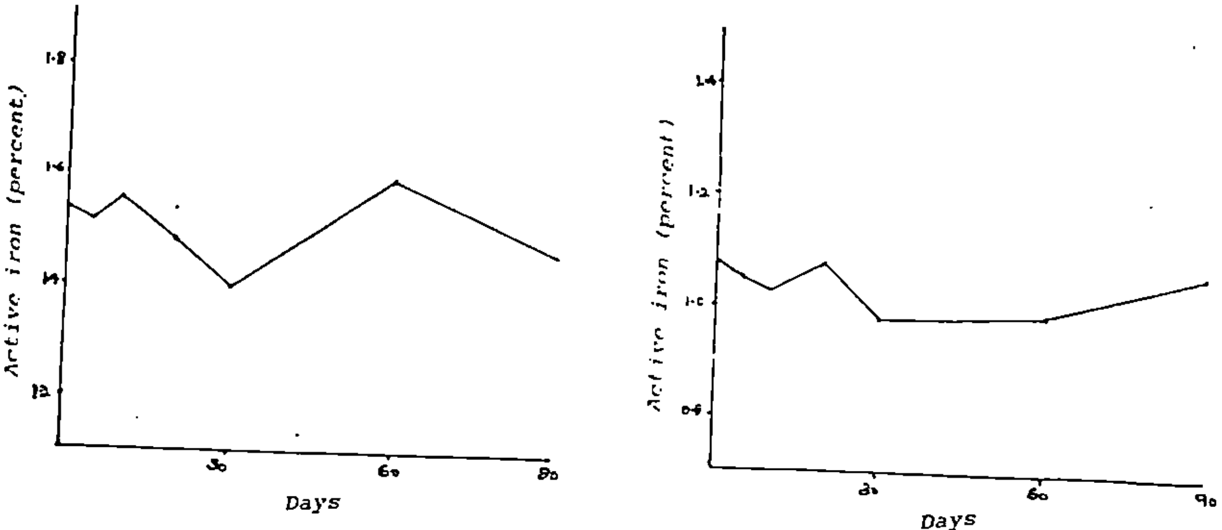
$F_{(30,36)} = 0.47$

CD = 0.24



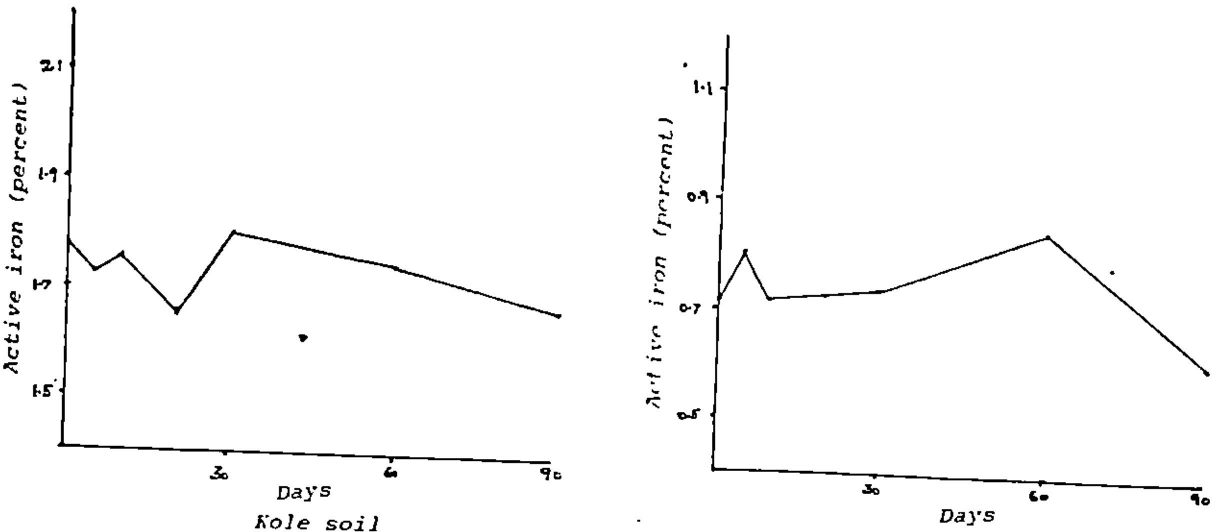
Lateritic alluvium

Kari soil



Kayal soil

Karappadom soil



Kole soil

Pokkali soil

Fig.4 Effect of submergence on the mean content of active iron in soil

The results are in agreement with the findings of Thind and Chahal (1986) who noticed that all forms of iron except active form increased due to submergence and organic manuring.

Correlation study (Table 15) indicated a significant positive correlation with free iron oxides ($r = 0.2097^{**}$), total amorphous ($r = 0.3123^{**}$), amorphous organic ($r = 0.1409^{*}$) and amorphous inorganic ($r = 0.3370^{**}$) forms of iron.

5. Free iron oxides (Dithionite extractable)

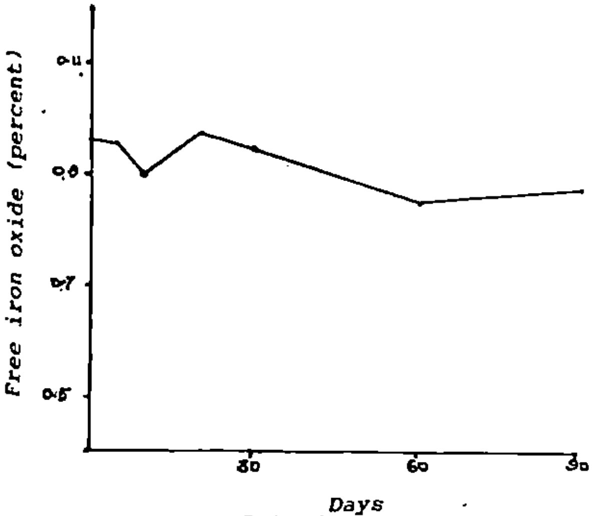
The free iron oxide content (Table 10, Fig.5) in all the soils remained almost constant during submergence (He Qun and Xu Zu-yi, 1980). Analysis of variance indicated no significant change in the content of this form due to submergence, but the content varied among the soils significantly. The mean content of free oxide ranged from 0.85 to 0.97 per cent in lateritic alluvium, 1.07 to 1.12 per cent in kari soil, 0.96 to 1.02 per cent in kayal soil, 0.83 to 0.93 per cent in karappadom soil, 0.97 to 1.08 per cent in kole soil and 0.75 to 0.84 per cent in the pokkali soil. The highest content was observed in kari and the least in pokkali soils. Lowest content of free oxides (Fe_d) in pokkali soils can be attributed to the restricted drainage

Table 10 Effect of interaction - Soil and submergence on the mean content of free oxide (per cent)

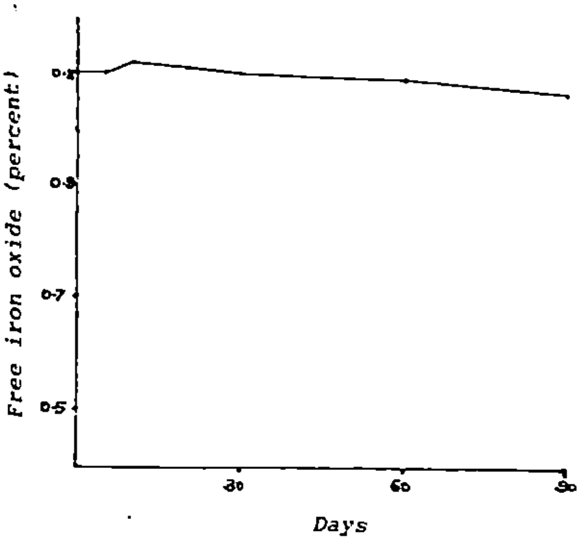
Soil	Days of submergence						
	0	5	10	20	30	60	90
1. Lateritic alluvium	0.96	0.95	0.90	0.97	0.94	0.85	0.88
2. Kari	1.10	1.10	1.12	1.11	1.10	1.09	1.07
3. Kayal	1.02	0.98	0.99	1.01	0.96	1.00	0.99
4. Karappadom	0.89	0.83	0.85	0.85	0.91	0.93	0.86
5. Kole	1.06	1.07	1.08	1.07	0.98	0.97	1.08
6. Pokkali	0.75	0.77	0.82	0.77	0.84	0.75	0.78

$F_{(30,36)} = 0.77$

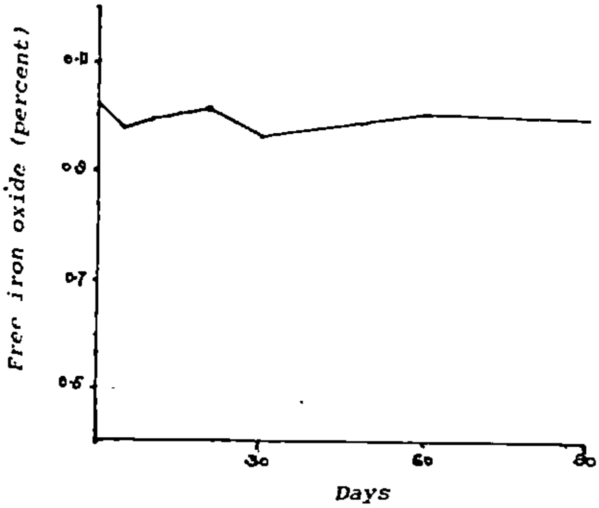
CD = 0.05



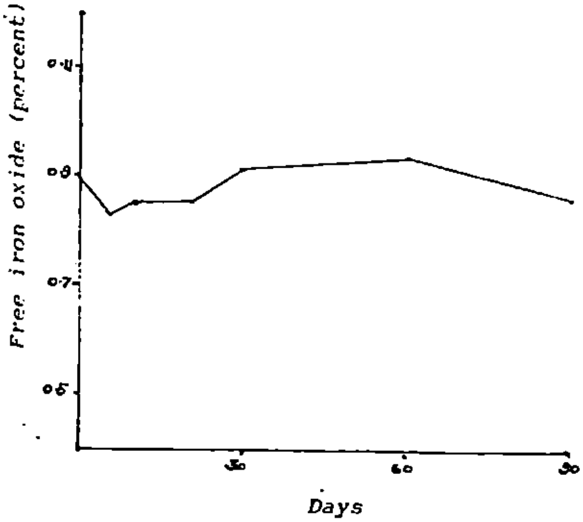
Lateritic alluvium.



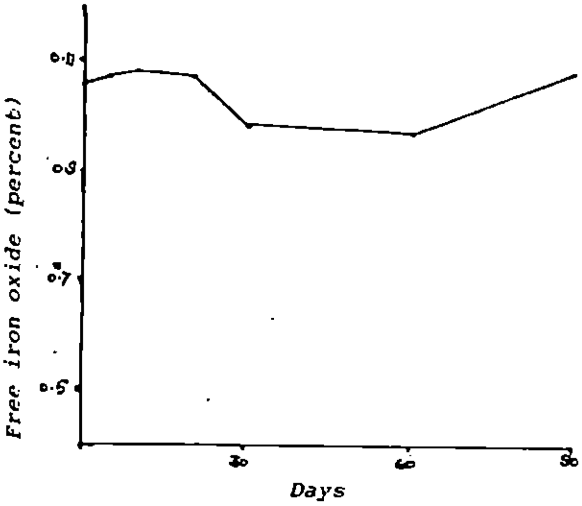
Kari soil.



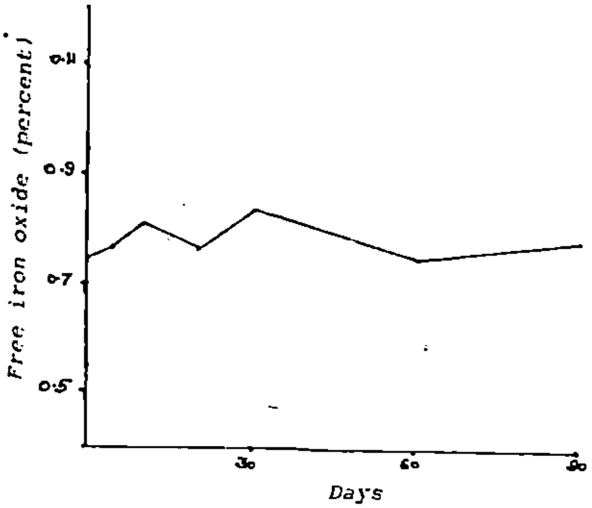
Kayal soil



Karappadom soil.



Kole soil



Pokkali soil.

Fig.5 Effect of submergence on the mean content of free iron oxide in soil.

condition of the soil. Udo (1980) reported low contents of free iron oxides constituting nearly nine per cent of the total iron in poorly drained soils, while the well drained soils had the highest content frequently exceeding 61 per cent. In the present study, the free iron oxides in the soil have not shown remarkable change after incubation. He Qun and Xu Zu-yi (1980) studied the transformations of iron oxides during the course of submergence and have obtained nearly steady values. Ottow (1980) however, in an inoculation study with anaerobes, reported a decreasing trend of free oxides (Fe_d) with period of submergence.

Correlation studies (Table 15) indicated a significant positive relationship with total amorphous ($r = 0.8937^{**}$), amorphous organic ($r = 0.6691^{**}$) and amorphous inorganic ($r = 0.8289^{**}$) forms of iron.

6. Total amorphous iron

The total amorphous iron content significantly increased in all the soils under the influence of submergence (Table 11, Fig.6). Similar observation was made by Willett and Higgins (1980). In lateritic alluvium, the content increased from 0.15 per cent on the day of submergence to a maximum of 0.53 per cent on the 30th day and thereafter remained more or less steady till the 90th day.

The kari soil registered an increase from 0.46 per cent to 0.78 per cent on 30th day of submergence and remained steady upto 90th day.

The increase in the total amorphous iron content in kayal soil was noticed from the initial value of 0.35 per cent to 0.68 per cent on the 60th day and then remained almost steady with further period of submergence.

The karappadom soil recorded an increase from 0.25 per cent on the zero day to 0.62 per cent on the 60th day of submergence with subsequent steady value upto 90th day.

The kole soil which had 0.36 per cent total amorphous iron on zero day showed a decrease from its peak content of 0.74 per cent on the 30th day to 0.68 per cent on 90th day.

The pokkali soil which had an initial content of 0.22 per cent total amorphous iron on submergence increased to a value of 0.54 per cent as on the 30th and 0.56 on the 60th day. However, 0.54 and 0.56 are statistically on par.

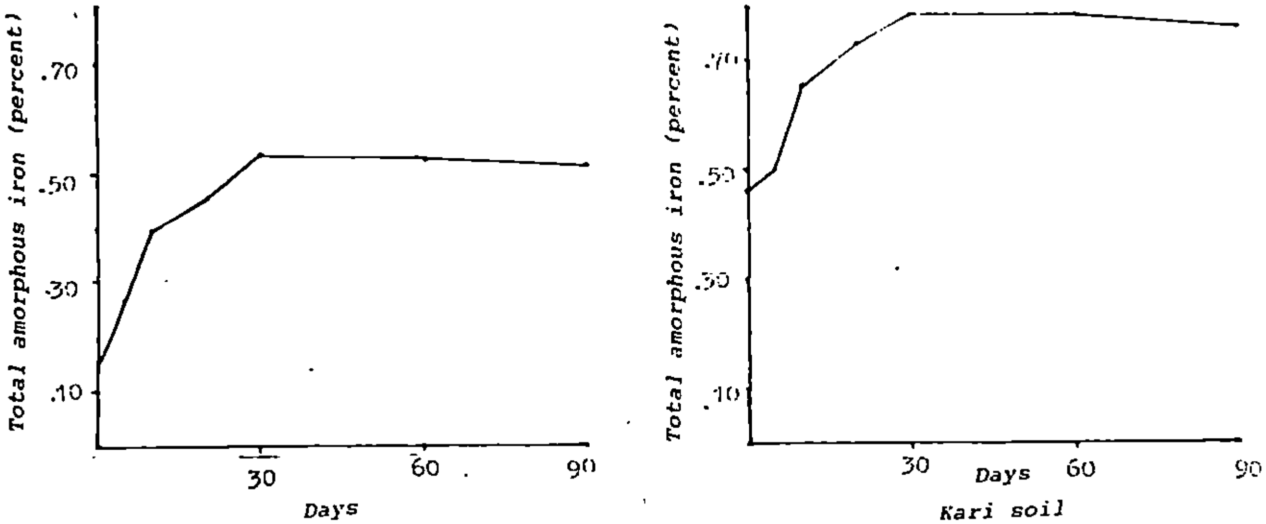
The increase in total amorphous iron (Fe_o) noticed in all the soils must have occurred due to the influence of microbial action in the soil on the crystalline iron converting it to the amorphous form.

Table 11 Effect of interaction - Soil and submergence on the mean content of total amorphous iron (per cent)

Soil	Days of submergence						
	0	5	10	20	30	60	90
1. Lateritic alluvium	0.15	0.26	0.39	0.45	0.53	0.52	0.51
2. Kari	0.46	0.50	0.65	0.73	0.78	0.78	0.76
3. Kayal	0.35	0.45	0.46	0.55	0.64	0.68	0.68
4. Karappadom	0.25	0.26	0.33	0.53	0.55	0.62	0.62
5. Kole	0.36	0.43	0.53	0.61	0.74	0.74	0.68
6. Pokkali	0.22	0.38	0.46	0.51	0.54	0.56	0.54

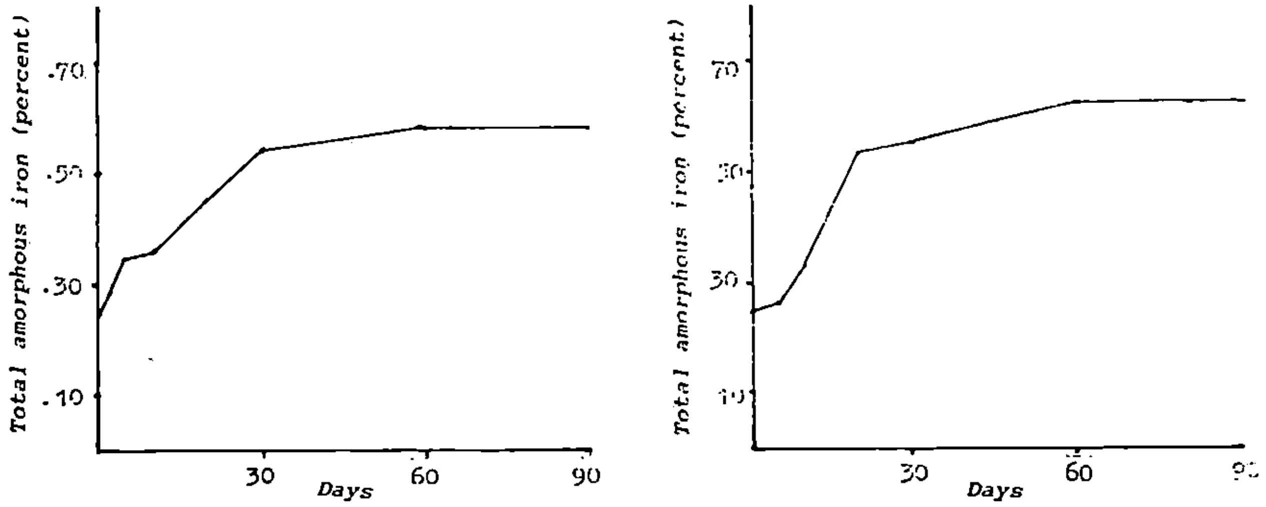
$F_{(30,36)} = 9.79^{**}$

CD = 0.04



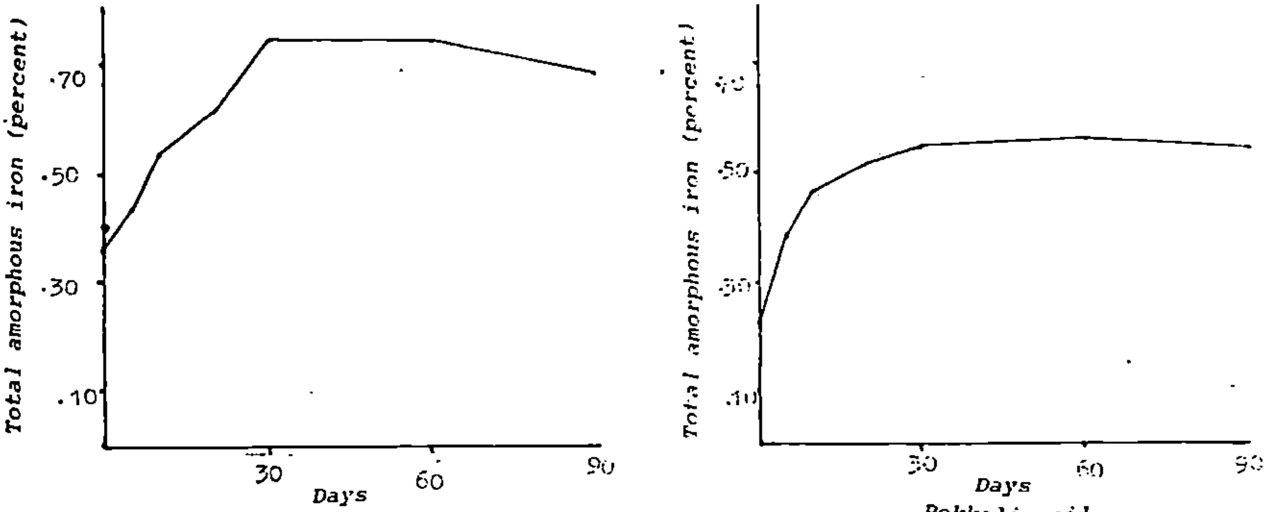
Lateritic alluvium

Kari soil



Kayal soil

Karappadom soil



Kole soil

Pokkali soil

Fig.6 Effect of submergence on the mean content of total amorphous iron in soil

While studying the reduction of pedogenic iron oxides by the activity of <u>Clostridium</u> <u>butyricum</u> on gley, pseudogley and red clay soils with different $Fe_o : Fe_d$ ratios, Munch and Ottow (1980) found that in a soil with high activity ratio, there was a rapid decrease in the content of Fe_d and Fe_o during incubation, while crystalline iron and $Fe_o : Fe_d$ remained relatively constant. However, with $Fe_o : Fe_d \approx 0.1$, Fe_o fraction is lowered only during the first days of incubation with subsequent increase and that Fe_d and $Fe_{(d-o)}$ decreased showing preferential action on crystalline iron oxide by bacteria, the crystalline iron oxide functioning as terminal electron acceptor. Ponnamperuma (1972) assumed that lower the degree of crystallinity, the higher is the extent to which the pedogenic iron oxides may be reduced. The crystalline fractions $(Fe_d - Fe_o)$ rather than the amorphous iron (Fe_o) become reduced preferentially by iron reducing bacteria.

7. Amorphous organic iron

The content of amorphous organic iron varied significantly among soils under submergence on the day of submergence, the maximum content of 0.21 per cent was observed in kole soil and the minimum of 0.06 per cent in the lateritic alluvium (Table 12, Fig.7).

In the lateritic alluvium an increase in amorphous organic iron content was noticed from 0.06 per cent on the day of submergence to 0.37 per cent on the 30th day which decreased gradually to 0.29 per cent on the 90th day.

In kari soil, however significant increases in the content of amorphous organic iron could be noted during each interval of submergence. The initial content of 0.19 per cent increased upto 0.53 per cent on the 30th day and then decreased to 0.47 per cent on the 90th day.

In the kayal, karappadom, kole and pokkali soils increase was observed from their initial content of 0.18, 0.16, 0.21 and 0.15 per cent to 0.43, 0.36, 0.41 and 0.32 per cent on the 30th day followed by a decrease to 0.37, 0.28, 0.32 and 0.26 per cent respectively on the 90th day.

In all the soils the content of amorphous organic iron on the 90th day was found to be much higher than the initial content on the zero day.

The increase in content of this form under the influence of submergence have also been reported by He Qun and Xu Zu-yi (1980) and Patra and Mohanty (1989). The highest

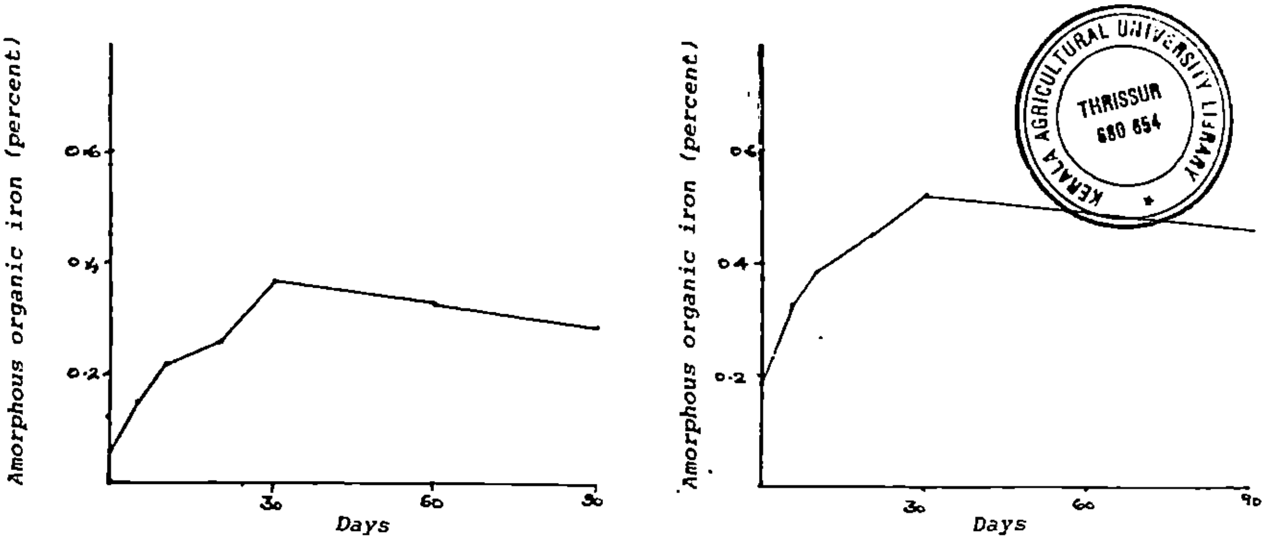
Table 12 Effect of interaction - Soil and submergence on the mean content of amorphous organic iron (per cent)

Soil	Days of submergence						
	0	5	10	20	30	60	90
1. Lateritic alluvium	0.06	0.15	0.22	0.26	0.37	0.33	0.29
2. Kari	0.19	0.33	0.39	0.46	0.53	0.50	0.47
3. Kayal	0.18	0.24	0.31	0.34	0.43	0.38	0.37
4. Karappadom	0.16	0.19	0.23	0.35	0.36	0.29	0.28
5. Kole	0.21	0.31	0.34	0.37	0.41	0.37	0.32
6. Pokkali	0.15	0.21	0.24	0.27	0.32	0.29	0.26

$F_{(30,36)} = 4.69^{**}$

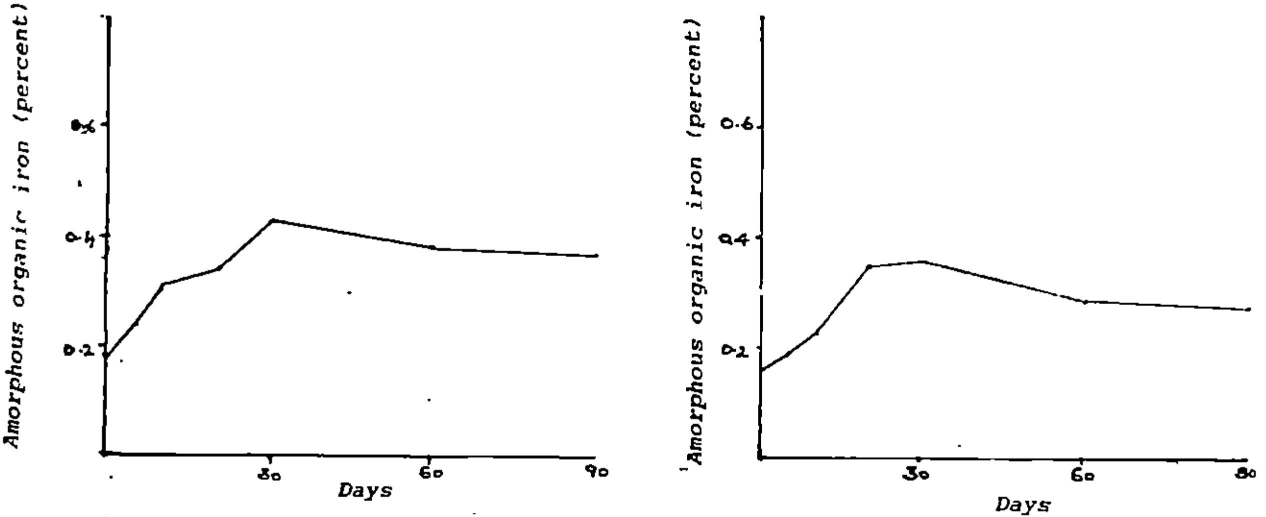
CD = 0.03

170551



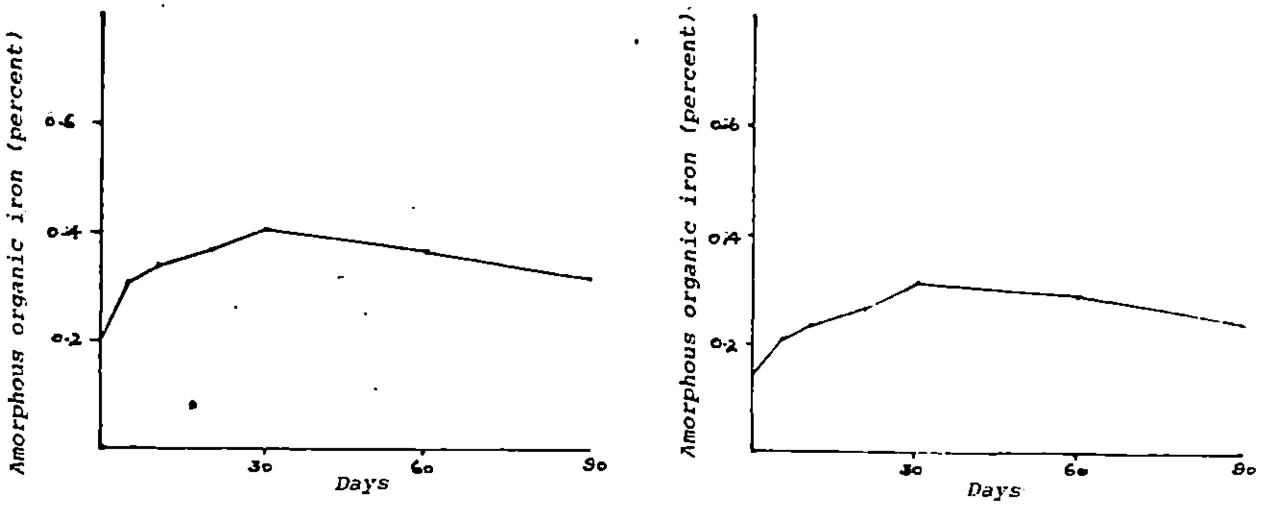
Lateritic alluvium

Kari soil



Kayal soil

Karappadom soil



Kole soil

Pokkali soil

Fig.7 *Effect of submergence on the mean content of amorphous organic iron in soil* content of this form in kari and kole soils can be attributed to the high organic matter content of these soils. Yu Tian-ren (1980) obtained a linear correlation between the amount of this form and organic matter content of the soil.

8. Amorphous inorganic

In all the six soils studied, the content of amorphous inorganic iron increased significantly due to submergence from the 0 day to 90th day (Table 13, Fig.8).

In lateritic alluvium and kari soils the content increased from 0.09 and 0.27 per cent on the 0 day to 0.17 and 0.26 per cent respectively on the 20th day, after which the content remained almost steady till 90th day.

In Kayal, karappadom and pokkali soils the maximum content of 0.30, 0.33 and 0.27 per cent was reached on 60th day from an initial content of 0.17, 0.09 and 0.07 per cent respectively. After attaining the peak values, the content remained almost steady in all these soils upto the 90th day.

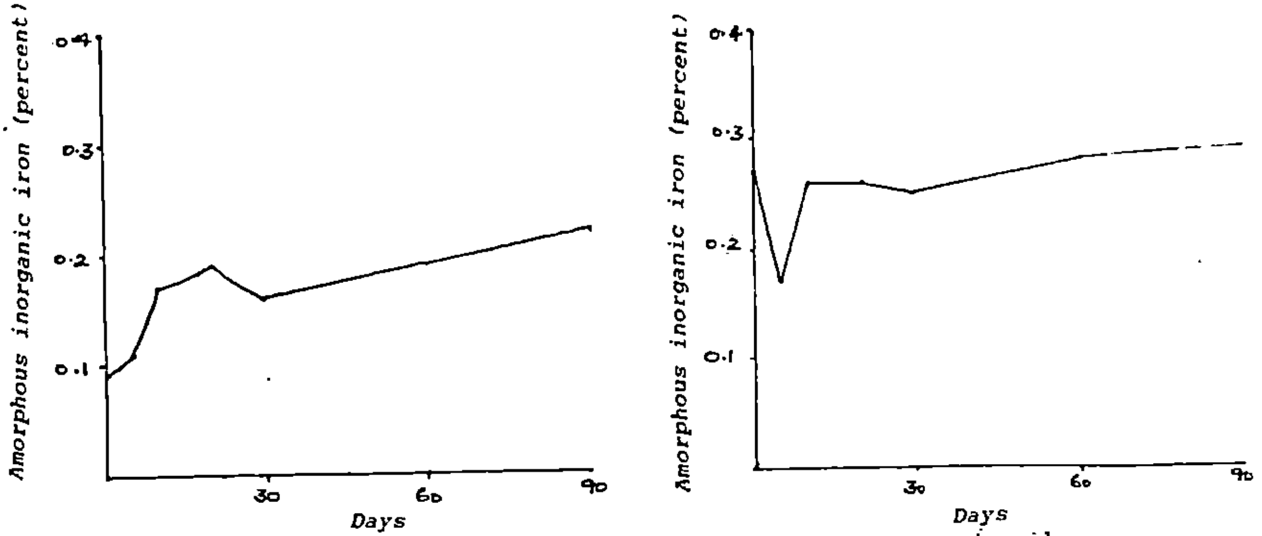
In the kole soil, the content increased from 0.15 on the 0 day to 0.33 per cent on the 30th day and then the value steadied till 90th day.

Table 13 Effect of interaction - Soil and submergence on the mean content of amorphous inorganic iron (per cent)

Soil	Days of submergence						
	0	5	10	20	30	60	90
1. Lateritic alluvium	0.09	0.11	0.17	0.19	0.16	0.19	0.22
2. Kari	0.27	0.17	0.26	0.26	0.25	0.28	0.29
3. Kayal	0.17	0.21	0.15	0.21	0.21	0.30	0.31
4. Karappadom	0.09	0.07	0.10	0.18	0.19	0.33	0.34
5. Kole	0.15	0.12	0.19	0.24	0.33	0.37	0.36
6. Pokkali	0.07	0.17	0.22	0.24	0.22	0.27	0.28

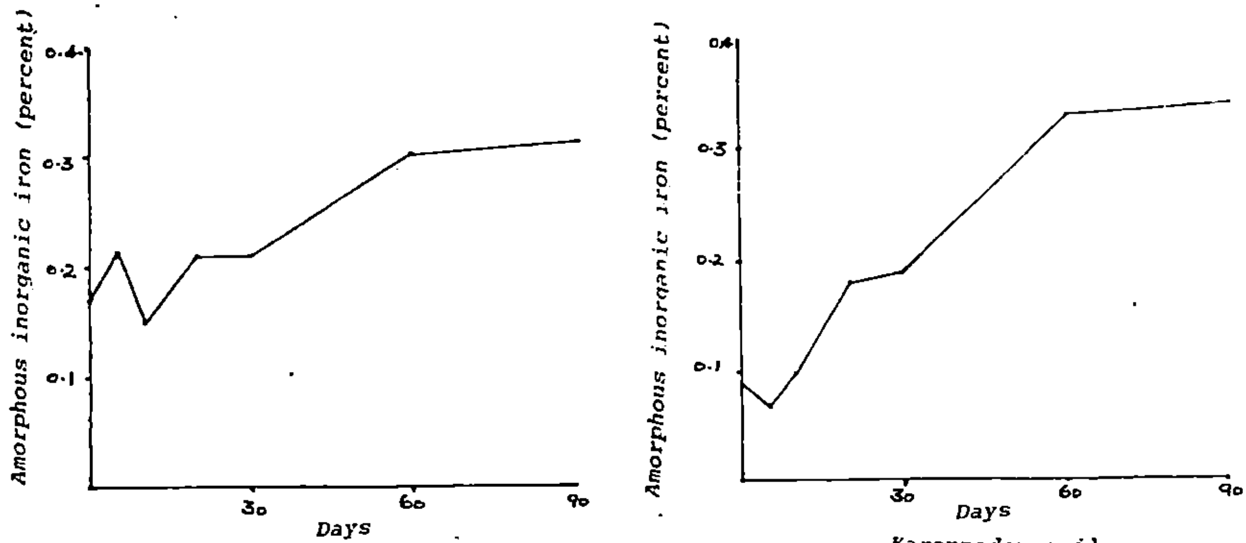
$F_{(30,36)} = 8.33^{**}$

CD = 0.05



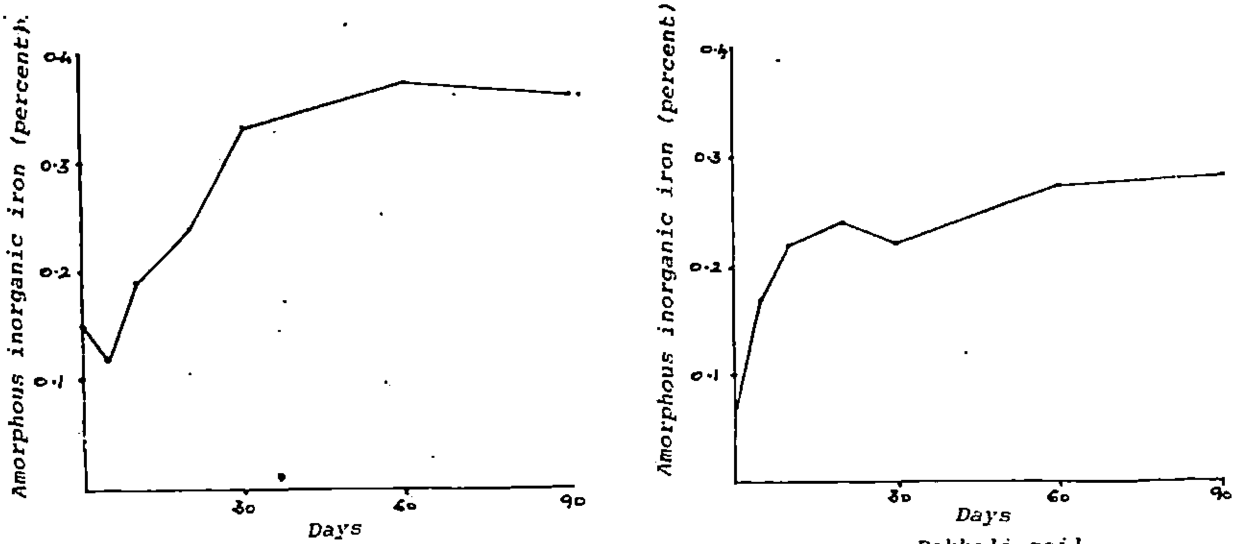
Lateritic alluvium

Kari soil



Kayal soil

Karappadom soil



Kole soil

Pokkali soil

Fig.8 Effect of submergence on the mean content of amorphous inorganic iron in soil

Among the soils, the highest initial content was noticed in kari and the least in pokkali soils, while on the 90th day kole registered the highest content and the least the lateritic alluvium.

9. Crystalline iron

Among the soils the variation in the contents of crystalline iron under the influence of submergence was statistically significant (Table 14, Fig.9).

In the lateritic alluvium, the content of crystalline iron decreased from 0.81 per cent on the 0 day to 0.37 per cent on 90th day.

In kari soil, however decrease from the initial content of 0.64 per cent to 0.32 per cent was observed on 30th day and later the content remained almost steady upto 90th day.

In kayal soil decrease in crystalline iron content could be noticed upto 30th day of submergence. However, beyond 30 days the content remained steady.

In the karappadom soil decrease in value could be noticed upto the 60th day and then remained steady.

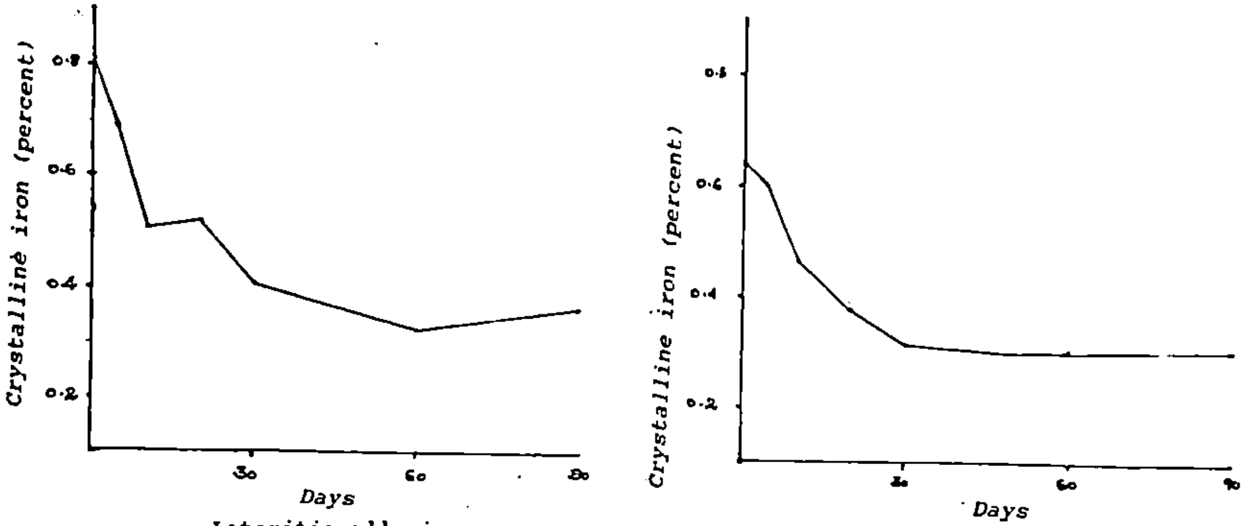
The kole soil registered the lowest content on 30th day.

Table 14 Effect of interaction - Soil and submergence on the mean content of crystalline iron (per cent)

Soil	Days of submergence						
	0	5	10	20	30	60	90
1. Lateritic alluvium	0.81	0.69	0.51	0.52	0.41	0.33	0.37
2. Kari	0.64	0.60	0.47	0.38	0.32	0.31	0.31
3. Kayal	0.67	0.53	0.53	0.46	0.32	0.32	0.31
4. Karappadom	0.64	0.57	0.52	0.32	0.36	0.31	0.24
5. Kole	0.70	0.64	0.55	0.46	0.24	0.23	0.40
6. Pokkali	0.53	0.39	0.36	0.26	0.30	0.19	0.24

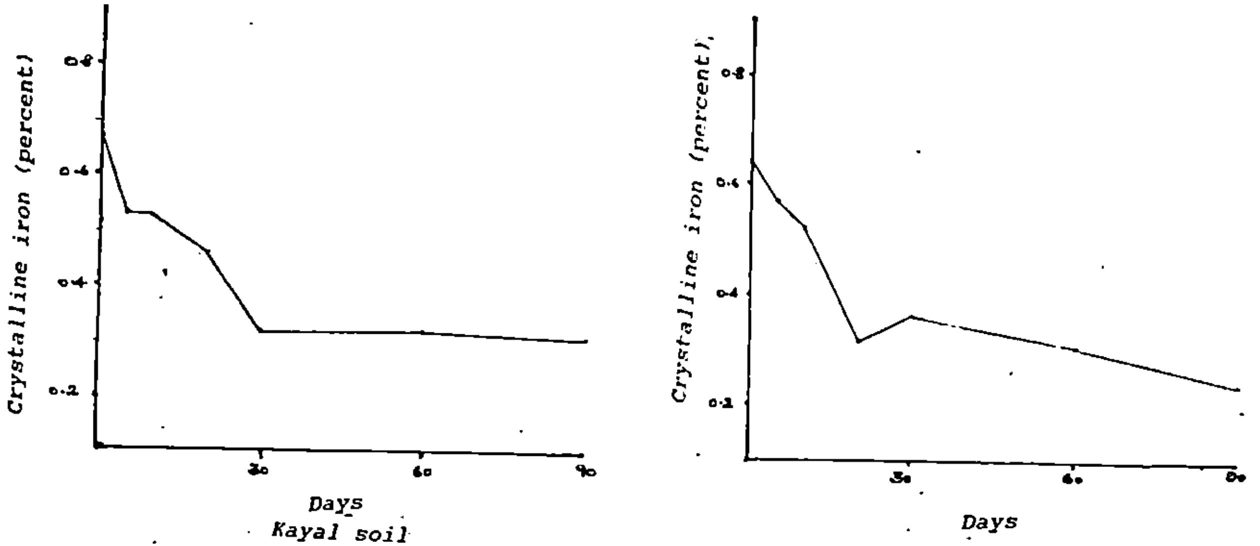
$F_{(30,36)} = 11.41^{**}$

CD = 0.06



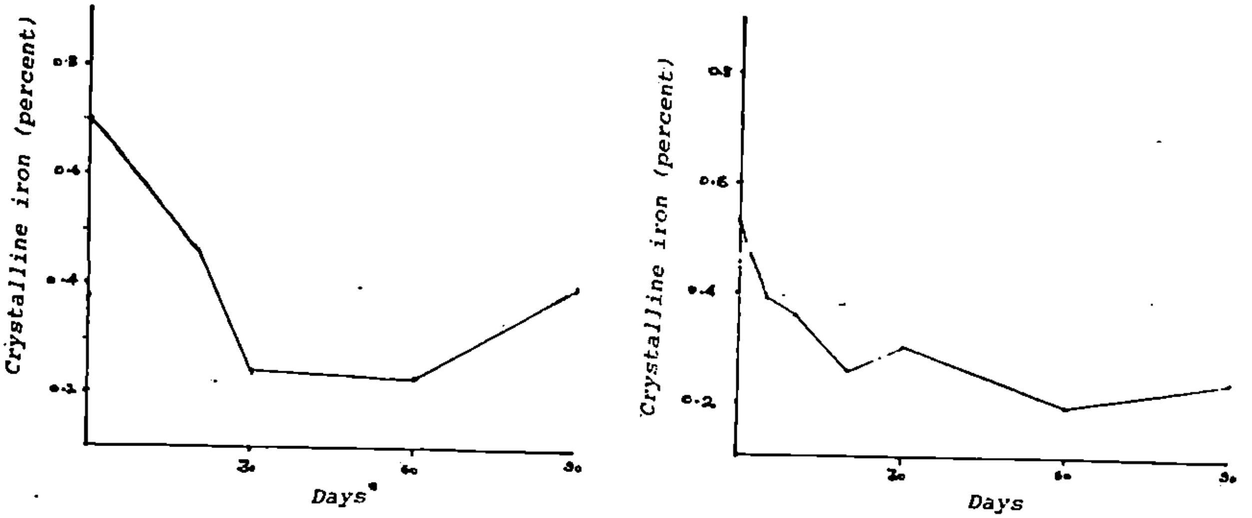
Lateritic alluvium

Kari soil



Kayal soil

Karappadom soil



Kole soil

Pokkali soil

Fig.9 Effect of submergence on the mean content of crystalline iron in soil

Table 15 Correlation matrix of different forms of iron

n=210

Forms of iron	Water soluble	Exchangeable	Active	Free oxide	Total amorphous	Amorphous organic	Amorphous inorganic	Crystalline
Water soluble	1.0000							
Exchangeable	0.8003**	1.0000						
Active	0.0009	0.0083	1.0000					
Free oxide	0.3129**	0.4785**	0.2097**	1.0000				
Total amorphous	0.3659**	0.5871**	0.3123**	0.8937**	1.0000			
Amorphous organic	0.7627**	0.8192**	0.1409*	0.6691**	0.7298**	1.0000		
Amorphous inorganic	0.0899	0.3509**	0.3370**	0.8289**	0.9372**	0.4454**	1.0000	
Crystalline	-0.0318	-0.1035	-0.1049	0.1079	0.0009	0.0370	0.0200	1.0000

* Significant at 5% level

** Significant at 1% level

n = sample size

In pokkali soils the lowest value of crystalline iron content reached on the 60th day of submergence was maintained till the 90th day of submergence.

b) Effect of management practices on soil reaction and solubilisation of the major forms of iron under submergence

1. Organic matter

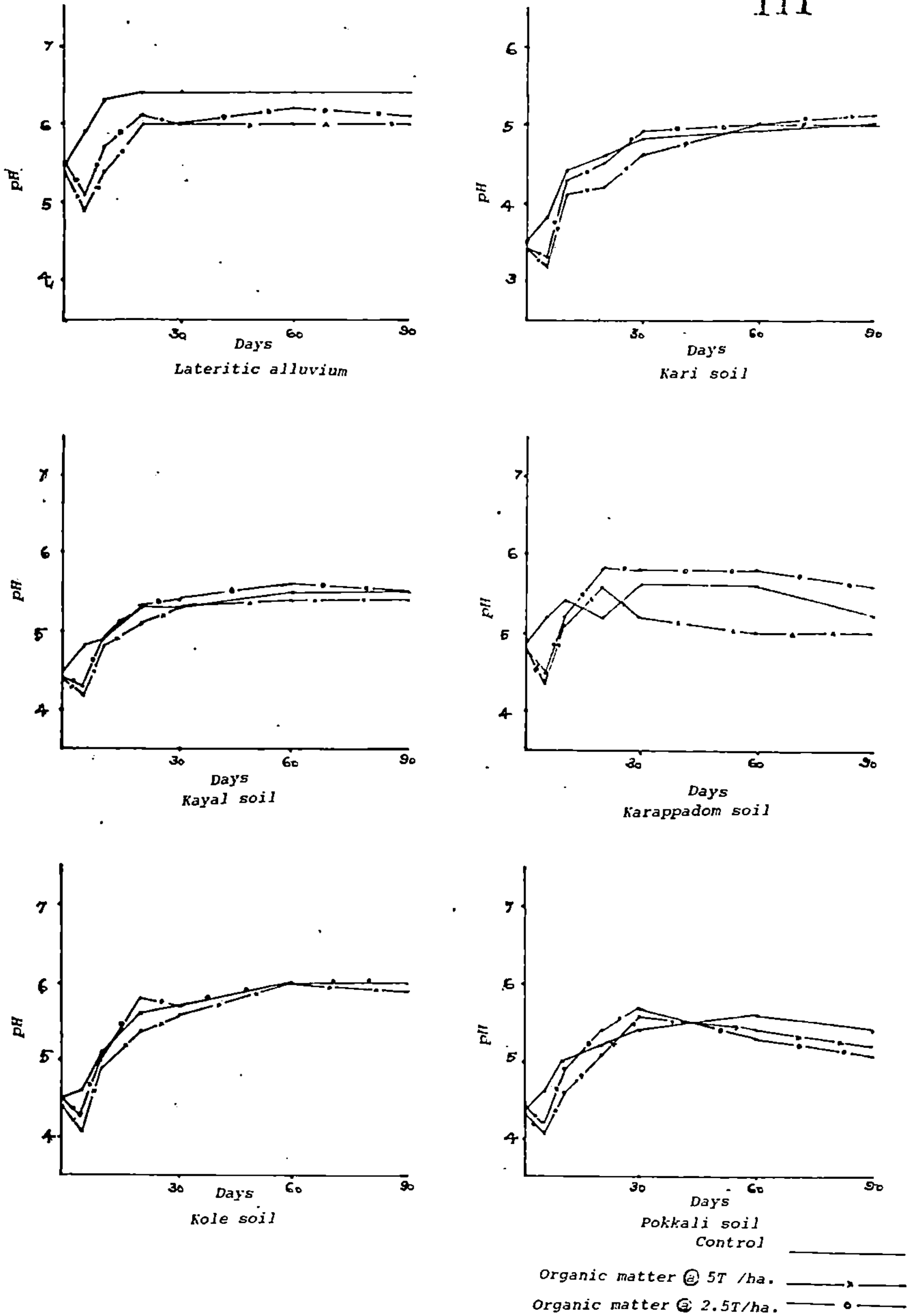
The results relating to the effect of two levels of organic matter, viz., 2.5 t/ha and 5.0 t/ha on soil reaction and forms of iron with period of submergence are discussed below.

i) Soil reaction

Table 16 and Fig.10 indicate that addition of organic matter to soils decreased the soil pH, which continued upto 5th day of submergence and then increased towards neutrality with further periods, while the overall effect of submergence alone was to raise the pH of all the soils. In the lateritic alluvium and karappadom soils treated with higher level of organic matter, the pH reached a maximum of 6.0 and 5.6 respectively on 20th day of submergence, while in pokkali soils the pH was raised to a maximum of 5.6 on the 30th day. For kari, kayal and kole soils it took 60 days to attain the maximum pH of 5.0, 5.4 and 6.0 respectively.

The organic matter at lower dose applied to soils also resulted in the same pattern of pH changes and same periods to attain the peak pH values as for the higher dose organic matter treatment. The maximum pH values attained by lateritic alluvium, kari, kayal, karappadom, kole and pokkali were 6.2, 5.0, 5.6, 5.8, 6.0 and 5.7 respectively.

While the organic matter decomposition lead to organic acids thereby tending to lower the pH of soils till the decomposition is completed, the effect of submergence is to raise the pH of the soils due to anaerobic reduction processes going on in submerged condition. The chemical kinetics of flooded soils show that within a few weeks of submergence, most soils go through a period of intense biological activity characterised by soil reduction and production of CO_2, Fe^{2+}, Mn^{2+} and organic reduction products in high concentrations. The peak chemical activity is followed by a relatively steady state. The fact that the pH of the organic matter treated soil also increases with period of submergence indicates the rise of pH under the influence of submergence alone at all stages over the effect of decreasing pH under the influence of organic matter. The graph shown indicates that though the rise in pH by organic matter follows the same trend as submergence effect, the extent of rise in pH by organic matter treatment is always lower than that in the control.



Lateritic alluvium

Kari soil

Kayal soil

Karappadom soil

Kole soil

Pokkali soil

Fig.10 Effect of organic matter on the pH of soil under submergence

ii) Water soluble iron

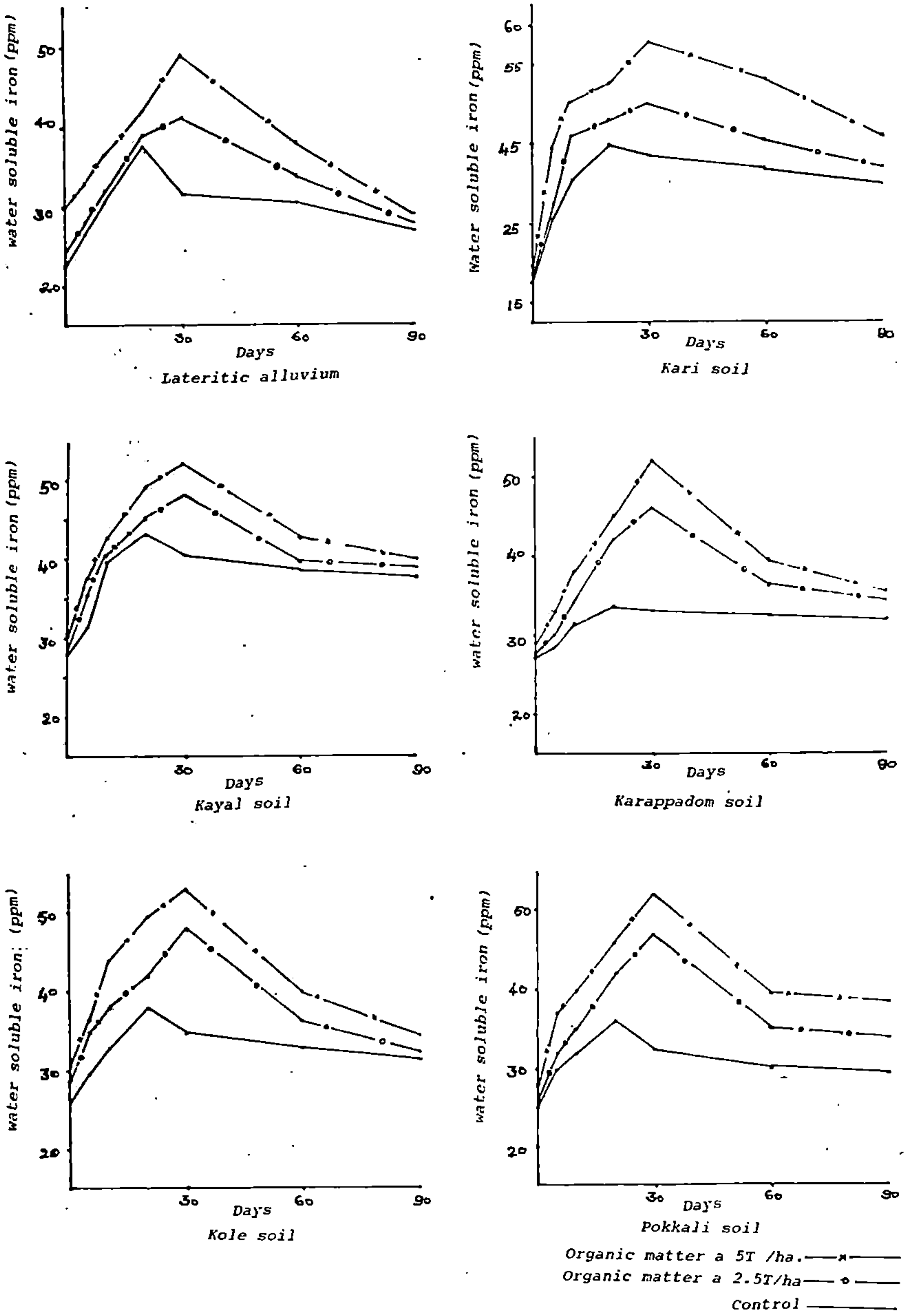
Data on the mean release of water soluble iron resulting from the addition of two levels of organic matter to soils under submergence are given in Fig.11.

It is clear from the Table 17 that the addition of organic matter to soils under submergence caused a significant increase in the water soluble iron content over the control. Organic matter application at 2.5 t/ha released 35.0 ppm water soluble iron from the soils, while the higher dose of organic matter viz., 5 t/ha released 39.3 ppm. The control treatment was found to release 33.2 ppm soluble iron. Statistical analysis indicated that the iron release resulting from the higher dose of organic matter treatment was significantly more than that from the lower level of organic matter and control treatments.

The effect of interaction between treatment and period of submergence is given in the mean Table 18. The Table indicates that full dose of organic matter treatment which had initially recorded 32.9 ppm mean content of water soluble iron significantly increased to 36.9 ppm on 5th day, 40.3 ppm on the 10th day and the maximum of 44.7 ppm on the 30th day. Beyond 30 days significant decreases in water soluble iron could be noticed at all subsequent sampling periods till the 90th day. The treatment of organic matter at lower dose also resulted in similar significant increases in water soluble iron from soils under submergence over the control. The initial content of water soluble iron indicated increases with time of submergence until the peak concentration of 39.8 ppm reached on the 30th day. Continued submergence beyond that period till the 90th day significantly decreased the water soluble iron content to 33.5 ppm.

The effect of interaction between soils and treatment given in Table 21 indicates that increase in the water soluble iron content from the lateritic alluvium, kari, kayal, karappadom, kole and pokkali soils on submergence in presence of higher dose of organic matter application were significantly higher than the control. The maximum water soluble iron release could be observed in kari soil and the minimum in kayal soil. The lower dose of organic matter treatment also resulted in similar increased release of water soluble iron due to submergence in all the soils than that of the control.

The increased iron solubilisation by submergence, is aggravated by organic matter treatment. This may be due to the intensified reduction operations in the soil.



Lateritic alluvium

Kari soil

Kayal soil

Karappadom soil

Kole soil

Pokkali soil

Fig.11 Mean content of water soluble iron in soil under submergence as influenced by organic matter

Higher dose of organic matter has caused the release of higher amounts of iron at all stages of submergence compared to the lower dose. The peak value of water soluble iron was found to be around 30th day of submergence in all the soils. The increase in water soluble iron with period of submergence is due to an increase in the concentration of CO_2 and the PCO_2 resulting from organic matter decomposition. The anaerobic decomposition of organic matter leading to organic acids also contribute towards progressive increase in the concentration of water soluble iron by dissolving the insoluble ferric iron compounds in the soil. Similar findings have also been reported by Islam and Elahi (1954), Mandal (1961), Motomura (1962), Meek et al. (1968), Takkar (1969), Ramasubramonian (1989). The subsidence of water soluble iron after the peak value may be due to the fall in the concentration of CO_2 and precipitation of iron as $Fe_3(OH)_8$.

Among the soils, kari soil has recorded the highest content of water soluble iron under the influence of organic matter and submergence. The low pH, high content of free iron and organic matter may be the reason for the increased contents of water soluble iron. Takkar (1969) has also reported similar findings in low pH soils.

iii) Exchangeable iron

Mean content due to the addition of organic matter under the influence of submergence is given in Fig.12.

It is clear from the Table 17 that addition of both levels of organic matter to soils under submergence caused a significant increase in the exchangeable iron content over the control. Lower levels of organic matter released 184.1 ppm exchangeable iron from soils while higher dose of organic matter released 216.1 ppm. Statistical analysis indicated that the exchangeable iron content resulting from the higher dose of organic matter treatment was significantly higher than that from the lower levels of organic matter and control treatments.

Mean Table 19 indicated that full dose of organic matter treatment which had initially recorded a mean content of 130.5 ppm exchangeable iron, significantly increased to 158.0 ppm on the 5th day and attained a maximum of 279.3 ppm on the 60th day, after which decreased to 250.3 ppm on the 90th day. The treatment of organic matter at lower level also resulted in similar significant increases in exchangeable iron content over the control. The initial content of 106.8 ppm exchangeable iron showed increase with period of submergence until the peak value of 246.0 ppm is reached on the 60th day and then declined to 229.0 ppm on the 90th day.

The effect of interaction between soils and treatments given in Table 22 indicated that the increase

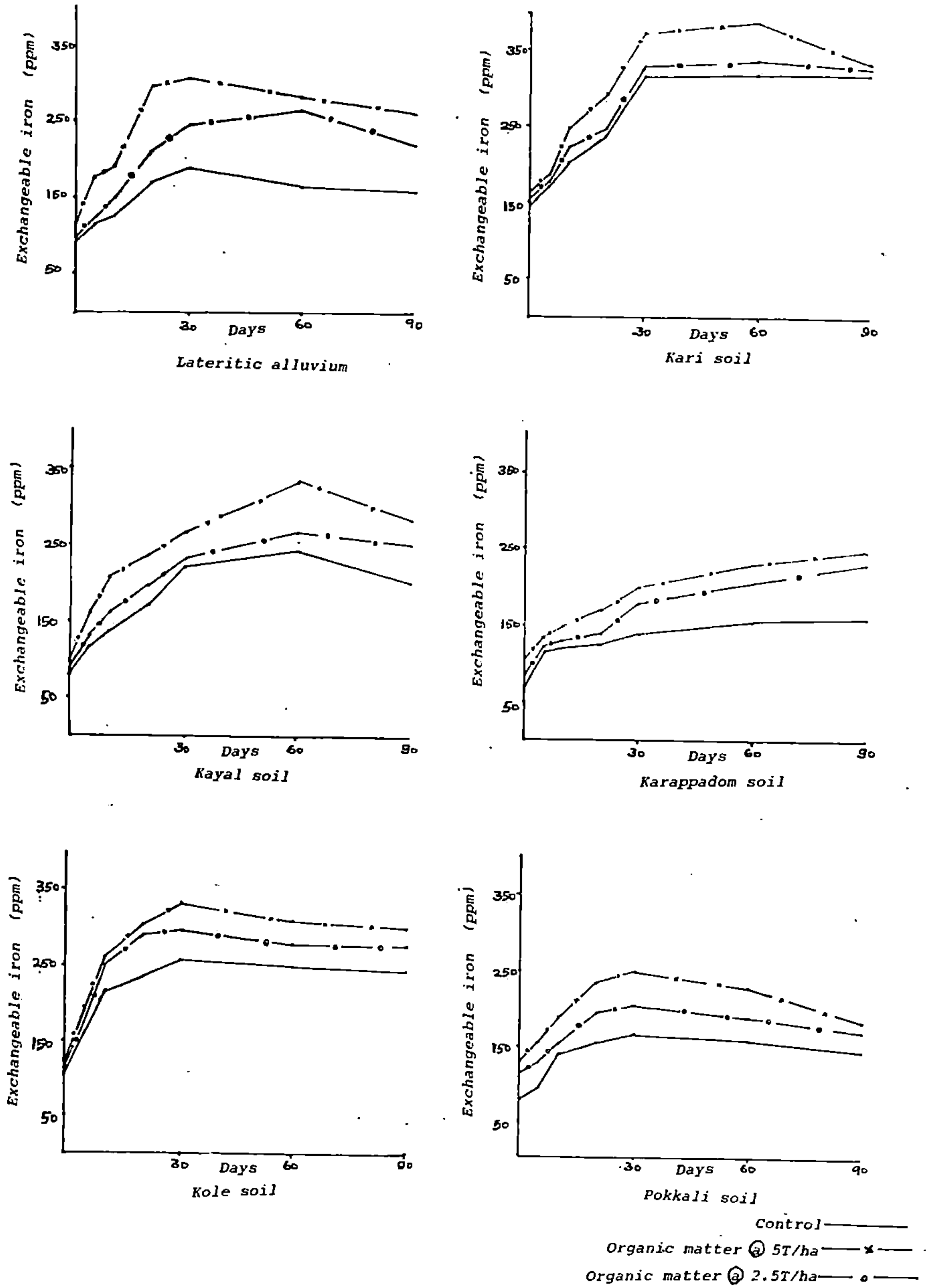


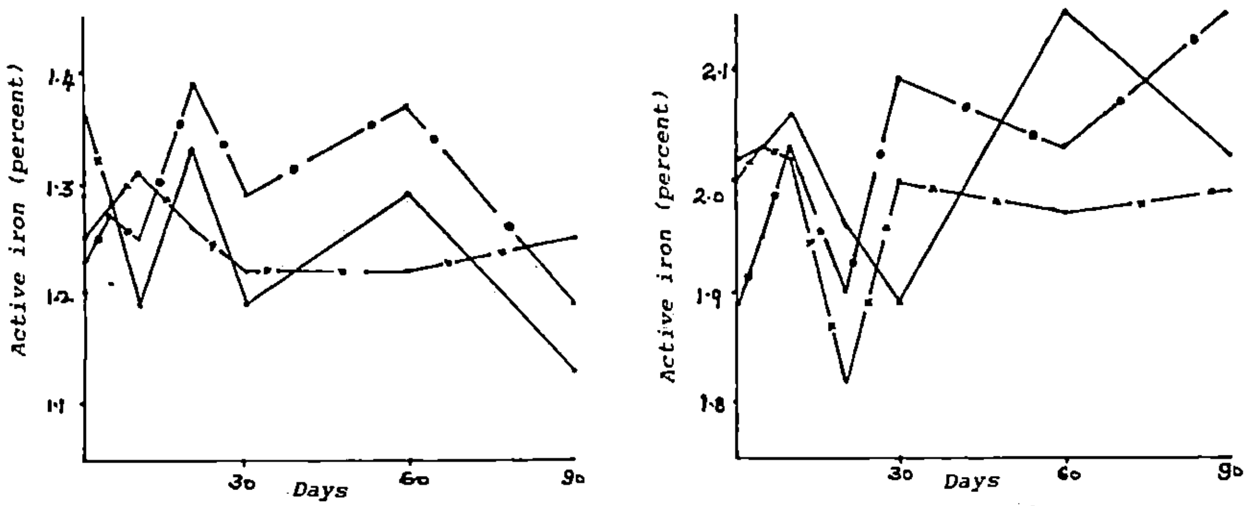
Fig.12 Mean content of exchangeable iron in soil under submergence as influenced by organic matter

in exchangeable iron contents from the lateritic alluvium, kari, kayal, karappadom, kole and pokkali soils under submergence in the presence of full dose of organic matter and half dose of organic matter applications were significantly higher than the control. The highest content was observed in kari soil, which might be due to its high clay content, high CEC, high organic matter content and low pH. However, the maximum release of exchangeable iron could be observed in the lateritic alluvium and the minimum in kari soil.

Addition of organic matter has been found to enhance the release of exchangeable iron which can be attributed to the nature of clay minerals present in the soils. The soils studied have mostly kaolinite type of clay wherein the exchange occurs only at edges and is rapid. The decreased concentration of exchangeable iron after the peak values may be due to subsequent physico-chemical changes occuring in soil colloids under the influence submergence and lesser microbial activity. Similar findings were reported by Jayaram and Nayar (1972) and Kabeerathumma (1975).

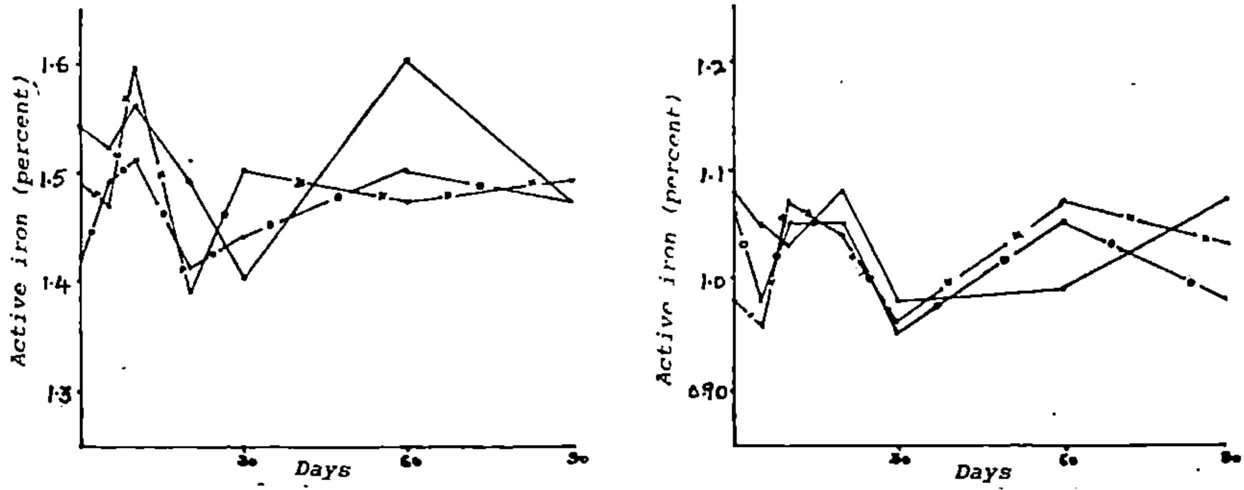
iv) Active iron

The mean active iron content under the influence of organic matter on submerged soils are given in Fig.13.



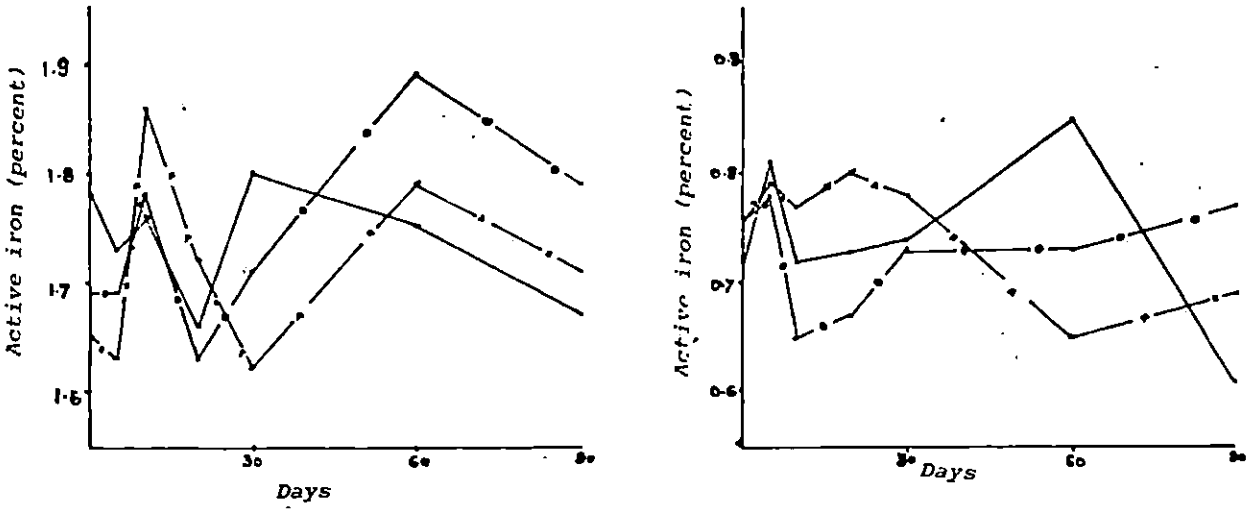
Lateritic alluvium

Kari soil



Kayal soil

Karappadom soil



Kole soil

Pokkali soil

Control ——

Organic matter @ 5T/ha —•—

Organic matter @ 2.5T/ha —×—

Fig.13 Mean content of active iron in soil under submergence as influenced by organic matter

Table 16 Effect of treatments on the pH of soils under submergence

Soils	Treatment *	Days of submergence						
		0	5	10	20	30	60	90
Lateritic alluvium	T_0	5.5	5.9	6.3	6.4	6.4	6.4	6.4
	T_1	5.6	6.5	6.4	6.6	6.4	6.3	6.2
	T_2	5.6	6.3	6.2	6.2	6.1	6.0	6.0
	T_3	5.4	4.9	5.4	6.0	6.0	6.0	6.0
	T_4	5.5	5.1	5.7	6.1	6.0	6.2	6.1
Kari	T_0	3.5	3.8	4.4	4.6	4.8	4.9	5.0
	T_1	3.6	4.8	5.4	5.6	5.4	5.0	5.0
	T_2	3.7	4.3	4.8	5.4	5.1	5.0	5.0
	T_3	3.4	3.2	4.1	4.2	4.6	5.0	5.0
	T_4	3.4	3.3	4.3	4.5	4.9	5.0	5.1
Kayal	T_0	4.5	4.8	4.9	5.3	5.3	5.5	5.4
	T_1	4.5	6.2	6.2	5.9	5.6	5.6	5.6
	T_2	4.6	5.7	5.8	5.2	5.1	5.4	5.6
	T_3	4.4	4.2	4.8	5.1	5.3	5.4	5.4
	T_4	4.4	4.3	4.9	5.3	5.4	5.6	5.5

Contd....

Table 16 Contd....

Soils	Treatment*	Days of submergence						
		0	5	10	20	30	60	90
Karappadom	T_0	4.9	5.2	5.4	5.2	5.6	5.6	5.2
	T_1	4.9	6.3	6.0	5.8	5.8	5.5	5.5
	T_2	5.0	5.5	5.0	5.0	5.5	5.4	5.2
	T_3	4.8	4.4	5.1	5.6	5.2	5.0	5.0
	T_4	4.9	4.5	5.2	5.8	5.8	5.8	5.6
Kole	T_0	4.5	4.6	5.1	5.6	5.7	6.0	6.0
	T_1	4.6	6.0	6.0	6.0	5.8	5.9	5.9
	T_2	4.5	5.8	5.8	5.6	5.8	6.2	6.0
	T_3	4.4	4.1	4.9	5.4	5.6	6.0	5.9
	T_4	4.5	4.3	5.0	5.8	5.7	6.0	6.0
Pokkali	T_0	4.4	4.6	5.0	5.2	5.4	5.6	5.4
	T_1	4.5	6.2	6.0	5.9	5.6	5.2	5.3
	T_2	4.6	5.6	5.9	5.9	5.4	5.2	5.1
	T_3	4.3	4.1	4.6	5.1	5.6	5.4	5.2
	T_4	4.4	4.2	4.9	5.4	5.7	5.3	5.1

* T_0 - Control
T_1 - Lime at full LR
T_2 - Lime at half LR
T_3 - Organic matter at 5 t/ha
T_4 - Organic matter at 2.5 t/ha

Table 17 Effect of treatments on the mean content of the major forms of iron in soils under submergence

Treatment	Water soluble iron (ppm)	Exchangeable iron (ppm)	Active iron (%)
T_0	33.2	156.7	1.38
T_1	20.2	94.7	1.39
T_2	24.2	116.2	1.38
T_3	39.3	216.1	1.37
T_4	35.0	184.1	1.36
$F_{(4,30)}$	364.72^{**}	1676.55^{**}	0.44
CD	1.20	3.48	0.10

Table 18 Effect of interaction - Treatment and period of submergence on the mean content of water soluble iron in soils (ppm)

Treatment	Period in days						
	0	5	10	20	30	60	90
T_0	26.3	29.8	34.5	38.8	36.0	34.4	32.9
T_1	14.6	13.9	17.6	22.6	26.0	23.8	22.5
T_2	18.0	16.1	23.3	28.2	30.8	26.6	24.3
T_3	32.9	36.9	40.3	43.3	44.7	40.9	36.3
T_4	29.6	32.4	35.3	38.5	39.8	36.0	33.5

$F_{(24,180)} = 10.12^{**}$

CD = 1.37

Table 19 Effect of interaction - Treatment and period of submergence on the mean content of exchangeable iron in soils (ppm)

Treatment	Period in days						
	0	5	10	20	30	60	90
T_0	93.0	118.3	139.8	164.3	196.0	198.0	187.5
T_1	53.8	61.8	89.7	101.3	116.1	116.3	123.7
T_2	71.8	82.3	108.2	123.6	135.8	146.0	146.7
T_3	130.5	158.0	187.2	237.7	269.8	279.3	250.3
T_4	106.8	122.1	156.2	195.4	233.3	246.0	229.0

$F_{(24,180)} = 31.98^{**}$

CD = 7.43

Table 20 Effect of interaction - Treatment and period of submergence on the mean content of active iron in soils (per cent)

Treatment	Period in days						
	0	5	10	20	30	60	90
T_0	1.40	1.40	1.39	1.37	1.33	1.44	1.33
T_1	1.41	1.39	1.41	1.35	1.37	1.44	1.40
T_2	1.39	1.39	1.39	1.34	1.37	1.39	1.41
T_3	1.34	1.36	1.38	1.34	1.37	1.43	1.39
T_4	1.37	1.36	1.44	1.34	1.35	1.36	1.36

$F_{(24,180)} = 1.30$

Table 21 Effect of interaction - Soils under submergence and treatment on the mean content of water soluble iron (ppm)

Soils	Treatments				
	T_0	T_1	T_2	T_3	T_4
1. Lateritic alluvium	29.4	17.3	19.7	34.1	30.2
2. Kari	39.5	22.4	28.0	48.7	42.1
3. Kayal	36.9	19.6	24.7	41.4	38.5
4. Karappadom	31.1	20.1	25.0	35.9	33.0
5. Kole	31.7	23.3	27.4	38.4	34.0
6. Pokkali	30.7	18.4	22.3	38.6	35.1

$F_{(20,30)} = 4.50^{**}$

CD = 2.94

Table 22 Effect of interaction - Soils under submergence and treatment on the mean content of exchangeable iron (ppm)

Soils	Treatments				
	T_0	T_1	T_2	T_3	T_4
1. Lateritic alluvium	145.0	58.8	75.3	237.9	185.5
2. Kari	242.9	126.7	177.9	281.4	251.0
3. Kayal	165.0	88.1	107.0	225.6	180.7
4. Karappadom	124.4	92.4	110.4	172.6	152.4
5. Kole	127.1	106.4	115.9	182.2	169.2
6. Pokkali	135.8	95.6	110.6	196.6	165.8

$F_{(20,30)} = 44.34^{**}$

CD = 8.52

Table 23 Effect of interaction - Soils under submergence and treatment on the mean content of active iron (per cent)

Soils	Treatments				
	T_0	T_1	T_2	T_3	T_4
1. Lateritic alluvium	1.23	1.27	1.29	1.28	1.27
2. Kari	2.02	2.01	2.03	2.01	1.98
3. Kayal	1.51	1.52	1.46	1.46	1.49
4. Karappadom	1.04	1.05	1.04	1.02	1.02
5. Kole	1.74	1.72	1.72	1.74	1.71
6. Pokkali	0.74	0.78	0.75	0.73	0.75

$F_{(20,30)} = 0.93$

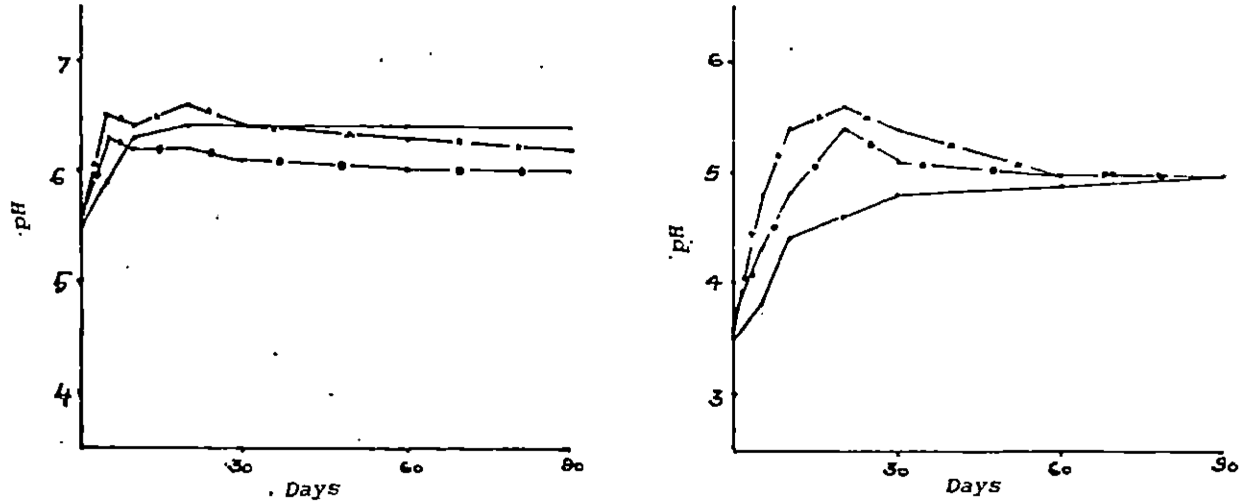
The content of this form remained without any significant change under the influence of organic matter throughout the period of submergence (Table 17). The interaction between treatment and period of submergence (Table 20) and treatment and soils (Table 23) also showed no significant change in content of this form due to application of both levels of organic matter. This is in agreement with the findings of Singh and Patiram (1975), Mitra and Mandal (1983) and Thind and Chahal (1986).

2. Liming

The results relating to the effect of two levels of lime. viz., full lime requirement and half lime requirement, on soil reaction and forms of iron with period of submergence are discussed below.

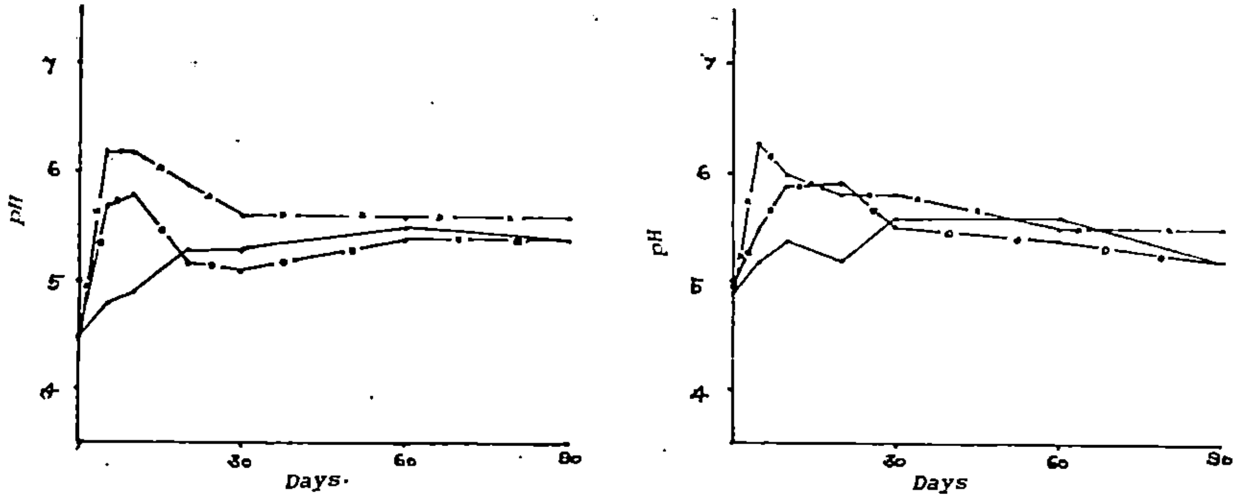
i) Soil reaction

The influence of levels of lime on the pH changes in soils under submergence is given in Table 16 and Fig.14. It was found that, in general, liming increased the soil pH in all the soils between 5th and 10th day of submergence except in kari soil. Higher level of lime brought about greater increases in soil pH compared to the lower level. However, in kari soil, the initial pH of 3.6 increased to 5.6 on the 20th day of submergence under the



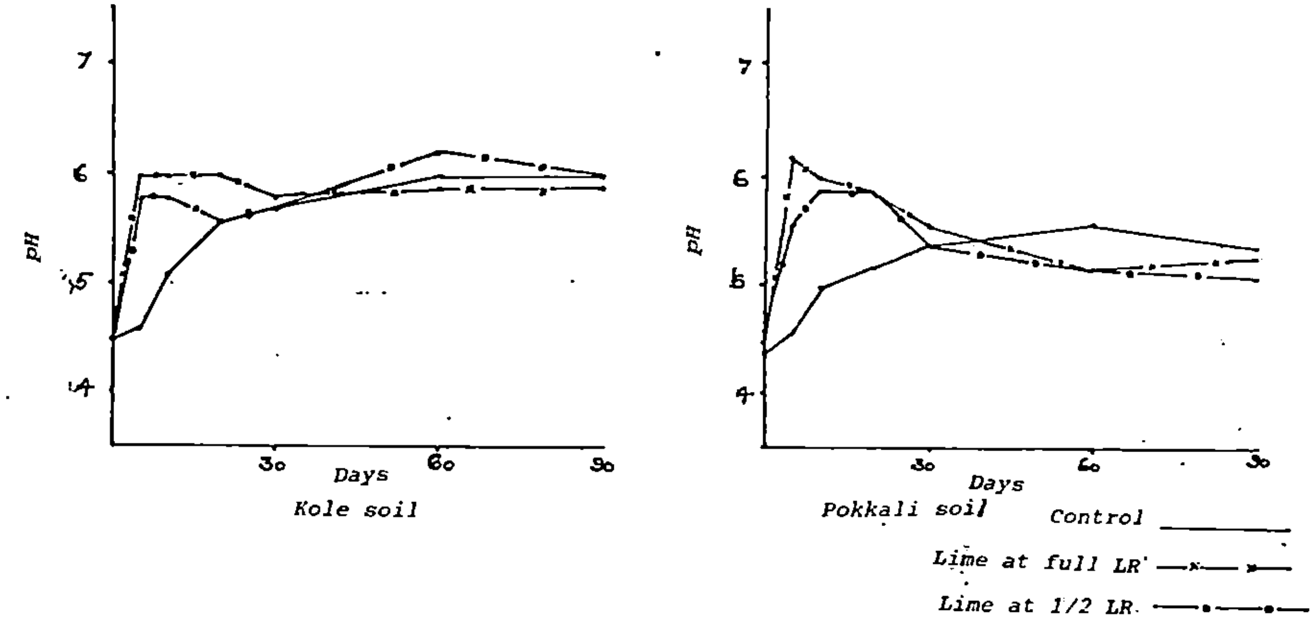
Lateritic alluvium

Kari soil



Kayal soil

Karappadom soil



Kole soil

Pokkali soil

Fig.14 Effect of lime on the pH of soil under submergence influence of higher level of lime and thereafter decreased gradually. The lower level of lime also caused a gradual increase in pH from 3.7 to 5.4 on the 20th day. In other soils maximum increase in pH were noticed around the 10th day.

The usefulness of lime as an ameliorant for the acid lateritic low land rice soils is well known. In the soils under study the kari soil, being the most acidic, has taken 20 days to reach the maximum rise in pH in presence of lime, while in other soils, maximum pH was noticed on the 10th day of submergence, after which the pH decreased. The higher CEC and buffer capacity of the kari soil might have contributed to this longer period for attaining the maximum pH and subsequent slow decreases thereafter. The beneficial effect of lime on soil was also reported by Ponnamperuma (1960), Subramoney (1961), Mandal (1961), Nhung and Ponnamperuma (1966), Sahu (1968), Kabeerathumma (1975), Van Breemen and Moorman (1978), Ponnamperuma and Solivas (1981), Kabeerathumma and Patnaik (1982) and Bishnoi et al. (1988).

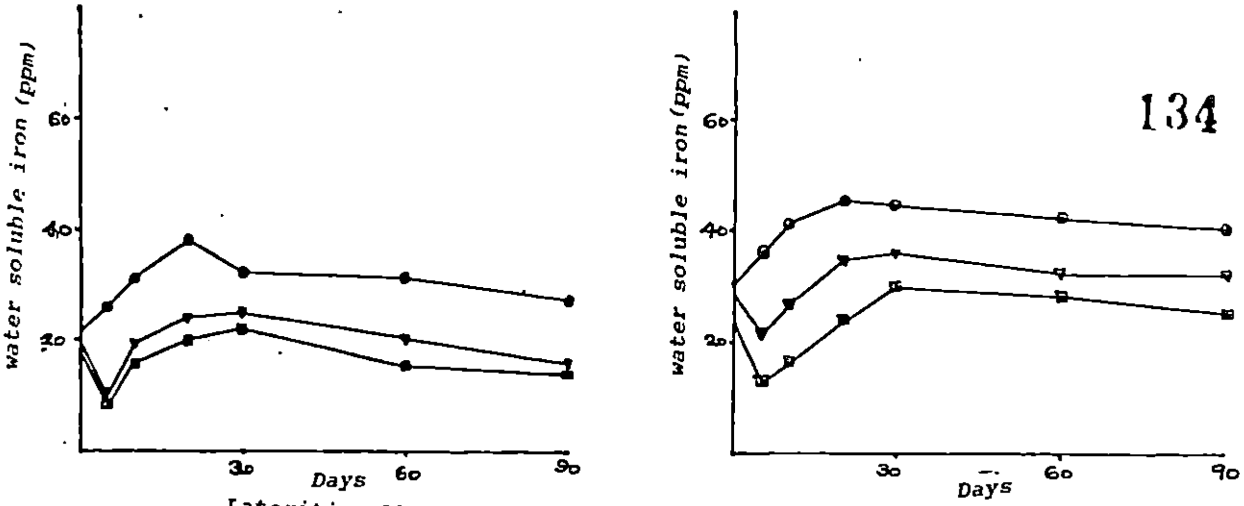
ii) Water soluble iron

Fig.15 which gives the water soluble iron in the soils under submergence indicates that while submergence alone could increase the contents, liming resulted in its suppression. Higher level of lime could bring about greater decrease in the water soluble iron content compared to the lower level of lime.

It may be seen from the mean Table 17 that liming at half LR level resulted in significant decrease of water soluble iron from 33.2 ppm to 24.2 ppm and full LR level could reduce the iron content to 20.2 ppm. The decrease in water soluble iron resulting from liming the soils at full LR level was also significant over control and the half LR level.

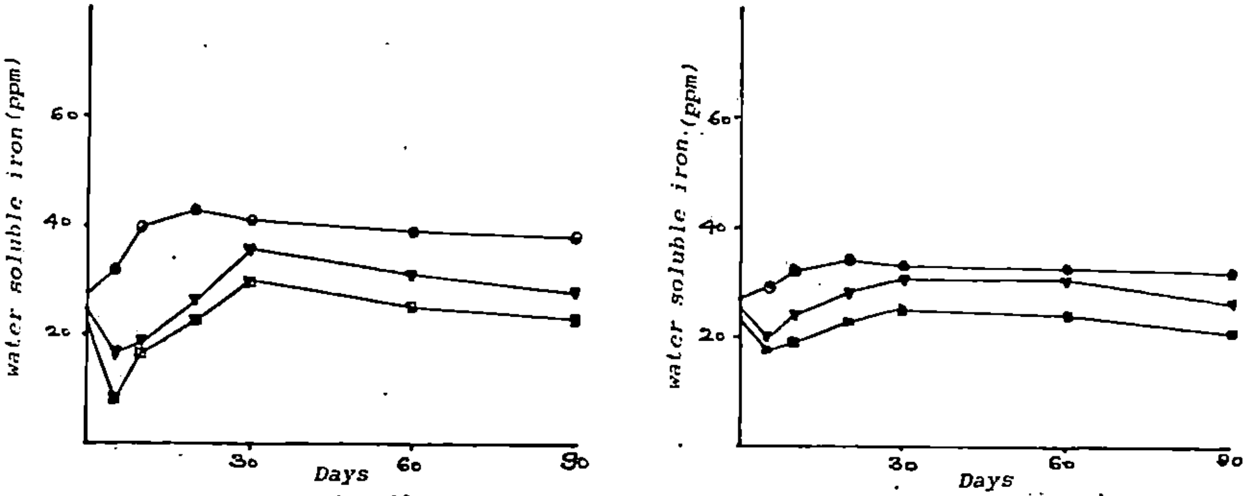
The interaction effect of treatment and period of submergence of soils on the iron release is given in Table 18. It could be seen that while increases in iron concentration were noted in control treatment from the zero day submergence upto the 20th day followed by decreases thereafter, the lime treated soils showed decrease in iron content upto the 5th day (first sampling period) followed by increases upto the 30th day. The content thereafter decreased with further period of submergence. The increases in soluble iron brought about under the influence of submergence in lime treated soils were always significantly less than in the control pots during the entire period. The water soluble iron released in the soils treated with lime at full LR level on the 5th day of submergence was 13.9 ppm and with lime at half LR level was 16.1 ppm while the control recorded 29.8 ppm. It could be seen that the reduction brought about by the full LR and half LR levels of lime were 53.3 per cent and 45.9 per cent respectively over the control. On the 10th day of submergence the iron concentration in the control treatment was 34.5 ppm while the full LR level lime treatment registered 17.6 ppm and half LR level lime treatment registered 23.3 ppm which was 48.9 per cent and 32.5 per cent respectively over the control. While submergence alone resulted in the maximum mean release of 38.8 ppm of water soluble iron on the 20th day, the soils treated with full LR level of lime resulted in the release of 22.6 ppm during this period and further increased to a peak value of 26.0 ppm on the 30th day after which decreases could be noticed. Liming at half LR level also resulted in the progressive increase in water soluble iron content to 28.2 ppm on the 20th day and a maximum of 30.8 ppm on the 30th day followed by decreases in iron concentrations with further periods of submergence.

Table 21 indicates the effect of interaction between soils and treatments. Significant differences could be noticed between the soils in relation to the release of iron under submergence. Lateritic alluvium



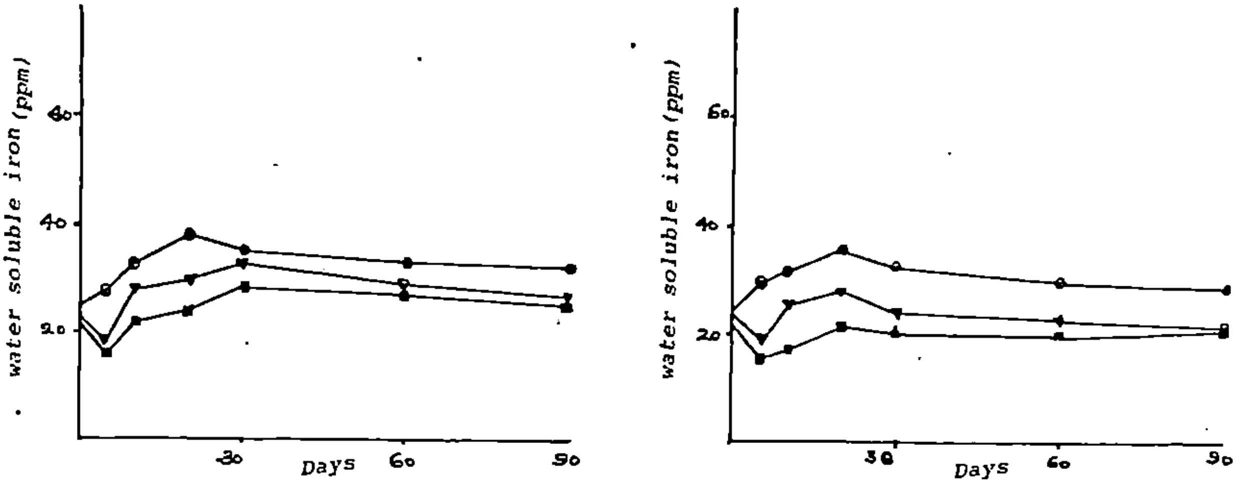
Lateritic alluvium

Kari soil



Kayal soil

Karappadom soil'



Kole soil

Pokkali soil

Control ○

Lime at full LR □

Lime at 1/2 LR ▽

Fig.15 Mean content of water soluble iron in soil under submergence as influenced by lime.

treated with full LR lime level suppressed 12.1 ppm iron while with half LR level, the suppression was 9.7 ppm. Kari, kayal, karappadom, kole and pokkali soils could suppress the release of water soluble iron to 17.1, 17.3, 11.0, 8.4 and 12.3 ppm respectively when limed at full LR level. Half LR level of lime was found to suppress the releases of 9.7, 11.5, 12.2, 6.1, 4.3 and 8.4 ppm soluble iron in lateritic alluvium, kari, kayal, karappadom, kole and pokkali soils respectively. Maximum suppression of soluble iron could be observed in kayal and kari soil and minimum in kole soil.

The decrease in the content of water soluble iron on liming is primarily because of the increase in pH. The CaO added to soil gets converted to $Ca(OH)_2$ and releases OH^- ions. The increased pH also causes release of OH^- ions to soil solution. This OH^- ions combine with iron and precipitate as their hydroxides ($Fe_3(OH)_8$) or oxides ($Fe_3O_4.nH_2O$).

iii) Exchangeable iron

Fig.16 indicates that exchangeable iron content in the soil could be reduced by liming while submergence alone resulted in an increase in its content. Higher levels of lime could bring about significant decreases in the exchangeable iron content compared to the lower lime level. It may be seen from the mean Table 17 that liming at half LR level resulted in significant decrease in exchangeable iron from 156.7 ppm to 116.2 ppm while full LR level further reduced the exchangeable iron content to 94.7 ppm which was statistically significant over the half LR level and control.

The interaction effect of treatments and period of submergence of soils on the release of exchangeable iron from soils is given in Table 19. The exchangeable iron content increased with period of submergence in the control treatment upto the 60th day followed by decreases. The full LR and half LR levels of lime treated soils showed increases in exchangeable iron content upto the 90th day. However, the half LR lime treated soils showed a tendency to reach peak values on the 60th day which almost levelled off during subsequent period, while in the full LR lime treated soils, continuous increase in exchangeable iron content could be seen. The increases in exchangeable iron content brought about by the influence of submergence in lime treated soils were always significantly less than the control during the entire period of submergence. The exchangeable iron released from soils treated with lime at full LR and half LR levels on the 5th day of

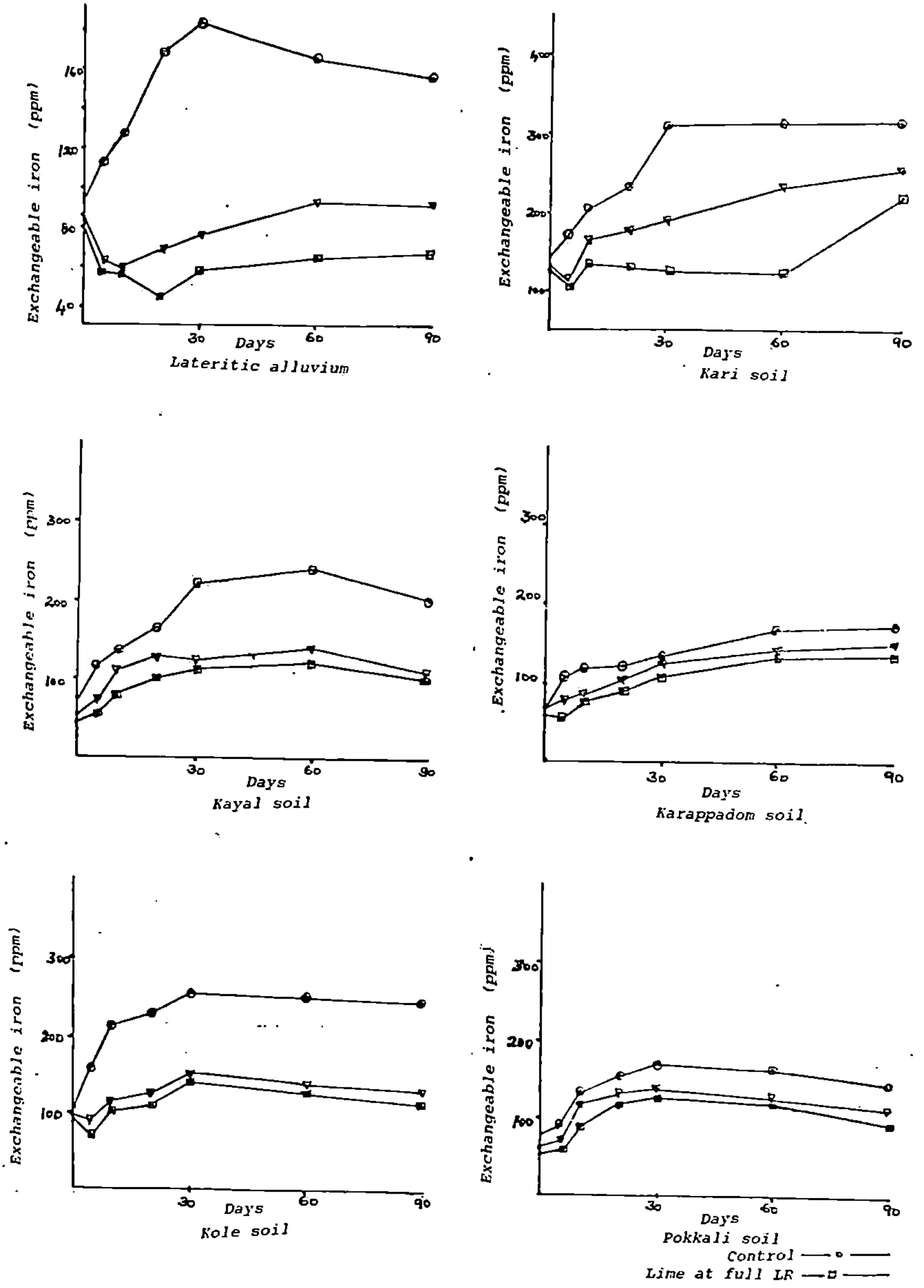


Fig.16 Mean content of exchangeable iron in soil under submergence as influenced by lime

submergence were 61.8 and 82.3 ppm respectively, while the release from the control pot was 118.3 ppm. The reduction brought about by liming at full LR and half LR levels were 47.7 per cent and 30.4 per cent respectively, over the control. Submergence alone resulted in the maximum mean release of 198.0 ppm of exchangeable iron on the 60th day, followed by a significant decrease of 187.5 ppm on 90th day. However, in the soils treated with full LR and half LR levels of lime, the exchangeable iron content progressively increased to 116.3 ppm and 146.0 ppm respectively on the 60th day followed by significant increase to 123.7 ppm in the full LR lime treatment and almost same content in the half LR treatment on the 90th day.

Table 22 gives the effect of interaction between soils and treatments. Significant differences could be noticed between the soils in relation to release of exchangeable iron under submergence. The lateritic alluvium, kari, kayal, karappadom, kole and pokkali soils could suppress the release of exchangeable iron to 86.2, 116.2, 76.9, 32.0, 20.7 and 40.2 ppm respectively at full LR level. Half LR level of lime was found to suppress the exchangeable iron release to 69.7, 65.0, 58.0, 14.0, 11.2 and 25.2 ppm in the lateritic alluvium,

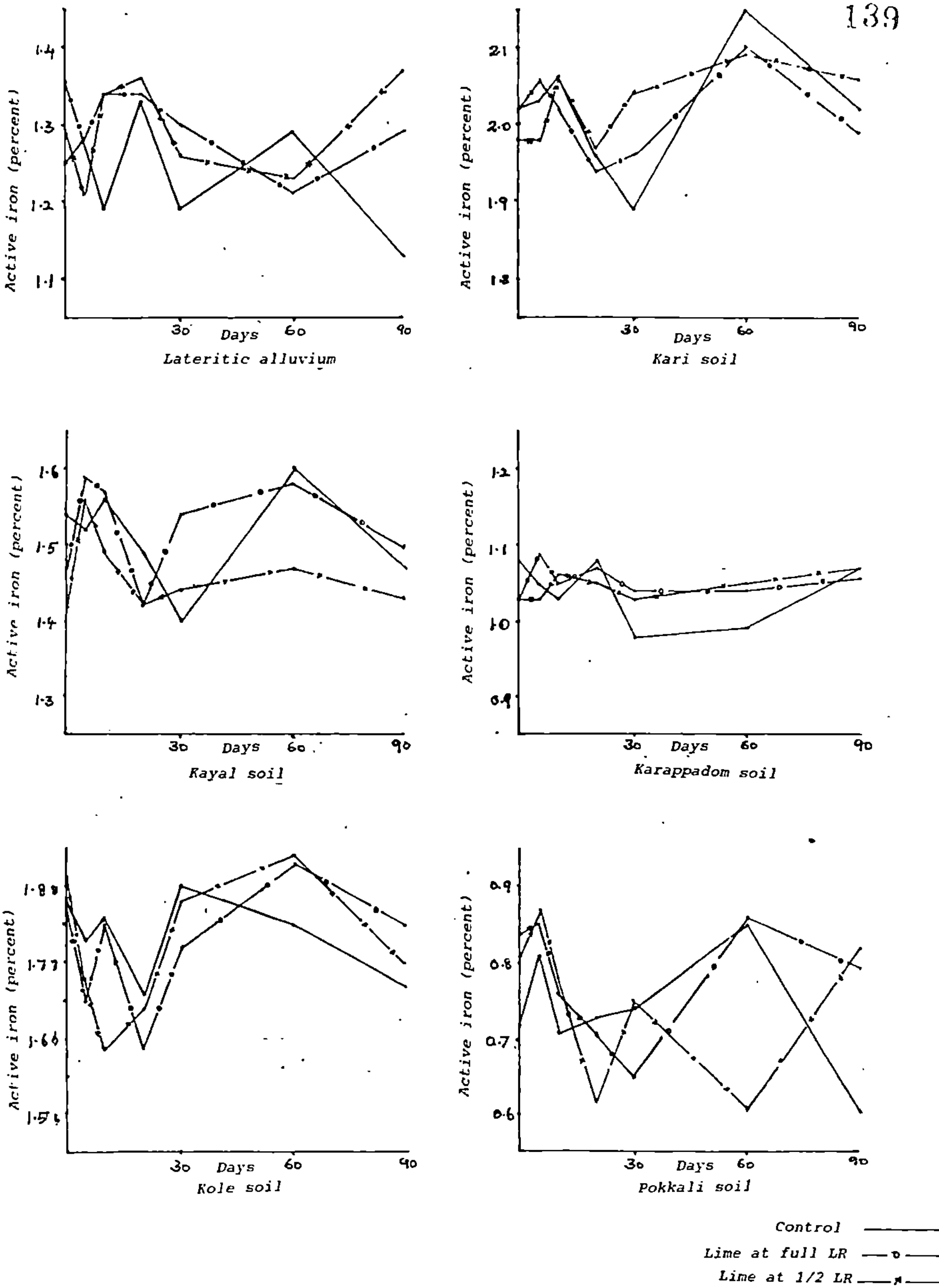


Fig.17 Mean content of active iron in soil under submergence as influenced by lime

kari, kayal, karappadom, kole and pokkali soils respectively. Maximum suppression of exchangeable iron was observed in kari soil and minimum in kole soil.

The decrease in content of exchangeable iron by liming can be attributed to the displacement of Fe^{2+} by Ca^{2+} ions from clay lattice. The OH^- ions present in the soil solution from $Ca(OH)_2$ due to high pH react with Fe^{2+} and precipitate as oxides $(Fe_3O_4 \cdot nH_2O)$ and hydroxides $(Fe_3(OH)_8)$. Similar findings have also been reported by Ponnamperuma (1960), Vaculik (1963) and Kabeerathumma (1975).

iv) Active iron

Fig.17 gives variations in active iron content due to submergence. The mean content of active iron in soils due to lime treatment given in Table 17 indicated no significant change. The variation in content of this form due to the interaction between treatments and period of submergence (Table 20) and treatments and soils (Table 23) also showed no significant variations in content.

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

A study was undertaken to assess the different forms of iron, their distribution, dynamics under submergence and the effect of management practices such as addition of organic matter and lime on the major forms of iron in the six acid rice soils of Kerala viz., lateritic alluvium of the Vellayani wet land, kari, kayal, karappadom soils of Kuttanad, kole soils of Trichur and pokkali soils of Vytilla. The physico-chemical characteristics of these soils were also studied along with the correlation of some of these characteristics with the forms of iron. The different forms of iron studied were water soluble, exchangeable, active, free iron oxide, total amorphous, amorphous organic, amorphous inorganic and crystalline forms in addition to total iron.

The major findings from the above study are summarised below:

The profile studies on the different rice soil types revealed the following results.

1. In the lateritic alluvium, pH remained steady throughout the profile, electrical conductivity increased upto II layer, organic carbon increased

upto the III layer CEC increased upto the II layer and the total iron and aluminium decreased with depth.

2. In kari soil, the pH showed a slight decrease with depth. Electrical conductivity was steady upto the III layer and decreased with further depth. The organic carbon showed progressive increases with depth. The CEC, total iron and aluminium decreased with depth.

3. In kayal soil, pH decreased with depth except for the slight increase in the II layer. The electrical conductivity increased with depth while the organic carbon content, total iron and aluminium decreased. Much variation could not be observed in CEC.

4. In Karappadom soil, the pH, electrical conductivity, CEC and organic carbon decreased with depth. However, the total iron showed a slight increase and the aluminium content remained almost steady with depth.

5. In kole soil, the pH was steady throughout the profile. The organic carbon content increased down the profile while the CEC, total iron and aluminium showed decreasing trends.

6. In pokkali soil, the electrical conductivity registered very high values throughout the profile. Organic carbon increased slightly with depth while CEC, total iron and total aluminium decreased.

The study of the surface soils of the different soil types revealed the following results:

7. Among the six soils studied, lateritic alluvium had the highest content of coarse sand and fine sand, karappadom had the highest silt and kari had the highest clay content.

8. The kari soil had the lowest pH and the highest content of organic carbon, CEC and electrical conductivity.

9. Water soluble iron content was maximum in kari soil. The other five soils had almost similar contents, but less than kari soil. A significant negative correlation was noticed with pH and positive correlation with clay content, organic matter and CEC of the soil.

10. Exchangeable iron content in the six soils varied from 74 to 129 ppm with the highest in kari and least in karappadom soils. A significant positive correlation with clay content, CEC, organic carbon and a significant negative correlation with pH existed.

11. The active iron content among the six soils varied from 0.82 to 1.72 per cent with the highest content in kari soil. A significant positive correlation existed between this form and organic carbon and a non-significant but positive correlation with electrical conductivity.

12. The free iron oxide content was maximum in kari soil with 0.69 per cent and minimum in pokkali with 0.47 per cent. A non-significant positive correlation with clay content could be observed.

13. Total amorphous iron was found to be the highest in kari soil (0.45 per cent), while the pokkali soil registered the lowest value of 0.27 per cent. A positive correlation with organic carbon could be observed.

14. Amorphous organic iron was the highest in kari soil and the least in lateritic alluvium. Significant positive correlation with organic carbon was observed.

15. Kari and kayal soil had the highest content of amorphous inorganic iron while pokkali soil registered the least content.

16. Crystalline iron was the highest in the lateritic alluvium with 0.30 per cent and lowest in karappadom soil with 0.15 per cent.

17. Total iron content was maximum in kole soil with 6.38 per cent and minimum in the karappadom soil with 2.45 per cent.

In the incubation studies to find out the influence of length of submergence on soil reaction and different forms of iron, the following observations could be made.

18. The pH of the soil increased with time of submergence to reach peak value after a few days. It was found that a peak pH of 6.4 was attained on the 20th day of submergence in lateritic alluvium, 5.6 on 30th day in karappadom and 5.5, 6.0 and 5.6 on 60th day in kayal, kole and pokkali soils respectively. However, kari soil, which had an initial pH of 3.5 showed only slow increases and only a pH of 5.0 was attained even on 90th day.

19. Water soluble iron content increased and attained the maximum content of 37.5, 45.0, 43.0, 33.5, 38.0 and 36.0 ppm on 20th day of submergence of lateritic alluvium, kari, kayal, karappadom, kole and pokkali soils from an initial content of 22.5, 30.0, 28.0, 27.0, 26.0, and 25.0 ppm respectively.

20. Exchangeable iron increased significantly under the influence of submergence. The highest content was observed in kari soil. While lateritic alluvium, kole and pokkali soils showed increases upto the 30th day of submergence, kari and kayal soils recorded the highest value on the 60th day. Karappadom soils,

however, showed a steady increase in content throughout the period of submergence.

21. Submergence had no significant influence on the active iron and free iron oxide contents of the soil.

22. Total amorphous, amorphous organic and amorphous inorganic forms of iron increased under the influence of submergence.

23. Crystalline iron content decreased with the period of submergence. The decrease continued upto 90th day in lateritic alluvium. In kari, kayal and kole soils, the decrease continued upto the 30th day, while in karappadom and pokkali soils the decrease continued upto 60th day, after which the content remained steady in both the cases.

24. The addition of organic matter at the rate of 5 t/ha and 2.5 t/ha decreased the pH of the soil upto the 5th day of submergence after which increased towards neutrality. The lowering of pH was more in the higher level of organic matter treatment.

25. Water soluble and exchangeable iron contents significantly increased due to the addition of organic matter. The increase due to higher level of organic matter treatment was significantly higher than that of the lower level.

26. Active iron remained unaltered by the organic matter treatment.

27. Liming at full LR and half LR levels resulted in sharp increase in the soil pH between the 5th and 10th day of submergence in all the soils, except in kari soil where the peak value could be observed only on the 20th day.

28. Water soluble iron and exchangeable iron contents decreased due to liming. Liming at full LR significantly decreased their content compared to the lowest level.

29. Active iron remained almost steady for the lime treatments during the 90 days period of study.

The study has thus enabled a better understanding on the effect of submergence on the different forms of iron, relationship between the different forms of iron and soil chemical characteristics and the effect of levels of organic matter and lime on the changes in pH, water soluble, exchangeable and active forms of iron in soils under submergence.

These basic studies highlight the need for further detailed work on the several aspects of iron dynamics in submerged acid rice soils as indicated below:

(i) Effect of alternate wetting and drying on the variation in the available forms of iron and other micro-nutrients in Kuttanad rice soils

(ii) Effect of zinc, manganese and silicate on the available forms of iron during submergence

(iii) Critical level of iron in soil for toxicity to rice crop in wet lands

(iv) Effect of different liming materials and other soil ameliorants and their optimum doses in controlling iron to below the toxic level for rice in iron toxic soils

(v) Role of active iron on the release of plant available forms of iron during prolonged submergence.

REFERENCES

REFERENCES

Abichandani, C.T. and Patnaik, S. (1957). Analysis of wet rice soils. Joint working party meeting of the Int. Rice Comm., Vercelli, Italy. pp.5.

Agarwala, S.C. and Sharma, C.P. (1976). Plant nutrients - their function and uptake. In "Soil Fertility - Theory and Practices", publised by ICAR, New Delhi. pp.7-64.

Aiyer, R.S., Rajagopal, C.K. and Money, N.S. (1975). Available zinc, copper, iron and manganese status of the acid soils of Kuttanad, Kerala State. Agric. Res. J. Kerala., **13** : 15-19.

Allaway, W.H. (1957). pH, soil acidity and plant growth. In "Soil". Year Book of USDA. pp. 67-71.

Arulandoo Xavier (1981). Management of acid sulphate soils in the Muda irrigation Scheme, Kedah, Penninsular Malaysia. Proc. Bangkok Symp. Acid sulphate soils., 18-24 Jan. 1981. Ed. N. Dost and N. Van Breemen.

Asami, T. and Kumada, K. (1959). A new method for estimating free iron in paddy soils. Soils and Plant Food, **5** : 141-146.

Bandyopadhyay, B.K. and Bandyopadhyay, A.K. (1984). Transformation of iron and manganese on coastal saline soil. J. Indian Soc. Soil Sci., **32** : 57-61.

* Bao Xuo-ming., Zhu Kuang Liu., Chun Wu and Tian-ren, Yu. (1964). Studies on oxidation - reduction processes in paddy soils. 7. Forms of ferrous iron. Acta Pedologica Sinica, 12 : 297-306 (in Chinese).

Bertic, B., Vukadinovis, V., Kovacevic, V. and Juric, I. (1988). Influence of liming on soil acidity and iron availability. Journal of plant nutrition, 11 : 1361-1367.

Bishnoi, S.K., Tripathi, B.R. and Sharma, P.K. (1988). Studies on liming of acid soils of Himachal Pradesh. J. Indian Soc. Soil Sci., 36 : 257-263.

* Biswas, T.D. (1953). J. Indian Soc. Soil Sci., 1 : 21.

Chakravorty, S.N. and Kar, A.K. (1970). Effect of water logging on redox potential, available P and pH in some Indian acid soils. J. Indian Soc. Soil Sci., 18 : 249-258.

* Coulter, J.K. (1973). Proc. Int. Symp. Acid Sulphate Soils., 1 : 353.

De, S. and Banerjee, S.K. (1977). Effect of different nitrogenous substance on pH and availability of iron and Mn in some soils under two moisture regimes. Indian Agriculturist, 21 : 99-106.

Dolui, A.K., Chandran, P., Nayik, A.K. (1988). Studies on status of iron and aluminium in some Terai and Teesta alluvial soils of West Bengal. Proceedings of the Indian National Science Academy, B (Biological Sciences), 54 : 81-87.

Dubey, D.D., Khedkar, S., Sharma, O.P. (1983). Forms of iron in salt affected black soils of western part of MP. J. Indian Soc. Soil Sci., 31 : 320-24.

Fageria, N.K. (1988). Influence of iron on nutrient uptake by rice. International Rice Research News Letter, 13 : 20-21.

FAO (1978). Guide lines for soil descriptions. Soil survey and fertility branch, Rome.

* Fresneda, M.R.M., Romero, M., Fernandez, F.G. and Caro, M. (1979). Extraction of free iron oxides from calcareous soils with dithionite and oxalate in comparison with pyrophosphate extraction. Anales de Edafologia 4 Agrobiologia, 38 : 1339-1349.

Ghosh, R.C. and Banerjee, S.K. (1979). Distribution of different forms of iron in some soils of West Bengal. Indian Forester, 105 : 773-778.

Ghosh, S.N., Kar, A.K. and Dhua, S.P. (1976). Effect of sampling variation in Eh, pH, available P, Fe and Mn in submerged rice soil. J. Indian Soc. Soil Sci., 24 : 86-87.

Gotoh, S. and Patrick, W.H., Jr. (1974). Transformation of iron in a water logged soil as influenced by redox potential and pH. Soil Sci. Soc. Amer. Proc., 38 : 66-71.

Harmsen and Van Breemen, N. (1975). A model for the simultaneous production and diffusion of ferrous iron in submerged soils. J. Soil Sci. Soc. America. 39 : 1063-1068.

He Qun and Xu Zu-yi (1980). Influence of transformation of iron oxides on soil structure. Proc. symposium on paddy soils., Nanjing (China). pp.699-703.

Iri, H., Maruta, I., Takahashi, I. and Kubota, M. (1958). The variation of ferrous iron content in soil profiles under flooded conditions of rice field. (Part I). Soil and Pl. Food, 3 : 36-47.

IRRI (1964). Annual Report. Int. Rice Res. Inst., Los Banos, Manila, Philippines.

IRRI (1977). Annual Report. Int. Rice Res. Inst., Los Banos, Manila, Philippines.

Islam, M.A. and Elahi, M.A. (1954). Reversion of ferric iron to ferrous iron under water logged conditions and its relation to available phosphorus. J. Agric. Sci. Camb. 45 : 1-2.

Jackson, M.L. (1973). "Soil Chemical Analysis". Prentice Hall of India (P) Ltd., New Delhi.

Jaggi, T.K. and Russel, M.B. (1973). Effect of moisture regimes and green manuring on ferrous iron concentration in soil and growth and yield of paddy. J. Indian Soc. Soil Sci., 21 : 71-76.

Jayaram, N.S. and Nayar, P.K. (1972). Effect of organic matter on soil iron and manganese in newly developed rice growing areas of Thungabhadra Project Region. Mysore J. Agric. Sci., 6 : 34-37.

Jeffery, J.W.O. (1961). Defining the state of reduction of paddy soil. J. Soil Sci., 12 : 172-179.

Jones, U.S., Katyal, J.C. Mamaril, C.P. and Park, C.S. (1980). Paper presented at the special international symposium on Rice Research Strategies for the future held at IRRI, Philippines., April 21-25, 1980.

Jugsujinda, A., Delaune, R.D. and Patrick, W.H., Jr. (1987). A comparison of microbially and chemically reducible iron in three soils. Plant and Soil, 103 : 281-284.

Kabeerathumma, S. (1975). Chemistry of low productive acid lateritic and acid sulphate soils and their amelioration for growing rice. Ph.D. Thesis, Orissa University of Agriculture and Technology, Bhubaneswar.

Kabeerathumma, S. and Chithranjan Nair, N. (1973). Effect of liming on exchangeable cations and pH of acid soils of Kuttanad. Agri. Res. J. Kerala., 11 : 9-13.

Kabeerathumma, S. and Patnaik, S. (1982). Effect of flooding on the changes in lime potential of acid alluvial, red and laterite soils growing rice. J. Indian Soc. Soil Sci., 30 : 275-278.

Kamala Devi, C.B., Wahid, P.A. and Pillai, N.G. (1974). Implication of changes on soil pH in the Al, Fe and Mn status of major coconut growing soils of Kerala. Agric. Res. J. Kerala., 12 : 28-35.

Kanwar, B.B., Tripathy, B.R. and Kanwar, B.S. (1986). Distribution of total and DTPA extractable iron in relation to soil properties in some soil profiles of north western Himalayas. Himachal Journal of Agricultural Research, 12 : 108-118.

Kanwar, J.S. and Randhawa, N.S. (1974). Micronutrient research in soils and plants in India. A review. Indian Council of Agricultural Research Tech. Bull. (Agric) No.50.

* Kapp, L.C. (1936). Study of the relation of growth to nutrition of the rice plant. Ark. Agric. Exp. Sta. Bull. No.335.

Karamova, L.A. (1978). General patterns of the ratio and distribution of iron in major genetic soil groups. Soviet Soil Science, 10 : 446-458.

Katyal, J.C. and Deb, D.L. (1982). Nutrient transformation in soils. In Review of Soil Research in India. Published by IARI, New Delhi. pp.150-151.

* Kaurichev, I.S., Sidorenko, O.D. and Savich, V.I. (1981). Oxidation reduction potential of meadow Chernozemic soils under rice. Izvestiya Timiryazevskoi Sel's Kokhozaistvennoi Akademii, 4 : 60-68.

Lindsay, W.L. (1984). Soil and plant relationships associated with iron deficiency with emphasis on nutrient interaction. Journal of plant nutrition, 7 : 489-500.

Loeppert, R.H., Hossner, L.R. and Chmielewski, M.A. (1984). Indigenous soil properties influencing the availability of iron in calcareous hot spots. Journal of plant Nutrition, 7 : 135-147.

* Lopes, M.S. (1987). Occurence of orange discolouration in irrigated rice. Lavoura Arrozeira, 40 : 28-29.

Mahapatra, I.C. (1968). Effect of flooding on soil reaction and immobilization of various nutrients. J. Indian Soc. Soil Sci., 16 : 149-153.

Mahendra Singh and Dahiya, S.S. (1975). Effect of $CaCO_3$ and iron on the availability of iron in a high textured soil. J. Indian Soc. Soil Sci., 23 : 247-252.

Mandal, L.N. (1961). Transformation of iron and manganese in waterlogged rice soils. Soil Sci., 91 : 121-126.

* Mandal, L.N. (1962). Levels of iron and manganese in soil solution and the growth of rice in water logged soils in relation to the oxygen status of soil solution. Soil Sci., 94 : 387-391.

Mandal, L.N. and Mitra, R.R. (1982). Transformation of iron and manganese in rice soils under different moisture regimes and organic matter application. Plant and Soil, 69 : 45 - 56.

Mandal, S.C. and Sinha, M.K. (1964). Effect of liming on Mn nutrition of crops in upland soils of Chotanagpur. *J. Indian Soc. Soil Sci.*, **12** : 405-409.

Mckeague, J.A. (1967). An evaluation of 0.1 M pyrophosphate and pyrophosphate - dithionite in comparison with oxalate as extractants of the accumulation products in podzols and some other soils. *Can. J. Soil Sci.*, **47** : 95-99.

McKeague, J.A., Brydon, J.E. and Miles, N.M. (1971). Differentiation of forms of extractable iron and aluminium in soils. *Proc. Soil Sci. Soc. America.*, **35** : 33-38.

McKeague, J.A. and Day, J.H. (1966). Dithionite and oxalate extractable Fe and Al as aids in differentiating various classes of soil. *Can. J. Soil Sci.*, **46** : 13-22.

Meek, B., Mackenzie, A. and Grass, L. (1968). Effect of organic matter, flooding time and temperature on the dissolution of Fe and Mn from soil insitu. *Soil Sci. Soc. Amer. Proc.*, **32** : 634-638.

Misra, S.G. and Pande, Padmakar (1975). Distribution of different forms of iron in soils of UP. *J. Indian Soc. Soil Sci.*, **23** : 242.

Mitra, R.R. and Mandal, L.N. (1983). Distribution forms of Fe and Mn in rice soils of West Bengal in relation to soil characteristics. J. Indian Soc. Soil Sci. 31 : 38-42.

Mohanty, S.K. and Patnaik, S. (1973). Nutrients limiting rice production in different soils. Indian J. Agric. Sci., 43 : 778-780.

* Motomura, S. (1962). The effect of organic matter on the formation of ferrous iron in soil. Soil Sci. and Pl. Nutr., Japan., 8 : 20-29.

Munch, J.C., Hillebrand, Th. and Ottow, J.C.G. (1978). Transformations in the Fe_o/Fe_d ratio of pedogenic iron oxides affected by iron reducing bacteria. Can. J. Soil Sci., 58 : 475-486.

Munch, J.C. and Ottow, J.C.G. (1980). Preferential reduction of amorphous to crystalline iron oxides by bacterial activity. Soil Science, 129 : 15-21.

Najeeb, P.H. (1989). Influence of forms of organic matter on the mineralisation of applied phosphorus in submerged rice soils. M.Sc.(Ag.) Thesis, Kerala Agricultural University.

Nhung, Mai-Thi.My. and Ponnamperuma, F.N. (1966). Effects of calcium carbonate, manganese di oxide $Fe(OH)_3$ and prolonged flooding on the chemical and electro chemical changes and growth of rice in a flooded acid sulphate soil. Soil Sci., 102 : 29-41.

Oades, J.M. (1963). The nature and distribution of iron compounds in soils. Soils Fert., 26 : 69-89.

Olomu, M.O., Racz, G.J. and Cho, C.M. (1973). Effect of flooding on the Eh, pH and concentration of Fe and Mn in several Mannitoba soils. Soil Sci. Soc. Amer. Proc., 37 : 220-224.

Olsen, R.V. (1965). Methods of soil analysis Part II. Edited by Black C.A. pp.963-973.

Olsen, R.V. and Carlson, C.W. (1949). Iron chlorosis in sorghum and trees as related to extractable soil iron and manganese. Soil Sci. Soc. Amer. Proc., 14 : 409.

Ottow, J.C.G. (1980). Mechanism of bacterial iron-reduction in flooded soils. Proc. Symp. Paddy Soils., Nanjing (China). pp.330-343.

Patel, G.R. and Dangarwala, R.T. (1983). Extractable iron in rice soils of South Gujarat. J. Indian Soc. Soil Sci., 31 : 638-640.

Pathak, A.N., Singh, R.K. and Singh, R.S. (1979). Effect of Fe and Mn interaction on yield, chemical composition and their uptake in crops. Fertilizer News, 24 : 35-40.

Patnaik, S. and Bhadrachalam, A. (1965). Effect of increased concentration of iron and manganese in the growth medium on grain yield and composition of indica rice. Indian J. Expt. Biol., 3 : 199-207.

Patra, B.N. and Mohanty, S.K. (1989). Effect of ammendments on transformation of Fe and Mn in Fe-Toxic rice soils under submergence. J. Indian Soc. Soil Sci., 37 : 276-283.

* Patrick, W.H., Jr. (1964). Trans. 8th Int. Congr. Soil Sci., 4 : 605-610. Acad. Socialist Rep., Roumania.

Patrick, W.H., Jr. and Henderson, R.E. (1981). Reduction and reoxidation cycles of Mn and Fe in flooded soils and in water solution. Soil Sci. Soc. Amer. Journal., 45 : 855-859.

Piper, C.S. (1966). Soil and Plant Analysis. Inter Science Publ., New York.

Pisharody, P.N. (1965). Forms and distribution of iron and manganese in rice soils of Kerala. M.Sc.(Ag) Thesis, University of Kerala.

* Ponnamperuma, F.N. (1955). The chemistry of submerged soils in relation to the growth and yield of rice. Ph.D. thesis. Cornell University, Ithaca, New York.

Ponnamperuma, F.N. (1960). The benefit of liming acid laterite rice soils of Ceylon. Trans. 7th Int. Congress of Soil Sci., Madison, Wisc., USA, III : 285-292.

Ponnamperuma, F.N. (1965). Dynamic aspects of flooded soils and the nutrition of the rice plant. In "The Mineral Nutrition of Rice". The John Hopkins Press, Baltimore, Maryland.

Ponnamperuma, F.N. (1967). A theoretical study of aqueous carbonate equilibria. Soil Sci., 103 : 90-100.

Ponnamperuma, F.N. (1972). The chemistry of submerged soils. Adv. Agron., 24 : 29-36.

Ponnamperuma, F.N. (1976). Specific soil chemical characteristics for rice production in Asia. IRRI Res. Pap. Ser. No.2.

Ponnamperuma, F.N. (1977). Physico-chemical properties of submerged soils in relation to fertility. IRRI Res. Pap. Ser. No.5.

Ponnamperuma, F.N. (1978). Electro chemical changes in submerged soils and the growth of rice. In "Soil and Rice" pp. 421-441. IRRI, Los Banos, Philippines.

Ponnamperuma, F.N. (1980). Some aspects of the physical-chemistry of paddy soils. Proc. Symp. Paddy Soils., Nanjing (China). pp.59-94.

Ponnamperuma, F.N. (1984). Effects of flooding on soils. In "Flooding and plant growth". Edited by Kozlowski, T.T., Academic Press, New York.

Ponnamperuma, F.N., Attanandana, T. and Beye, G. (1973). Amelioration of three acid sulphate soils for low land rice. Proc. Int. Symp. Acid Sulphate Soils., Wageningen. 2 : 391-406.

Ponnamperuma, F.N. and Castro, R.U. (1964). Redox systems in submerged soils. Trans. 8th Int. Congr. Soil Sci., Bucharest, Romania, 3 : 379-386.

Ponnamperuma, F.N. and Solivas, J.L. (1981). Field amelioration of an acid sulphate soil for rice with MnO_2 and lime. Proc. Bangkok Symp. Acid Sulphate Soils., pp. 213-222.

Ponnamperuma, F.N., Tianco, E.M. and Loy, T.A. (1967). Redox equilibria in flooded soils I. The iron hydroxide system. Soil Sci., **103** : 374-382.

Rajagopal, C.K., Moosa Sheriff, M., Selvakumari, G. and Jebarani, W. (1977). Status of available micronutrient cations in the soils of Kerala. Agric. Res. J. Kerala., **15** : 165-171.

Ramasubramonian, P.R. (1989). Studies on the solubilisation of iron in submerged soils and methods to minimise its solubility and toxic concentration to paddy. Ph.D. Thesis, Kerala Agricultural University.

* Redman, F.H. and Patrick, W.H., Jr. (1965). Effect of submergence on several biological and chemical soil properties. Bull. La. Agric. Exp. Sta., No.592 : 28.

Sadana, U.S. and Takkar, P.N. (1985). Effect of salt, alkali and zinc on iron equilibrium in submerged soils. Journal of Agricultural Sciences, U.K. **104** : 275-279.

Sah, R.N. and Mikkelson, D.S. (1986). Effects of anaerobic decomposition of organic matter on sorption and transformation of phosphate in drained soils. 2. Effects of amorphous iron content and P transformation. Soil Sci., 142 : 346-351.

Sahu, B.N. (1968). Browning disease of rice in Orissa as influenced by soil type and manuring and its control. J. Indian Soc. Soil Sci., 16 : 41-54.

Sakal, R., Singh, A.P. and Singh, S.P. (1988). Distribution of available zinc, copper, iron and manganese to rice and wheat. J. Indian Soc. Soil Sci., 36 : 59-63.

Savant, N.K. and Kibe, M.M. (1971). Influence of continuous submergence on pH, exchangeable acidity in rice soils. Plant&Soil, 35 : 205-208.

Savant, N.K. and McClellan, G.H. (1987). Do iron oxide system influence soil properties and nitrogen transformation in soils under wet land rice based cropping system. Commun. in soil sci. Plant anal., 18 : 83-113.

Schoemaker, H.E., McLean, E.O. and Pratt, P.F. (1961). Buffer methods for determining lime requirements of soil with appreciable amounts of extractable aluminium. Soil Sci. Soc. Amer. Proc., 25 : 274-277.

Sharma, S.K. and Banerjee, S.K. (1983). Ferrous iron formation in presence of nitrogenous salts as influenced by moisture regimes of soils. J. Indian Soc. Soil Sci., 31 : 598-600.

Sharma, C.P. and Sharma, P.N. (1987). Mineral nutrient deficiencies affect plant water relations. Journal of Plant nutrition, **10** : 1637-1643.

Shavrova, T. Yu. (1984). Forms of iron compounds in podzolic and sod podzolic soils. *Moscow University. Soil Sci. Bullettin.*, **39** : 78-80.

* Silveira, P.M. Da., Ribeiro, A.C. and Costa, L.M.Da. (1987). Iron availability in submerged soils as affected by liming and water management. *Revistaceres*, 34 : 400-406.

Sims, J.L. and Patrick, W.H., Jr. (1978). The distribution of micro nutrient cations in soil under conditions of varying redox potential and pH. *Soil Sci. Soc. Amer. Journal.*, **42** : 258-262.

* Singh, S.S. (1964). *Soil Sci.*, **98** : 363.

Singh, S. and Patiram (1975). Distribution of iron in paddy soils of eastern UP. *J. Indian Soc. Soil Sci.*, **23** : 253-255.

Singh, S. and Patiram (1977). Changes in solubility of phosphorus and its availability to rice plant in the water logged soils. *J. Indian Soc. Soil Sci.*, **25** : 129-133.

Snell, F.D. and Snell, C.T. (1949). Colorimetric methods of analysis. Vol.2, D. Van Nostrand Co., New York, pp. 950.

* Socorro Quesada, U. and Bolomou, H.J.P. (1981). Dynamics of Fe, P_2O_5 and pH in flooded soils. Centro Agricola, 8 : 3-12.

Subramoney, N. (1960). Sulphur bacterial cycle : Probable mechanism of toxicity in acid soils of Kerala. (Note). Science and Culture, 25 : 637-638.

Subramoney, N. (1961). Studies on soils of Kuttanad : Part I. Toxic factors. Agric. Res. J. Kerala., 1 : 53.

Subramoney, N. and Kurup, T.K.B. (1960). Investigation on the phenomenon of scum formation in paddy soils of Kerala State. J. Indian Soc. Soil Sci., 9 : 253-256.

Subramoney, N. and Kurup, T.K.B. (1961). A physiological disease of paddy due to iron toxicity. Agric. Res. J. Kerala., 1 : 100.

Sukla, U.C., Gupta, B.L. and Raghbir Singh (1975). Available and potentially available forms of iron and manganese in surface arid brown soils of Haryana. J. Indian Soc. Soil Sci., 23 : 484-488.

Takkar, P.N. (1969). Effect of organic matter on soil iron and manganese. Soil Sci., 108 : 108-112.

Takkar, P.N. (1978). Land and water management in the Indus Basin (India). Vol. I. Natn. Symp. pp.348.

* Takkar, P.N. and Randhawa, N.S. (1978). *Fert. News.*, **26** : 22.

Tanaka, A. and Navasero, S.A. (1966). Growth of rice plant on acid sulphate soils. *Soil Sci. Plant Nutr.*, **12** : 107-114.

Tananaka, A. and Yoshida, S. (1970). Nutritional disorders of the Rice Plant in Asia. *Int. Rice Res. Inst.* Los Banos, Philippines. pp.1-51.

Tandon, P.K. and Saxena, H.K. (1987). Influence of Zn, Fe and P supply on the rate of photosynthesis and content of sugars and ascorbic acid in rice. Indian Journal of Agricultural Chemistry, **19** : 75-86.

Tejinder Singh and Pasricha, N.S. (1978). Ionic equilibria. *J. Indian Soc. Soil Sci.*, **26** : 130-144.

* Thenabadu, M.W. (1966). Chemistry of rice soils and principles of fertilizer use. *Trop. Agricst.*, **122** : 101-108.

Thind, H.S. and Chahal, D.S. (1986). Effect of green manuring on different forms of iron on redrying of submerged soils. Journal of Research, PAU XXIII : 564-568.

Udo, E.J. (1980). Profile distribution of iron sesquioxide contents in selected Nigerian Soils. Journal of Agricultural Science, U.K. **95** : 191-198.

* Vaculik, R. (1963). Changes in the mobile forms of iron and aluminium in podzols. Sobrn vys Skol zemed Berne 3A : 243-252.

Van Breemen, N. and Moorman, F.R. (1978). Iron toxic soils In "Soil and Rice". IRRI, Los Banos, Philippines, pp. 781-800.

Venugopal, V.K. (1980). Pedological studies on laterite catenary sequence occuring in Kerala. Ph.D. Thesis, Kerala Agricultural University..

Venugopal, V.K. and Koshy, M.M. (1982). Minerology of a toposequence in the mid upland laterite regions of Kerala State. Abstract 12th International Congress of Soil Science, New Delhi, India. 8-16 Feb. 1982.

Verma, T.S. and Neue, H.U. (1988). Influence of soil pH and MnO_2 application on the chemical kinetics, yield and mineral nutrition of rice in a flooded acid sulphate soil. J. Indian Soc. Soil Sci., 36 : 90-100.

Verma, T.S. and Tripathy, B.R. (1984). Bronzing disease of rice - its causes and remedial measures in acid alfisols of Himachal Pradesh. J. Indian Soc. Soil Sci., 32 : 504-506.

* Wang, T.S.L. (1971). Effects of $CaCO_3$, $CaSiO_3$ and organic manure on the growth and yield of rice. J. Taiwan Agric. Res., 20 : 47-55.

Willett, I.R. and Higgins, M.L. (1980). Phosphate sorption and extractable iron in soils during irrigated rice upland crop rotations. Australian Journal of experimental Agriculture and Animal Husband~~a~~ry, 20 : 346-353.

Yu Tian-ren (1980). Oxidation - reduction properties of paddy soils. *Proc. Symp. Paddy Soils*., Nanjing (China) pp. 95-106.

* Original not seen

APPENDIX - I

Description of the soil profile

Profile 1

I Information on the site

a) Profile Number : 1

b) Soil name : Lateritic alluvium

c) Higher category classification : Ultisol

d) Location : Wet lands of the Instructional Farm, College of Agriculture, Vellayani, Trivandrum

e) Elevation : 25 metres above MSL

f) Slope on which profile is located : Flat

g) Land use : Paddy field

h) Climate : Humid tropical

II General information on the soil

a) Parent material : Lateritic alluvium

b) Drainage : Well drained

c) Moisture condition in the profile : Moist throughout the profile

d) Depth of ground water table : Below 122 cm

Description of the profile

Depth (in cm)	Description
0-18	Yellowish brown (10 YR 5/8) when moist; clay loam; sticky and plastic when wet; fine roots of paddy and weeds plenty; moderately rapid permeability; diffuse wavy boundary; pH 5.0.
19-55	Strong brown (7.5 YR 5/8) when moist; clay loam; sticky and plastic when wet; moderately rapid permeability; diffuse wavy boundary; pH 5.5.
56-91	Dark brown (7.5 YR 4/4) when moist; clay loam; slightly sticky and plastic when wet; moderately rapid permeability; diffuse wavy boundary; pH 5.5.
92-122	Dark brown (7.5 YR 4/4) when moist; clay loam; sticky and plastic when wet; moderately rapid permeability; ground water below 122 cm; pH 5.0.

Profile 2

I Information on the site

a) Profile Number : 2

b) Soil name : Kari soil, Acid sulphate soils

c) Higher category classification : Entisol

d) Location : Experimental field on AICRP on Agricultural Drainage, KAU, Karumady, Alleppey

e) Elevation : 1 metre below MSL

f) Slope on which profile is located : Flat

g) Land use : Wet land paddy field

h) Climate : Humid tropical

II General information on the soil

a) Parent material : Sub recent estuarine deposit

b) Drainage : Moderately drained

c) Moisture condition in the profile : Moist throughout the profile

d) Depth of ground water table : Below 116 cm

Description of the profile

Depth (in cm)	Description
0-9	Very dark grey (5 Y 3/1) moist; silty loam; coarse prismatic; slightly sticky and plastic when moist; hard when dry; jarosite present; organic matter at different stages of decomposition; many fine roots of rice and weeds; fossil pneumatophores of mangrove; slowly permeable; diffused smooth boundary; pH 4.0.
10-37	Very dark grey (2.5 Y 3/0) moist; reddish brown hydroxide and oxide mottlings; silty loam; moderate medium sub-angular blocky; sticky and plastic when moist; ferriorganan cutans; jarosites; sulphates; organic matter at different stages of decomposition; few fine roots; slowly permeable; gradually wavy boundary; pH 3.5.
38-59	Very dark grey (2.5 Y 3/0) when moist; reddish brown hydroxide and oxide mottlings; silty clay loam; moderately massive structure; sticky and plastic when moist; ferri organan

Depth (in cm)	Description
	cutans; pyrite observed; organic matter at different stages of decomposition; roots absent slightly permeable; gradual wavy boundary; pH 4.0.
60-85	Very dark grey (2.5 Y 3/0) when moist; silty clay loam; moderately massive structure; sticky and plastic when moist; ferriorganan cutans; pyrite mineral nodule; organic matter at different stages of decomposition; slowly permeable; diffused smooth boundary; pH 4.0.
86-116	Very dark grey (2.5 Y 3/0) when moist; sandy clay loam; massive structure; slightly sticky and plastic when moist; pyrite mineral nodule present; organic matter at different stages of decomposition; slowly permeable; ground water below 116 cm; pH 4.0.

Profile 3

I Information of the site

a) Profile Number : 3

b) Soil name : Kayal soil

c) Higher category classification : Entisol

d) Location : Mathikayal situated at Venattukara Pokkam, Pulinkunnu Panchayat, Alleppey District

e) Elevation : Below 2 metre MSL

f) Slope on which profile is located : Flat

g) Land use : Wet land paddy cultivated

h) Climate : Humid tropical

II General information on the soil

a) Parent material : Sub recent estuarine

b) Drainage : Class I, poorly drained

c) Moisture condition in the profile : Wet throughout the profile

d) Depth of ground water table : Below 62 cm

Depth (in cm)	Description
00-13	Dark greyish brown (2.5 Y 3/2) when moist; clay loam; massive breaking into weak granular structure; slightly sticky and plastic when moist; preponderance of mica and pyrite mineral nodules; coarse and fine roots of paddy and weeds abundant; slowly permeable; abrupt gradual smooth boundary; pH 4.0.
14-28	Dark greyish brown (2.5 Y 4/2) when moist; few iron mottlings of goethite present; clay loam; moderate medium subangular structure; sticky and plastic when moist; iron hydroxide coatings present; mica and pyrite mineral nodules seen; few fine roots; slowly permeable; abrupt gradual smooth boundary; pH 4.5.
29-48	Dark greyish brown (2.5 Y 4/2) few iron mottlings; sandy clay loam; massive structureless; slightly plastic and sticky when moist; coatings of iron hydroxide; few mica and pyrite mineral nodules; roots absent; slowly permeable; diffused boundary; pH 4.5.

Depth (in cm)	Description
49-62	Olive brown (5 YR 4/4) when moist; mottlings of goethite; sandy clay loam; less massive; slightly sticky and plastic when moist; iron hydroxide coatings present; a few mica and pyrite mineral nodules; slowly permeable; ground water below 62 cm; pH 4.5.

Profile 4

I Information of the site

a) Profile Number : 4

b) Soil name : Karappadom

c) Higher category classification : Entisol

d) Location : Rice Research Station, Moncompu

e) Elevation : Below 1 metre MSL

f) Slope on which profile is located : Flat

g) Land use : Wet land paddy cultivated

h) Climate : Humid tropical

II General information on the soil

a) Parent material	:	Fluvial deposit
b) Drainage	:	Moderately drained
c) Moisture condition in the profile	:	Wet throughout the profile
d) Depth of ground water table	:	Below 103 cm

Description of the profile

Depth (in cm)	Description
0-10	Very dark greyish brown (2.5 Y 3/2) when moist; silty clay loam; coarse prismatic structure; sticky and plastic when moist; partly decayed organic matter present; coarse and fine roots abundant; slowly permeable; gradual wavy boundary; pH 5.0.
11-30	Very dark brown (10 YR 2/2) when moist; yellowish brown jarosite and reddish brown goethite colour mottlings; silty clay loam; coarse prismatic to sub angular blocky; sticky

Depth (in cm)	Description
	and plastic when moist; cutans of jarosites and ferriginans present in ped faces and pores; argillan and clay ferran cementation; moderately porous; few fine roots and partially decomposed mangrove roots; slowly permeable; gradual smooth boundary; pH 4.5.
31–74	Very dark greyish brown (10 YR 3/2) when moist; jarosite and few goethite colour mottlings; clay loam; subangular blocky; sticky and plastic when moist; jarositans, ferrans and few argillan cutans and cementation; pyrite minerals; partially decomposed mangrove roots; slowly permeable; gradual smooth boundary; pH 4.0.
75–103	Very dark grey (10 YR 3/1) when moist; silty clay texture; massive; slightly sticky and plastic when moist; pyrite minerals present; roots absent; slightly permeable; pH 4.0.

Profile 5

I Information on the site

a) Profile Number : 5

b) Soil name : Kole soil

c) Higher category classification : Inceptisol

d) Location : 10 km from Kunnamkulam at Pappirithi, Chiryankad, Kattukambal

e) Elevation : Below 2 metre MSL

f) Slope on which profile is located : Flat

g) Land use : Wet land paddy

h) Climate : Humid tropical

II General information on the soil

a) Parent material : Estuarine deposit

b) Drainage : Moderately drained

c) Moisture condition in the profile : Wet throughout the profile

d) Depth of ground water table : Below 56 cm

Description of the profile

Depth (in cm)	Description
0-10	Yellowish brown (10 YR 5/4) when moist; sandy clay loam; prismatic to coarse subangular blocky; slightly sticky and plastic when moist; plenty of fine roots; slowly permeable; wavy boundary; pH 5.0.
11-27	Greyish brown (10 YR 4/1) when moist; greyish white mottlings; sandy clay loam; massive medium subangular blocky slightly sticky and plastic when moist; a few fine roots; slowly permeable; gradual wavy boundary; pH 5.0.
28-42	Dark brown (10 YR 4/3) when moist; reddish brown to greyish mottlings; gravelly sandy clay loam; subangular blocky; sticky and plastic when moist; roots very few; slowly permeable; abrupt wavy boundary; pH 5.0.
43-56	Yellowish red (2.5 YR 4/8) when moist; reddish brown mottlings; gravelly sandy clay loam; massive; sticky and plastic when moist; roots scarcely present; ground water below 56 cm; pH 5.0.

Profile 6

I Information on the site

a) Profile Number : 6

b) Soil name : Pokkali

c) Higher category classification : Entisol

d) Location : Rice Research Station, Vyttila, Ernakulam Dt.

e) Elevation : Below 2 metre MSL

f) Slope on which profile is located : Flat

g) Land use : Wet land paddy cultivation

h) Climate : Humid tropical

II General information on the soil

a) Parent material : Sub recent marine deposit

b) Drainage : Poorly drained

c) Moisture condition in the profile : Wet throughout the profile

d) Depth of ground water table : Below 95 cm

Description of the profile

Depth (in cm)	Description
0-10	Dark grey (2.5 Y 4/0) when moist; silty clay loam; coarse prismatic to subangular blocky; very sticky and plastic when moist; fine roots plenty; slowly permeable; diffursed boundary; pH 5.5.
11-31	Dark greyish brown (2.5 Y 4/2) when moist; few brownish yellow mottlings; silty clay; massive; sticky and plastic when moist; scattered occurrence of goethite mineral; few fine roots; slowly permeable; gradual smooth boundary; pH 5.5.
32-62	Dark greyish brown (2.5 Y 4/2) when moist; brownish yellow mottlings; silty clay loam; massive structure; sticky and plastic when moist; scattered occurrence of goethite mineral; few macro roots of coconut trees which are in nearby bunds; slowly permeable; clear smooth boundary; pH 5.0.
63-95	Dark grey (5 Y 4/1) when moist; mottlings absent; silty clay loam; moderate massive structure; slightly sticky and plastic; scattered occurrence of goethite mineral; roots absent; slowly permeable; ground water below 95 cm; pH 5.0.

ABSTRACT

The main objectives of the study were to understand the pattern of distribution of water soluble, exchangeable, active, free oxide, total amorphous, amorphous organic, amorphous inorganic and crystalline forms of iron and their variation under the influence of submergence, the effect of management practices on the variations in the available forms of iron under submergence and the relationship between soil reaction and the forms of iron in the major acid rice soils of Kerala. viz., lateritic alluvium, kari, kayal, karappadom, kole and pokkali.

The pattern of distribution of different forms of iron studied, varied significantly among the six soils. The water soluble, exchangeable, active, free oxide, total amorphous and amorphous organic forms of iron were maximum in the kari soil, while crystalline iron was maximum in the lateritic alluvium. Kari and kole soils had the highest content of amorphous inorganic form of iron. The minimum content of water soluble iron was recorded in the kole and the lateritic alluvium, exchangeable and crystalline iron in karappadom soil, active, free oxide, total amorphous and amorphous inorganic forms of iron in pokkali soil and the amorphous organic iron in the lateritic alluvium. The total iron was highest in the kole and the lowest in the karappadom soils.

Correlation studies indicated that pH had a significant negative correlation with water soluble and exchangeable forms of iron, while electrical conductivity, CEC, organic matter and clay content had positive correlation. Electrical conductivity and organic matter were positively correlated with active iron.

Submergence significantly increased the pH and the contents of some of the forms of soil iron. Crystalline iron however, decreased with submergence. Active and free oxide forms of iron had no significant effect. The pH attained peak value on the 20th day of submergence in the lateritic alluvium, 30th day in the karappadom soil and 60th day in kayal, kole and pokkali soils. However, kari soil showed steady slow increases throughout the period of submergence.

The addition of organic matter @ 5 t/ha and 2.5 t/ha decreased the pH slightly upto 5th day and then increased and equalled that of the control on the 90th day in all the soils. The decrease in pH was significantly more in the higher level of treatment than in the lower level. Water soluble iron increased significantly due to the treatments in all the soils. The maximum increase was observed in kari soil and the minimum in kayal and karappadom soils. However, the release of water soluble iron due to the higher level treatment was more than that of the lower level. The exchangeable iron also increased due to the organic matter treatment. The maximum increase was observed in the lateritic alluvium and the minimum in karappadom soils. The increase in the content of exchangeable iron due to higher level of organic matter was significantly higher than that due to the lower level.

The lime application at full LR and half LR levels substantially increased the pH upto the 5th day in all the soils except in the kari soil, after which it decreased with further periods of submergence. However, in the kari soil, a peak value could be noticed on the 20th day. Water soluble and exchangeable iron decreased significantly due to the lime treatment. The decrease due to full LR treatment was significantly more than that due to the lower level.

The active iron neither increased nor decreased significantly due to the organic matter and the lime treatments.