EFFECT OF DRYING AND WETTING ON THE PHYSICAL, PHYSICO-CHEMICAL AND CHEMICAL PROPERTIES OF THE SUBMERGED SOILS OF KUTTANAD

BY

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THESIS

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1988

DECLARATION

I hereby declare that this thesis entitled "Effect of drying and wetting on the physical, physico-chemical and chemical properties of the submerged soils of Kuttanad" 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, of any other University or Society.

RAJU, P.V.

Vellayani,
8th January, 1988.

CERTIFICATE

Certified that this thesis entitled "Effect of drying and wetting on the physical, physico-chemical and chemical properties of the submerged soils of Kuttanad" is a record of research work done independently by Sri Raju, P.V. 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.

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INTRODUCTION

INTRODUCTION

Kuttanad is a very unique agricultural tract extending over 874 km^2 and distributed over 79 villages which fall in the Kottayam, Pathanamthitta and the Alleppey districts of Kerala State. Of the total area of 874 km^2 approximately 304 km^2 are garden land with an average elevation of one metre above MSL and about 490 km^2 where the bed level ranges between 0.6 - 2.1 m below sea level are presently used for growing paddy. The areas below sea level are subjected to severe flooding during monsoon period, by the water drained by four rivers viz., Meenachil, Pamba, Manimala and Achenkoil.

According to Velu Pillay (1940) the entire area of Kuttanad was a bay in the geological past. Large quantities of sediments were deposited in this bay by the rivers year after year during monsoons. Sand embankments were slowly formed and the nearest points were linked together and the bay was thus converted into a lagoon and this lagoon was gradually silted up and eventually transformed into the present paddy lands and garden lands of Kuttanad. Artificial reclamation was also carried out during various periods in the near past.

Based on the distinct soil, topography and water conditions, the soils of Kuttanad can be classified into three, locally known as Kari, Karapadom and Kayal soils.

The Kari lands are inferior swampy areas with black peaty soil seen in the northern (Thuravoor and Vaikom-Vadayar areas) and in southern (Purakkad) extremities of Kuttanad. The Karapadom lands are old reclamations which are widely distributed in the upper Kuttanad region. The Kayal lands are those which were reclaimed in the southernmost part of Vembanad lake. The approximate extent of different soil groups are given below: (K.S.S.P., 1978)

Soil group	Extent ha
Kari	6,100
Karapadom	42,500
Kayal	8,100

The whole area in Kuttanad where paddy is grown is divided into a number of padashekarams each of area 50-250 ha. The padashekarams are formed on the basis of topography, soil type, drainage channels and proximity to rivers.

Efforts to develop Kuttanad as a rice growing area, dates back to nearly a century. In the early phases, reclamation of land and flood control work were largely undertaken at the initiative of private farmers through the active assistance of the State Government. But later on some Government projects were undertaken which were intended to intensify paddy cultivation by controlling floods and by preventing intrusion of salinity from the backwaters. Thus a spillway was constructed at Thottapally to control the flood water in Kuttanad during the monsoon season. To prevent the intrusion of salt water from the sea into Kuttanad during summer, a 1402 m long salt water barrier (Thaneermukkom regulator) was constructed at Thaneermukkom. The combined effect of the spillway and the regulator is not, however, said to be very satisfactory. A number of unexpected adverse effects, both on farming and on the general ecology of the region are also said to have surfaced after the completion of these projects.

The area has many soil problems which sometimes make rice culture an uncertain undertaking. During 1982-83 the entire Kerala, especially Kuttanad experienced a very intense drought. Following this during 1983-84, it was reported that rice seedlings failed to establish in some parts of the region. Therefore it was assumed that excessive drying, followed by submergence had given rice to certain conditions, the nature of which was not fully understood. Farmers who had left their paddy fields dry reported that they experienced an adverse change in the top soil which resulted in the total failure of the succeeding crop.

Reclamation of potentially acid sulphate swamps by preventing sea water intrusion at high tides often lead to strong acidification and abandonment of the land. This effect becomes more serious in areas with a pronounced dry season. Such an effect has occurred in Sierra Leone following reclamation efforts (Bloomfield and Coulter, 1973). Similar experiences were reported from China (Huan-Chi-Mao, 1958) and Bangladesh (Bloomfield and Coulter, 1973). In such soils reduction after flooding is usually strong and the pH rises rapidly and levels of excess aluminium are short lived. High iron content, however, prevails for a long time and strong acidification of the surface water is usually common (Sudjadi et al. 1973). Thus often crop failures have been reported from such areas.

As conditions similar to those reported above from Sierra Leone, China and Bangladesh exist in Kuttanad, the present investigation was undertaken with the following objectives:

1. To study the general microbiological and physico-chemical properties of these soils

2. To study the effect of drying on their physical, physico-chemical and chemical characteristics

3. To study the effect of drying under simulated field conditions on the soil characteristics

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Millions of hectares of land on the coastal plains in different parts of the world are characterised by the presence of acid sulphate soils, which are used for paddy cultivation. A typical paddy soil is characterised by alternate periods of reducing conditions, when it is cropped to rice, and oxidising conditions during dry season. Intense drying of soil can take place in areas with a pronounced dry season. These alternate periods of drying and wetting of soil lead to marked changes in the physical, physico-chemical, chemical and microbiological properties of such soils. Work done on some of these aspects which have a bearing on the acid sulphate soils of Kuttanad is briefly reviewed in this chapter.

Acid sulphate soils

The acid sulphate soils of Netherlands were first described by Linnaeus in 1733 (Poelman, 1973). These soils have a pH below 4.0, somewhere within a 50 cm depth that is directly or indirectly caused by sulphuric acid formed by oxidation of pyrite or rarely of some other reduced sulphur compound (van Breemen and Pons, 1978).

Genesis and Occurrence

It was believed that acid sulphate soils were derived usually from marine and estuarine sediments that had high contents of sulphides (Wilshaw, 1940; Watts, 1960; Nhung and Ponnamperuma, 1966; Kevie, 1973; van Breemen and Pons, 1978). However Chenery (1954) and Poelman (1973) have reported their genesis from parent materials other than marine and estuarine sediments. The environmental conditions under which acid sulphate soils are formed include a tropical climate, flat topography and a vegetation of mangrove forests (Thorton and Giglioli, 1965; Marius and Turenne, 1968).

Genesis of acid sulphate soils includes three main stages, the cumulative and reductive geochemical phase, oxidative phase and neutralization phase. Geochemical phase includes the sedimentary pyrite formation which involves bacterial reduction of sulphate to sulphide, partial oxidation of sulphide to elemental sulphur and interaction between ferrous or ferric ion with sulphide and elemental sulphur (Ponnamperuma, 1971; Richard, 1973; van Breemen, 1976).

The main chemical reactions are as follows:

$$SO_4^{--} + 4H_2 + 2H^+ \longrightarrow H_2S + 4H_2O$$

$$H_2S + \tfrac{1}{2}O_2 \longrightarrow S + H_2O$$

$$Fe^{++} + S^{--} \longrightarrow FeS$$

$$FeS + S \longrightarrow FeS_2$$

In the oxidative phase the pyrite is oxidized, by the lowering of the water table and the overall reaction can be expressed as follows.

$$FeS_2 + 7/_2O_2 + H_2O \longrightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$$

The rate of this reaction is enhanced by the bacteria Thiobacillus ferroxidans (van Breemen, 1973; Bloomfield and Coulter, 1973).

In the neutralization phase the sulphuric acid reacts with the bases in the sediments. If the amount of bases in the sediments is small compared to sulphates present there will be extensive acidification of the soils, the ultimate pH depending on the sulphur-base ratio.

The acid sulphate soils have been reported to occur in various parts of the world, predominantly in the tropical and subtropical deltas (Pons, 1973) and also in certain inland areas (Chenery, 1954).

These soils have been reported to occur along the Atlantic Coast of U.S.A. (Beye, 1971), Finland, Holland and Sweden (Coulter, 1973), Germany (Buurman et al. 1973), China (Kung and Chou, 1964), Philippines (van Breeman et al. 1977), South Korea (Park and Park, 1969), Thailand (Kevie and Yenmanas, 1972), Vietnam (Tram and Pham, 1975) and Japan (Murakami, 1969).

In India acid sulphate soils occur in the west coast of Kerala in the Kuttanad region. They are locally known as Kari Soils (Sahadevan, 1966; Murty, 1971; Subramoney and Sukumaran, 1973; Yadav, 1976; Bhargava and Abrol, 1984).

Acid sulphate soils of Kuttanad - physical, physico-chemical and chemical characteristics

Texturally Kari soils can be classified as clay or clay loam (Subramoney, 1957), with top horizons containing more sand than lower horizons (Pillai, 1964). Venugopal (1969) in a general study of Kerala soils reported the lowest value of apparent density for Kari soils. Koshy and Varghese (1971) reported that Kari soils are characterised by a deep black colour, heavy texture, poor drainage, extremely high contents of organic matter and very strong acidity. Varghese (1973) reported that Kari soils varied from sandy loam to clay. In a Thottapally profile the maximum percentage of coarse sand was found. He reported a particle density of 2.08-2.76 g cm^{-3}, a bulk density of 0.96-1.62 g cm^{-3} and a pore-space of 31.58-62.53% for these soils. Bhargava and Abrol (1984) reported a great deal of heterogenity in Kuttanad soils, with regard to soil characteristics such as colour of soil matrix and mottles.

Subramoney (1947) reported that the high acidity of Kuttanad soils on drying is due to the oxidation of sulphur compounds to sulphuric acid. Pillai (1964) and Suseela Devi (1965) reported very low pH for the top horizon of Kari soils which again got reduced on further drying. As regards soil reaction the Kari soils are extremely acidic with pH below 4.0. The other soil groups of Kuttanad, viz., the Kayal and Karapadom soils are less acidic than the Kari soils (Pisharody, 1965; Karthikakuttiamma, 1967; Kabeerathumma, 1969 and Ghosh et al. 1973). Kurup and Aiyer (1973) got maximum and minimum values of soil pH when sampled during periods of October to November and March to April respectively. However Bhargava and Abrol (1984) reported a wide variation in the pH of Kuttanad soils.

Iyer (1928) reported that the infertility of Kari soils was due to the enormous amounts of water soluble salts in them. But Nair (1945) showed that the fertility of Kuttanad soils and their salt concentrations have no relation to each other. Gopalakrishnan (1963) was of the opinion that the concept of saline soils, as commonly understood is not fully applicable to the salt affected soils of Kerala. Suseela Devi (1965) reported that the conductivity of Kari soils depended on the soil, season and horizon. She got a conductivity range of 8.5-15.0 mmhos cm^{-1} for air dried samples and 2.6-5.0 mmhos cm^{-1} for fresh samples. Varghese (1973) also reported that these soils are slightly saline. Kurup and Aiyer (1973) studied the seasonal variations in conductivity and got the minimum value in October to November and maximum value in March to April corresponding to the periods of monsoon floods and the sea water intrusion respectively. Bhargava and Abrol (1984) reported wide variations in conductivity viz., 0.5 mmhos cm^{-1} to 40.5 mmhos cm^{-1}.

The total nitrogen content of these soils was high because of the presence of high organic matter content. Pillai (1964) reported available nitrogen in the range of 140-590 ppm in Kari soils. Kabeerathumma (1969) reported the available nitrogen content of Kari soil as 112 ppm and Karapadom soils as 185 ppm. This may be due to the slow mineralization of organic nitrogen because of low microbial activity.

The acid sulphate soils of Kuttanad are deficient in available P_2O_5 content. Venugopal (1969), Varghese et al. (1970) and Ghosh et al. (1973) have reported a low P_2O_5 content in these soils.

Pillai (1964) reported an exchangeable potassium level of 60-77 ppm in Kari soils. But Kabeerathumma (1969) and Varghese (1973) got comparatively low levels of exchangeable potassium in Kari soils compared to the Kayal and Karapadom soils. Ghosh et al. (1973) reported exchangeable potassium content in the range of 0.14-0.20, 0.17-0.30 and 0.2-0.40 me 100 g^{-1} in Kari, Karapadom and Kayal lands respectively.

Subramoney (1960) proposed the presence of sulphur compounds and sulphur oxidizing and reducing bacteria in

Kuttanad soils. This author further reported the presence of soluble chlorides and sulphides to be one of the toxic factors in Kuttanad soils. According to Murthy (1971) the annual sea water intrusion adversely affected soil fertility.

Acid sulphate soils of Kuttanad are characterised by high contents of exchangeable iron and aluminium. Pillai and Subramonian (1931) suggested that <u>Kari</u> soils contained large quantities of iron and aluminium salts along with sulphur compounds. Money and Kurup (1961) in their investigations on the scum formation of rice soils in Kerala revealed that in the acid soils of Kuttanad appreciable amounts of Fe^{2+} are brought into solution by submergence. Analysis of this scum showed 18.96% Fe_2O_3, 11.84% Al_2O_3 and 36.60% sulphate (Suseela Devi, 1965).

Exchangeable aluminium levels of these soils are also high (Kurup, 1967; Karthikakuttiamma, 1967). They reported KCl extractable aluminium contents of 685-3700, 85-202 and 216-2000 ppm in the <u>Kari</u>, <u>Karapadom</u> and <u>Kayal</u> soils respectively. Kabeerathumma (1969) reported 14.34 and 11.87 me 100 g^{-1} of exchangeable aluminium in the

Kari and *Karapadom* soils respectively. Ghosh et al. (1973) reported 510-580, 30-130 and 20 ppm of exchangeable aluminium in the *Kari*, *Karapadom* and *Kayal* lands respectively.

Pisharody (1965) reported an exchangeable Fe^{2+} content of 41 ppm in *Karapadom* and 24 ppm in *Kari* soils under waterlogged conditions and 30 ppm in *Karapadom* and 19.1 ppm in *Kari* soils under dry conditions. Kabeerathumma (1969) reported an exchangeable Fe^{2+} of 105 ppm in *Kari* soils and 70 ppm in *Karapadom* soils. Ghosh et al. (1973) got exchangeable iron of 19-32 ppm in *Kari*, 8-13 ppm in *Karapadom* and 22 ppm in *Kayal* lands.

Microbial properties

Waksman (1923) reported that peat soils contained over six million bacteria g^{-1} even at a pH as low as 5.9. Pochan (1956) found that acid peats (pH 3.6-4.6) showed low activity and population of soil micro-organism and a very low ratio of bacteria to fungi which may be due to the combined effects of high acidity, high organic matter content and wide C/N ratio. Frencks and Puffee (1960) got increased counts of bacteria and decreased counts of fungi in moor soils when the pH was increased from 3.2 to 7.0.

In Kuttanad soils the total microbial count recorded is rather very low especially when there is no crop and the land is under water. Pillai (1964) recorded very low microbial activity in <u>Kari</u> soils ie. 0.27 - 0.44 m g^{-1} at pH values ranging from 3.6 to 3.7. In top layers he got a total count of the order of a few thousands only. But as depth increased microbial count also increased. Suseela Devi (1965) got lowest counts in <u>Kari</u> soils in the sample collected in the month of August. But the total count increased gradually in the months that followed. Total count varied from 0.23 to 8.40 m g^{-1} in surface layer and at low pH values the count was rather low. Fungi predominated in the upper layer whereas bacteria were more dominant in the lower layer.

Harmsen (1969) reported that flooding with salt water decreased microbial activity. Ambroz (1970) while studying the effect of drying and wetting on enzymatic activity of soils reported that the activity of proteases was markedly decreased by air drying. Re-moistening activated it to a lesser extent and repeated drying and wetting decreased enzymatic activity beyond recovery on further wetting.

Physico-chemical changes

Changes in pH

The pH of most soils tend to change towards neutral after submergence. Ponnamperuma (1955) reported that when an aerobic soil is submerged its pH decreases during the first few weeks, reaches a minimum and then increases asymptotically to a fairly stable value of 6.7-7.2 after a few weeks. In acid soils the overall effect is an increase in soil pH. Mahapatra (1968), Chakravarty and Kar (1970), Mukherjee and Basu (1971) and Islam and Islam (1973) also got similar results.

Initial decrease in pH shortly after submergence is probably due to the accumulation of CO_2 produced by the aerobic bacteria. The subsequent increase in pH is due to soil reduction (Ponnamperuma et al. 1966). According to van Breemen and Pons (1978) the reduction of ferric oxides to dissolved Fe^{2+} is by a process that consumes acidity which can be represented as follows:-

$$Fe(OH)_3 + \frac{1}{4} CH_2O + 2H^+ \longrightarrow Fe^{2+} + \frac{1}{4} CO_2 + 11/4 H_2O$$

But in acid sulphate soils flooding increases the soil pH only slowly and it rarely exceeds 6.0 after six months of submergence. Ponnamperuma et al. (1973) and van Breemen (1976) attributed this slow increase in pH to conditions which are not conducive for microbial reduction, low contents of metabolizable organic matter and low contents of easily reducible ferric oxide. Even more important may be the high buffer capacity due to exchangeable and dissolved aluminium, the basic sulphates of aluminium and iron and adsorbed sulphate which requires reduction of large amounts of iron to produce a significant increase in pH.

Kabeerathumma (1975) reported that there was only a small increase in soil pH due to submergence of acid sulphate soils of Kerala, and on no occasion did it exceed 5.0. She attributed this to low microbial activity, low initial pH and high exchangeable aluminium.

Drying of submerged soils increases soil acidity. This was reported as early as in 1923 by Rost and Fieger. Krickman (1925) reported that sun drying enhanced soil acidity and that drying at higher temperatures increased acidity still further. Raupauch (1951) suggested that these changes in pH consisted of recognition of all the factors contributing to H^+ concentration. Bowser and Leat

(1958) also attributed the variations in pH to changes in soil moisture regimes. Moorman (1963) reported that pH values in acid sulphate soils were extremely variable. These seasonal variations were more pronounced in periodically inundated lands. During inundation pH increases and eventually comes to neutral, whereas during the following dry period it drops quickly. Upon drainage and aeration such soils show severe acidification due to oxidation of sulphides which leads to the formation of sulphuric acid.

Low soil pH of acid sulphate soils had a marked effect on iron and aluminium concentrations, leading to toxicities, as shown by the following equations:

$$pH - \frac{1}{2} PFe^{2+} = 5.4 \text{ (Ponnamperuma, 1955)}$$

$$pH - \frac{1}{3} PAl_{M} = 2.2 \text{ (Raupauch, 1963)}$$

$$PAl - 0.77\ pH + 1.78 \text{ (van Breemen, 1976)}$$

Accordingly, the activities of water soluble aluminium and iron will be high at low pH values usually encountered with drying of recently flooded acid sulphate soils.

At a pH below 3.5 to 4.0 rice in solution culture is directly affected by H^+ (Ponnamperuma et al., 1973), Thawornwong and van Diest, 1974). But at such pH levels, aluminium toxicity becomes more important in soils. Optimum pH for rice is about 6.6 (Ponnamperuma, 1978). At that pH, microbial release of nitrogen and phosphorus and availability of phosphorus were high and supplies of copper, zinc and molybdenum were adequate and iron and aluminium below toxic values.

Changes in specific conductance

Redman and Patrick (1965) studied specific conductance of 26 soils using 1:1 soil water suspension. Submergence for 30 days increased specific conductance of all the 26 soils studied. The specific conductance of the solutions of most soils increased after submergence, attained a maximum and then declined to a fairly stable value, which varied from soil to soil. The increase in conductance during the first few weeks of flooding was due to the release of Fe^{2+} and Mn^{2+} from insoluble oxide hydrates (Ponnamperuma, 1976).

Janardhan and Murty (1972) reported that mortality of seedlings of eight high yielding varieties of rice was 17.8, 58.1 and 77.0 percent at 2-4, 6-8 and 10-12 mmhos cm^{-1} respectively. Grain yield was only 93%, 63% and 39% of control at these three salinity levels. The germination was not affected upto about 12 mmhos cm^{-1} but seedling growth was affected above 4.6 mmhos cm^{-1} (IRRI, 1968). Ikehashi and Ponnamperuma (1978) reported 50% yield reduction in the salinity range of 6.0 to 7.0 mmhos cm^{-1}.

Subramoney (1961) attributed the toxicity in Kuttanad soils to soluble salts consisting of chlorides and sulphates. Nair (1963) reported that rice plants tolerated NaCl only upto a conductivity of 4 mmhos cm^{-1}. According to Murty (1971) annual sea water intrusion had an adverse effect on the fertility of these soils. Plants affected by salt injury showed leaf rolling and white discolouration of the upper parts of the leaf blade.

Availability of Nitrogen

Nitrogen occurs in soils chiefly as complex organic substances with only a small fraction (2-5%) being converted to the inorganic form annually. Inorganic forms of nitrogen are NO_3^-, NO_2^- and NH_4^+. In aerated soils NO_3^- is the stable inorganic form resulting from the decomposition of organic matter. But in flooded soils due to paucity of oxygen, nitrogen mineralization stops at the NH_4^+ stage. However even in flooded soils there is an aerobic surface layer which causes instability of nitrogen, by nitrification-denitrification reactions (Patrick and Reddy, 1978). The main reactions taking place in a flooded soil include, accumulation of NH_4^+, denitrification and nitrogen fixation.

Mineralisation of organic nitrogen in submerged soils stops at the NH_4^+ stage, so that it tends to accumulate. Ammonia is derived mainly from the anaerobic deamination process, hydrolysis of urea and degradation of purines; with less than one percent coming from nitrate reduction (Woldendrop, 1965). Mohanty and Patnaik (1973) also reported accumulation of NH_4^+ due to flooding.

Eventhough anaerobic deamination is slower than aerobic deamination, the release of inorganic nitrogen is larger and faster in submerged soils (Acharya, 1935). William et al. (1968) reported nitrogen release in straw even at 0.6% nitrogen content. Broadbent and Reyes (1971) also reported more nitrogen availability under submerged conditions.

Ponnamperuma (1972) reported 2-100 ppm nitrogen after 2 weeks of submergence depending on texture and organic matter content. Boko (1973) studied the changes in concentration of water soluble NH_4^+-N in submerged acid sulphate soils. He noticed an increase in water soluble ammonia reaching peak values two weeks after flooding and then declining rapidly. But in acid sulphate soils of Thailand, Kawaguchi and Kyuma (1969) and Motomura et al. (1975) have reported low production of ammonia due to low pH and the paucity of phosphorus.

Air drying the soil before flooding significantly affects nitrogen availability. Mitsuii (1955) conducted research in Japan and reported that the air drying of the soil between successive rice crops significantly affected nitrogen availability. Drying treatments, prior to re-submergence caused a flush of ammonification. This has been reported by Yoshino and Dei (1974) and Marumoto and Higashi (1977). According to Dei and Yamasaki (1979) this kind of drying effect gives maximum benefit when a wet land rice is followed by a dry land crop in rotation rather than when it is followed by a wet land rice crop. Broadbent (1979) also got significant increase in nitrogen availability due to drying.

Air drying treatments have more significant relationships with denitrification. Jagnow (1972) reported that air drying for 3 and 21 weeks before wetting showed no significant relationship in nitrogen mineralisation but denitrification was 1.221 $\pm$ 0.106 times higher after 21 weeks of air drying than after three weeks of air drying. Ponnamperuma (1972) showed that the denitrification reactions follow first order kinectics, the velocity constant being low for acid soils. Kohl et al. (1976) also got similar results. Since denitrification needs organic matter for carbon it is not of much importance in most Indian soils.

Alternate drying and wetting also causes severe nitrogen losses. This has been reported by Wijler and Deluriche (1954) and by Macrae et al. (1968). Reddy and Patrick (1975) reported a greater nitrogen loss in a two day aerobic-anaerobic cycle than in a longer cycle. However the conducive pH of soil micro-organism mediating denitrification is between 6.5 and 7.2.

The well known ability of 2:1 type of clay minerals to entrap ammonium ions between the silica sheets, often accompanied by a contraction in interlayer spacing, has only limited importance in rice soils, probably because fixation is often associated with drying to moisture levels below those normally encountered in low land rice culture (Broadbent, 1979).

Battacharya (1971) reported increase in NH_4^+-N in soil, on flooding due to expansion of clay lattice, but Simpi and Savant (1975) reported that NH_4^+ retention was more under flooded conditions.

Agrawal et al. (1971) reported that more nitrogen was released from soil when it was incubated after air drying. He attributed this to the microbial stimulation and increase in temperature of soil. Piispanen et al. (1983) reported that drying of peat in Finland caused a reduction in total nitrogen content (8.6% vs 6.3%) but it caused a four fold increase in soluble nitrogen compounds. In pot trials in Japan, Nozoki (1983) found that the drying of the soil for 43 days before potting increased grain yields mainly through increases in panicle weight. The effect of soil drying on mineralisation of nitrogen persisted upto one month after transplanting.

Availability of phosphorus

The most important chemical change that occurs when a soil is flooded is the increased availability of phosphorus. Eventhough phosphorus is not directly involved in oxidation-reduction reactions in submerged soils its behaviour is significantly affected by flooding due to its reactivity with a number of redox elements. Perhaps the most important effect of anaerobic conditions on phosphorus is its increased availability to wet land rice (Akoi, 1941; Mitsuii, 1960; Chiang, 1963).

De Datta (1981) has summarised the phosphorus transformations in a submerged soil as follows:

1. Reduction of insoluble ferric phosphate ($FePO_4\ 2H_2O$) to a more soluble ferrous phosphate ($Fe_3\ (PO_4)_2 \cdot 8H_2O$) (Islam and Elahi, 1954).

2. Hydrolysis of aluminium and iron phosphate at a higher soil pH that occurs after submergence (Ponnamperuma, 1955).

3. The dissolution of apatite because of the higher CO_2 pressure in the soil solution (Khan and Mandal, 1973).

4. Desorption of phosphorus from clay and oxides of aluminium and iron.

5. Release of occluded phosphate by reduction of hydrated ferric oxide coating (Bradley and Seiling, 1953).

6. Displacement of phosphate from ferric and aluminium phosphate by organic anions (Mandal and Mandal, 1973).

Among these reactions the reduction of ferric phosphate to ferrous phosphate appears to be the dominant one because iron phosphate is the major fraction of inorganic phosphorus occurring in submerged soils. Basak and Battacharya (1962) reported that Fe-P and Al-P constituted about 46.6% of the total phosphorus of puddled, alluvial rice soils of West Bengal.

Chang (1965), Khan and Mandal (1973) and Nair (1986) reported the dominance of Fe-P in rice soils.

Chiang (1963) and Hsu (1964) found that phosphate added to a flooded soil is slowly converted into Fe-P, a process that is greatly affected by the presence of crop roots and iron oxides. This transformation might be due to the direct conversion of applied phosphorus into Fe-P under submergence (Mahapatra and Patrick, 1969) or due to the interconversion of Al-P formed at the initial stages to Fe-P with time (Srivastava and Pathak, 1972).

Thus phosphate chemistry in flooded soils is so linked to iron chemistry and the conditions that increase the solubility of iron in soil, usually increases phosphorus solubility also. So when such a soil is kept submerged the availability of phosphorus increases rapidly. Shapiro (1958) reported that increase in available phosphorus by flooding as measured by a values of phosphorus is considerable in an acid soil rich in Fe-P, but the increase is not appreciable in a calcareous soil low in Fe-P. Thus he concluded that the phosphorus availability is mainly due to reduction rather than hydrolysis. David (1960) also reported the beneficial effects of flooding on phosphorus availability, depending on the intensity of reduction and the iron content of the soil. In another study with five flooded soils, Patrick and Mahapatra (1968) also reported that the increase in availability after flooding is primarily due to reduction of $FePO_4$ and secondarily due to hydrolysis of $AlPO_4$.

When a soil is dried, the reoxidation results in enhanced activity of the sesquioxide fraction of soil which leads to an increase in phosphorus fixing capacity.

Babayan and Gasparan (1962) reported that air drying generally increased the soluble phosphorus content of non calcareous soils and decreased it in calcareous soils.

Ahmed (1967) studied the changes in the forms of inorganic phosphorus under submerged and dry phases of four rice soils of North Trinidad. During dry phase the availability of phosphorus was significantly less than in the submerged phase. Chang (1971) postulated the changes in the availability of Fe-P in soils as influenced by submergence and drying. According to him changes in availability is partly due to changes in solid phase, ie., during drying the easily soluble colloidal form changes to crystalline form by dehydration and thus the availability gets reduced. Goswami and Banerjee (1978) reported that differences in soil moisture regime cause inconsistent responses of phosphorus fertilizers in rice culture.

The high acidity coupled with high content of sesquioxides will favour fixation of phosphorus. By drying a soil phosphorus fixation is also enhanced. Soils containing hydrated iron and aluminium oxides, halloysites and allophane fix phosphorus in both upland and lowland soils (De Datta et al. 1966).

Yuan et al. (1960) reported that prolonged alternate wetting and drying reduced the percentage of Al-P and increased the percentage of Fe-P. Mandal and Khan

(1975), while studying the transformations of inorganic phosphorus in rice soils of West Bengal, reported that repeated cycles of alternate submerging and saturated conditions lowered extractable phosphorus irrespective of the nature of the soils. De Datta (1981) also reported that alternate wetting and drying decreases the percentage of phosphorus in aluminium form and increases the percentage in iron form.

Drying a soil subsequent to flooding generally decreases the solubilities of both native and added phosphates (Paul and Delong, 1949). Drying leads to conversion of soluble phosphates to less rapidly extractable forms and a decrease in organic phosphorus fraction occurs. Savant et al. (1970) reported that resubmergence of air dried or oven dried soil samples resulted in decreased availability of phosphorus in acid clayey soils, possibly because of high contents of active iron in them.

Availability of Potassium

The transformation of potassium in flooded soils has not been studied adequately. Potassium is present in soils in four forms, which are in a dynamic equilibrium with each other which can be represented as follows (Su, 1976).

Soluble K $\rightleftharpoons$ exchangeable K $\rightleftharpoons$ non exchangeable K $\rightleftharpoons$
$\rightleftharpoons$ mineral K

Flooding a soil may increase the availability of potassium. Ponnamperuma (1965) reported that flooding a soil increased the K^+ concentration in the soil solution due to soil reduction and increase in specific conductivity. Islam and Islam (1973) observed that soil submergence increased the concentration of potassium in the soil solution and that growth, yield and nutrient content were higher in plants grown in submerged soils than in plants grown in soils with moisture at field capacity. Islam and Ullah (1973) also got similar results. Biswas (1974) also attributed vigorous growth of rice in submerged soil to the increased availability of potassium. Murty and Singh (1975) reported an initial decrease in available potassium during the first week of flooding, followed by a gradual increase.

The mechanism governing potassium fixation and release during drying and wetting of soils is not clearly understood. In 1938, Bray and De Turk reported that heating soils at 200°C could release non exchangeable potassium in soils where initial exchangeable levels were low. They attributed this to the effect of heat in hastening a return to the equilibrium potassium level. Ayres (1944), Seatz and Winters (1944) and Lee (1946) reported potassium release during drying.

Attoe (1947) found that air drying increased the exchangeable potassium content over that in moist state except for the sample of highest exchangeable level. When these soils were dried at relative humidities ranging from 10-100% release increased with reducing humidities. He concluded that there are two types of potassium fixation viz.,

1. Fixation in moist soils which is enhanced by liming
2. Fixation due to drying which is independent of pH

Rouse and Bertramson (1949) reported that oven drying of some Indiana soils at 70°C increased exchangeable potassium over that in the moist state, the increase being almost double in several cases. Neiderbudde (1967) reported potassium fixation on drying in alluvial soils of the Federal Republic of Germany, with high amounts of organic matter. Singh and Ram (1976) found that continuous submergence and a drying-wetting cycle of 30 days interval increased exchangeable potassium content. The effect was more pronounced in the alternate wetting and drying treatment. Luo and Jackson (1985) reported release of potassium during air drying.

Page and Baver (1939) related the fixation of cations by 2:1 minerals upon drying to the size of the unhydrated ions. The unhydrated ion due to its radii, forms the most stable configuration. During wet condition only micas, vermiculite and illite are able to fix potassium but under dryness smectites also fix potassium due to the shrinkage of the mineral. Larson (1949) suggested that release or fixation can take place during drying due to a shift in the mechanism. The behaviour of clay minerals in relation to potassium fixation or release on drying, however, is by no means clear cut (Ahmad and Davis, 1971). It is also uncertain how far the laboratory or field data on fixation and release of potassium can be extended to submerged soils in which rice is actively growing.

Availability of Iron

The most important chemical change that takes places when a soil is submerged is the reduction of Fe^{3+} and the accompanying increase in its solubility. Excess of iron is toxic to rice. The chemistry of flooded soils is dominated more by iron than by any other redox element, the major reason being that large amounts of iron can undergo reduction, usually exceeding the total amount of other redox elements by a factor of 10 or more.

According to Motomura (1961) the reduction of iron is a consequence of the anaerobic metabolism of bacteria and appears to be chiefly a chemical process brought about by bacterial metabolites. But Kamura et al. (1963) and Ottow and Glathe (1971) are of the opinion that direct reduction coupled with respiration may be involved. Alexander (1965) opined that the increase in Fe^{2+} in a waterlogged soil was entirely the result of biological action.

Subramoney and Kurup (1961) reported that considerable Fe^{2+} was brought into solution by acidity as well as bacteria in Kuttanad soils.

The reduction of iron could be illustrated as follows:

$$\underset{\text{Reducible Iron}}{Fe(OH)_3} + \underset{\text{Organic matter}}{\tfrac{1}{4} CH_2O} + \underset{\text{low pH}}{2H^+} \xrightarrow{\text{Microbial activity}} Fe^{2+} + \tfrac{1}{4} CO_2 + 11/4\, H_2O$$

According to Ponnamperuma (1972) such a reduction is accompanied by the following four consequences:

1. Concentration of water soluble iron increases
2. pH increases
3. Cations are displaced
4. Solubility of phosphorus increases

Because of the consumption of acid, the reduction of $Fe(OH)_3$ to Fe^{2+} causes an increase in pH. Ponnamperuma (1965) reported a pH of 6.4 to 7.0 within 2-5 weeks after flooding.

On the basis of their studies with 26 soils Redman and Patrick (1965) reported that the Fe^{2+} concentration after flooding ranged from 567 ppm to 2230 ppm. Ferrous ion concentration after submergence was positively correlated with clay and organic matter with 'r' values of 0.625 for clay and 0.674 for organic matter.

Most of the studies on acid sulphate soils agree that upon flooding, the concentration of the dissolved Fe^{2+} increases, often rather gradually to peak values between several hundreds to thousands ppm. Except when the pH is increased to near neutral reaction by liming,

Fe^{2+} shows little tendency to decrease to non toxic levels, as in most normal rice soils.

Connell and Patrick (1968) reported a prolonged high concentration of Fe^{2+} in acid sulphate soils under submergence. But sulfides formed from the reduction of sulphates which are present in excess of Fe^{2+} in these soils, will eventually lower Fe^{2+} by precipitation of FeS, but below pH 5.0 sulphate reduction is a slow process and so Fe^{2+} decreases only after prolonged submergence.

Ponnamperuma (1972) showed that after a peak in the concentration of water soluble iron, the activity of Fe^{2+} in most rice soils is related to pH according to the equation.

$$\log (Fe^{2+}) + 2\ pH = \log K$$

While log K generally varies between 9.9 and 10.6, this constancy indicates apparent equilibrium between Fe^{2+} and $Fe(OH)_2$, (hypothetical ferrous hydroxide) with a solubility product of $10^{-18.1}$ to $10^{-17.4}$. Assuming log K = 9.9 and an activity coefficient of 0.5, the equation predicts that the concentration of Fe^{2+} is 8.9 ppm at pH 7, 89 ppm at pH 6.5 and 890 ppm at pH 6.

Kuruvila and Patnaik (1973) also reported more than 100-300 ppm of Fe^{2+} in the acid sulphate soils of Kerala.

Ponnamperuma (1976) got Fe^{2+} concentrations as high as 5000 ppm within a few weeks of submergence in acid sulphate soils. Nhung and Ponnamperuma (1966) also reported high persisting concentrations of Fe^{2+} in acid sulphate soils under flooded conditions. After prolonged flooding dissolved Fe^{2+} will be lowered mainly by precipitation of ferrous sulphide, but this may take from six months to one year (van Breeman, 1976). However, care has to be taken while extrapolating these data from pot experiments to the field. In pots the dissolved ferrous sulphate formed in reduced acid sulphate soils diffuses upward and is oxidised to ferric hydroxide and sulphuric acid near the surface of the soil, giving the surface water pH values (2.4-3.5) that hamper further soil reduction. The same process takes place in the field but flood water is normally replaced and drained laterally, so the effect is less. Secondly when pyrite occurs within about 50 cm of the soil surface, reduction of ferric oxide by pyrite during flooding contributes considerably to high levels of Fe^{2+} (van Breeman, 1976).

On drying an acid sulphate soil, oxidation of pyrite takes place and the soil gets acidified (Brinkman, 1970). Pyrite is oxidised to dissolved ferrous sulphate and sulphuric acid. van Breeman and Pons (1978) expressed the overall reaction as follows:

$$FeS_2 + 7/2\ O_2 + H_2O \longrightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$$

Chemical oxidation of pyrite is slow but the oxidation rate increases greatly in the presence of microbes of the genus Thiobacillus. These autotrophs, some of which can function below pH 2.0 derive energy from the oxidation of reduced sulphur compounds and in case of T. ferroxidans, from the oxidation of Fe^{2+} to Fe^{3+}. Dissolved Fe^{3+} rapidly oxidises pyrite according to the equation

$$FeS_2 + 14\ Fe^{3+} + 8\ H_2O \longrightarrow 15\ Fe^{2+} + 16\ H^+ + 2\ SO_4^{2-}$$

Iron toxicity can occur when dissolved iron is in excess of 300-400 ppm (Ponnamperuma et al., 1955). Tomlinson (1957) reported iron toxicity at 1000 ppm levels. Ponnamperuma et al. (1973) reported death of plants due to iron toxicity in acid sulphate soils of Philippines. A physiological disease due to excess iron in the soils of Kuttanad was reported by Subramoney and Kurup (1961).

Parischa and Ponnamperuma (1976) reported that high salinity favour the production of Fe^{2+}, probably by slightly depressing the soil pH, and by lowering the activity coefficient of Fe^{2+}, causing higher equilibrium concentrations.

Availability of Aluminium

Submerging an acid sulphate soil, decreases, dissolved aluminium as the pH rises regardless of whether the pH increase is due to soil reduction, liming or leaching. The solubility of aluminium is decreased with increasing pH (Richenberg and Adams, 1970) and exchangeable aluminium in soils is negatively correlated with pH (Lev-Minzi et al., 1971).

Dissolved Al^{3+} in soil samples from Thailand fields behaved as if regulated by the hypothetical basic aluminium sulphate $AlOHSO_4$, showing at constant SO_4^{2-} activity, a tenfold decrease per unit increase in pH (van Breeman et al., 1973). The effect of pH on aluminium availability can be shown by the equations.

$$pH - \frac{1}{3} P\,Al_M = 2.2 \qquad - 1$$

Raupauch (1963)

$$PAl = 0.77\,pH + 1.78 \qquad - 2$$

According to equation one, the activities of water soluble aluminium at different pH are as follows:

pH	Concentration of water soluble aluminium (ppm)
3.0	700
3.5	70
4.0	7
5.0	0.07

Thus toxic concentrations of aluminium can occur below pH 4.0. Jackson (1963) and Mc Lean et al. (1964) reported that above pH 5.0, polymerization of Al^{+++} is set in and higher polymers of aluminium which were formed at higher soil pH were not displaced by KCl.

Continuous decrease in aluminium concentration of acid sulphate soils with increasing periods of submergence was reported by Nhung and Ponnamperuma (1966) and van Breeman (1976).

Kuruvila (1974) reported an initial increase in aluminium concentration, followed by continuous decrease with increasing period of submergence in some acid sulphate soils of Kerala. Kabeerathumma (1975) reported a marked decrease in exchangeable aluminium in Kari, Kole and Pokkali soils, during the first 20 days attaining minimum values in the range 88 to 316 ppm, after which a gradual increase occurred during the next 50 days of flooding. In Karapadom and Kayal lands there was an initial decrease, which was fluctuated afterwards. But in all the three types, it continued to occur in moderate concentrations. Cate and Sukhai (1964) suggested that under reduced conditions of typical rice soils, exchangeable aluminium was replaced by exchangeable iron probably by a neutralization reaction which can be depicted as follows:

$$2\ Al - Clay + 3\ Fe\ (OH) \longrightarrow 3\ Fe\ Clay + 2\ Al\ (OH)_3$$

When the soil got oxidised due to subsequent drying, Al reappeared probably through reverse neutralization.

Aluminium toxicities in acid sulphate soils were reported by Tomlinson (1957), Hesse (1963) and Kabeerathumma (1975). Young rice seedlings growing in the range of pH 3.5 to 5.4 suffered from 0.05-2.00 ppm dissolved aluminium; 3-4 week old plants suffered from more than 2.5 ppm aluminium (Cate and Sukhai, 1964; Thowornwong and van Diest, 1974). Tomlinson (1957) reported the critical level as 250 ppm. Regardless of the type of acid sulphate soil, such toxic levels occur at pH values below 4.5 to 5.0 for seedlings and below 3.5-4.2 for older plants.

Phosphate counteracts aluminium toxicity, partly due to co-precipitation of aluminium and phosphorus outside the plants and in the roots (Rorison, 1973). The low availability and high fixation of phosphorus in acid sulphate soils may therefore aggravate aluminium toxicity (Hesse, 1963; Watts, 1969). Kabeerathumma (1975) also reported counteraction of phosphorus under conditions of aluminium toxicity.

A high aluminium level, affects cell division, disrupts certain enzyme systems and hampers intake of phosphorus, calcium and potassium (Rorison, 1973).

MATERIALS AND METHODS

MATERIALS AND METHODS

Kuttanad is an unique agricultural tract, which falls in the Alleppey, Pathanamthitta and Kottayam districts of Kerala State. There are three types of soils occurring in Kuttanad, which are locally known as Karapadom, Kari and Kayal soils. During 1982-83, the area experienced very intense drought conditions. Following this, during the succeeding crop season, it was reported that the rice seedlings failed to establish in some parts of the region. Preliminary studies showed that the soil contained, excessively large amounts of soluble iron. Excessive drying followed by submergence had given rise to certain conditions the nature of which was not fully understood. Hence the present investigation was intended for investigating the effect of drying and wetting on the physical, physico-chemical and chemical properties of the submerged soils of the Kuttanad region of Kerala. For convenience, the whole project was split into three parts.

I. PHYSICAL, PHYSICO-CHEMICAL, CHEMICAL AND MICRO-BIOLOGICAL PROPERTIES OF THE DIFFERENT SOILS IN KUTTANAD

For this study the collection of soil samples was done during May-June, 1985. All the surface stubbles and weeds were removed and by the use of a spade, the vertical 0-15 cm depth of soil was removed and it was immediately packed in polythene covers. A total number of 31 samples were collected, randomly, from different parts of Kuttanad, 14 samples from Karapadom lands, 11 from Kari lands and six from Kayal lands. The location of the samples is given below:

Karapadom soils

Sample No.	Location
1	Ayyanad West
2	Ayyanad Puthenkari-A
3	Ayyanad Puthenkari-B
4	Chembil Padashekaram, Chennankari
5	Puthumada Punathuram, Kainakari-A
6	Puthumada Punathuram, Kainakari-B
7	Puthupparam block
8	RRS, Moncompu, A Block
9	RRS, Moncompu, B Block
10	RRS, Moncompu, C Block
11	Nattayam padom, Chempakulam
12	Chattukampadom, Edathua
13	Mankotta, Edathua
14	Munduthodu, Edathua

Kari soils

Sample No.	Location
1	Vadakkeputhusseri Padashekaram, Vadayar
2	Alamkari Padashekaram, Vadayar
3	Kolathar Padashekaram, Vadayar
4	Nadukkari Padashekaram, Vadayar
5	Kavil padom, Karumadi-A
6	Kavil padom, Karumadi-B
7	Munduthodu padom, Karumadi
8	Pathinettum padom, Karumadi
9	Thalithekke block, Thottapally
10	Marackanmandu, Chennankara
11	Appathikiri, Purakkad

Kayal lands

1	Irumbanam kayal, Kainakari
2	Punnackan kayal
3	Kannatta kayal
4	Kanakasseri, Kainakari
5	Bhagavati padom-A
6	Bhagavati padom-B

The soil samples were packed in airtight polythene covers and transported to the laboratory. In the laboratory, various analysis were first carried out, maintaining the soil samples in the original moist condition itself. The moisture content of the soil samples was estimated using gravimetric methods, so that from the weight of the moist soil taken for analysis, the corresponding weight of the dry soil could be known. The microbiological and physico-chemical analyses were carried out in the moist soil samples.

A portion of moist soil was taken air dried and was powdered using a wooden hammer. The soil was then passed through a 2 mm sieve and was used for physical analysis.

I. Physical Analysis

1. Mechanical analysis: Mechanical analysis of the soil was carried out using hydrometer method (Piper, 1966)

2. Bulk density and particle density

Bulk density and particle density were measured using a Keen-Raczkowski box.

II. Physico-chemical Analysis

1. pH: Soil pH was determined in a 1:2.5 soil solution ratio, after equilibrating for 30 minutes, in distilled

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II. <u>Physico-chemical Analysis</u>

1. <u>pH</u>: Soil pH was determined in a 1:2.5 soil solution ratio, after equilibrating for 30 minutes, in distilled

water, using a Perkin-Elmer pH meter.

2. pH in salt solution: Soil pH was determined in N KCl also to avoid fluctuations (Hesse, 1971).

3. Conductivity

Specific conductance was measured by measuring the electrical conductivity in 1:5 soil solution ratio, using a solu bridge.

III. Chemical Analysis

1. Available Nitrogen

Available nitrogen was determined by the alkaline permanganate method of Subbiah and Asija (1956).

2. Available phosphorus

Available phosphorus was extracted using Bray No.1 reagent and was determined colorimetrically, by phosphomolybdo blue colour method in a Klett-Summerson Photoelectric Colorimeter, using a red filter.

3. Available potassium

Available potassium was extracted with neutral normal ammonium acetate and was determined using an EEL flame photometer.

4. Forms of Iron

Three different extractants were used to extract the available and exchangeable forms of iron. The extractants used were the following:

1. Neutral normal ammonium acetate (Jackson, 1967)

From the moist soil sample, 25 g of soil was quickly weighed out, placed in a 500 ml conical flask and 250 ml of extractant was added. The suspension was shaken vigorously for 20-30 seconds and was filtered quickly on a Buchner funnel fitted with Whatman No.5 filterpaper. Three successive 50 ml portions of the extractant was employed for further extraction. Entire extraction was completed in 5 minutes. The filtrate was evaporated to dryness and the traces of organic matter were removed by treatment of the residue with aqua-regia. After evaporation, the iron was taken into solution in 1 ml of IN HCl followed by water to give the correct dilution.

2. Normal KCl

Using a funnel, fitted with a filterpaper, ten g of soil was leached using 100 ml of extractant, slowly, taking not less than two hours. The filtrate was collected in a 100 ml volumetric flask and was made up with the extractant.

3. 0.005 M DTPA (Lindsay and Norwell, 1978)

The available iron was extracted with a soil solution ratio of 1:2, after shaking for two hours. After the treatment with aqua-regia the residue was dissolved in 1 ml of IN HCl, followed by water to give the correct dilution.

The iron was determined colorimetrically with O-phenanthroline, in a Klett-Summerson photo-electric colorimeter, using a green filter.

5. Exchangeable Aluminium

Exchangeable aluminium was extracted with IN KCl (Pratt and Bair, 1961) and was read in a Atomic Absorption Spectrophotometer (Model 3030).

IV. Microbiological Analysis

Total count

Total microbial count was determined using the Thornton's standardised agar media, having the following composition:

Dipotassium hydrogen phosphate, K_2HPO_4 -	1.00 g
Magnesium sulphate, $MgSO_4\ 7H_2O$	0.20 g
Calcium chloride, $CaCl_2\ 2H_2O$	0.10 g
Sodium chloride, NaCl	0.10 g
Ferric chloride, $FeCl_3\ 7H_2O$	0.002 g
Potassium nitrate, KNO_3	0.50 g
Asparagin	0.50 g
Mannitol	1.0 g
Agar	15 g

Distilled water - 1 litre

The pH was adjusted to 7.4 using HCl or KOH and the medium was sterilized at 15 lb pressure for 30 minutes.

The soils were plated in the medium at 1:10,000 and 1:1,00,000 dilutions in two replications each. The plates were incubated for four days at 30°C and the number of colonies developed in each plate was counted and expressed in millions g^{-1} Bacterial, fungal and total microbial count were separately expressed.

II. THE EFFECT OF AIR DRYING AND SUN DRYING ON THE PHYSICO-CHEMICAL CHARACTERISTICS OF THE SOILS

Six samples of soil were selected for the experiment, two each from Kari, Kayal and Karapadom region. The location of the selected samples is given below:

Karapadom A. Ayyanad puthenkari-A

B. Mankotta padom, Edathua

Kari A. Vadakkeputhussery, Vadayar

B. Kavil padom, Karumadi

Kayal A. Irumbanam kayal

B. Punnackan kayal

The physico-chemical properties of these selected samples are given in the Table 1.

The soil samples were packed in polythene covers and transported to the laboratory. In the laboratory the samples were subjected to three different treatments. The wet soil in polythene covers was divided into three portions. One portion for air drying, second one for sun drying and the third one maintained at the moist condition to be used for control.

For air drying of soil, six uniformly sized, polythene covered wooden trays of size 60 x 40 x 10 cm was taken and serially denoted as Karapadom-1, Karapadom-2,

Table 1 Physico-chemical properties of samples (air dried) selected for experiment

Sl. No.	Location	Bulk density g cm^{-3}	Particle density g cm^{-3}	Mechanical Analysis (%) Coarse sand	Fine sand	Silt	Clay	Av. N	Av. P	Av. K	pH	TSS	Av. Fe	Ex. Al
								ppm						
	Karapadom													
1.	Ayyanad puthenkari-A	1.21	2.18	28	11.1	22.8	38.1	295	16.0	201	4.0	0.60	29	241
2.	Mankottapadom Edathua	1.13	2.05	20	24.0	14.0	42.0	209	16.9	110	4.7	0.05	26	41
	Kari													
1.	Vadakke-puthusseri, Vadayar	1.12	2.02	5	2.0	35.0	55.0	210	6.7	348	4.4	0.60	37	12
2.	Kavilpadom, Karumadi	1.21	2.05	66	6.0	4.0	24.0	177	7.1	62	3.8	0.70	30	155
	Kayal													
1.	Irumbanam kayal	1.12	2.20	27	10.0	30.0	33.0	235	11.1	152	4.2	0.075	30	35
2.	Punnacken kayal	1.13	2.12	3	7.0	48.0	42.0	201	6.6	177	3.8	0.05	28	38

<u>Kari</u>-1, <u>Kari</u>-2, <u>Kayal</u>-1 and <u>Kayal</u>-2, corresponding to each soil sample. The wet soil sample was spread at a depth of 5 cm, in the wooden tray. Thus six wooden trays were filled with wet soil corresponding to each sample and was kept for natural air drying, in the laboratory, for a period of 12 weeks. As the drying proceeded, analysis for pH, conductivity, available NPK, ammonium acetate extractable iron, potassium chloride extractable iron and potassium chloride extractable aluminium was done, periodically at intervals of 1 day, 1 week, 2 weeks, 3 weeks, 4 weeks, 8 weeks and 12 weeks.

The second portion of bulk sample was subjected to sun drying. Wooden trays of size 60 x 40 x 10 cm were taken, laid with polythene and the wet soil was spread at a depth of 5 cm. The trays were serially numbered corresponding to each soil sample as in the above case. The soil filled trays were subjected to sun drying for a period of three months. Daily exposure to sunlight was given from 10 AM to 2 PM except during a few rainy days. Periodical estimations were carried out for various parameters as in the above case.

Table 1 Physico-chemical properties of samples (air dried) selected for experiment

Sl. No.	Location	Bulk density g cm^{-3}	Particle density g cm^{-3}	Mechanical Analysis (%) Coarse sand	Fine sand	Silt	Clay	Av. N	Av. P	Av. K	pH	TSS	Av. Fe	Ex. Al
								ppm						
	Karapadom													
1.	Ayyenad puthenkari-A	1.21	2.18	28	11.1	22.8	38.1	295	16.0	201	4.0	0.60	29	241
2.	Mankottapadom Edathua	1.13	2.05	20	24.0	14.0	42.0	209	16.9	110	4.7	0.05	26	41
	Kari													
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2.	Punnackan kayal	1.13	2.12	3	7.0	48.0	42.0	201	6.6	177	3.8	0.05	28	38

The third portion of bulk sample was kept as control. It was maintained in the wet condition itself packed in airtight polythene covers. Six polythene packed soil samples were there, corresponding to each soil sample. These polythene packed soil samples were kept in the laboratory for a period of three months. Polythene covers were opened at periodical intervals, for drawing out the required quantities of soil for analytical estimations. While doing so, care was taken to cause only minimum disturbance to the control wet soil. Immediately after taking samples for analysis the soil samples were again packed airtight. Periodical estimations for different parameters were carried out as in the case of air drying and sun drying.

Statistical Analysis

Data obtained were analysed in a 3 x 3 x 8 Factorial CRD with two replications.

Factor A Soil groups S_1 - Karapadom soil

S_2 - Kari soil

S_3 - Kayal soil

Factor B Soil treatment

C_1 - wet soil

C_2 - air drying

C_3 - sun drying

Factor C Period of observation

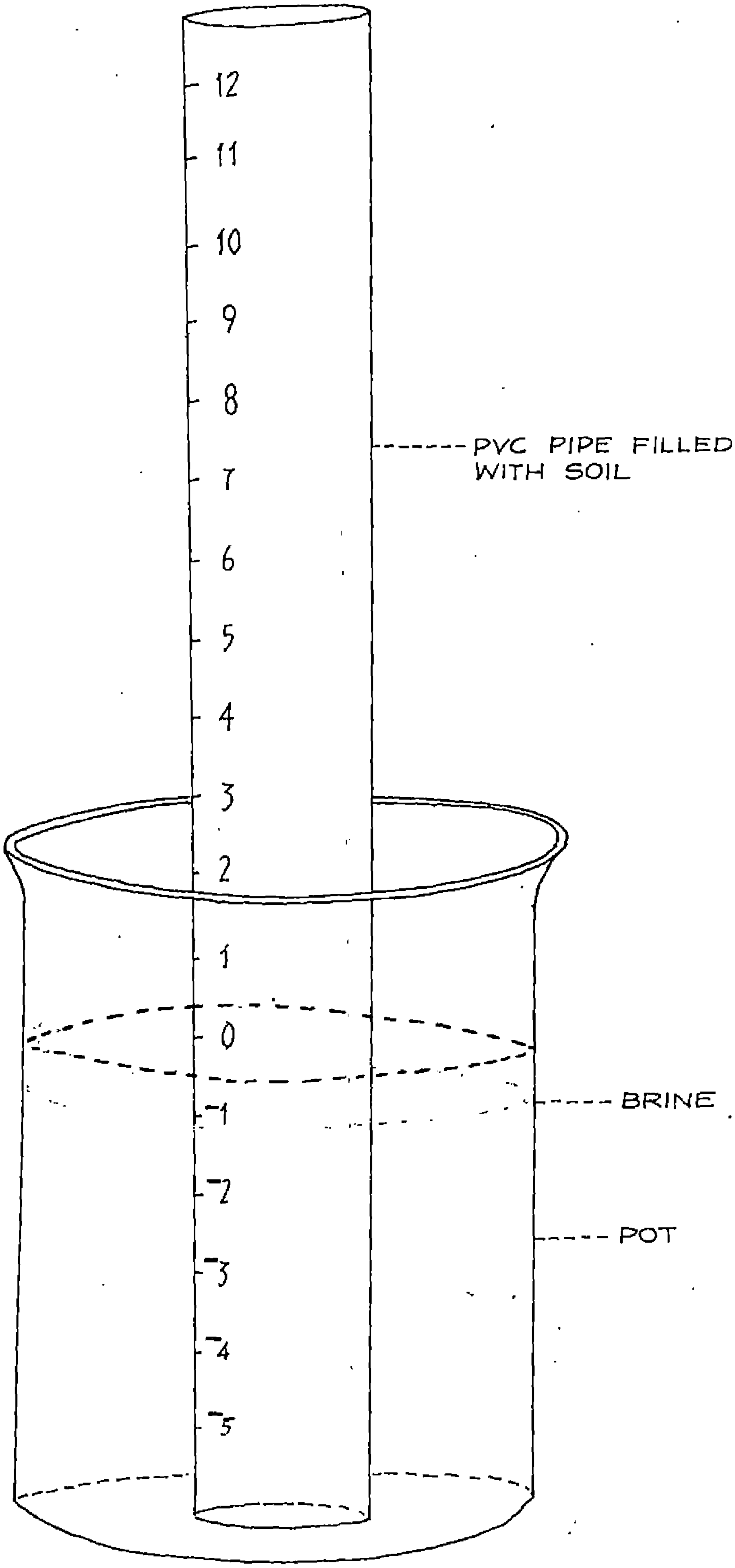
P_1 - 0 day	P_5 - 3 weeks
P_2 - 1 day	P_6 - 4 weeks
P_3 - 1 week	P_7 - 8 weeks
P_4 - 2 week	P_8 - 12 weeks

There were 72 treatment combinations. The significance of variance was tested using 'F' test.

III. AIR DRYING UNDER SIMULATED FIELD CONDITIONS

Two soil samples from each group were selected for this experiment also. The selected samples were the same as those used for the drying experiment. The samples were intensively dried, powdered using a wooden hammer and was passed through a 2 mm sieve. PVC pipes of length 18" and diameter 3" were taken and each pipe was longitudinally split into two equal halves and then again joined together, using cellophane tape. Dried and sieved soil was packed in the reunited PVC pipes. After filling with soil, the PVC pipes were labelled with the name of the soil group and location. The soil filled PVC pipes were then kept vertical in Porcelain pots containing sea water, so that only the lower six inches of the soil was in contact with sea water.

FIG. 1. AIR DRYING UNDER FIELD SIMULATED CONDITIONS



Diagrammatic representation of the arrangement is given in the figure. This arrangement was to simulate the field conditions in Kuttanad. During periods of extreme drought the water table lowers and there will be an influx of saline water from the sea.

The sea water used for the experiment had the following composition:

N	-	15 ppm
P	-	0.07 "
Al	-	0.01 "
Fe	-	0.01 "
Cl	-	10,000 "
Na	-	10,500 "
K	-	380 "
Ca	-	400 "
Mg	-	1,350 "

Electrical conductivity - 58.35 mmhos cm^{-1}

The porcelain pots with PVC tubes packed with the soil samples were kept in a vertical undisturbed position in the laboratory using wooden stands. The six inch level of sea water in the porcelain pots was checked daily and the decrease in level was made up by adding additional quantities of sea water. For one month the PVC tubes packed with soil samples were kept in six inch sea water for giving sufficient time for the salt water to rise up in the PVC pipe, under capillarity. After the prescribed period of one month the PVC tubes packed with samples were taken out, and the cellophane tapes were detatched, so that the two longitudinal halves of each PVC pipe were split open and the soil column was taken out. The soil column above and below the water level was divided into segments of one inch length. Thus there were six one inch portions below the water table and twelve one inch portions above the water table.

From each portion of the column soil were drawn out for various estimations which included pH, conductivity and different forms of iron and aluminium. Moisture content was estimated by gravimetric methods and the weight of soil for each analysis was adjusted to that equivalent to oven dried soil.

The data obtained were analysed in a factorial RBD.

<u>Factor 1</u>. Soil group

S_1 - <u>Karapadom</u> soil

S_2 - <u>Kari</u> soil

S_3 - <u>Kayal</u> soil

<u>Factor 2</u>. Height of soil above water column.

D_1, D_2, D_3 ...... D_{18} representing 11"-12", 10"-11" .... ⁻5" to ⁻6" respectively.

No. of Replications - 2

The values obtained in lower 6" submerged column and upper 12" aerobic column were compared. The analysis of variance was tested using the 'F' test.

RESULTS

RESULTS

I. PHYSICAL, PHYSICO-CHEMICAL, CHEMICAL AND MICROBIOLOGICAL PROPERTIES OF DIFFERENT SOILS OF KUTTANAD

Thirty one soil samples were collected from various parts of Kuttanad and estimations for various parameters were carried out.

Fresh moist soil was used for the physico-chemical and chemical analysis. Weight of moist soil was adjusted based on the moisture content determined previously. The results obtained are presented here.

Mechanical analysis

Soil textural analysis by hydrometer method in different soils is given in Table 2.

The Karapadom soils were predominantly clays and clay loams. The clay content was highest in the Munduthodupadom in Edathua. Out of the 14 soil samples from Karapadom nine were clayey and the remaining ones clay loams. In Kari soils the sand portion was comparatively high. Out of eleven samples, four soils were clayey, six soils were sandy clay loams and the remaining

Table 2 MECHANICAL ANALYSIS OF DIFFERENT SOILS

	Coarse sand	Fine sand	Silt	Clay	Texture
	Percentage				
KARI SOILS					
1. Vadakkeputhusseri Vadayar	5	2	38	55	Clay
2. Alamkari, Vadayar	3	6	35	56	Clay
3. Kolathar, Vadayar	4	3	37	56	Clay
4. Nadukari, Vadayar	5	3	37	55	Clay
5. Kavilpadom, Karumadi A	66	6	4	24	Sandy clay loam
6. " B	65	7	4	24	Sandy clay loam
7. Munduthodu, Karumadi	33	9	26	32	Sandy clay loam
8. Pathinettumpadom, Karumadi	35	8	26	31	Sandy clay loam
9. Thalithekke block, Thottapally	8	61	8	17	Sandy loam
10. Marackanmandu, Chennankara	36	12	24	28	Sandy clay loam
11. Appathikiripadom, Purakkad	36	10	26	28	Sandy clay loam
KAYAL SOILS					
1. Irumbanam kayal	27	10	30	33	Clay loam
2. Punnackan kayal	3	9	40	48	Clay
3. Kannatta kayal	30	18	26	26	Sandy clay loam
4. Kanakasseri kayal	26	14	20	40	Clay
5. Bhagavati kayal A	4	4	40	52	Clay
6. " " B	3	3	39	55	Clay

Table 2 contd.

Sl. No.	Location	SOIL PARTICLES				Textural class
		Coarse sand	Fine sand	Silt	Clay	
KARAPADOM SOILS						
1	Ayyanad West	28	11	23	38	Clay loam
2	Ayyanad puthenkari A	28	11	21	40	Clay
3	" B	28	11	21	40	Clay
4	Chembil padashekaram	2	19	28	51	Clay
5	Puthumada punathuram A	5	31	28	36	Clay loam
6	" B	6	31	28	35	Clay loam
7	Puthupparam block	8	10	30	52	Clay
8	RRS, Moncompu A	7	12	40	41	Clay
9	RRS, Moncompu B	13	11	38	38	Clay loam
10	RRS, Moncompu C	14	11	37	38	Clay loam
11	Nattayampadom	3	22	33	42	Clay
12	Chattukampadom, Edathua	4	4	40	52	Clay
13	Mankottapadom	20	20	20	40	Clay
14	Munduthodupadom	5	6	34	55	Clay

one was a sandy loam. The Kavilpadom, Karumadi (72%) and Thottapally *Kari* soil (69%) recorded the highest levels of sand fractions while clay contents were highest in the Vadayar *Kari* soils (55-56%). The *Kayal* soils also were predominantly of a clay texture. Out of the six samples four were clayey, one was a clay loam and one a sandy clay loam. The clay content was highest in Bhagavati *Kayal* padom (52-55%).

Bulk density and particle density

The bulk density and particle density of the different soils are given in Table 3. There was no significant difference between the bulk densities of *Karapadom*, *Kari* and *Kayal* soils.

However there was significant difference in particle density. *Kari* soils recorded a significantly lower mean particle density of 2.01 g cm^{-3}, as compared to 2.14 g cm^{-3} for *Karapadom* soils. *Kayal* soils recorded a mean particle density of 2.07 g cm^{-3}, which was on par with *Kari* and *Karapadom* soils.

Soil pH in water

Soil pH of the different soils of Kuttanad as

Table 3 Physical and physico-chemical properties of *Karapadom*, *Kari* and *Kayal* soils of Kuttanad

Soil group	Sl. No.	Description	Bulk density g cm^{-3}	Particle density g cm^{-3}	pH_W	pH_S	Specific conductance mmhos cm^{-1}	Moisture %
KARAPADOM SOILS	1	Ayyanad West	1.11	2.12	4.2	3.8	0.10	39.8
	2	Ayyanad Puthenkari A	1.21	2.18	4.0	3.6	0.25	39.5
	3	" B	1.21	2.02	3.7	3.4	0.10	38.2
	4	Chembilpadom	1.10	2.08	3.7	3.8	0.20	36.6
	5	Puthumada, Punathuram A	1.11	2.18	4.1	3.8	0.20	27.7
	6	" B	1.13	2.16	4.1	4.1	0.08	45.2
	7	Puthupparam	1.20	2.30	4.4	4.0	0.08	44.9
	8	RRS, Moncompu A	1.05	2.42	4.7	4.1	0.05	28.6
	9	" " B	1.02	2.00	4.5	3.6	0.05	25.6
	10	" " C	1.08	2.07	4.2	3.5	0.10	26.0
	11	Nattayampadom	1.12	2.18	3.8	3.1	0.10	29.4
	12	Chattukampadom	1.10	2.15	4.5	3.9	0.05	35.8
	13	Mankottapadom	1.13	2.05	4.6	4.0	0	30.1
	14	Munduthodupadom	1.10	2.02	4.3	3.7	0	47.0
		Mean	1.11	2.14	4.20	3.74	0.097	35.31

Table 3 contd.

Soil group	Sl. No.	Description	Bulk density g cm^{-3}	Particle density g cm^{-3}	pH_W	pH_S	Conductivity mmhos cm^{-1}	Moisture %
1	2	3	4	5	6	7	8	9
	1	Vadakkeputhusseri	1.12	2.02	4.0	3.5	0.10	44.7
	2	Alam kari	1.08	2.01	3.5	3.2	0.30	32.0
	3	Kolathar	1.07	1.96	3.1	3.0	1.20	56.7
	4	Nadu kari	0.98	1.97	3.8	4.1	0.20	52.7
KARI SOILS	5	Kavil padom A	1.21	2.05	4.0	3.8	0.20	25.4
	6	" " B	0.90	2.01	3.8	3.1	0.08	26.4
	7	Munduthodu	1.21	2.06	3.6	3.0	0.20	30.7
	8	Pathinettum padom	1.08	2.05	3.5	3.0	0.30	32.0
	9	Thalethekke block	1.08	1.98	2.8	2.1	3.30	46.0
	10	Marackanmandu	1.12	1.98	4.3	3.3	0.50	28.4
	11	Appathikari	1.13	2.04	3.8	3.4	0.40	16.8
		Mean	1.09	2.01	3.66	3.23	0.62	35.61

Table 3 contd.

1	2	3	4	5	6	7	8	9
	1	Irumbanam	1.12	2.20	5.0	4.5	0.05	28.7
	2	Funnackan	1.13	2.12	5.4	4.7	0	36.5
	3	Kannatta	1.11	2.01	6.0	5.0	0	25.1
Kayal Soils	4	Kanakasseri	1.11	2.07	4.3	3.9	0.10	16.4
	5	Bhagavati A	1.07	2.03	5.4	5.1	0	16.0
	6	Bhagavati B	1.07	2.01	5.4	5.1	0	16.1
		Mean	1.10	2.07	5.25	4.72	0.025	23.13
		CD	-	0.07	0.34	0.34	-	8.03
		Karapadom vs Kari	-	0.09	0.41	0.41	-	9.72
		Karapadom vs Kayal	-	0.09	0.42	0.42	-	10.12
		Kari vs Kayal	0.02	0.02	0.11	0.11	0.16	2.60
		SE						

measured in 1:2.5 soil-solution ratio is given in Table 3. There was significant difference between the soil pH of all the three soils. Kari soils were extremely acidic with a mean pH of 3.7. The Karapadom soils had a mean pH of 4.2 and Kayal soils had a significantly higher mean pH of 5.3. Thottapally Kari soils recorded the lowest pH of 2.8 and Kannatta Kayal recorded the highest pH of 6.0.

Soil pH in N KCl

Soil pH measured in N KCl is given in Table 3. The pH measured in salt solution recorded lower values when compared to the pH measured in water. This decrease was noticed in all cases. There was significant difference between the three soils for the pH in N KCl as in the case of pH in water. Kari soils recorded an extremely acidic mean pH of 3.2, Karapadom soils had an intermediate mean pH of 3.7 and Kayal soils a high mean pH of 4.7.

Conductivity

The specific conductances of Karapadom, Kari and Kayal soils are given in Table 3. All the three soils registered very low values of mean specific conductance. The mean values were 0.62, 0.03 and 0.10 mmhos cm^{-1} respectively in Kari, Kayal and Karapadom soils. There was no significant difference in the mean specific conductance of the three soil groups.

Available Nitrogen

Available nitrogen content estimated by the alkaline permanganate method in the different soils of Kuttanad is given in Table 4. Karapadom, Kari and Kayal soils registered mean available nitrogen contents of 238, 227 and 240 ppm respectively. There was, however, no significant difference between the available nitrogen contents of the Karapadom, Kari and Kayal soils. In the individual soil samples nitrogen content ranged from 122 ppm in Kari soils of Munduthodu padom in Karumadi to 334 ppm in the Karapadom soils of Kankotta padashekaram in Edathua.

Available Phosphorus

Available phosphorus of the different soils of Kuttanad are given in Table 4. Karapadom, Kari and

Table 4 Chemical properties of Karapadom, Kari and Kayal soils of Kuttanad

Soil group	Sl. No.	Description	Av. N	Av. P	Av. K	DTPA.Fe	NH_4-OAC Fe	KCl-Fe	Ex. Al
			ppm						
1	2	3	4	5	6	7	8	9	10
KARAPADOM SOILS	1	Ayyanad West	244	23	80	148	28	150	138
	2	Ayyanad Puthenkari A	302	10	220	131	32	46	250
	3	Ayyanad Puthenkari B	204	21	140	129	10	92	183
	4	Chembil padom	253	30	220	128	14	31	188
	5	Puthumada Punathuram A	208	24	110	108	53	23	71
	6	Puthumada Punathuram B	237	25	160	117	16	523	27
	7	Puthupparam	237	9	130	106	17	1012	28
	8	RRS, Moncompu A	181	19	50	82	6	452	36
	9	" " B	213	14	70	148	34	46	115
	10	" " C	224	5	110	137	11	38	114
	11	Nattayam padom	200	21	90	131	14	38	294
	12	Chattukam padom	272	5	50	129	12	362	55
	13	Mankotta	334	13	110	132	4	442	26
	14	Munduthodu	228	17	200	123	6	692	27
		Mean	238.4	16.9	124.3	124.9	18.4	281.9	110.9

Table 4 contd.

1	2	3	4	5	6	7	8	9	10
	1	Vadakkeputhusseri	285	18	230	92	7	473	22
	2	Alamkari	291	11	80	95	9	192	342
	3	Kolathar	181	25	90	60	30	188	400
	4	Nadukari	311	17	100	106	20	1346	18
	5	Kavil padom A	231	37	60	131	11	196	66
KARI SOILS	6	" " B	181	22	140	122	9	154	248
	7	Munduthodu	127	7	100	120	14	269	147
	8	Pathinettum padom	291	10	120	115	25	385	247
	9	Thalethekke block	154	21	230	111	16	58	134
	10	Marackanmandu	224	35	250	122	10	19	105
	11	Appathikari	228	153	80	105	5	42	32
		Mean	227.2	32.4	134.6	107.2	15.1	302.0	160.1

Table 4 contd.

1	2	3	4
	1	Irumbunam	294
	2	Punnackan	266
KAYAL SOILS	3	Kannatta	224
	4	Kanakasseri	189
	5	Bhagavati A	224
	6	Bhagavati B	220
		Mean	239.5

CD

Karapadom vs Kari -

Karapadom vs Kayal -

Kari vs Kayal -

SE 13.60

5	6	7	8	9	10
30	100	134	35	169	19
20	90	123	10	256	45
24	100	100	15	231	39
16	110	137	24	15	90
10	160	116	16	427	33
10	158	120	18	420	35
18.3	119.7	121.7	19.7	261.7	43.5
-	-	-	-	-	-
-	-	-	-	-	-
-	-	-	-	-	-
6.78	15.64	4.71	2.93	83.74	26.75

Kayal soils recorded mean available phosphorus contents of 16.9, 32.4 and 18.3 ppm respectively. There was no significant difference between the different soils. However, within the individual soil groups there were significant variations. In individual soil samples the available phosphorus content widely ranged from 5 ppm in Karapadom soils of R.R.S., Moncompu (C Block) to 153 ppm in Appathikari padom of Purakkad.

Available (exchangeable) Potassium

Exchangeable potassium extracted with neutral normal ammonium acetate in the different soils of Kuttanad are given in Table 4. Karapadom, Kari and Kayal soils registered mean exchangeable potassium contents of 124, 135 and 120 ppm respectively. But there was no significant difference between the different soil groups. In the individual soil samples exchangeable potassium content varied widely from 50 ppm in Chattukam Karapadom soils of Edathua to 250 ppm in Marackanmandu Kari soils of Chennankara.

Different forms of Iron

a. DTPA extractable available iron

The available iron content of Karapadom, Kari and Kayal soils are given in Table 4. The mean available iron contents in Karapadom, Kari and Kayal soils were 125, 107 and 122 ppm respectively. There was no significant difference between soil groups or between the individual soils of the same soil group.

b. Ammonium acetate extractable Iron

Ammonium acetate extractable iron contents of different soils in Kuttanad are given in Table 4. The values were very low when compared to that of DTPA extractable iron. The mean iron contents were 18, 15 and 20 ppm respectively in Karapadom, Kari and Kayal soils. There was no significant difference between the different soil groups.

c. Potassium chloride extractable Iron

Potassium chloride extractable iron contents of different soils of Kuttanad are given in Table 4. The values were higher than that of ammonium acetate extractable iron. The mean values were 282, 302 and 262 ppm in Karapadom, Kari and Kayal soils respectively. But there was no significant difference between Karapadom, Kari and Kayal soils. However in the individual soil samples wide variations were noted from a mere 15 ppm in Kanakasseri Kayal to 1346 ppm in Nadukkari padom of Vadayar. The values obtained were inconsistent within the soil groups.

Exchangeable Aluminium

Exchangeable aluminium contents of different soils are given in Table 4. The Karapadom, Kari and Kayal soils recorded mean contents of 111, 160 and 44 ppm respectively. There was no significant difference between the three soil groups. In individual soil samples wide variations of 18-400 ppm were noted for this parameter.

Microbial count

The total microbial count recorded in different soil samples using Thornton's agar media is given in Table 5.

Total microbial counts recorded were very low and the mean values were 0.27, 0.20 and 0.28 millions g^{-1} in Karapadom, Kari and Kayal soils respectively. There was no significant difference between the three soils of Kuttanad. In Kari soils the fungal population was

Table 5 Microbial properties of Karapadom, Kari and Kayal soils of Kuttanad

Soil group	Sl. No.	Description	Total count $(m\ g^{-1})$	Fungal population $(m\ g^{-1})$	Bacterial population $(m\ g^{-1})$
1	2	3	4	5	6
	1	Ayyanad West, Pulimkunnu	0.36	0.04	0.32
	2	Ayyanad Puthenkari A	0.26	0.04	0.22
	3	" " B	0.22	0.02	0.18
	4	Chembil padashekaram, Chenenkari	0.31	0.02	0.29
	5	Puthumada punathuram, Kainakari A	0.10	0.03	0.07
	6	" " B	0.26	0.01	0.25
KARAPADOM SOILS	7	Puthuparam block	0.15	0.02	0.13
	8	R.R.S., Moncompu block A	0.33	0.03	0.30
	9	R.R.S., Moncompu block B	0.23	0.01	0.22
	10	R.R.S., Moncompu block C	0.24	0.03	0.21
	11	Nattayampadom, Champakulam	0.26	0.04	0.22
	12	Chattukampadom, Edathua	0.52	0.02	0.50
	13	Mankottapadom "	0.42	0.02	0.40
	14	Munduthodupadom "	0.15	0.03	0.12
		Mean	0.272	0.026	0.245

Table 5 contd.

1	2	3	4	5	6
	1	Vadekkeputhusseri, Vadayar	0.17	0.04	0.13
	2	Alamkari, Vadayar	0.26	0.06	0.20
	3	Kolathar, Vadayar	0.26	0.04	0.22
	4	Nadukari, Vadayar	0.27	0.05	0.22
	5	Kavilpadom, Karumadi A	0.24	0.06	0.18
KARI SOILS	6	" " B	0.19	0.04	0.15
	7	Munduthodu, Karumadi	0.09	0.03	0.04
	8	Pathinettumpadom, Karumadi	0.25	0.02	0.23
	9	Thalithekke block, Thottapally	0.17	0.04	0.13
	10	Marackanmandu, Chennankara	0.16	0.04	0.12
	11	Appathikaripadom, Purakkad	0.08	0.02	0.06
		Mean	0.195	0.04	0.153

Table 5 contd.

1	2	3	4	5	6
	1	Irumbanam kayal, Kainakari	0.23	0.03	0.20
	2	Punnackan kayal	0.35	0.04	0.31
KAYAL SOILS	3	Kanatta padashekaram	0.26	0.03	0.23
	4	Kanakasseri kayal	0.23	0.02	0.11
	5	Bhagavatipadom A	0.31	0.01	0.30
	6	" " B	0.31	0.01	0.30
		Mean	0.282	0.023	0.242
		C.Ds.			
		Karapadom vs Kari	-	0.040	0.076
		Karapadom vs Kayal	-	0.011	0.092
		Kari vs Kayal	-	0.012	0.096
		SE	0.024	0.003	0.025

significantly higher when compared to Karapadom and Kayal soils and the bacterial population was significantly lower in Kari soils, when compared to Kayal and Karapadom soils.

II. EFFECT OF DRYING ON THE DIFFERENT SOIL GROUPS OF KUTTANAD

Different soils of Kuttanad viz., Karapadom, Kari and Kayal were subjected to air drying and sun drying for a period of twelve weeks. Soil pH, specific conductance, available NPK and different forms of iron and aluminium were estimated after one day, one week, two weeks, three weeks, four weeks, eight weeks and twelve weeks. The results obtained are given below:

Effect of drying on soil pH in water

Soil pH measured in water in the different soils, under different types of drying treatments and at various intervals are given in Table 6.

There was a marked decrease in soil pH in all the soils due to drying. In Karapadom soils the pH was reduced from an initial level of 5.6 to 4.2, 4.2 and 4.5 respectively as a result of air drying, sun drying and wet soil incubation at the end of 12 weeks. In Kari soils also, 12 weeks of air drying, sun drying and wet soil incubation reduced the pH to 4.0, 3.9 and 4.5 respectively, from an initial pH of 5.6. In Kayal

Table 6 Effect of drying on the soil pH_w of different soils of Kuttanad

Soil group	Treatments	Periods							
		0 d	1 d	1 w	2 w	3 w	4 w	8 w	12 w
Karapadom	Control	5.60	5.55	5.35	5.20	5.10	4.90	4.90	4.45
	Air drying	5.60	5.65	4.75	4.55	4.40	4.25	4.25	4.20
	Sun drying	5.60	5.55	4.55	4.45	4.40	4.25	4.30	4.20
Kari	Control	5.60	5.60	5.40	5.25	5.20	5.05	5.05	4.45
	Air drying	5.60	5.55	4.60	4.25	4.15	4.15	4.15	4.00
	Sun drying	5.60	5.60	4.45	4.20	4.05	4.10	3.95	3.90
Kayal	Control	5.60	5.55	5.55	5.50	5.40	5.40	5.35	5.20
	Air drying	5.60	5.60	4.70	4.60	4.50	4.50	4.55	4.55
	Sun drying	5.60	5.40	4.60	4.45	4.40	4.50	4.50	4.55

SE = 0.199

Mean table

	C_1	C_2	C_3	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	Mean S
S_1	5.13	4.70	4.66	5.60	5.58	4.88	4.73	4.63	4.46	4.48	4.28	4.83
S_2	5.20	4.56	4.48	5.60	5.57	4.82	4.57	4.47	4.43	4.38	4.12	4.74
S_3	5.44	4.83	4.75	5.60	5.52	4.95	4.85	4.47	4.80	4.80	4.77	5.01
				Mean P								
Mean C	5.26	4.70	4.63	5.60	5.56	4.88	4.72	4.62	4.57	4.56	4.39	
P_1	5.60	5.60	5.60									
P_2	5.57	5.60	5.50									
P_3	5.43	4.68	4.53									
P_4	5.32	4.47	4.37									
P_5	5.23	4.35	4.28									
P_6	5.12	4.30	4.28									
P_7	5.10	4.32	4.25									
P_8	4.70	4.25	4.22									

CD

CD(S) = 0.12

CD(C) = 0.12

CD(P) = 0.19

CD(SC) = 0.20

CD(SP) = 0.33

soils from an initial value of 5.6 the soil pH was reduced to 4.6 in case of air drying and sun drying and 5.2 in the case of wet soil incubation after the 12 week period.

Between different soils the mean pH was significantly higher in <u>Kayal</u> soils (5.0) when compared to <u>Kari</u> soils (4.7) and <u>Karapadom</u> soils (4.8). The mean soil pH of wet soil at different periods was significantly higher (5.3). However air dried and sun dried samples also registered a statistically equal mean pH value.

The mean pH value for different periods of observation was gradually reduced from the first day onwards. The reduction in soil pH was faster in the initial stages. There was significant reduction in the mean values of the pH at the end of the different periods viz., one, three and twelve weeks. There were significant differences between air drying, sun drying and wet soil incubation during the different periods of observation. In all the three cases there was a steady decrease in soil pH. But the decrease was quicker and more significantly pronounced in air drying. In wet soils the significant reduction in soil pH had started from the third week only, but in air drying and sun drying significant reduction had started from the first week of drying itself.

Soil pH measured in normal KCl

The soil pH measured in N KCl in different soils, maintained in wet, air dried and sun dried conditions, for different periods of observations are given in Table 7.

Soil pH measured in salt solution also registered a similar trend as in the above case. In Karapadom soils the pH dropped from an initial level of 5.5 to 3.8, 4.0 and 4.1 respectively in the wet, air dried and sun dried soil after the 12 week period. In Kari soil from an initial pH of 5.6, air drying, sun drying and wet incubation reduced the pH to 4.0, 4.1 and 3.7 respectively. In Kayal soils the pH was reduced from an initial level of 5.5 to 4.1 by air drying, 4.0 by sun drying and 4.6 by moist incubation at the end of 12 week.

In general the pH measured in salt solution

Table 7 Effect of drying on the pH_S of different soils of Kuttanad

Soil group	Treatments	Periods							
		0 d	1 d	1 w	2 w	3 w	4 w	8 w	12 w
Karapadom	Control	5.50	5.45	5.20	4.95	4.75	4.35	4.05	3.80
	Air drying	5.50	5.50	4.60	4.30	4.30	4.25	4.25	4.00
	Sun drying	5.50	5.40	4.45	4.30	4.30	4.20	4.05	4.10
Kari	Control	5.55	5.55	5.10	4.30	4.25	3.95	3.85	3.65
	Air drying	5.55	5.45	4.45	4.35	4.10	4.05	4.00	4.00
	Sun drying	5.55	5.45	4.30	4.10	4.20	4.10	4.00	4.10
Kayal	Control	5.45	5.45	5.45	5.10	5.00	4.95	4.80	4.60
	Air drying	5.45	5.50	4.50	4.20	4.10	4.10	4.05	4.05
	Sun drying	5.45	5.40	4.15	4.15	4.10	4.10	4.00	4.00

SE = 0.176

Mean table

	C_1	C_2	C_3	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	Mean S
S_1	4.80	4.59	4.56	5.50	5.47	4.75	4.52	4.45	4.27	4.18	4.07	4.65
S_2	4.54	4.49	4.48	5.55	5.38	4.55	4.32	4.12	4.07	4.00	4.03	4.50
S_3	5.10	4.49	4.37	5.45	5.22	4.70	4.48	4.40	4.38	4.28	4.22	4.64
				Mean P								
Mean C	4.81	4.53	4.46	5.50	5.36	4.67	4.44	4.32	4.24	4.16	4.11	
P_1	5.50	5.50	5.50									
P_2	5.38	4.48	5.20									
P_3	5.18	4.52	4.30									
P_4	4.85	4.28	4.18									
P_5	4.60	4.17	4.20									
P_6	4.45	4.13	4.13									
P_7	4.30	4.10	4.07									
P_8	4.23	4.02	4.07									

CDs

CD(S) = 0.10

CD(C) = 0.10

CD(P) = 0.17

CD(SC) = 0.18

CD(SP) = 0.29

showed lower values when compared to the pH measured in water.

The mean pH of *Kari* soils (4.5) was significantly lower than that of the *Karapadom* (4.7) and *Kayal* soils (4.6). The mean pH of the air dried and sun dried samples was significantly lower than, that of the wet soil. There was a continuous reduction in the mean pH at the end of different periods, till the end of the 12 week period, significant reductions occurring at one day, one week, three weeks and eight weeks.

The behaviour of the different soils was not consistent with regard to the treatments. In *Kari* soils the mean pH values due to the different drying treatments were statistically on par. But in *Karapadom* and *Kayal* soils the mean soil pH in wet soil was significantly higher than that of air drying and sun drying.

The behaviour of soils was also not consistent for the different periods of drying. The mean pH at the end of each period showed a gradual reduction, throughout the experiment. In *Karapadom* soils significant reduction in mean soil pH occurred at the end of the different periods of observation, viz., one, three and 12 weeks. In Kari and Kayal soils significant reductions occurred at the end of the one week and three weeks period. In these soils the reduction in soil pH had been faster and pH had got stabilised after three weeks of drying. But in Karapadom soils, even at 12 weeks periods, pH was getting reduced significantly, but the rate of decrease was slower.

Specific conductance

The specific conductance measured in 1:5 soil water ratio in different soils under different methods of drying for varying periods are given in Table 8.

There were no significant differences in conductivity after the drying treatments, though a marginal increase was noted. In Karapadom soils, conductivity increased from 0.28 mmhos cm^{-1} to 0.33 mmhos cm^{-1} by air drying and sun drying for 12 weeks. There was no change in the wet incubated soil. In Kari soils conductivity increased to 0.65 mmhos cm^{-1} from 0.60 mmhos cm^{-1} by the air drying and sun drying treatments. In Kayal soils conductivity was increased to 0.07 mmhos cm^{-1} by air drying and to 0.08 mmhos cm^{-1} by sun drying after 12 weeks from the initial level of 0.05 mmhos cm^{-1}.

Table 8 Effect of drying on specific conductance of different soils of Kuttanad (mmhos cm^{-1})

Soil group	Treatments	Periods							
		0 d	1 d	1 w	2 w	3 w	4 w	8 w	12 w
Karapadom	Control	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
	Air drying	0.28	0.28	0.28	0.30	0.30	0.33	0.33	0.33
	Sun drying	0.28	0.28	0.33	0.33	0.33	0.33	0.33	0.33
Kari	Control	0.60	0.58	0.65	0.65	0.60	0.55	0.55	0.55
	Air drying	0.60	0.60	0.60	0.65	0.65	0.65	0.65	0.65
	Sun drying	0.60	0.60	0.65	0.65	0.65	0.65	0.65	0.65
Kayal	Control	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	Air drying	0.05	0.05	0.05	0.07	0.07	0.07	0.07	0.07
	Sun drying	0.05	0.05	0.07	0.07	0.07	0.08	0.08	0.08

SE = 0.153

Mean table

	C_1	C_2	C_3	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	Mean S
S_1	0.28	0.30	0.31	0.28	0.28	0.28	0.30	0.30	0.31	0.31	0.31	0.29
S_2	0.58	0.63	0.63	0.58	0.59	0.63	0.63	0.63	0.62	0.62	0.62	0.61
S_3	0.05	0.59	0.06	0.05	0.05	0.58	0.06	0.06	0.06	0.06	0.06	0.06
				Mean P								
Mean C	0.30	0.33	0.34	0.30	0.31	0.33	0.33	0.33	0.33	0.33	0.33	
P_1	0.30	0.30	0.30									
P_2	0.30	0.31	0.31									
P_3	0.33	0.31	0.34									
P_4	0.31	0.34	0.35									
P_5	0.31	0.34	0.35									
P_6	0.29	0.35	0.35									
P_7	0.29	0.35	0.35									
P_8	0.29	0.35	0.35									

CD(S) = 0.08

There were significant differences between the mean specific conductivities of different soils. Specific conductance was highest in <u>Kari</u> soil (0.61 mmhos cm^{-1}), followed by <u>Karapadom</u> soil (0.29 mmhos cm^{-1}) and least in <u>Kayal</u> (0.06 mmhos cm^{-1}) soil.

In all the three soils, sun drying had produced a faster increase in specific conductance than air drying. For example, in <u>Karapadom</u> soils one week of sun drying increased the conductivity of 0.33 mmhos cm^{-1} and thereafter, there was no change. But it took four weeks of air drying for reaching this value.

<u>Available Nitrogen</u>

The available nitrogen content of the different soils under different methods of drying treatments for varying periods are given in Table 9.

There were no significant changes in available nitrogen due to air drying and sun drying for varying periods. In <u>Karapadom</u> soils from the initial level of 316 ppm, the available nitrogen content decreased to 252 ppm and 250 ppm respectively by air drying and sun drying. Wet soil incubation increased available

Table 9 Effect of drying on the available N content of different soils of Kuttanad (ppm)

Soil group	Treatments	Periods							
		0 d	1 d	1 w	2 w	3 w	4 w	8 w	12 w
Karapadom	Control	316.0	318.0	324.0	357.5	371.0	498.5	483.5	451.5
	Air drying	316.0	318.5	292.5	284.0	237.5	329.5	261.5	252.0
	Sun drying	316.0	252.5	260.5	232.0	279.0	253.0	268.5	250.0
Kari	Control	258.0	258.0	265.5	314.5	302.0	341.0	322.5	313.5
	Air drying	258.0	256.5	208.5	202.0	218.0	215.0	193.5	193.5
	Sun drying	258.0	153.5	171.5	203.0	231.5	145.0	201.5	179.0
Kayal	Control	290.0	290.0	309.0	352.5	326.5	418.5	374.0	368.0
	Air drying	290.0	278.0	240.5	231.0	237.5	273.0	254.5	218.0
	Sun drying	290.0	240.5	260.5	279.0	264.5	177.0	275.0	174.0

SE = 35.65

Mean table

	C_1	C_2	C_3	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	Mean S
S_1	390.0	280.2	263.9	316.0	296.3	292.3	291.2	295.8	343.7	337.8	317.8	311.4
S_2	296.9	218.1	192.9	258.0	222.7	215.2	239.9	250.5	233.7	239.2	228.7	236.0
S_3	341.1	252.8	245.1	290.0	269.5	270.0	287.5	276.2	289.5	301.2	253.3	279.7
				Mean P								
Mean C	342.6	250.4	234.0	288.0	262.8	259.2	272.8	274.2	289.0	292.7	266.6	
P_1	288.0	288.0	288.0									
P_2	288.7	284.3	215.5									
P_3	299.5	247.2	230.8									
P_4	341.5	239.0	238.0									
P_5	333.2	231.0	258.3									
P_6	419.3	255.8	191.7									
P_7	393.3	236.5	248.3									
P_8	377.7	221.2	201.0									

CD(S) = 20.5

CD(C) = 20.5

CD(SP) = 35.5

nitrogen content to 452 ppm after the 12 week period. In the wet *Kari* soils, 12 week incubation increased available nitrogen content to 314 ppm from the initial level of 258 ppm whereas air drying and sun drying decreased the nitrogen content to 194 ppm and 179 ppm respectively. In *Kayal* soils from an initial available nitrogen content of 290 ppm, wet soil incubation had increased it to 368 ppm, whereas air drying and sun drying reduced it to 218 ppm and 174 ppm respectively at the end of 12 weeks.

There were significant differences between the mean available nitrogen content of different soils. *Karapadom* soils registered a mean value of 311 ppm, followed by *Kayal* soils with 280 ppm and *Kari* soils with 236 ppm. The mean available nitrogen content was significantly higher in moist soils (343 ppm) when compared to air drying (250 ppm) and sun drying (234 ppm). The mean available nitrogen contents recorded at different periods of drying were statistically on par. The values fluctuated between 259 and 289 ppm.

At the varying periods of observation different treatments behaved inconsistently. In the wet soil, available nitrogen content increased significantly from 238 ppm to 419 ppm after four weeks and thereafter it fluctuated and ended with 378 ppm at the end of the 12th week. In the case of air drying the available nitrogen content was gradually reduced in 12 weeks to 221 ppm with a significant drop at the end of first week of drying. In sun drying on the first day itself the available nitrogen content decreased significantly to 215 ppm and thereafter a marginal and gradual reduction to 201 ppm was noticed. During later periods of drying, there was not much of differences between air drying and sun drying.

Available Phosphorus

The available phosphorus content of the different soils under different methods of drying for varying periods are given in Table 10.

Drying of the soil had resulted in a significant and marked reduction in the available phosphorus content. In *Kerapadom* soils, from the initial level of 45 ppm, air drying, sun drying and wet soil incubation decreased the available P content to 16.5, 15.5 and 31.0 ppm respectively, after 12 weeks. In *Kari* soils, from the

Table 10 Effect of drying on the available P content of different soils of Kuttanad (ppm)

Soil group	Treatments	Periods							
		0 d	1 d	1 w	2 w	3 w	4 w	8 w	12 w
Karapadom	Control	45.0	45.0	41.0	40.5	41.0	43.5	35.0	31.0
	Air drying	45.0	23.0	21.0	19.0	17.5	18.0	20.5	16.5
	Sun drying	45.0	24.0	20.5	18.0	18.5	16.5	15.0	15.5
Kari	Control	37.0	35.5	29.5	29.0	23.5	23.5	25.0	26.5
	Air drying	37.0	17.5	12.0	9.5	7.5	7.5	7.5	8.0
	Sun drying	37.0	17.5	10.5	11.0	11.5	9.5	6.5	5.0
Kayal	Control	26.0	24.5	14.0	16.0	17.0	18.0	17.5	18.0
	Air drying	26.0	26.0	12.0	10.0	10.0	7.5	9.0	9.0
	Sun drying	26.0	13.5	14.0	10.5	8.5	9.5	6.5	6.5

SE = 7.21

Mean table

	C_1	C_2	C_3	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	Mean S
S_1	40.2	22.5	21.6	45.0	30.6	27.4	25.8	25.5	26.0	23.6	21.0	28.1
S_2	28.6	13.3	13.6	37.0	23.4	17.5	16.5	14.2	13.3	12.9	13.2	18.5
S_3	18.9	14.0	11.5	26.1	21.3	13.4	11.9	11.8	11.6	11.1	11.2	14.8
				Mean P								
Mean C	29.2	16.6	15.6	36.0	25.1	19.4	18.0	17.2	16.9	15.9	15.1	
P_1	36.0	36.0	36.0									
P_2	34.9	22.1	18.3									
P_3	28.2	14.9	15.2									
P_4	28.4	13.0	12.8									
P_5	27.1	11.5	12.8									
P_6	28.2	11.7	11.0									
P_7	26.0	12.3	9.3									
P_8	25.2	11.1	9.2									

CD(S) = 4.2

CD(C) = 4.2

CD(SC) = 7.2

initial level of 37 ppm, air drying, sun drying and wet soil incubation decreased the available phosphorus levels to 8.0, 5.0 and 26.5 ppm respectively. In Kayal soils air drying, sun drying and wet soil incubation decreased phosphorus levels to 9.0, 6.5 and 18.0 ppm respectively after 12 weeks from the initial level of 26.0 ppm.

As regards the mean available phosphorus content there were significant differences between the soils. The mean available phosphorus content was highest in the Karapedom soil (28.1 ppm) and least in the Kayal soil (14.8 ppm) and intermediate (18.5 ppm) in the Kari soils. The mean available phosphorus contents of air dried (16.6 ppm) and sun dried samples (15.6 ppm) were significantly lower than that of the wet incubated soils (29.2 ppm).

The average phosphorus content at the end of the different periods of observation was gradually decreased from 36.0 ppm to 15.1 ppm at the end of 12 weeks, significant reductions occurring at the one day and one week periods. No significant interaction between factors was observed.

Available Potassium

The available potassium content of the different soils under different methods of drying for varying periods are given in Table 11.

The mean available potassium content had decreased with periods of drying, irrespective of the treatment and group of soil. In Karapadom soils from the initial level of 392 ppm, air drying, sun drying and wet soil incubation, decreased the available potassium content to 156, 160 and 165 ppm respectively after 12 weeks. In Kari soils also potassium content decreased from 535 ppm to 205, 215 and 145 ppm respectively on air drying, sun drying and moist soil incubation for 12 weeks. In Kayal soils, too, similar results were obtained. From the initial level of 387 ppm available potassium content decreased to 166, 175 and 95 ppm respectively on air drying, sun drying and wet soil incubation for 12 weeks.

The mean available potassium content was significantly higher in Kari soils (327 ppm) as compared to Karapadom (266 ppm) and Kayal soils (257 ppm), which

Table 11 Effect of drying on the available K content of different soils of Kuttanad (ppm)

Soil group	Treatments	Periods							
		0 d	1 d	1 w	2 w	3 w	4 w	8 w	12 w
Karapadom	Control	392.0	389.5	362.5	223.0	203.5	214.5	191.0	165.0
	Air drying	392.0	370.0	274.0	303.5	260.5	240.0	176.5	155.5
	Sun drying	392.0	368.5	225.0	230.0	233.0	245.0	206.5	160.0
Kari	Control	534.5	534.5	310.5	305.0	287.5	297.0	189.0	145.0
	Air drying	534.5	414.0	303.5	292.5	281.5	300.0	217.5	205.0
	Sun drying	534.5	441.0	410.0	369.0	310.0	300.0	221.5	215.0
Kayal	Control	386.5	360.5	280.5	243.5	206.5	214.0	241.0	95.0
	Air drying	386.5	386.5	246.5	234.0	221.5	255.5	184.0	165.5
	Sun drying	386.5	351.5	218.5	241.0	224.5	239.0	220.0	175.0

SE = 83.53

<u>Mean table</u>

	C_1	C_2	C_3	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	Mean S
S_1	267.6	271.5	258.0	392.0	376.0	288.5	252.2	232.3	233.2	191.3	160.2	265.7
S_2	352.4	305.4	350.1	501.2	463.2	341.3	322.2	291.3	299.0	209.3	188.3	326.9
S_3	253.4	259.9	257.0	386.5	366.2	248.5	239.5	217.5	236.2	215.0	144.8	256.8
				Mean P								
Mean C	282.2	278.9	288.4	426.6	401.8	292.8	271.3	247.1	256.1	205.2	164.4	
P_1	437.7	404.3	437.7									
P_2	428.2	390.2	387.0									
P_3	317.8	274.7	285.8									
P_4	257.2	276.7	280.0									
P_5	232.5	252.8	255.8									
P_6	241.8	265.2	261.3									
P_7	207.0	192.7	216.0									
P_8	135.0	175.0	183.3									

CD(S) = 48.1

CD(SC) = 83.3

were statistically on par. There was no significant difference between the different methods of soil drying. During the initial periods of experiment, air drying and sun drying produced a greater reduction in available potassium. But in later periods, wet soil incubation resulted in a greater reduction in available potassium more particularly with Kari and Kayal soils. With increase in period of drying, the available potassium content started decreasing from 427 ppm to 164 ppm, at the end of 12 week period; significant reductions occurring after one day and four weeks.

KCl extractable Iron

The exchangeable iron content extracted with N KCl from different soils under different methods of drying for the various periods are given in Table 12.

There was a sharp reduction in the KCl extractable iron on drying. In Karapadom soils the initial extractable iron content was 640 ppm. By air drying it got reduced to 168 ppm on the first day and to 40 ppm after the first week and to 23 ppm after the second week and thereafter got stabilised. Sun drying also produced a similar result and the iron content was reduced to

Table 12 Effect of drying on the KCl extractable Fe content of different soils of Kuttanad (ppm)

Soil group	Treatments	Periods							
		0 d	1 d	1 w	2 w	3 w	4 w	8 w	12 w
Karapadom	Control	640.0	637.5	424.5	393.0	389.0	346.0	349.0	346.0
	Air drying	640.0	168.0	40.0	23.0	22.0	19.0	20.0	23.0
	Sun drying	640.0	135.5	34.0	23.0	22.5	21.0	23.0	21.5
Kari	Control	676.0	674.0	476.0	396.0	407.5	334.0	228.0	334.5
	Air drying	676.0	444.0	120.0	40.0	33.0	29.0	30.0	28.0
	Sun drying	676.0	458.0	83.5	38.0	37.5	38.0	40.0	36.0
Kayal	Control	518.0	328.0	319.5	302.0	257.5	221.0	206.0	213.5
	Air drying	518.0	480.0	43.5	35.0	26.0	28.0	15.5	16.5
	Sun drying	518.0	435.0	16.0	17.0	19.0	15.0	15.5	16.0

SE = 104.5

Mean table

	C_1	C_2	C_3	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	Mean S
S_1	440.6	119.4	115.1	64.0	313.7	166.2	146.3	144.5	128.7	130.7	130.2	225.0
S_2	453.3	175.0	176.4	676.0	525.3	228.3	158.0	159.2	133.7	132.7	132.8	26.8
S_3	295.6	145.3	131.4	518.0	414.3	126.2	118.0	100.9	88.0	78.5	82.0	190.7
				Mean P								
Mean C	396.5	146.6	141.0	611.3	417.8	173.6	140.8	134.8	116.8	113.9	115.0	

	C_1	C_2	C_3
P_1	611.3	611.3	611.3
P_2	546.5	364.0	342.8
P_3	406.8	67.7	46.2
P_4	363.7	32.7	26.0
P_5	351.3	27.0	26.2
P_6	300.3	25.3	24.7
P_7	294.0	21.8	26.0
P_8	298.0	22.5	24.5

CD(S) = 60.1

CD(C) = 60.1

CD(SC) = 104.2

23 ppm, in a period of two weeks. In incubated wet soil the iron content was reduced to 346 ppm at the end of the twelfth week. In Kari soils also the exchangeable iron content sharply decreased from the initial level of 676 ppm to 40 ppm and 38 ppm respectively due to air drying and sun drying during a period of two weeks. In the wet soil which was kept incubated, there was a gradual reduction of exchangeable iron to 333 ppm at the end of the twelfth week. In Kayal soils, exchangeable iron content sharply decreased to 44 ppm and 16 ppm from the initial level of 518 ppm during the first week itself, due to air drying and sun drying respectively. Gradual reductions occurred in the wet soil which was kept incubated and the exchangeable iron content reached a value of 214 ppm, at the end of the twelfth week.

The mean exchangeable iron content was significantly higher in Kari soils (268 ppm) as compared to Kayal soil (191 ppm). In Karapadom soils, it was 225 ppm and was on par with both the other soil types.

The mean exchangeable iron content was significantly higher in the wet soil which was kept incubated, when compared to the samples subjected to air drying and sun drying.

As the period of drying increased, the average exchangeable iron content got reduced from 611 ppm to 115 ppm, significant reductions occurring on the first day and at the end of the first week.

All the three different factors behaved independently.

Ammonium acetate extractable Iron

The exchangeable iron extracted with neutral normal ammonium acetate from different soils, under different methods of drying for varying periods are given in Table 13.

In this case the three factor interaction was significant. In Karapadom soils the initial exchangeable iron content was 269 ppm. On air drying the soil, it was significantly reduced to 76 ppm in one day and again significantly reduced to 48 ppm in one week and thereafter it got stabilised. In the case of sun drying on the first day exchangeable iron significantly decreased to 71 ppm and on the second week it again got significantly reduced to 33 ppm and thereafter it was stabilised. In the incubated wet soil also there

Table 13 Effect of drying on the NH_4- OAc extractable Fe content of different soils of Kuttanad (ppm)

Soil group	Treatments	Periods							
		0 d	1 d	1 w	2 w	3 w	4 w	8 w	12 w
Karapadom	Control	268.5	268.5	124.0	53.5	51.0	52.5	45.5	33.5
	Air drying	268.5	76.0	48.0	43.0	35.0	32.0	32.0	27.5
	Sun drying	268.5	70.5	60.0	32.5	34.5	29.0	28.0	28.0
Kari	Control	324.0	324.0	157.0	75.5	48.8	48.0	48.0	45.0
	Air drying	324.0	60.5	49.5	44.5	35.0	35.0	33.5	33.5
	Sun drying	324.0	64.5	53.0	49.5	36.0	38.5	38.5	35.0
Kayal	Control	199.5	199.5	95.0	55.0	50.0	43.0	43.0	32.5
	Air drying	199.5	55.0	41.0	35.0	32.0	32.0	32.0	29.0
	Sun drying	199.5	59.0	51.0	47.5	39.5	39.5	38.0	33.5

SE = 8.84

<u>Mean table</u>

	C_1	C_2	C_3	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	Mean S
S_1	112.1	70.3	68.3	268.5	133.3	77.3	43.0	38.5	37.8	35.2	29.7	83.5
S_2	133.8	76.9	79.9	324.0	149.7	86.5	56.5	39.8	40.5	40.0	37.8	96.9
S_3	89.7	56.9	63.4	199.5	104.5	62.3	45.8	40.5	38.2	37.7	31.7	70.0
				Mean P								
Mean C	111.9	68.0	70.5	264.0	130.8	75.4	48.4	39.6	38.8	37.6	33.1	
P_1	264.0	264.0	264.0									
P_2	264.0	63.8	64.7									
P_3	125.3	46.2	54.7									
P_4	61.3	40.8	43.2									
P_5	49.8	34.0	35.0									
P_6	47.8	33.0	35.7									
P_7	45.5	32.5	34.8									
P_8	37.0	30.0	32.2									

CD(S) = 5.1
CD(C) = 5.1
CD(SC) = 8.8
CD(P) = 8.3
CD(SP) = 14.4
CD(CP) = 14.4
CD(SCP) = 24.9

were sharp significant decreases during the one week and two week periods. After the second week, there were no significant differences between the three treatments, though there was a slightly higher value in the incubated wet soil. There was a significantly higher exchangeable Fe, in the wet soil as compared to air dried and sun dried soils during the one day and one week periods.

In Kari soils the initial level of exchangeable Fe was 324 ppm. By air drying, there was a sharp significant reduction to 61 ppm in one day and again a significant reduction to 35 ppm in the third week. The effect of sun drying was also similar with a significant decrease in exchangeable iron to 65 ppm in one day and to 36 ppm after three weeks. In the wet soil which was kept incubated, significant reduction in exchangeable iron occurred after one week, two week and three week periods. During the initial periods of drying (upto second week), there was significantly higher exchangeable iron in wet soil when compared to air drying and sun drying. However during the later stages all the three treatments were statistically on par.

In Kayal soils the initial level of exchangeable iron was 200 ppm. By air drying, it was significantly reduced to 55 ppm on the first day itself and again it got reduced with a significant drop to 29 ppm in twelve weeks. Sun drying gave similar results with significant decrease in the exchangeable iron occurring on the first day and after 12 weeks. In the wet soil which was kept incubated, significant reductions in exchangeable iron occurred during the first week (95 ppm) and further during the second week (55 ppm) also. During the initial periods (upto first week) there were significantly higher exchangeable iron contents in wet soil, but after that all the three treatments were statistically on par.

Exchangeable Aluminium

Exchangeable aluminium extracted with N KCl from the different soils under different methods of drying for various periods are given in Table 14.

There were no significant changes in exchangeable aluminium content due to drying. In Karapadom soils, from the initial exchangeable aluminium level of 430 ppm, air drying, sun drying and wet soil incubation gradually decreased the level to 141, 141 and

Table 14 Effect of drying on the available Al content of different soils of Kuttanad (ppm)

Soil group	Treatments	Periods							
		0 d	1 d	1 w	2 w	3 w	4 w	8 w	12 w
Karapadom	Control	430.0	432.5	430.0	237.5	164.5	154.5	151.5	150.0
	Air drying	430.0	385.5	179.5	152.0	148.5	154.5	140.5	141.0
	Sun drying	430.0	198.5	163.5	152.0	146.5	152.0	141.0	140.5
Kari	Control	134.5	134.5	132.5	132.5	128.5	117.0	116.5	114.5
	Air drying	134.5	113.0	103.5	101.0	97.0	91.0	86.5	83.5
	Sun drying	134.5	92.5	86.0	83.5	82.0	72.0	69.0	74.0
Kayal	Control	64.5	64.5	64.0	64.0	64.0	65.0	64.0	64.5
	Air drying	64.5	56.0	45.5	46.5	41.5	37.0	36.0	36.5
	Sun drying	64.5	55.5	54.0	52.5	54.0	41.0	39.5	41.0

SE = 119.10

<u>**Mean table**</u>

	C_1	C_2	C_3	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	Mean S
S_1	302.1	216.4	146.3	338.2	258.3	244.7	177.7	153.2	144.8	143.8	312.0	221.6
S_2	126.3	101.3	86.8	113.3	107.3	105.7	102.5	93.3	90.7	90.7	134.7	104.8
S_3	64.3	45.4	45.7	58.7	54.5	54.3	55.2	47.7	46.5	47.3	52.3	51.8
				Mean P								
Mean C	164.2	121.0	92.9	170.1	140.1	134.9	111.1	98.1	94.0	93.9	166.3	
P_1	209.8	184.8	115.5									
P_2	209.5	109.5	101.2									
P_3	208.8	99.8	96.0									
P_4	143.5	95.7	94.2									
P_5	111.7	94.2	88.3									
P_6	111.2	87.7	83.2									
P_7	109.7	87.0	85.2									
P_8	209.7	209.7	79.7									

CD(S) = 68.58

150 ppm respectively, at the end of twelve weeks. In _Kari_ soils from initial level of 135 ppm, exchangeable aluminium content decreased to 84, 74 and 115 ppm respectively due to air drying, sun drying and wet soil incubation for 12 weeks. In case of air drying and sun drying sharp reductions were noted on the first day itself. In _Kayal_ soils also, drying failed to produce any significant changes. From the initial level of 65 ppm, air drying, sun drying and wet soil incubation resulted in a reduction in exchangeable aluminium to 37, 41 and 65 ppm respectively during a 12 week period.

The mean exchangeable aluminium content was significantly higher in _Karapadom_ soils (222 ppm) as compared to that of the _Kayal_ (52 ppm) and _Kari_ soil (105 ppm), which were statistically on par. There were no significant differences in mean exchangeable aluminium contents for the different methods of drying. The average aluminium content of different periods were also statistically on par, though a slightly fluctuating decrease was noticed.

III. EFFECT OF AIR DRYING UNDER SIMULATED FIELD CONDITIONS

The results of the experiment conducted to study the effect of air drying under simulated field conditions are given here.

Soil pH in water

pH of Kari, Kayal and Karapadom soils, under field simulated air drying is given in Table 15.

Of the different soils in Kuttanad, Kayal soils recorded, the highest mean pH of 5.0, which was on par with Karapadom soils having a mean pH value of 4.9. Kari soils recorded a significantly lower mean pH of 4.2.

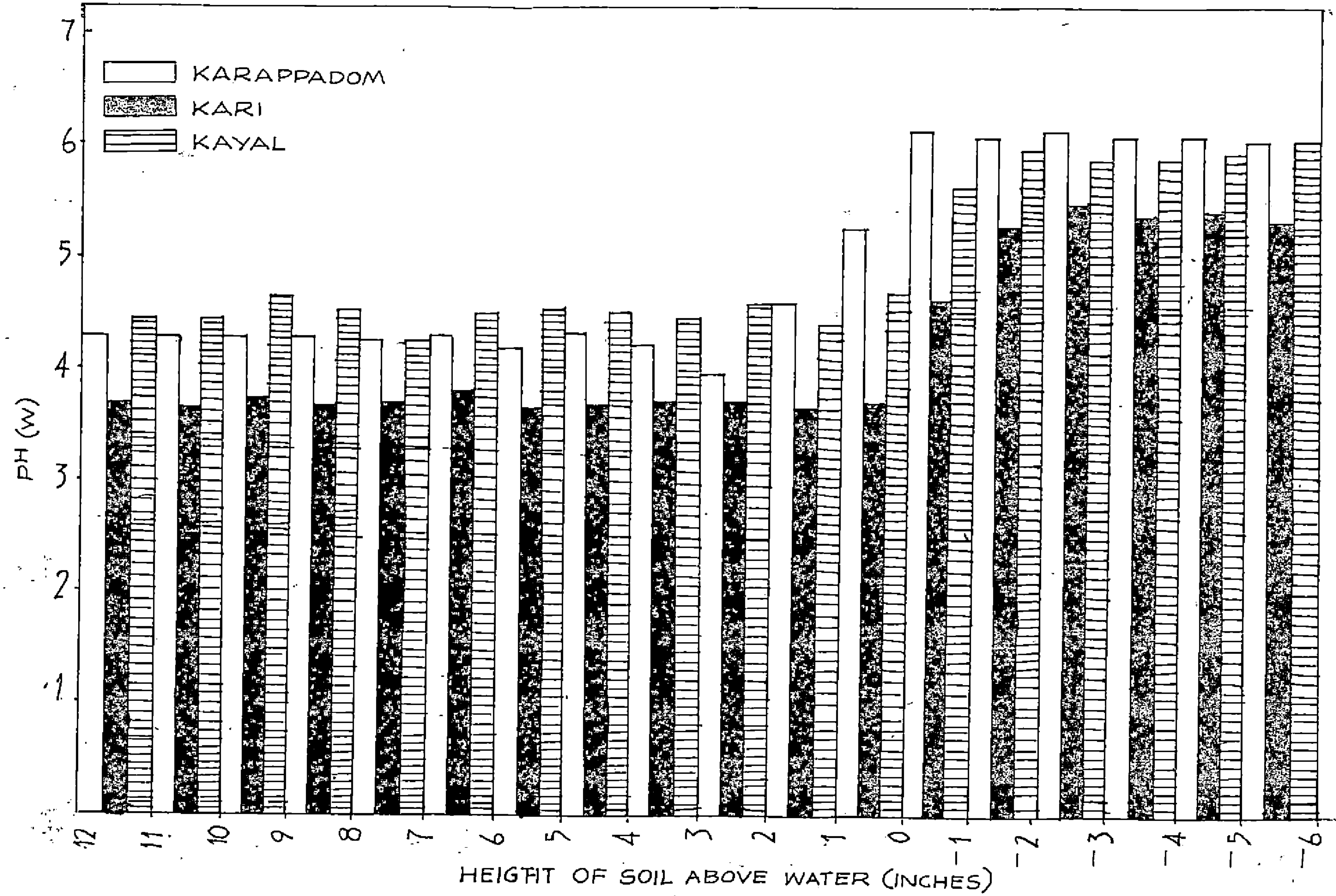
A definite pattern was noticed in all the three soils, for the pH values recorded in different portions of soil column. There was no significant statistical difference between the twelve aerobic top layers (0-1", 1"-2" ...... 11"-12"). However significant difference was obtained between the aerobic and anaerobic layers, even between the 0-1" and 0-⁻1" portions. In the saturated soil portions, from 0-⁻1" to ⁻6"-⁻5", the mean pH values were again statistically on par for the different layers. In the bottom saturated 6" layer of the soil the pH was

Table 15 Effect of air drying under simulated field conditions on soil pH_w, in different soil types of Kuttanad

Height of soil above water (inches)	Soil types Karapadom	Kari	Kayal	Marginal means
11-12	4.30	3.70	4.40	4.13
10-11	4.30	3.65	4.45	4.13
9-10	4.30	3.75	4.40	4.15
8-9	4.30	3.70	4.55	4.18
7-8	4.25	3.70	4.50	4.15
6-7	4.30	3.80	4.50	4.20
5-6	4.20	3.65	4.55	4.13
4-5	4.35	3.65	4.50	4.17
3-4	4.20	3.70	4.45	4.12
2-3	3.95	3.70	4.55	4.07
1-2	4.55	3.65	4.40	4.20
0-1	5.25	3.70	4.70	4.55
-1-0	6.15	4.65	5.65	5.48
-2- -1	6.10	5.30	6.00	5.80
-3- -2	6.15	5.50	5.95	5.87
-4- -3	6.15	5.45	5.90	5.83
-5- -4	6.10	5.40	5.95	5.82
-6- -5	6.10	5.35	6.05	5.83
Marginal means	4.94	4.20	5.00	

CD (soil type) = 0.400
CD (height) = 0.70
SE = 0.25

FIG. 2 EFFECT OF AIRDRYING UNDER SIMULATED FIELD CONDITIONS ON SOIL pH (W) IN DIFFERENT SOILS OF KUTTANAD



more or less stabilised and was significantly higher than the pH of the 12" layer of top aerobic soil.

The *Karapadom* soils recorded a soil pH range of 6.1-6.2 in the submerged layer and a pH range of 4.0-5.3 in the portion above the sea water. *Kari* soils recorded a pH range of 4.7-5.5 in the submerged soil column and a pH range of 3.7-3.8 in aerobic portion. *Kayal* soils recorded a pH range of 5.7-6.1 in the submerged soil column and a pH range of 4.4-4.7 in the portion above the sea water.

Both factors viz. soil group and height of soil above water column behaved independently with no significant interaction between the two.

Soil pH in salt

Soil pH of the different soils in Kuttanad measured in N KCl under field simulated air drying is given in Table 16.

The pH measured in IN, KCl tended to be lower, when compared to the pH in water, in all the cases. But the definite pattern, noticed in the former case was seen here also. *Kayal* soils recorded the highest mean soil pH

Table 16 Effect of air drying under simulated field conditions on soil pH_s in different soil types of Kuttanad

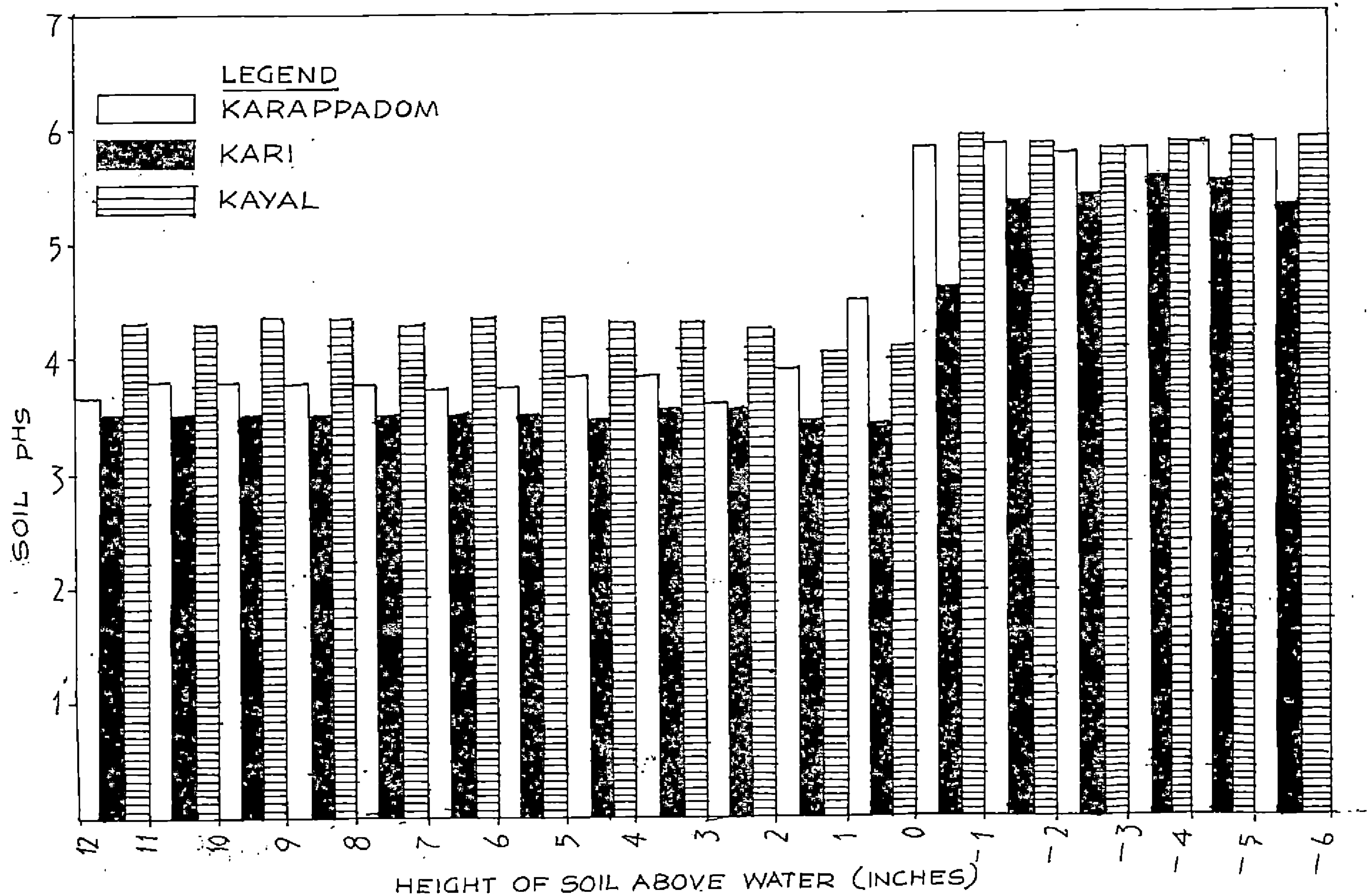
Height of soil above water	Soil types			Marginal means
	Karapadom	Kari	Kayal	
(inches)				
11-12	3.65	3.50	4.30	3.82
10-11	3.80	3.50	4.30	3.87
9-10	3.80	3.50	4.35	3.88
8-9	3.80	3.50	4.35	3.88
7-8	3.80	3.50	4.30	3.87
6-7	3.75	3.50	4.35	3.87
5-6	3.75	3.50	4.35	3.87
4-5	3.85	3.45	4.30	3.87
3-4	3.85	3.50	4.30	3.88
2-3	3.60	3.55	4.25	3.80
1-2	3.90	3.45	4.05	3.80
0-1	4.50	3.40	4.10	4.00
-1-0	5.85	4.60	5.90	5.45
-2-⁻1	5.85	5.35	5.85	5.68
-3-⁻2	5.75	5.40	5.80	5.65
-4-⁻3	5.80	5.55	5.85	5.73
-5-⁻4	5.75	5.50	5.90	5.72
-6-⁻5	5.85	5.30	5.90	5.68
Marginal means	4.49	4.09	4.81	

CD (soil type) = 0.1876

CD (depth) = 0.4594

SE = 0.28

FIG.3 EFFECT OF AIR DRYING UNDER SIMULATED FIELD CONDITIONS ON SOIL pHs DIFFERENT SOILS OF KUTTANAD



of 4.8, followed by Karapadom soils with a mean of 4.5 and Kari soils with a mean value of 4.1. All the three soils significantly differed among themselves.

As regards the second factor viz., the height of the soil above water, there was significant difference only between the submerged anaerobic bottom six inches of soil column and the top aerated twelve inch layer. The mean pH in the submerged portion varied from 5.5 to 5.7 and in the aerobic portion it varied from 3.8 to 4.0. A mean pH of 4.0 was noted in the 0-1" layer and in -1"-0 layer the mean soil pH was 5.5. Except these intermediary layers, aerobic (3.8 to 4.0) and anaerobic (5.5 to 5.7) soil columns recorded almost uniform values within themselves.

In the submerged soil column the pH was significantly higher. Ranges of 5.8-5.9, 4.6-5.6, 5.8-5.9 were recorded for pH in the Karapadom, Kari and Kaval soils in the submerged six inch column. In the aerobic 12" column the pH ranged from 3.6-4.5, 3.4-3.5, 4.1-4.4 respectively in these three soils.

Both factors, viz., soil group and height of soil behaved independently without any interaction between themselves.

Specific conductance

Specific conductance of the Karapadom, Kari and Kayal soils, in the different layers, under air drying in simulated field conditions are given in Table 17.

The mean specific conductance was significantly higher in the Karapadom soils (5.8 mmhos cm^{-1}) than in the Kari (3.0 mmhos cm^{-1}) and Kayal soils (3.7 mmhos cm^{-1}), which were statistically on par.

Between different portions of soil column the marginal means ranged from 3.1 to 4.9 mmhos cm^{-1}. But, there was no significant difference between the different layers irrespective of the aerobic or anaerobic conditions. The two factors behaved independently with no interaction, between themselves.

Different forms of Iron

a. DTPA extractable iron

DTPA extractable available iron content of the Karapadom, Kari and Kayal soils, in the different portions of soil column under field simulated air drying experiment is given in Table 18.

Table 17 Effect of air drying under simulated field conditions on specific conductance in different soil types of Kuttanad

Height of soil above water	Soil types			Marginal means
	Karapadom	Kari	Kayal	
(inches)		($mmhos\ cm^{-1}$)		
11-12	5.60	2.45	2.75	3.60
10-11	4.75	2.15	2.40	3.10
9-10	4.85	2.30	2.55	3.23
8-9	5.30	2.45	2.75	3.50
7-8	5.35	2.50	2.80	3.55
6-7	5.65	2.70	3.10	3.82
5-6	5.85	2.90	3.30	4.02
4-5	5.70	3.00	3.45	4.05
3-4	5.50	3.05	3.55	4.03
2-3	5.90	3.05	3.60	4.18
1-2	6.00	3.15	3.95	4.37
0-1	6.55	3.40	4.15	4.70
-1-0	6.50	3.55	4.55	4.87
-2- -1	5.80	3.45	4.60	4.61
-3- -2	5.95	3.45	4.50	4.63
-4- -3	6.40	3.60	4.55	4.85
-5- -4	6.30	3.45	4.60	4.78
-6- -5	6.00	3.45	4.65	4.70
Marginal means	5.78	3.00	3.66	

CD (soil type) = 0.906

SE = 1.36

Table 18 Effect of air drying under simulated field conditions on DTPA extractable iron in different soil types of Kuttanad

Height of soil above water	Soil types			Marginal means
	Karapadom	Kari	Kayal	
(inches)		ppm		
11-12	183.0	270.5	219.5	224.33
10-11	187.5	274.5	217.0	226.33
9-10	191.0	285.5	222.5	233.00
8-9	198.5	281.0	237.0	238.83
7-8	192.5	291.0	243.5	242.33
6-7	183.5	280.0	244.5	236.00
5-6	206.0	285.0	252.5	247.83
4-5	215.0	295.0	259.5	256.50
3-4	215.5	287.0	257.0	253.17
2-3	237.0	299.0	283.0	273.00
1-2	246.0	280.0	308.75	278.25
0-1	257.0	276.5	326.0	286.50
-1-0	295.0	301.0	382.0	326.00
-2-⁻1	255.5	300.0	371.0	308.83
-3-⁻2	261.5	297.0	371.0	276.50
-4-⁻3	264.5	303.0	362.0	309.83
-5-⁻4	298.5	286.0	377.0	320.50
-5-⁻6	295.5	310.5	377.0	327.67
Marginal means	232.39	289.03	295.0	

CD (soil type) = 53.42

SE = 79.97

FIG. 4 EFFECT OF AIR DRYING UNDER SIMULATED FIELD CONDITIONS ON SPECIFIC CONDUCTANCE IN DIFFERENT SOILS OF KUTTANAD

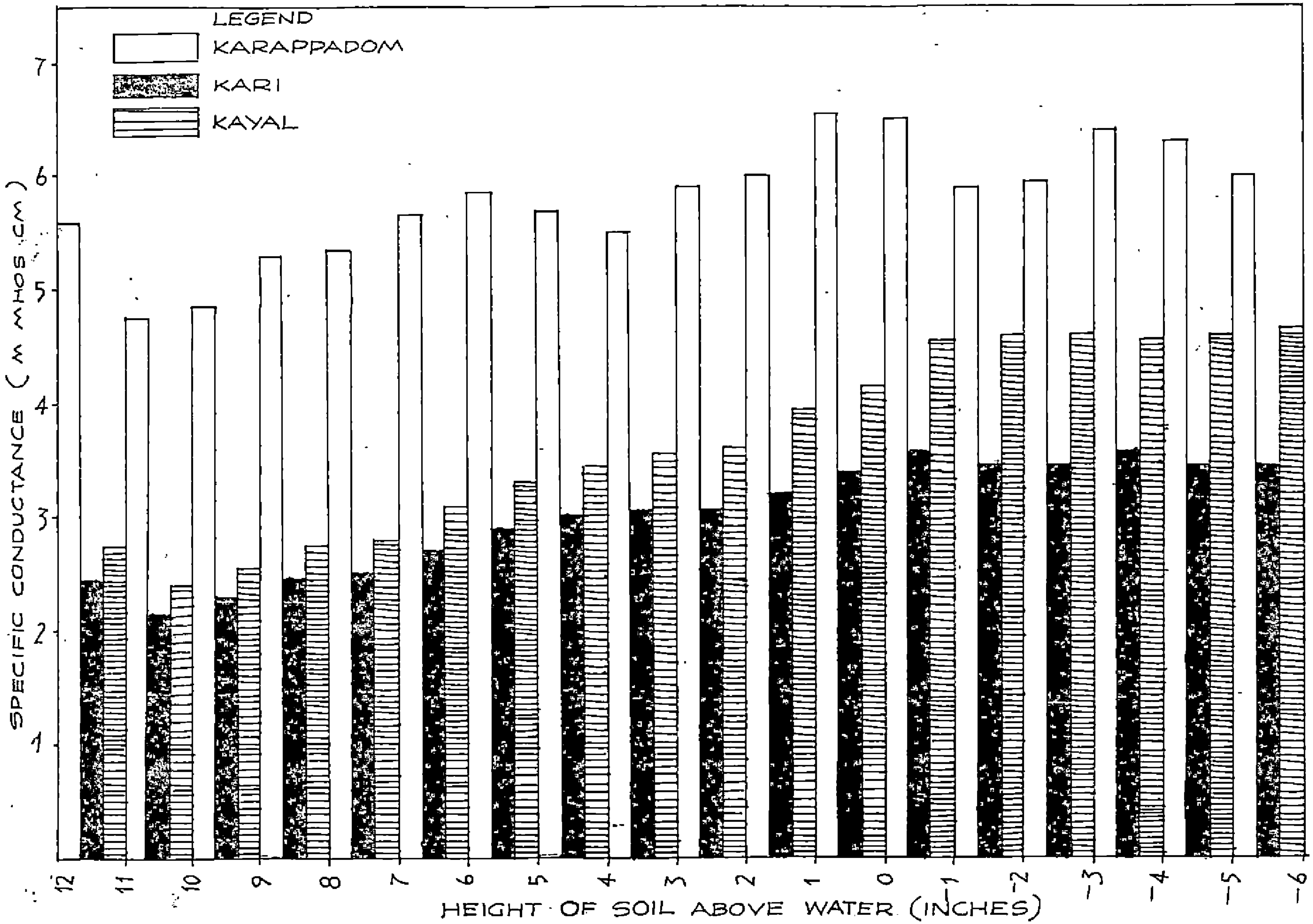
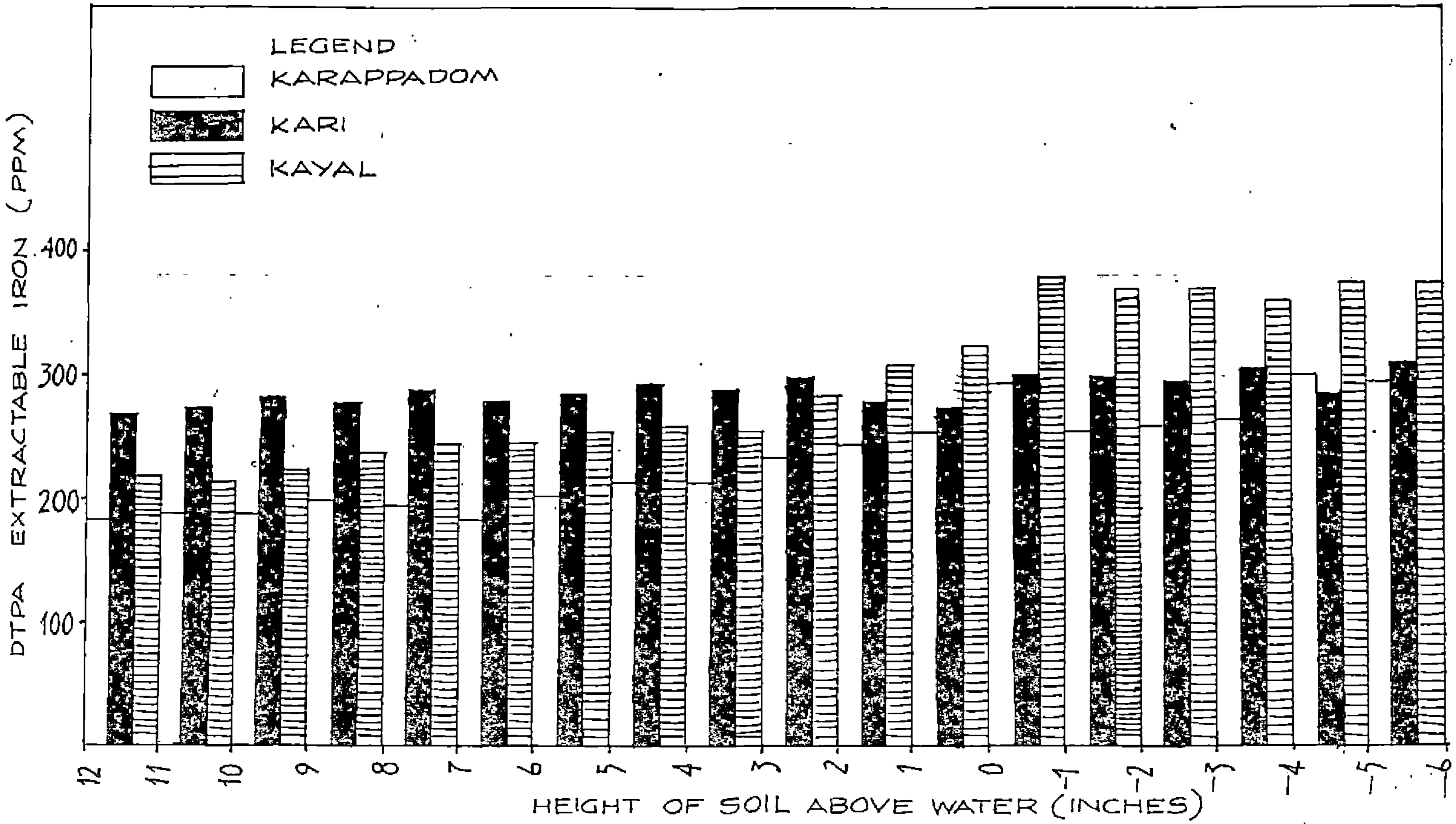


FIG. 5 EFFECT OF AIR DRYING UNDER SIMULATED FIELD CONDITIONS ON DPTA EXTRACTABLE IRON IN DIFFERENT SOILS OF KUTTANAD



The *Kayal* and *Kari* soils recorded a significantly higher mean available iron content of 295 and 289 ppm respectively when compared to the mean available iron content of 232 ppm in the *Karapadom* soils. There was no significant difference between the different one inch portions of the soil column irrespective of the aerobic or anaerobic conditions. The marginal means of different portions ranged from 224 to 328 ppm.

There was no factorial interaction. Both the factors behaved independently.

b. Ammonium acetate extractable Iron

Ammonium acetate extractable iron contents in the *Karapadom*, *Kari* and *Kayal* soils in air drying under simulated field conditions are given in Table 19.

There was significant interaction between the two factors, viz., soil type and height of soil above the water level. In *Karapadom* soils, the exchangeable iron content in the aerobic layers ranged from 17-113 ppm and there was no significant difference between the different one inch portions of the aerobic soil column. But in the anaerobic submerged layers of soil column the

Table 19 Effect of air drying under simulated field conditions on NH_4-OAc extractable iron in different soil types of Kuttanad

Height of soil above water	Soil types			Marginal means
	Karapadom	Kari	Kayal	
(inches)		ppm		
11-12	16.5	25.0	14.5	18.67
10-11	19.0	20.5	14.0	17.83
9-10	19.5	22.0	15.5	19.00
8-9	17.0	20.5	15.5	17.67
7-8	18.5	22.5	17.5	19.50
6-7	18.0	18.5	20.5	19.00
5-6	20.0	27.5	23.5	23.67
4-5	20.5	28.0	23.0	23.83
3-4	20.0	31.5	23.5	25.00
2-3	22.0	32.0	26.5	26.83
1-2	31.5	42.5	36.5	36.83
0-1	113.0	41.0	67.5	73.83
-0--1	817.0	269.0	621.0	569.00
-2--1	838.5	400.0	676.0	638.17
-3--2	919.5	404.0	731.0	684.83
-4--3	884.5	400.0	721.0	668.50
-5--4	924.5	373.0	696.0	664.50
-6--5	903.5	461.5	804.0	723.00
Marginal means	312.39	146.61	252.61	

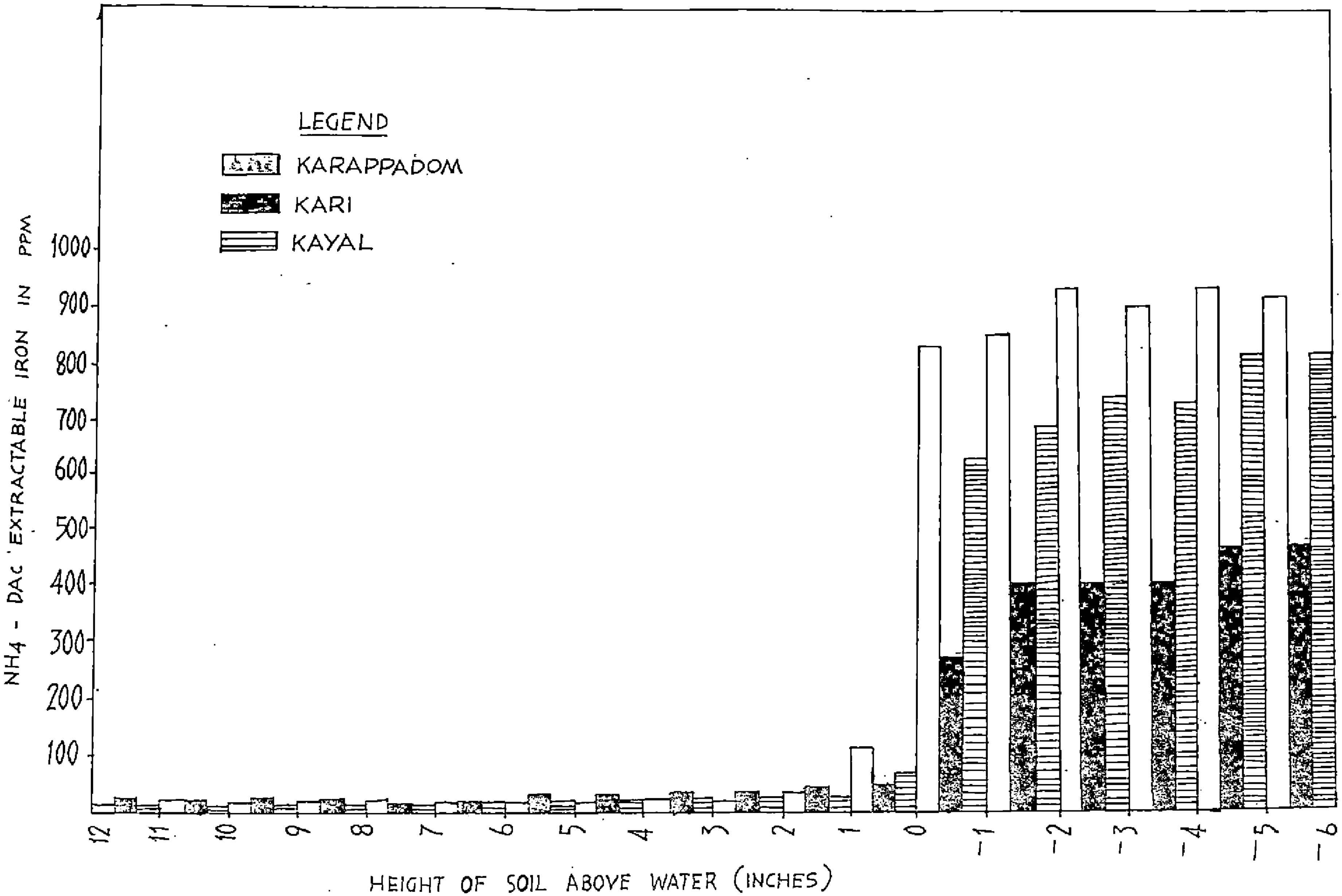
CD (soil type) = 49.26

CD (height) = 120.67

CD (soil type x height) = 210.96

SE = 73.75

FIG.6. EFFECT OF AIR DRYING UNDER SIMULATED FIELD CONDITIONS ON NH_4-DAc EXTRACTABLE IRON IN DIFFERENT SOILS OF KUTTANAD



exchangeable iron content was significantly higher, the values ranging from 817 to 925 ppm.

In *Kari* soils also the top 12" aerobic soil column recorded significantly lower exchangeable iron values in the range of 19-43 ppm. There was no significant differences between the one inch soil portions in the aerobic column. In the submerged column of soil, the exchangeable iron contents were significantly higher and were in the range of 269-462 ppm.

In *Kayal* soils also, there was significant difference, only between the submerged anaerobic column and the aerobic coluan of the soil column. The ranges were from 14.0 to 67.5 and 621 to 804 ppm respectively in the aerobic and anaerobic columns.

In the submerged soil column, there were significant differences between the different soil groups. In all the three soils the exchangeable iron contents were very high and in toxic proportions. The *Karapadom* soils recorded significantly highest average exchangeable iron content in the submerged layer, followed by the *Kari* and *Kayal* soils. All the three soils differed significantly with regard to the exchangeable iron content in submerged soil layer.

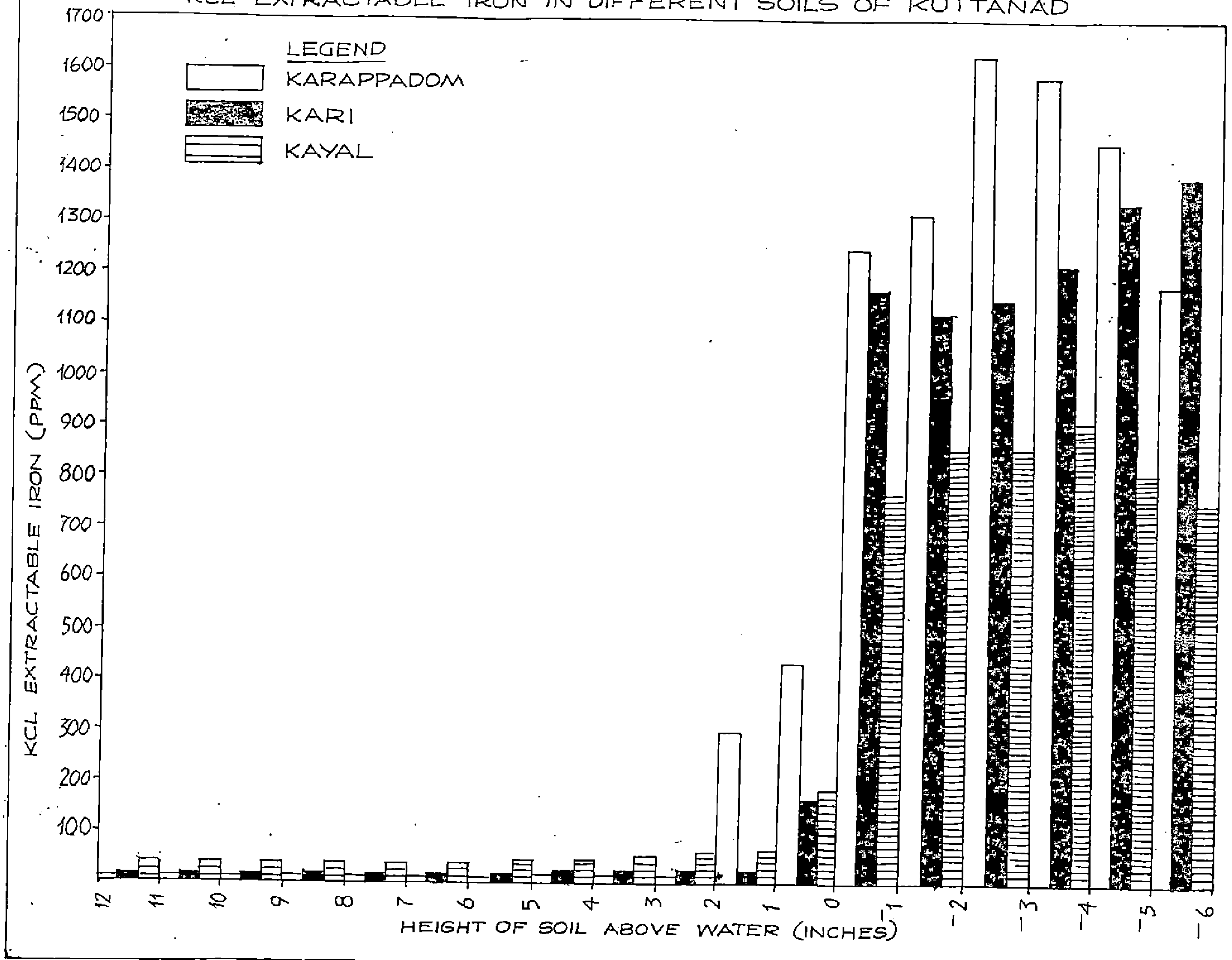
Table 20 Effect of air drying under simulated field conditions on KCl extractable iron, in different soil types of Kuttanad

Height of soil above water	Soil types			Marginal means
	Karapadom	Kari	Kayal	
(inches)		ppm		
11-12	13.5	21.0	44.0	26.17
10-11	13.5	21.0	44.0	26.17
9-10	13.5	21.0	44.0	26.17
8-9	13.5	23.0	44.0	26.80
7-8	13.5	25.0	44.0	27.50
6-7	13.5	27.0	44.0	28.17
5-6	13.5	27.0	48.0	29.50
4-5	17.0	29.0	52.0	32.66
3-4	17.0	29.0	61.5	35.83
2-3	17.0	33.0	65.5	38.50
1-2	303.5	33.0	71.0	135.83
0-1	426.5	173.0	284.5	294.67
-1-0	1246.5	1173.0	765.5	1061.67
-2--1	1323.0	1115.5	861.5	1100.00
-3--2	1631.0	1150.0	857.5	1212.83
-4--3	1592.5	1223.0	907.5	1241.00
-5--4	1462.0	1334.5	815.0	1203.83
-6--5	1177.0	1384.5	754.0	1105.17
Marginal means	517.08	435.69	322.64	

CD (height) = 485.84

SE = 296.92

FIG.7 EFFECT OR AIR DRYING UNDER SIMULATED FIELD CONDITIONS ON KCL EXTRACTABLE IRON IN DIFFERENT SOILS OF KUTTANAD



c. KCl extractable exchangeable Iron

KCl extractable iron contents in the *Karapadom*, *Kari* and *Kayal* soils upon field simulated air drying is given in Table 20.

KCl extractable exchangeable iron also behaved similar to the ammonium acetate extractable iron in that, significantly higher iron content was observed in the submerged column than in the aerobic column.

There was no significant factor interaction. Both factors behaved independently. There was no significant difference between the *Karapadom*, *Kari* and *Kayal* soils. However, there was significant difference between the aerobic and anaerobic soil columns. In the aerobic 12" soil column the mean exchangeable iron content was significantly lower and in the range of 26-295 ppm. In the submerged 6" soil column the mean exchangeable iron contents were very high (1062-1241 ppm) and in toxic concentrations.

Exchangeable Aluminium

Exchangeable aluminium in the different portions of the core samples, of *Karapadom*, *Kari* and *Kayal* soils under field simulated air drying is given in Table 21.

The *Kari* and *Karapadom* soils registered significantly higher mean values of 137 ppm and 123 ppm respectively than the *Kayal* soils which showed a mean of 29 ppm.

There was also significant difference between the different soil layers. From 11"-12" to 0-1" the marginal means were statistically on par. In the bottom six inch submerged column also the means were on par. But significant differences was noted between the 0-1" layer and the 1"-2" layer. The intermediate layer between aerobic and anaerobic soil columns ie. 0-1" portion recorded an intermediate value which was on par with the values on either side. The exchangeable aluminium content in the submerged soil column was significantly lower than the aerobic soil column. In the aerobic 12" soil column the range of values was 120-205, 92-231 and 35-52 ppm respectively in the *Karapadom*, *Kari* and *Kayal* soils. In *Kayal* soils in the aerobic zone the exchangeable aluminium content was significantly lower than that of the other two soils.

In the submerged six inch portion of soil, exchangeable aluminium contents were reduced to negligible

Table 21 Effect of air drying under simulated field conditions on KCl extractable aluminium, in different soil types of Kuttanad

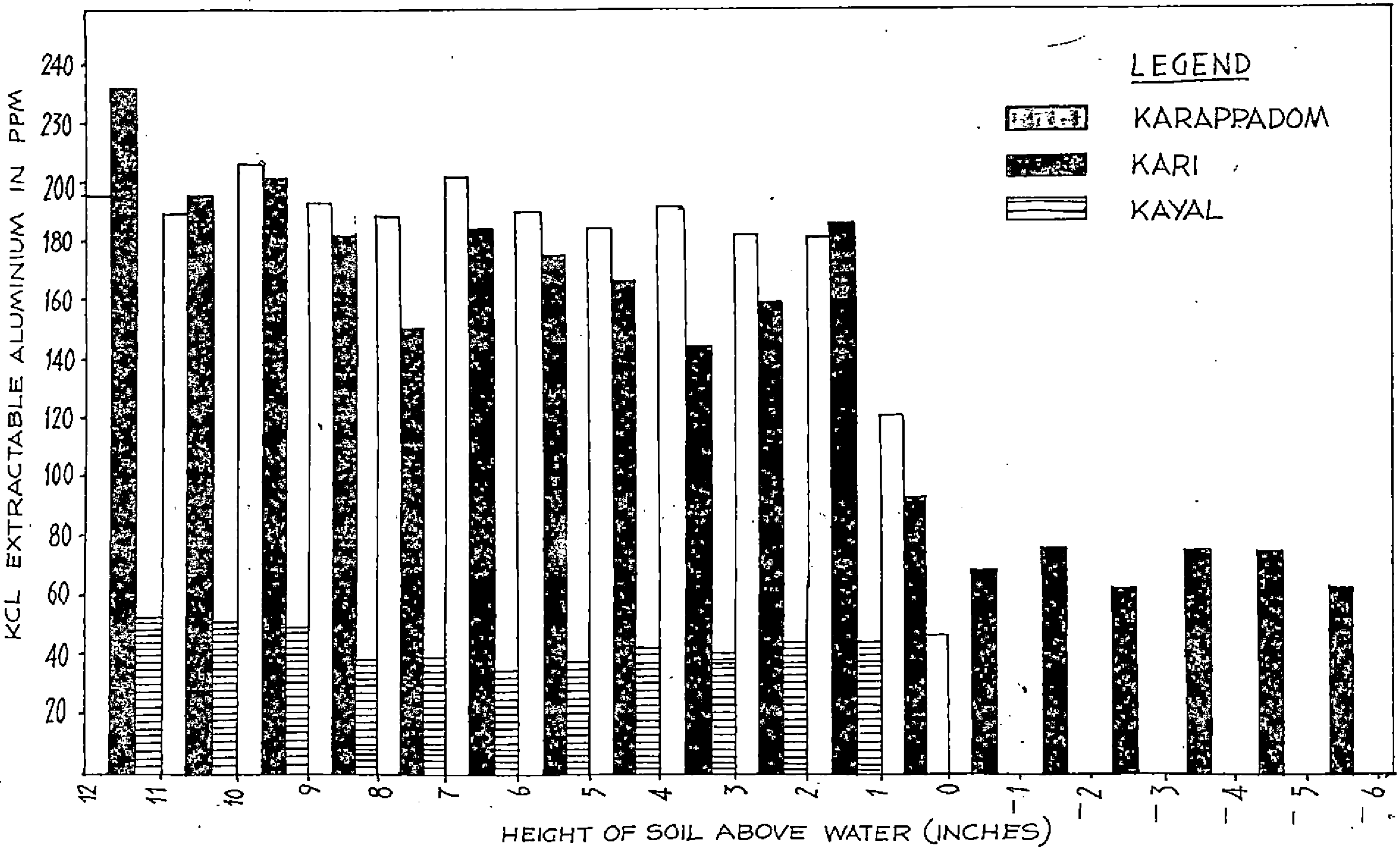
Height of soil above water	Soil types			Marginal means
	Karapadom	Kari	Kayal	
(inches)		ppm		
11-12	195.0	230.5	51.5	159.00
10-11	189.0	194.5	50.5	144.67
9-10	204.5	200.5	49.0	151.33
8-9	192.25	181.5	38.0	137.25
7-8	188.0	149.5	38.5	125.33
6-7	201.5	184.0	35.0	140.16
5-6	190.0	174.5	37.0	133.83
4-5	184.0	164.5	42.0	130.16
3-4	191.0	143.5	40.0	124.83
2-3	181.5	158.5	43.5	127.83
1-2	180.5	186.0	44.0	136.83
0-1	119.5	91.5	46.0	85.67
-1-0	traces	67.5	traces	22.50
-2-‾1	"	75.5	"	25.17
-3-‾2	"	60.0	"	20.00
-4-‾3	"	74.5	"	24.83
-5-‾4	"	74.0	"	24.67
-6-‾5	"	62.0	"	20.67
Marginal means	123.15	137.36	28.61	

CD (soil type) = 43.43

CD (height) = 106.39

SE = 65.02

FIG.8 EFFECT OF AIR DRYING UNDER SIMULATED FIELD CONDITIONS ON KCL EXTRACTABLE ALUMINIUM IN DIFFERENT SOILS OF KUTTANAD



values in the Karapadom and Kayal soils. But the Kari soils recorded significant exchangeable aluminium contents in the range of 60-76 ppm.

There was no factorial interaction. Both the factors behaved independently.

DISCUSSION

DISCUSSION

I. PHYSICO-CHEMICAL, CHEMICAL AND MICROBIOLOGICAL PROPERTIES OF SUBMERGED SOILS OF KUTTANAD

The physical, physico-chemical and chemical properties of the Kari, Karapadom and Kayal soils of Kuttanad are briefly discussed below:

Physical properties

There was no significant difference in the bulk densities of the different soils. The average bulk density of Kari soil was the lowest. This was due to the relatively high content of organic matter. The particle density of Kari soil (2.01 g cm^{-3}) was significantly lower than that of the Karapadom soils (2.14 g cm^{-3}). Kayal soils had an intermediate value (2.07 g cm^{-3}). There was a wide variation in soils with regard to soil texture. Karapadom soils were predominantly of a clayey or clay loam texture. But in the case of Kari and Kayal soils, the proportion of sand was more and the texture varied from clay to silty clay and sandy clay loams. Varghese (1964), Venugopal (1969) and Varghese (1973) have reported similar results for the physical properties of Kuttanad soils.

Physico-chemical properties

The soil pH was significantly lower in the *Kari* soils (3.7) as compared to the *Kayal* (5.3) and *Karapadom* soils (4.2). Thottapally *Kari* registered the minimum pH of 2.8 and the Kannatta *Kayal* registered the maximum pH of 6.0. The soil pH measured in IN KCl also followed the same trend, but the values always tended to be lower than the pH measured in water, by a few decimal units. This must be due to the fact that the K ions replace more H^+ from the exchange complex, thereby increasing the acidity. Hesse (1969), Kabeerathumma (1969) and Ghosh et al. (1973) also reported a low pH in *Kari* soils and a slightly higher pH in the *Kayal* and *Karapadom* soils.

Specific conductance of the different soils in Kuttanad was very low and negligible. The mean specific conductance was 0.62 mmhos cm^{-1} in *Kari* soil, 0.10 mmhos cm^{-1} in *Karapadom* soils and 0.03 mmhos cm^{-1} in *Kayal* soils. Many earlier workers have reported a higher specific conductance in Kuttanad soils. There are several reasons for this low level of observed salinity. In Kuttanad there is a seasonal fluctuation in soil conductivity (Ayer, 1975 and Bhargava and Abrol, 1984). The minimum values of conductivity were reported during monsoons floods, when fresh water washes off the salinity and the maximum during the summer season viz., March-April, corresponding to sea water intrusion. In the present case, samples were collected in the month of June. Besides, as the result of the commissioning of Thaneermukkom bund and Thottapolly spillway, sea water intrusion had been successfully prevented for the past few years, which might have resulted in a steady decrease in the specific conductance.

Available nutrients

The available nitrogen contents were fairly high. The average available nitrogen in the different soils were 238, 227 and 240 ppm respectively in the Karapadom, Kari and Kayal soils. But there was no significant, difference between the soils. Pillai (1964) has reported similar results. But Kabeerathumma (1969) reported a lower available nitrogen content in Kari soils and suggested that this might be due to the low, microbial activity and a consequently low nitrogen mineralization.

There was no significant difference in available phosphorus content also, the mean content of available phosphorus in Karapadom, Kari and Kayal soils being 16.9, 32.4 and 18.3 ppm respectively. Within the soils there existed wide variations. Many earlier workers have reported very low contents of available phosphorus in Kuttanad soils (Venugopal, 1969; Varghese et al., 1970 and Ghosh et al., 1973). In the present case the wet soil from the field was used for analysis without air drying, after accounting for the moisture content and hence the extractant was able to extract a portion of Fe-P, which will be available under submerged conditions. The sanctity of applying the soil test results from air dried samples to submerged soil conditions, with regard to available phosphorus has been already questioned by many workers like Mahapatra and Patrick (1971) and Nambiar et al. (1973).

The mean exchangeable potassium content were 124, 135 and 130 ppm respectively in the Karapadom, Kari and Kayal soils. There was no significant difference between soils. Ghosh et al. (1973) have reported similer results.

Exchangeable Iron and Aluminium

Exchangeable and available iron was extracted using three different extractants, namely neutral normal ammonium acetate, IN KCl and 0.005 M DTPA. The mean ammonium acetate extracted iron content was 18.4 ppm in Karapadom soils, 15.1 ppm in Kari soils and 19.7 ppm in Kayal soils. The mean KCl extractable iron contents were 281.9 ppm in Karapadom soils, 302.0 ppm in Kari soils and 261.7 ppm in Kayal soils. The mean DTPA extracted available iron content were 124.9 ppm in Karapadom soils, 107.2 ppm in Kari soils and 121.6 ppm in Kayal soils. There was no significant difference between the different soils, in all the three cases. Within soils ammonium acetate extractable iron content and KCl extractable iron content registered wide variations. But DTPA available iron recorded rather consistent values. Potassium is a stronger cation than ammonium and therefore it was able to displace more Fe^{2+} from the exchange complex as shown by the higher contents of KCl extractable iron in the different soils. Pisharody (1965) and Ghosh et al. (1973) have reported more or less similar values of ammonium acetate extractable iron in Kuttanad soils.

Microbial count

The total microbial count recorded in Kuttanad soils was very low and there was no significant difference between the soils. The mean total microbial counts were 0.27, 0.20 and 0.28 m g^{-1} respectively in the Karapadom, Kari and Kayal soils. Pillai (1964) and Devi (1965) had reported only similar low microbial counts in Kuttanad soils. The low microbial activity in acid sulphate soils is due to various inherent soil characteristics that hinders microbial growth. High acidity, high organic matter content and wide C/N ratio hinder microbial growth. Sea water inundation also decreases microbial activity (Harmsen, 1969). As only surface soil samples were taken for analysis, the effect of pH was more pronounced. Besides the samples were taken during June when there was no crop and when the land was under water. There was a significantly higher fungal count in Kari soils as compared to the other soils; but the bacterial count was significantly lower. This was due to low pH of Kari soils, as compared to other soils. Low pH will inhibit bacterial growth, but fungal growth is not affected and hence fungal population will predominate at low soil pH.

II. EFFECT OF DRYING ON THE DIFFERENT SOIL GROUPS OF KUTTANAD

The drying of a submerged rice soil, results in several physical, chemical and biological changes. The chemical changes are set in motion by the biological redox processes that result from increased oxygen availability. These oxidation-reduction systems have an important bearing on the availability of different nutrients and physico-chemical characteristics of the soil.

Changes in soil pH

In all the three soils, drying had produced a marked decrease in soil pH, measured in water as well as in normal KCl solution. There was no significant differences between the effects of air drying and sun drying. But the mean soil pH_w and pH_s of the wet soil were significantly higher than the mean pH values under conditions of air drying and sun drying.

Drying an acid sulphate soil results in a decrease of the soil pH. In well aerated, but moist soil, the fine grained pyrite is oxidised to ferrous sulphate and sulphuric acid. The overall reaction can be expressed as follows:

$$FeS_2 + 7/2 O_2 + H_2O \longrightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$$

(Bloomfield and Coulter, 1973)

Chemical oxidation is a slow process but the rate is enhanced by the presence of microbes of the genus *Thiobacillus*. The H^+ produced results in increased acidity. Subramoney (1947), Suseela Devi (1965) and Kurup and Aiyer (1973) have reported a drop in soil pH during the drying of soils in Kuttanad and they attributed this to the oxidation of sulphur compounds to sulphuric acid. Among the different soils studied *Kari* soils became most acidic, as a result of the drying treatments.

In the incubated wet soil samples also, there was a marked decrease in soil pH with increase in period of time. During the experiment the wet samples were packed airtight in polythene bags but the frequent disturbing of the soil for taking analytical samples, might have increased oxygen availability and thereby pyrite oxidation. Moreover in over-dried soil samples, pyrite oxidation cannot take place as the reaction requires moisture (refer equation). Microbial activity also becomes affected at low moisture levels. But in moist samples, which were kept incubated, there are greater chances of extreme acidity to develop.

Changes in specific conductance

The specific conductance of the different soils was negligible and there were no significant changes during sun drying and air drying. There was a marginal increase, which could be attributed to concentration effects due to the evaporation of water.

Changes in the availability of nitrogen

Soil drying, both air drying and sun drying had resulted in a decrease in the availability of nitrogen, in all the three soils.

Nitrogen occurs in soils chiefly as organic constituents and only a small portion that is inorganic is available to the plants, which includes NO_3^-, NO_2^- and NH_4^+. In a flooded soil due to the paucity of oxygen, NH_4^+ is the stable inorganic form while in an aerobic soil NO_3^- is the stable form. In submerged soils, availability of nitrogen is higher because of the accumulation of ammonia (Patnaik, 1975; Murty and Singh, 1978). Eventhough an aerobic deamination is slower, the release of inorganic nitrogen is larger and faster in submerged soils because of less immobilization. Broadbent and Reyes (1971) also reported increased availability of nitrogen under submerged conditions. Mathew (1986) also reported increased nitrogen availability under submergence in the acid sulphate soils of Kerala. During the experiment available nitrogen of the wet soil, increased with the period. The increase can also be attributed to the microbial stimulation, due to high temperature and aeration (Agrawal et al., 1971).

During air drying and sun drying the above changes get reversed. As a result of oxygen availability nitrogen mineralization proceeds upto the NO_3^- level. The microbial immobilization will be more and drying to moisture contents below field capacity further decreases mineralization. Drying the soil to moisture contents below those normally encountered in low land rice culture can cause fixation of NH_4^+ ions in between the lattices of 2:1 types of clay minerals, thereby causing a reduction in the availability (Broadbent, 1979). But this aspect needs further study since contradictory results have been reported by Bhattacharya (1971) and several others.

Changes in the availability of Phosphorus

The most striking result obtained during soil drying was a reduction in the content of available phosphorus. In all the three soils available phosphorus got reduced significantly as a result of drying. The mean values of available phosphorus were significantly higher in the soil which was kept under wet condition when compared to that of the air dried and sun dried samples. But during the entire period of observation, in wet soil also available phosphorus registered a marked decrease, though not as significant as in the case of air dried and sun dried soils.

Phosphate availability is so linked with iron chemistry, that conditions favouring availability of iron, will also increase phosphorus solubility especially in those soils where Fe-P is the dominant fraction. As a general rule, Fe-P is the dominant phosphorus fraction in submerged soils (Basak and Bhattacharya, 1962; Chang, 1965; Khan and Mandal, 1973). The added phosphorus fertilizers in such soils are gradually converted to Fe-P (Chiang, 1963; Hsu, 1964). According to Nair (1986) in Kuttanad soils also Fe-P is the dominant fraction. Mathew (1986) reported increased availability of phosphorus in acid sulphate soils of Kerala.

When a soil gets dried, the soluble ferrous phosphate is slowly oxidised to ferric phosphate which is less available. The decrease in the availability of phosphorus on drying of soils can partly be due to changes in the solid phase reactions (Chang, 1971).

When the soil becomes dry phosphorus deficiency can also result. The major portion of the inorganic phosphorus in Kuttanad soils is constituted by Fe-P and conditions which control the solubility of iron will control phosphorus solubility also. So soluble ferrous phosphate under conditions of exposure to air will get oxidised to insoluble ferric phosphate and become unavailable to plants.

Changes in the availability of Potassium

There was a continuous decrease in the availability of potassium throughout the period of experiment irrespective of the soil and the method of drying. During the initial periods of observation the rate of decrease in availability was high in the air dried and sun dried soils. But during the later periods, the rate of decrease in availability was high in incubated wet soils. There were no significant differences between the available potassium contents at the end of three months drying.

Drying a soil can cause a reduction in the availability of potassium. But when a soil is flooded, more K^+ is displaced from the soil complex as a result of reduction reaction leading to an increase in specific conductivity (Ponnamperuma, 1964). During drying, the reverse process may happen, which results in the reduced availability of potassium.

Fixation of K^+ ions in between the lattices of clay minerals can also reduce the availability of potassium Neiderbudde (1967) reported increased K fixation on drying of soils. Page and Bavar (1940) related this fixation of K^+ by 2:1 minerals are due to the similarity in size of unhydrated ions and the lattice hole. But Ayres (1944) and Lee (1948) have reported a release of exchangeable potassium on drying, wherever initial exchangeable levels were low. Attoe (1949) concluded that two types of fixation can occur viz., (i) in moist soil which is enhanced by liming and (ii) by drying which is independent of soil pH.

However, the phenomenon of release or fixation of potassium on drying, is not clearly understood (Ahmed and Davis, 1971) and it is also highly uncertain how far these data can be extended to practical situations.

Changes in exchangeable Iron

In all the three soils drying had resulted in significant and striking decrease the content of exchangeable iron. In the wet soil, iron content decreased significantly and particularly during later stages of drying, there was no significant difference between the treatments.

On drying an acid sulphate soil oxidation of pyrite takes place and the soil gets acidified (Brinkman, 1970). The rate of oxidation is enhanced by the microbes of the genus Thiobacillus.

Changes in Exchangeable Alumunium

There were no significant changes in the contents of exchangeable aluminium during the period of experiment. The main reason for this is the non-redox nature of aluminium. But according to Cate and Sukhai (1964), when a soil gets oxidised due to drying, more aluminium ions reappear from the soil complex as a result of a neutralization reaction. But in this case, no significant changes were obtained in the content of exchangeable aluminium due to drying of the soil.

III. AIR DRYING UNDER SIMULATED FIELD CONDITIONS

To simulate field conditions in Kuttanad, the soil after intensive drying was packed in PVC pipes and was submerged in six inches of sea water in porcelain pots. The results obtained after analysing the soil column after a period of one month are briefly discussed below:

Changes in pH

pH values measured in water as well as in salt behaved similarly eventhough pH_s values were slightly lower. There were significant differences between mean soil pH of different soils. In the case of soil pH measured in water, *Kari* soils registered a significantly lower mean pH of 4.2 when compared to *Kayal* (5.0) and *Karapadom* soils (4.9). But in the case of pH in salt solution, the mean values of all the three soils differed significantly. The pH values obtained in salt solution, were more homogenous as evidenced by low critical differences.

Between different layers of the soil column, there was significant difference only between the bottom six inches submerged soil column and the top twelve inches aerobic column. In the submerged soil column, pH had increased significantly as compared to the upper portions, as shown below:

Soil pH range in aerobic column of different soils

	pH range in bottom 6" submerged soil column	pH range in top 12" aerobic soil column
pH_w	5.48-5.87	4.07-4.55
pH_s	5.45-5.73	3.80-3.88

When an aerobic acid soil is submerged its pH decreases during the first few weeks, reaches a minimum and then increases asymptotically to a fairly stable value of 6.7 to 7.2 after a few weeks (Ponnamperuma, 1955; Chakravarty and Kar, 1970; Mukherjee and Basu, 1971).

Initial decrease in soil pH may be due to accumulation of CO_2 produced by aerobic bacteria. But subsequent increase is due to a reduction of ferric oxides to dissolved Fe^{2+}, a process that consumes acidity.

$$Fe(OH)_3 + \frac{1}{4} CH_2O + 2H^+ \longrightarrow Fe^{2+} + \frac{1}{4} CO_2 + 11/4\ H_2O$$

(van Breemen and Pons, 1978)

In all the three soils, in submerged soil column, the pH hed got reduced due to reduction but it rarely exceeded 6.0.

Soil pH range in submerged soil column of different soils

	Karapadom	Kari	Kayal
pH_w	6.10-6.15	4.65-5.50	5.65-6.05
pH_s (submerged soil column)	5.75-5.85	4.60-5.55	5.80-5.90

In *Kari* soils, which are more of the acid sulphate character, the increase in pH was less. In acid sulphate soils flooding increases soil pH, only slowly. Ponnamperuma et al. (1973) and van Breemen (1976) reported that the pH of an acid sulphate soil rarely exceeds 6.0 even after six months of submergence. Kabeerathumma (1975) reported only a small increase in soil pH due to submergence in acid sulphate soils of Kerala and on no occasion it exceeded 5.0. The low increase in pH in *Kari* soils on flooding can be attributed to the following reasons:

1. adverse conditions for microbial reduction
2. low contents of metabolizable organic matter
3. low contents of easily reducible ferric oxide

4. high buffering capacity due to exchangeable and dissolved aluminium, the basic sulphates of aluminium and iron and adsorbed sulphate.
5. low initial pH of Kari soils compared to other soils

In submerged anaerobic column of soil the pH is more or less stabilised and the possibility of a low pH that can cause direct H^+ injury to plants does not arise at all. But extremely low pH values that can cause direct injury to plants was noticed in aerobic layer, but however in the field this situation is not so common and it occurs only when the water drains below the pyritic zone.

Changes in specific conductivity

The specific conductance of all the soils had increased on submergence. There was no significant differences between different soil layers irrespective of whether submerged or under aerobic conditions.

Ponnamperuma (1976) reported increase in specific conductance on submergence. In this experiment the soil core samples were kept freely in brine, so as to allow capillary rise and hence specific conductance had increased significantly. Besides release of Fe^{2+} and other ions, from insoluble oxide hydrates also increased conductivity (Ponnamperuma, 1976).

In *Karapadom* soils, the mean specific conductance was significantly higher than that of *Kari* and *Kayal* soils and this can be attributed to the good physical properties of *Karapadom* soils, which had permitted more capillary rise of salt water. *Karapadom* soils are of earlier reclamations and are therefore older among the Kuttanad soils.

To maintain a six inch level of sea water in porcelain pots, the following quantities of sea water had to be added to compensate for capillary and evaporational losses, during one month period.

Karapadom soils	-	340 ml
Kari soils	-	185 ml
Kayal soils	-	190 ml

This also reflects the increased capillary rise in *Karapadom* soils.

During periods of extreme drought a salt water influx has been reported in Kuttanad in some areas, even after commissioning of the Thaneermukkom bund and this influx can cause salt injury to plants. Subramoney (1961) attributed the toxicity in Kuttanad soils to soluble chloridea and sulphides. Nair (1963) reported that rice plants tolerated sodium chloride only upto a conductivity of 4 mmhos cm^{-1}. IRRI (1968) reported that germination is hampered by conductivities more than 12 mmhos cm^{-1} and seedling growth by conductivities above 4.6 mmhos cm^{-1}. So the higher values of specific conductance registered in the experiment in some cases can be encountered in practical situations also.

Changes in different forms of Iron

a. DTPA extracted available iron

There was no significant differences between different soil layers, irrespective of aerobic or anaerobic conditions. DTPA can extract that portion of inorganic iron which becomes available on submergence so it gives consistent results irrespective of aerobic or anaerobic conditions and hence it is of less use, in studying the changes occurring during submergence. Between different soils, DTPA extracted iron showed significant differences.

b. Exchangeable iron

Exchangeable iron was extracted using two different extractants viz., neutral normal ammonium acetate and normal potassium chloride. There was significant differences between the twelve inch aerobic column and the six inch submerged column of soil column. In submerged soil layers there were fairly high levels of exchangeable iron. The range of values obtained using different extractants, in different soil layers and in different soils are given in the following table, for comparison.

		SOIL TYPES		
		Karapadom	Kari	Kayal
			ppm	
NH_4-OAc extracted Fe	Submerged column	817-925	269-462	621-804
	Aerobic column	17-113	19-43	14-68
KCl extracted Fe	Submerged column	1247-1631	1116-1382	754-908
	Aerobic column	14-427	14-427	44-285

In the submerged soil column the range of exchangeable iron is very high and in most cases above toxic limit and in the aerobic soil column, exchangeable iron is very low and below the toxic limit. If a comparison is made between the two extractants, KCl had extracted more of exchangeable iron, because potassium is a stronger cation than ammonium.

The most important chemical change that takes place, when soil is submerged, is the reduction of iron and subsequent increase in its solubility. Reduction is by chemical as well as by micro-organisms (Motomura, 1961; Subramoney and Kurup, 1961; Alexander, 1972).

The process can be illustrated as follows (Ponnamperuma, 1972).

$$\underset{\text{Reducible iron}}{Fe(OH)_3} + \underset{\text{organic matter}}{\frac{1}{4}CH_2O} + \underset{\text{low pH}}{2H} + \text{microbes}$$

$$\longrightarrow Fe^{2+} + \frac{1}{4}CO_2 + 11/4\ H_2O$$

As a consequence of reduction, the concentration of water soluble iron increases and due to consumption of hydrogen ions the pH increases. But sulphides formed from the reduction of sulphates which is present in excess of Fe^{2+} in these soils will eventually lower Fe^{2+} by precipitation of FeS. Below a pH of 5.0, however, sulphate reduction is a slow process and Fe^{2+} decreases only after prolonged submergence (six months to one year) in acid sulphate soils (van Breemen, 1976). High salinity conditions which existed in the pots may also have favoured production of Fe^{2+} probably by slightly depressing the pH and by lowering the activity coefficient of Fe^{2+}, thereby causing higher equilibrium concentrations (Inada, 1965).

Nhung and Ponnamperuma (1966) and Ponnamperuma (1976) also reported persisting high contents of Fe^{2+}, even upto 5000 ppm in acid sulphate soils. Kuruvila and Patnaik (1976) reported 100-300 ppm, Fe^{2+} in the acid sulphate soils of Kerala.

While extrapolating these data to practical situation the following facts emerge.

According to van Breemen (1976) in similar pot experiments, dissolved $Fe\ SO_4$ formed in reduced acid sulphate soils, diffuses upwards and get oxidised to ferric hydroxide and sulphuric acid, giving surface water pH values in the range of 2.4-3.5 that hamper further soil reduction. But under field conditions, eventhough the same process takes place, due to replacement and drainage of flood water the effect will be much less.

When pyrite occurs within about 50 cm of soil surface, reduction of ferric oxide by pyrite during flooding contributes considerably to high levels of Fe^{2+} (van Breemen, 1976).

Even after one month of submergence, exchangeable Fe^{2+} levels failed to get stabilised and the concentrations were well above toxic limits. Ponnamperuma et al. (1973) reported that 300-400 ppm dissolved iron can cause toxicity. According to Tomlinson (1957) the critical level for iron toxicity is 1000 ppm. Subramoney and Kurup (1961) reported a physiological disease among rice plants due to iron toxicity, the symptoms of which were noticed during the crop damage succeeding the drought of 1982-83 also.

Changes in Exchangeable Aluminium

There was significant difference between the submerged layers and the aerobic layers in the soil column with regard to exchangeable aluminium content also. In the submerged six inch layer of soil column, the exchangeable aluminium contents were significantly low. In Karapadom and Kayal soils it was only in traces. But in Keri soils a range of 62-76 ppm was noticed.

The reason for the low contents of aluminium is the increased pH of submerged layer. The solubility of aluminium is reduced with increasing pH (Richenberg and Adams, 1970; Martinez, 1970). Dissolved Al_3^+ behaves as if regulated by the hypothetical basic aluminium sulphate $AlOHSO_4$, showing a constant SO_4^{2-} activity, a tenfold unit decrease per unit increase in pH. In lower six inches of soil, due to increase in pH, availability of aluminium was reduced considerably. In case of Kari soils, where there was 62-73 ppm of exchangeable aluminium in submerged column, the stabilised pH values were also significantly lower, when compared to Karapadom and Kayal soils.

Cate and Sukhai (1964) suggested a neutralization reaction for the reduction of aluminium. Exchangeable aluminium was replaced by exchangeable iron, probably due to the neutralization reaction.

$$2\ Al\text{-}Clay + 3\ Fe\ (OH) \longrightarrow 3\ Fe\ Clay + 2\ Al\ (OH)_3$$

As a result of such a reaction the aluminium gets precipitated as the hydroxide. Kuruvila (1974) and Kabeerathumma (1975) and Abraham (1985) have also reported decrease in exchangeable aluminium on submergence in the acid sulphate soils of Kerala.

In the top twelve inch aerobic soil column, exchangeable aluminium level was fairly high as depicted by the following table.

	Karapadom	Kari	Kayal
Exchangeable aluminium in aerobic zone -ppm-	181-205	143-231	35-52

The significantly high values of exchangeable aluminium in top layer were due to the lower pH in those layers. The intermediate one inch soil between the aerobic and anaerobic zones registered an intermediate value, which may be attributed to the intermediate pH values of this portion.

Aluminium toxicity occurs only at low pH values of 4.5-5.0. The stabilised pH values of submerged soil was higher than this. But exchangeable aluminium concentrations of the upper aerobic portions were well above toxic concentrations, in some cases. So aluminium toxicity can occur only if the pH is reduced considerably due to aeration or exposure of soil surface, when the land is under rice crop. Simpson (1958) has reported that more than 20 ppm aluminium extracted with neutral normal ammonium acetate, can cause toxicity. So chances of aluminium toxicity in Kari soils, where exchangeable aluminium was higher even in the submerged column, cannot be overlooked. Kabeerathumma (1975) and Abraham (1984) have also reported Al toxicity in the acid sulphate soils of Kerala.

SUMMARY

SUMMARY AND CONCLUSIONS

The effect of drying and wetting on the physical, physico-chemical and chemical characteristics of the submerged soils of Kuttanad region of Kerala State, was studied. Soil samples from Karapadom, Kari and Kayal soils were analysed for various physico-chemical properties such as texture, particle density, bulk density, microbial count, pH, conductivity, available NPK and different forms of iron and aluminium after maintaining the soil in fresh moist condition itself. To study the effect of drying, two samples from each soil groups were selected and were subjected to air drying and sun drying for a period of 12 weeks. A portion of those samples were maintained in wet condition to act as control. Estimations of pH, conductivity, available NPK and different forms of iron and aluminium were done at intervals of 1 day, 1, 2, 3, 4, 8 and 12 weeks, and the data analysed in a factorial RBD. To simulate the drying of soil under field conditions in Kuttanad, the soil after intensive drying was packed in PVC pipes of length 18" and diameter 3" and was kept in porcelain pots containing six inches of sea water. After one month the soil column was taken out separated into dried and submerged portions and divided into one inch portions. pH, conductivity and different forms of iron and aluminium in these samples were estimated. The results obtained are briefly summarized below:

1. Texturally Kuttanad soils were predominantly of clay and clay loam nature. However sand portion was more in Kari soils.

2. Bulk and particle densities were significantly lower in Kari soils due to their higher organic matter content.

3. The soils of Kari and Karapadom soils were extremely acidic. The Kayal soils recorded a significantly higher soil pH.

4. The specific conductance of all the soil groups was negligible owing to the seasonal effects and to the commissioning of Thaneermukkom bund and Thottapally spillway which has checked the intrusion of salt water.

5. The availability of major nutrients was fairly high and no significant differences existed between soil groups. The mean available phosphorus in Karapadom,

Kari and Kayal soils was 16.9, 32.4 and 18.3 ppm respectively. Since the analysis was carried out in moist state, the extractant was able to extract that part of Fe-P also which becomes available to plants during submergence of soils.

6. Exchangeable iron and aluminium, extracted using different extractants, recorded wide variations between individual samples. In few cases the levels were well above toxic limits. DTPA extracted iron recorded more or less uniform values.

7. The microbial count recorded was very low in all the soil groups, owing to their inherent properties that hinders microbial growth. Kari soils showed a predominance of fungi due to their low pH.

8. Drying of soil had resulted in marked changes in the physico-chemical properties of soils. However in all cases air drying and sun drying behaved similarly.

9. There was a sharp decrease in soil pH on drying. However the pH of moist soils also got reduced due to frequent disturbance for sampling and consequent oxidation.

10. There was only a negligible increase in specific conductance on drying of soils.

11. The availability of all major nutrients reduced on drying, more particularly with phosphorus.

12. Exchangeable iron contents reduced sharply on drying due to oxidation of iron to hydrated ferric oxides.

13. There was no significant change in the content of exchangeable aluminium probably due to the non-redox nature of the element.

14. Under conditions of field simulated air drying, the pH was stabilised to near neutral in the submerged soil column of Kayal and Karapadom soils. In Kari soils, the pH was still extremely acidic. In aerobic soil column, the pH was extremely acidic in all the soil groups.

15. Capillary rise and evaporation of sea water had resulted in increased specific conductance of all soils. The conductivity of Karapadom soils was higher and was in the toxic levels.

16. Ammonium acetate extracted iron and potassium chloride extracted iron contents were extremely high and well

So, after an extreme drought, when a subsequent crop is raised during the next season, chances for iron and aluminium toxicity exists in Kuttanad. In Kari soils the pH failed to get stabilised near neutral. There can be a saline water influx, under conditions of extreme drought which can cause salt injury to plants. The impact of artificial reclamation projects in Kuttanad also requires through study from the point of view on their impact on soil properties and hydrological conditions which decides the suitability of acid sulphate soils for rice culture. In Sierra Leone, Bangladesh and China (Bloomfield and Coulter, 1973; Huanchi Mao, 1958) where prolonged dry seasons exists as in Kuttanad, such reclamation projects intented for preventing sea water intrusion at high tides in acid sulphate soils, had often lead to strong acidification and subsequent iron toxicity and consequent abandonment of land.

above the critical levels of toxicity in the soil column in contact with sea water of all soil groups. The aerobic column recorded only negligible exchangeable iron content. DTPA extracted iron gave consistent results irrespective of aeroby or anaeroby.

17. Due to the stabilisation of pH to near neutrality, exchangeable aluminium content was only in traces in _Karapadom_ and _Kayal_ soils in submerged portion. But _Kari_ soils recorded an exchangeable aluminium of 62-76 ppm in submerged portion. In aerobic zone the contents were higher in all soils.

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APPENDICES

APPENDIX I

Abstract of Anova of physical, physico-chemical, chemical and microbiological properties of different types of soils in Kuttanad

Source	d.f.	Mean squares							
		Total count	Fungal population	Bacterial population	Bulk density	Particle density	Moisture	pH_W	pH_S
Treatments	2	0.0232*	$8.10^{*} \times 10^{-4}$	0.0296*	0.00174	0.0491*	367.18*	4.942*	4.306*
Error	28	0.00783	1.38×10^{-4}	0.00852	0.00415	0.00796	94.72	0.170	0.171

Source	d.f.	Mean squares							
		T.S.S.	Available N	Available P	Available K	DTPA-Fe	NH_4OAc Fe	KCl Fe	Available Al
Treatments	2	1.049	473.5	809.75	526.02	1020.05	51.11	3288.63	26638.13
Error	28	0.3199	2598.86	643.20	3423.53	310.07	119.98	98174.65	10020.22

APPENDIX II

Abstract of anova of effect of drying in different soil types of Kuttanad

Source	d.f.	pHW	T.S.S.	pHs	Av. N	Av. P	Av. K	Ammonium acetate Fe
Treatment	71	8.272*	2.2863*	10.875*	3.805*	2.560*	1.325	95.538*
Soil type (S)	2	10.790*	80.11*	5.340*	27.084*	21.811*	5.023*	55.329*
Type of drying (C)	2	72.409*	0.329	27.647*	64.842*	26.773*	0.0792	186.167*
SC	4	49.027*	0.0585	85.481*	1.162	8.498*	10.515*	735.815*
Period (P)	7	1.156	0.0422	9.689*	0.600	2.001	0.281	6.172*
SP	14	3.859*	0.0286	2.718*	4.251*	0.608	0.153	58.573*
CP	14	1.175	0.0154	1.023	0.442	0.214	0.187	17.723*
SCP	28	0.0929	0.0089	0.394	0.359	0.161	0.157	2.029*
Error	72							

*Significant at 5% levels of significance

APPENDIX II (contd.)

Source	d.f.	KCl Fe	Exchangeable Al
Treatment	71	4.745*	0.715
Soil type (S)	2	3.319*	12.767*
Type of drying (C)	2	46.852*	2.184
SC	4	28.320*	0.625
Period (P)	7	1.811	0.771
SP	14	1.185	0.205
CP	14	0.486	0.350
SCP	28	0.274	0.202
Error	72		

APPENDIX III

Abstract of Anova of effect of air drying under simulated field conditions in different soil types of Kuttanad

Source	d.f.	MEAN SQUARES						
		pH_w	pH_s	T.S.S.	KCl-Fe	DTPA-Fe	NH_4-OAc-Fe	KCl-Al
Treatments	53	1.466*	1.682*	3.582	601642*	5345.33	211453.2*	12483.55
(A) Height of soil column	17	3.660*	4.533*	2.008	1722254*	8177.24	568156.5*	18406.17*
(B) Soil type	2	7.255*	4.686*	75.620*	343286	43005.5*	253749.8*	125799.4*
AxB	34	0.0719	0.07884	0.151	56533.3	1714.07	30613.49*	2856.60
Error	54	0.1201	0.158	3.678	17632.1	12790.17	10876.85	8454.69
Total	108							

*Significant at 5% level

EFFECT OF DRYING AND WETTING ON THE PHYSICAL, PHYSICO-CHEMICAL AND CHEMICAL PROPERTIES OF THE SUBMERGED SOILS OF KUTTANAD

BY

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ABSTRACT OF THE THESIS
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ABSTRACT

A study was undertaken at the College of Agriculture, Vellayani to know the effect of drying and wetting on the physico-chemical properties of submerged acid sulphate soils of Kuttanad which are known locally as Karapadom, Kari and Kayal soils. Random soil samples were collected from various parts of Kuttanad and their physico-chemical properties such as pH, conductivity, available NPK status and different forms of iron and aluminium were estimated in moist state itself. Texturally Kuttanad soils were predominantly of clayey nature. Bulk and particle densities were significantly lower in Kari soils due to high organic matter as compared to Karapadom and Kayal soil. The pH values of Kayal soils were significantly higher than that of Kari and Karapadom soils which were extremely acidic. The conductivity of all soil groups were negligible probably due to seasonal effects and also due to the commissioning of Thaneermukkom bund and Thottapally spillway which prevented the ingress of sea water. The availability of major nutrients was fairly high and no significant differences existed between soils. Exchangeable iron and aluminium varied greatly

in individual samples and in few cases the levels were in toxic concentrations. The microbial count recorded was very low and the Kari soils showed a predominance of fungal population due to its low pH.

To study the effect of drying, two samples from each soil group were subjected to air drying and sun drying and compared with the soil incubated under moist condition. Estimations for pH, conductivity, available NPK and different forms of iron and aluminium were carried out at intervals of 1 day, 1, 2, 3, 4, 8 and 12 weeks.

Drying of soil had resulted in a marked and significant decrease in soil pH. The availability of all major nutrients got reduced, the maximum reduction being noticed in the case of phosphorus. Exchangeable iron levels also were reduced significantly as a result of oxidation upon drying of soils. There were no significant changes in the specific conductance and exchangeable aluminium content of the soil groups. Sun drying and air drying behaved similarly in all cases.

To simulate the process of drying under field conditions in Kuttanad, the selected soil samples after intensive drying were packed in PVC pipes of 18" length and 3" diameter and were kept in porcelain pots containing six inches of sea water, allowing free capillary rise. After one month, the soil column was taken out, divided into portions of one inch each and estimations for pH, conductivity, and different forms of iron and aluminium were carried out.

In the six inch submerged soil column, due to soil reduction there had been an increase in soil pH, to near neutral values except in Kari soils. The exchangeable aluminium contents were only in traces in Karapadom and Kayal soils, but Kari soils recorded a range of 62-76 ppm. The exchangeable iron, extracted using neutral normal ammonium acetate and normal potassium chloride were very high and above critical levels for imparting toxicity. Due to capillary rise of the sea water and consequent evaporation, the conductivity of the samples in the soil column increased significantly. Karapadom soils recorded a significantly higher specific conductance.

In the aerobic 12" soil column, the soil reaction was extremely acidic. Exchangeable iron content was negligible and the exchangeable aluminium contents were in the range of 35-231 ppm.

So, after an extreme drought, when a subsequent crop is raised during the next season, chances for iron and aluminium toxicity exists in Kuttanad. In *Kari* soils the pH failed to get stabilised near neutral. There can be a saline water influx, under conditions of extreme drought which can cause salt injury to plants. The impact of artificial reclamation projects in Kuttanad also requires through study from the point of view on their impact on soil properties and hydrological conditions which decides the suitability of acid sulphate soils for rice culture. In Sierra Leone, Bangladesh and China (Bloomfield and Coulter, 1973; Huanchi Mao, 1958) where prolonged dry seasons exists as in Kuttanad, such reclamation projects intented for preventing sea water intrusion at high tides in acid sulphate soils, had often lead to strong acidification and subsequent iron toxicity and consequent abandonment of land.