EVALUATION OF ACIDITY PARAMETERS IN WETLAND SOILS OF KERALA IN RELATION TO NUTRIENT AVAILABILITY

By

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DECLARATION

I hereby declare that this thesis entitled **"Evaluation of acidity parameters in wetland soils of Kerala in relation to nutrient availability"** 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.

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CERTIFICATE

Certified that this thesis entitled **"Evaluation of acidity parameters in wetland soils of Kerala in relation to nutrient availability"** is a research work done independently by **Smt. P. B. USHA** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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INTRODUCTION

INTRODUCTION

Evaluation of current and potential rice lands is highly essential to meet the pressing demand for rice in Asia. However because of the unique nature of flooded rice soils, this evaluation cannot be based on criteria developed for upland soils. Attempts to tackle this problem have been underway in many rice growing countries of the world during the past few decades. These studies have brought to light the significance of soil related constraints in rice production. With the introduction of high yielding varieties of rice, soil problems which had gone undetected earlier, are now assuming greater importance. Several nutrient disorders of rice related to deficiency and toxicity of essential nutrients have been unearthed in major rice growing countries including India. Instances of poor performance of rice varieties of high yield potential have also become frequent.

Soil acidity acclaims paramount importance among the chemical and electrochemical characteristics that influence the soil fertility. However, under wet land conditions, the factors that generate acidity are in a state of dynamic equilibrium in its specific soil environment and hence their evaluation in contributing to nutritional disorders have been an enigma to soil scientists. The wet land soils, whether natural or man made, have specific soil characteristics developed under the influence of temporary or permanent saturation of the soil horizons. Even the temporary saturation of the surficial horizons and consequent reducing conditions during specific seasons every year may induce permanent physical and chemical changes in the soil. The chemical and electrochemical changes in flooded soils that affect the soil fertility include changes in redox potential, soil and flood water pH, electrical conductivity, denitrification, accumulation of ammonia, nitrogen fixation, reduction of manganese, iron and sulphates and changes in the availability of N, P, K, S, B, Cu, Fe, Mn, Mo, and Zn and production of CO_2, organic acids and H_2S. The rates of these changes depend to a large extent on the intrinsic characteristics of the soils and their environment.

The wet land rice soils of Kerala, comprising an area of 6 lakh hectares are unique with regard to their constraints of fertility and crop production. They come under two broad groups depending on their origin namely natural wet lands and man made wet lands. Most of the natural wet lands are characterised by their nearness to sea and periodical inundation with salt water due to their geographic position below sea level. Based on geomorphology, hydrology, general characteristics and constraints of production, the wet land rice soils of Kerala have been indigenously classified as *Kayal* lands (lakes), *Kari* lands (acid peats), *Karapadom* (acid riverine alluvium), *Pokkali* and *Kaipad* lands (saline acid), *Kole* lands (acid hydromorphic) and *ela* lands (lateritic alluvium).

Though attempts have been made in the past to characterise these soils and assess the fertility status, detailed investigations on the nature and extent of soil acidity and its inter-relationship with nutrient availability and toxicity are scanty. The present study envisages an evaluation of different acidity parameters in the major wet land rice soils of Kerala in relation to nutrient availability so as to unveil the acid characteristics of these soils and suggest suitable management practices for achieving maximum benefit to farmers. Thus the study is oriented with the following objectives:

1. To characterise and quantify the acidity generating factors in the major natural and man made wet land rice soils of Kerala

2. To study the kinetics of pH, Eh and availability of nutrients under submergence.

3. To assess the most suitable method of determination of lime requirement of these soils

4. To study the inter-relationships between acidity parameters and nutrient availability in different wet land rice soils.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Wetland soils have got much importance in agriculture because they offer sustenance for rice, the staple food grain for majority of the world population. In India, it is estimated that there are about 4 million ha of wetlands. The wetland soils of Kerala comprise an area of 6 lakh ha. Out of this 1.13 lakh ha are highly acidic and periodically inundated with sea water. These problems highly reduce the production potential of these soils. Several investigations have been carried out by scientists all over the world to study the potentialities and constraints of rice soils. A review of various works in this aspect is attempted in this chapter.

2.1 Acid soils

Acid soils may be defined as those having pH less than 5.5 in 1:1 water extract (USDA, 1970). Acid soils in India cover about 30 per cent of the total area of the country.

2.1.1 Acid sulphate soils

The world wide extent of acid sulphate soils is about 10 million hectares (FAO-UNESCO map of the world), about one per cent of world's cultivated land. They are formed in the tropics and temperate zones (Brinkman,1982). Bhargava and Abrol (1984) reported that in India acid sulphate soils occur mainly in the coastal states of Kerala, Orissa and Bengal where they are subjected to seasonal inundation with brackish water from adjoining lakes or sea.

Dent (1986) postulated that acid sulphate soils develop as a result of the drainage of the coastal flood plain sedimentary parent materials that are rich in pyrite, FeS_2. According to Soil Survey Staff (1992) sulfidic materials contain oxidizable sulfur compounds and are mineral or organic soil materials with a pH value of more than 3.5 which, if incubated as a layer 1cm thick under moist aerobic conditions (field capacity) at room temperature, show a drop in pH of 0.5 or more units to a pH value of 4.0 or less within 8 weeks.

Based on Soil Survey Staff (1992) the sulfuric horizon is 15cm or more thick and is composed of either mineral or organic soil material that has a pH value of 3.5 or less and shows evidence that the low pH value is caused by sulfuric acid. This horizon should contain jarosite concentrations or directly underlying sulfidic materials or 0.05 per cent or more water soluble sulphate. A sulfuric horizon forms as a result of drainage, most commonly artificial and oxidation of sulfide rich mineral or organic soil materials.

According to Brinkman and Pons (1973), a pseudo-acid sulfate soil contains one or more horizons with characteristic yellow mottling (basic iron sulphates) commonly associated with acid sulphate conditions, but does not have a pH below 4 and does not contain free acids or more than about 60% exchangeable aluminium.

Carson *et al* (1982) identified jarosite in soils classified as Ultisols and/or Alfisols developed on the woodbine. Van Breemen (1973) found that in acid sulphate soils the upper limit of dissolved aluminium is regulated by a basic aluminum sulphate with composition $AlOH\ SO_4$. Pons and Van Breemen (1982) observed that potential acidity is built up predominantly in kaolinite rich, non-calcareous sediments in tidal flats below mean sea water level, with a dense mangrove vegetation amply flushed by saline or brackish tides at a sedimentation rate allowing for the mangrove to persist well below mean sea water level for at least several decades.

Fertility problems of acid sulphate soils are soil acidity, salinity, aluminium toxicity, iron toxicity, low nutrient content, low base status and H_2S toxicity (Attanandana and Sorasith, 1986).

Charoenchamratcheep *et al* (1987) studied four acid sulphate soils of Thailand and observed that reduced sulphur species accumulated under anaerobic conditions but oxidised rapidly when the system were aerated.

Iyer (1989) reported that in the acid sulphate soils of Kerala, Pyrrohtite (FeS) is the predominant sulphide mineral with a size range $< 2\ \mu$ along with small amounts of pyrites (FeS_2) which also are $< 2\ \mu$. Varghese *et al* (1992) found that in Kerala potential acid sulphate soils have an area of 50,000 hectares, which are below sea level by 0.5 to 2 metres. They included *Kari* soils of Kuttanad and *Pokkali* soils of Ernakulam district. They are extremely low in pH (3.0), highly buffered, high in soluble salts, rich in organic matter and wood fossils, poor in fertility and have toxic concentrations of soluble iron and aluminium. These soils are developed on fluvial and estuarine deposits and rice culture is the major land use.

Pal *et al* (1991) reported that coastal saline soil zone of West Bengal known as Sundarbans is highly acidic and has high amount of soluble sulphate. They can be classified as potential acid sulphate soils.

Unnikrishnan (1993) classified the *Kari* soils of Kuttanad as Typic Sulfaquents and *Pokkali* soils as Sulfic Tropaquepts. Maji *et al* (1993) conducted studies on coastal soils of Sundarbans and found that the availability of Fe is dominantly controlled by pH; manganese and zinc by available phosphorus and copper by organic carbon content of these soils.

2.2 Soil acidity contributing factors

Soil acidity is common in all regions where precipitation is high enough to leach appreciable quantities of exchangeable base forming cations (Ca^{2+}, Mg^{2+}, K^+ and Na^+) from the surface layers of soils. Two adsorbed cations, hydrogen and aluminium are largely responsible for soil acidity. The mechanism by which these two cations exert their influence depends on the degree of soil acidity and on the source and nature of the soil colloids. Other factors which influence soil acidity are organic matter, clay minerals, iron compounds, aluminium compounds, manganese compounds, sulphur compounds, nitrogen compounds, acid rains etc. (Brady, 1990).

2.2.1 Organic matter

Nair and Iyer (1948) found that the organic matter in *Kari* soils of Kerala is largely a ligno-protein complex consisting of large quantities of lignins, ether and alcohol soluble substances and some cellulose and polyceronoides. Kurup (1967) observed high values of organic carbon ranging from 5.35 to 17.55 per cent in *Kari* soils of Kuttanad. Koshy (1970) studied the chemical nature of organic complexes in *Kari* soils and observed that the major organic fraction was lignin ranging from 68.51 to 78.85 per cent. Several authors have noted a close relationship between the organic matter and pyrite contents of sediments

(Berner 1970) and suggested that the supply of organic matter commonly limits the amount of pyrite produced (Van Beers, 1962; Richard, 1973). Mandal and Nandi (1971) found that addition of organic matter increased the intensity of soil reduction under submerged condition, as a result of which the available phosphorus, iron and magnesium increased. Inorganic and organic acids produced by the decomposition of soil organic matter are common soil constituents that may affect soil acidity. Organic colloids exhibit preferential adsorption of H^+ ions. The organic compounds contain acidic groups that are highly selective for association with protons. The adsorbed H^+ ions are then considered part of the group or the surface. Bolt et al (1976) considered them more difficultly exchangeable against other cations.

Soil humus contains reactive carboxylic and phenolic groups that behave as weak acids. They will dissociate, releasing H^+ ions, depending on the dissociation constant of acid formed and pH conditions. (Tisdale *et al,* 1985).

Cang Dong Quing and Yu Rian-ren (1981) concluded that organic matter can affect the change of soil acidity during submergence in two ways. The organic reducing substances formed during the decomposition of organic matter may reduce the oxides of iron and manganese, causing the pH to increase due to the consumption of protons in the course of the reduction of oxides. Organic acids and CO_2 produced in the decomposition process of organic matter may decrease the pH. The buffering capacity of humus is larger by ten to one hundred times than the mineral part of the soil. The larger buffering capacity of fertile paddy soil is due to the higher content of organic matter and higher base saturation percentage. An experiment conducted by Pan Zhu Zheng et al (1982) showed that for a red soil containing very little organic matter, the sulphide content was very low even when it was submerged at a high temperature.

Neue (1985) concluded from the studies on organic matter dynamics in wetland soils that organic substrates are used as carbon source, electron acceptors and electron donors by anaerobic respiration. The kinetics of reduction and reduction products in wetland soils are determined largely by the nature and content of their organic matter. Both organic matter and pH/Eh influence rice growth, largely by controlling the availability of nutrients.

Ding Chang and Liu-Zhi Guang (1985) observed that organic reducing substances can further undergo electron exchange with ferric and manganic oxides and sulphates reducing them into Fe^{2+}, Mn^{2+} and S^{2-}.

Huduall (1989) proved that soil acidity arising from organic acid deprotonation is dependent upon the vegetation. This kind of acidity is predominant in Histosols. Iron and aluminium ions react with humus to form complexes which may undergo hydrolysis to yield hydrogen ions.

2.2.2 Clay minerals

Gopalaswamy (1961) conducted studies on the soils of Kuttanad and found abnormal variations of the clay content in the soils from different locations. This was attributed to the alternate deposition of peat and clay by tidal waters. There was an unbalanced proportion of calcium to magnesium in the soil which could be corrected by the application of lime. Clays of most of the soils of these profiles had high content of non-exchangeable potassium indicating the presence of illitic as well as montmorillonitic minerals.

Tan *et al* (1975) postulated that most clay particles interact with H^+ions. A hydrogen saturated clay undergoes a spontaneous decomposition. The Al^{3+}

ions released may hydrolyse and produce H^+ ions. A large portion of the H^+ ions present in soils will be adsorbed by the clay complex as exchangeable H^+ ions. The degree of potential H^+ ionization and dissociation into the soil solution determines the nature of soil acidity. The exchangeable H^+ ions are the reason for the development of reserve acidity.

Bolt et al (1976) observed that clay colloids adsorb H^+ ions by the non selective process. They accumulate on the charged surface as a swarm of counter ions. The relative proportion can be estimated with the Gapon equation.

In severely acid environment, an acid sulphate soil enhances the weathering of silicate minerals. Buffering under these severely acid conditions is attributed to acid hydrolysis of alumino silicate clays (Dent 1986). Dissolved Al^{3+} activity appears to be directly related to pH; as pH rises aluminium is precipitated as hydroxide or basic sulphate (Van Breemen 1976). Van Breemen (1987) found that clay and humic fractions act as buffer system. The soil cation exchange complex creates the development of potential and active acidity. The potential acidity will maintain the equilibrium with the active acidity. If the active H^+ ion concentration is neutralised by the addition of lime, the potential acidity will release exchangeable H^+ ions into the soil solution to restore the equilibrium and no change in soil reaction occurs until the reserve H^+ is exhausted.

2.2.3 Iron compounds

Pillai Narayana and Subramanyan (1931) observed that the *Kari* soils of Kerala contain large amounts of soluble iron and aluminium compounds. Analysis of the organic matter of the soils showed that it was derived partly from woody residues and partly from the present vegetation. The yellowing of rice plants in the *Kari* soils was due to toxic concentrations of iron in solution. The needle like incrustations on the soil surface were found to contain Fe, Al, Ca and SO_4. The production of free sulphuric acid by the hydrolysis of mineral sulphates was also postulated. Mutunayagam (1948) observed that *Kari* soils were rich in iron and pieces of decayed wood and stumps of trees were found in the soil at a depth of about 6 ft. Because of high content of organic matter, the organic acids formed during submergence had solubilised the iron.

Coleman and Thomas (1964) and Schwertmann and Jackson (1964) reported that sorbed Fe and Al ions, whether simple hexahydrates or hydroxy polymers can donate protons and thus are sources of soil acidity. The importance of amorphous alumino silicates in the soil acidity has also been reported by Birrel (1961).

Kabeerathumma and Nair (1973) in a study of *Kayal, Kari, Karapadom, Pokkali* and *Kole* soils of Kerala reported that active iron content were 2.7, 0.75, 0.78, 1.10 and 3.28 per cent respectively. Aiyer *et al* (1975) studied available iron, manganese, zinc and copper status of the acid rice soils of Kuttanad and found high amounts of iron in the *Kari* soil. Available copper was significantly and positively correlated with organic carbon and significantly and negatively correlated with pH. The result warrants application of copper in all the three types of Kuttanad soils and zinc in the *Kayal* soils.

Rice suffers from iron toxicity and generally shows bronzing when dissolved iron in the rooting medium is 300 to 500 ppm (Van Breemen and Moorman 1975). Kanwar (1976) observed that forms of iron found in solution were Fe^{3+}, $FeOH^{2+}$, $FeOH^{+}$, $Fe\ (OH)_2^{+}$ and Fe^{2+}. The availability of dissolved oxygen controls the occurrence of dissolved iron and at depths where reducing environments occur, a decrease in available oxygen increases the amount of iron (II) in solution.

The precipitation of iron (III) from iron (II) solutions is by hydrolysis.

$Fe^{2+} + 3H_2O \longrightarrow Fe(OH)_3 + 3H^+ + e^-$ and this oxidation of iron

(II) can result in drop in pH.

At low pH < 4.0 *Thiobocillus ferrooxidans* (autotrophic bacteria)

oxidises Fe^{2+} to Fe^{3+} (Dent 1986)

$$Fe^{2+} + 1/4\ O_2 + H^+ \xrightarrow[\textit{ferrooxidans}]{\textit{Thiobacillus}} Fe^{3+} + 1/2\ H_20.$$

Arkesteyn (1980) found that Fe^{3+} is appreciably soluble only at pH values less than 4. *Thiobacillus ferrooxidans* does not grow at a higher pH. Where the pH of the soil remains above 4.0, iron (III) oxides and hydroxides precipitate directly by oxidation of dissolved iron (II). Goethite (α FeO.OH) is the most commonly identified iron oxide in acid sulphate soils. Sometimes it may be slowly transformed into hematite. The hydroxide of trivalent ferric iron precipitates at pH values of 3.0 to 4.0 whereas ferrous hydroxide does not precipitate until a pH of 6.0 or higher is reached. When the soil is subject to alternate oxidising and reducing conditions, iron tends to accumulate in a layer and eventually forms what is known as "iron pan" (Tisdale et al 1985). Moore and Patrick (1989) found that iron can contribute towards the acidity of a soil by hydrolysis. The oxide goethite is insoluble and mostly formed by slow precipitation of iron at low pH. In drier regions hematite (α - Fe_2O_3) predominates and this oxide is seldom found in humid regions. In waterlogged soils oxidation of iron (II) hydroxide in the absence of CO_2 results in the formation of lepidocrocite (γ - FeO.OH) and this appears in the form of mottling. Two other oxides are magnetite (Fe_3O_4) which contains iron (II) and maghemite (γ - Fe_2O_3) which may form as an alteration product of magnetite by weathering.

Brady (1990) postulated that primary minerals of iron are usually associated with igneous rocks as iron ores, biotite micas and other ferromagnesium silicates. The primary minerals are concentrated in the larger sized fractions of soil. In the clay fraction iron occurs usually in the form of oxides, organic complexes and insoluble salts. Free or active iron is predominently in the form of oxides. Moore *et al* (1990) observed that in rice the uptake of divalent cations was most closely correlated to the divalent activity ratio. The best two variable models describing yield included pH and activity of iron. Shao and Wong (1991) studied the relationship between iron oxides and surface charge characteristics in soils and observed that precipitation of iron oxides into kaolinite markedly increased +ve charges and decreased -ve charges. Amorphous iron oxides having a larger surface area contributed more +ve charge sites and blocked more -ve charge sites in kaolinite than crystalline goethite.

Zhong *et al* (1991) studied the consumption of hydrogen ions and the accompanying changes in positive surface charge, soluble aluminium and exchange acidity with variable charge soils and observed that exchange acidity increased most markedly in the soil with highest iron oxide content.

2.2.4 Aluminium compounds

Hesse (1963) observed that rice grown in acid soils takes up large quantities of aluminium resulting in restricted root development. In severely acid environment of an acid suphate soil the weathering of silicate minerals enhanced markedly (Dent, 1986).

Buffering under these severely acid conditions is attributed to acid hydrolysis of alumino silicate clays. Dissolved Al^{3+} activity appears to be directly related to pH, as pH rises, aluminium is precipitated as hydroxide or basic sulphate (Van Breemen 1976). Acid sulphate soils have large pH dependent charges. Both monomeric $Al\ (OH)_2^+$ and polymeric species eg:- $Al_6(OH)_{15}^{3+}$ of aluminium are reported to occur in the soil solution. Gibbsite ($Al\ (OH)_3$) seems to control the activity of aluminium in the soil solution at higher pH. Moore and Patrick (1991) observed that jurbanite ($Al\ (SO_4)OH.5H_2O$) governs Al^{3+} activity under low pH and amorphous $Al(OH)_3$ at high pH. Most of the pH dependent CEC sites were due to organic matter which complex with aluminium.

Postma (1983) suggested that at pH values less than 3.5, H^+ and Fe^{3+} ions may inhibit plant growth but soluble aluminium is likely to be the principal hazard. Aluminium is the principal exchangeable cation in acid sulphate soils, it is also present as colloidal hydroxide or basic sulphate. At pH values less than 4 to 4.5 it is increasingly soluble. Van Breemen (1973, 1976) has shown that Al^{3+} activity is inversely related to pH, increasing roughly 10 fold per unit pH decrease. Al^{3+} can be toxic at concentrations as low as 1 to 2 ppm. Soluble aluminium accumulates in the root tissues preventing cell division and elongation, inhibiting enzymes concerned with the synthesis of cell wall material. Aluminium toxicity occur at pH levels below 5. Water soluble aluminium and the percentage aluminium saturation of CEC were negatively related to pH. The activity of Al^{3+} adversely affect the weight gain of rice. Tanaka *et al* (1987) in a study on the behaviour of aluminium combining ions at various pH's found that at pH values below 4.7 the Al^{3+} ion is predominant. While $Al\ (OH)_2^+$ is the principal species between 4.7 and 6.5, between pH 6.5 and 8.0, $Al\ (OH)_3$ is the major species and $Al\ (OH)_4$ is most prevalent at pH values above 8.0.

Coleman and Thomas (1967) found that exchangeable aluminium was the predominent cation in acid soils rather than exchangeable hydrogen. Ultisols and Oxisols, which are acidic in reaction (< pH 5.0) have a high aluminium saturation of the effective cation exchange capacity and a relatively high concentration of aluminium in the soil solution. The percentage of ECEC saturated with exchangeable aluminium was proposed as the criterion for liming of a mineral soil (Kamprath, 1970).

Devi Kamala *et al* (1974) studied the iron and manganese status of different soil groups of Kerala State. They found that soil pH was correlated negatively with KCl exchangeable aluminium in all soils except in the alluvial soil where it was not significant. Such a relationship was noted for exchangeable iron also in red sandy loam and the reclaimed marshy and coastal sandy soils. Water soluble and exchangeable manganese gave negative correlation coefficients with pH in three soils while easily reducible manganese was not correlated with pH except in coastal sandy soils.

Tanaka *et al* (1987) found that total aluminium concentration starts to decrease when the pH increases above 4.0 and reaches below 1 ppm at about pH 4.8. Elongation of barley roots is retarded by Al^{3+} and the degree of retardation is controlled by the activity of Al^{3+} rather than by the concentration. The presence of K, Ca and Mg at adequate concentrations alleviates the toxic effect of Al^{3+}. Reactive aluminium in the soil is essentially constituted by the free and adsorbed monomer (Al^{3+}) as well as aluminium hydroxy polymers possessing varying degrees of hydration.

Frageria (1988) considered CEC to be a more reliable parameter for defining aluminium toxic condition in the soil rather than the absolute values of exchangeable aluminium. Aluminium saturation of more than 20 per cent of the ECEC has been considered as critical for many sensitive plants including rice.

Brady (1990) suggested that under very acid soil conditions ($pH < 5.0$), much aluminium becomes soluble and is either tightly bound by organic matter or is present in the form of aluminium or aluminium hydroxy cations. These exchangeable ions are adsorbed in preference to the cations by the negative sides of calloids. The adsorbed aluminium is in equilibrium with the aluminium ions in the soil solution and aluminium ions contributed to soil acidity through their tendency to hydrolyse.

Edgardo and Shamshuddin (1991) found that growth of oilpalm seedlings in Typic Sulphaquepts and Sulfic Tropaquepts was affected by Al^{3+} and Al sum activities in the soil solutions above 100 and 700 µM respectively.

2.2.5 Manganese compounds

Active manganese consists mainly of easily reducible manganese, unless the pH is less than 6 when exchangeable manganese can be considered as active (Johanssan, 1962). Bacterial action upon hydrated manganese dioxide can form manganese (II) ions which are plant available. The manganese oxides occurs as a black coating around iron rich nodule. The nature and distribution of manganese in soils are largely dependent upon pH and redox potential. An increasing pH increases oxidation of manganese, at high pH manganese is relatively unavailable to plants. The deficiency of manganese in acid organic soils is due to leaching of the mobile manganese (II) ion. Active or free manganese can be regarded as water soluble plus exchangeable plus reducible manganese. It can be extracted from soils with sodium dithionite as free ion (Daniels *et al,* 1962).

Gotoh and Patrick (1972) in a study on the transformation of manganese found that under acid condition Mn^{2+} availability is high. As the pH is increased the ionic forms are changed first to the hydroxy ions and finally to insoluble hydroxides or oxides. The oxidation of manganese from the bivalent manganous form (Mn^{2+}) to a tetravalent form (MnO_2) can be carried on by certain bacteria and fungi.

2.2.6 Sulphur compounds

Subramoney (1959) established that the *Kari* soils and the wood fossils associated with them were found to contain different forms of sulphur such as free, organically combined, sulphide and sulphate forms. From the presence of sulphur oxidising and sulphur reducing bacteria in these soils it is assumed that there exists a sulphur bacterial cycle which involves the conversion of organic form of sulphur to the sulphuric acid form through the inorganic sulphides and sulphates. The production of sulphuric acid in this manner is considered to be responsible for the extremely acidic nature of the *Kari* soils. Subramoney (1960) found that wood fossils in *Kari* soils contain 5-8% sulphur. Iyer (1989) observed that the soils contain iron sulphide similar to marcasite and pyrrhotite which on exposure produces sulphuric acid and ferrous sulphate.

Upon long term submergence in the presence of the favourable conditions *Desulphovibrio desulphuricans*, a sulphate reducing bacteria contribute to the formation of pyrite from reductions of ferric sulphates (Ivarson *et al*, 1982) and produce dissolved sulphide (H_2S_{aq} and HS^-_{aq}). This dissolved sulphide reacts with sedimentary iron and precipitates as an iron sulphide such as mackinawite (tetragonal FeS). Dissolved sulphide and elemental sulphur can react to form polysulphides which in turn can react with FeS to form pyrite (FeS_2). Pyrite may form directly from polysulphides and FeS or indirectly through greigite that is formed as an intermediate (Goldhaber and Kaplan 1974). Berner (1970) indicated that dissolved organic matter may inhibit calcium carbonate precipitation and this carbonate alkalinity can be removed from the system by tidal action. The fact that potential acidity FeS_2 is immobile and the alkalinity that forms is mobile is the primary reason for acid sulphate soil development (Van Breemen, 1973). Berner (1964) produced pyrite by direct precipitation in less than a day at pH 4 and room temperature.

Dent (1986) observed that usually the source of sulphur will be sea water or brackish tidal water. Pyrite is also associated with sulphate rich ground waters. Sulphur from biological materials like algae, diatoms and ancient sediments which contain plant and animal remains are also sources of sulphate.

Dent (1986) found that oxidation of pyrite in acid sulphate soils takes place in several stages involving both chemical and microbiological processes. Initially dissolved oxygen reacts slowly with pyrite, yielding iron II and sulphate or elemental sulphur.

$$FeS_2 + 1/2\ O_2 + 2H^+ \rightarrow Fe^{2+} + 2S + H_2O.$$

Further oxidation of sulphur by oxygen is very slow but may be catalysed by autotrophic bacteria at pH values close to neutrality

$$S + 3/2\ O_2 + H_2O \rightarrow SO_4^2 + 2H^+$$

$$2FeS + 9/2O_2 + (n+2)H_2O \rightarrow Fe_2O_3\ n\ H_2O + 2\ SO_4^{2-} + 4\ H^+$$

Once the pH of the oxidising system is brought below 4.0, Fe^{3+} becomes appreciably soluble and brings rapid oxidation of pyrite. Ocean waters contain approximately 2700 ppm sulphate. Sulphur occurs in elemental form as well as sulphides, sulphates and in organic combinations with carbon and nitrogen. Sabu et al. (1990) found that total and organic sulphur of the soils were significantly correlated with clay and organic carbon content of soil. Adsorption of SO_4^{2-} decreased with increase in pH.

2.2.7 Nitrogen compounds

Nitrification (the biological oxidation of ammonia to nitrate) by *Nitrosomonas* and *Nitrobacter* (both obligate autotrophic bacteria) release H^+ ions into soil solution (Tisdale *et al*, 1985).

$$2NH_4^+ + 3O_2 \rightarrow 2\ NO_2^- + 2\ H_2O + 4H^+$$

The substrates on which the nitrite is produced include not only NH_4^+, but also amines, amides, hydroxylamines, oximes and number of other reduced nitrogen compounds. When commercial nitrogen fertilizers of the organic or ammoniacal form are applied to the soil, release of H^+ ions to soil occurs and results in the acidification of soil. Continued use of such forms of nitrogen will lower soil pH.

2.2.8 Acid rains

Around centres of industrial activity in which coal and other sulphur containing products are burned, sulphur dioxide is released into the air and much of this gas is later brought back to earth by the rain. Sulphur emissions are partly responsible for the acid rains (Tisdale *et al* 1985)

2.2.9 Total soluble salts

Mutunayagam (1948) from laboratory studies showed that Kuttanad soils flooded with sea water developed bad physical conditions by acquiring the hydrophilic properties associated with the presence of excess sodium and magnesium ions on the exchange complex. Hence the problem of reclaiming land damaged by sea water consists in restoring its tilth by removing the sodium and magnesium ions particularly sodium. This is possible by flooding of the soil with fresh water containing small amounts of calcium.

Nair and Money (1972) studied the chemical and mechanical properties of the salt affected rice soils of Kerala and found that there existed a high negative correlation between pH and the sulphate content of the soils. A high degree of positive correlation existed between the conductivity on the one side and sulphate, chloride and sesquioxide contents on the other. Conductivity was also positively correlated with the combined percentage of silt and clay. The cations of salts will displace adsorbed aluminium and cause an increase in the acidity of the soil solution. Divalent cations have a greater effect on lowering soil pH than monovalent metal cations. The addition of fertilizer in a band will result in a high soluble salt concentration immediately sorrounding this land. This in turn bring more aluminium, iron and manganese into solution, resulting through hydrolysis in a lowering of soil pH (Tisdale *et al* 1985).

2.2.10 Carbon dioxide

In soils near neutrality or those containing appreciable quantities of carbonates or bicarbonates the pH is influenced to a great extent by the partial pressure of CO_2 in the soil atmosphere (Ponnamperuma 1972). The pH of a soil containing free $CaCO_3$ and in equilibrium with carbon dioxide at the pressure of normal above ground air is 8.5. If the CO_2 pressure of soil at atmosphere in such a system increases to 0.02 atm, the pH will drop to about 7.5. Brady (1990) reported that decomposition of organic matter will result in the formation of CO_2 which combines with water to form carbonic acid. Dissociation of this weak acid into H^+ and HCO_3^- and thus provide another source of H^+ for soil acidification. Root activity and metabolism may also serve as sources of CO_2.

2.2.11 C.E.C.

Yuan *et al* (1967) and Syers *et al* (1970) observed that cation exchange capacity of soils is dependent on the clay and organic matter contents of soils of a particular mineralogy. Dahiya *et al* (1988) found that CEC was positively and linearly correlated with logarithms of saturation percentage ($r = 0.957^{**}$) in Haryana soils.

Venugopal and Koshy (1976) studied exchangeable cations of some important soil profiles of Kerala. They found that in *Kari* and black soils, the exchangeable sodium showed a higher content over potassium. The maximum amounts of exchangeable calcium, magnesium and potassium were observed in the black soil. The highest value of exchangeable hydrogen was noted in the *Kari* soil which also recorded very low values of pH. They have also studied cation exchange capacity in relation to the mechanical composition and organic matter status of some soil profiles of Kerala. Correlation between CEC and clay for all the soils taken together was positive and highly significant. The relationship between organic matter and CEC for all the samples together was positive but not significant.

2.2.12 Base saturation

Mutunayagam (1948) found that cropping for 20 years on a highly organic *Kari* soil with no fertilizer treatment resulted in a marked fall in exchangeable calcium, a net decrease in total exchangeable bases, a very significant increase in exchangeable hydrogen and therefore a fall in pH.

2.3 Components of acidity

Savant and Kibe (1970) concluded that in acid soils, acid producing cations counter permanent as well as pH dependent charge and their contribution to acidity depends on their activity in soil solution. The activity of various forms of acidity were as permanent charge $H^+ >$ permanent charge $Al^{3+} >$ organic matter acidity $>$ lattice Al - OH or Si - OH acidity.

Gowaikar and Datta (1971) found that major part of the total acidity was contributed by exchangeable acidity.

Mclean *et al* (1965) reported that a decrease in the pH dependent acidity by 63.33 per cent on destruction of organic matter. Igue and Fuentes (1972) reported that destruction of organic matter increased the exchangeable acidity of soils due to aluminium released from organic matter or by the solubilisation of inorganic forms of aluminium due to H_2O_2 treatment. Sharma and Tripathi (1988) found that the significance of amorphous Al_2O_3 and Fe_2O_3 with exchangeable acidity depends on their proportional amounts in soil. They also revealed that organic matter was the main component contributing towards pH dependent acidity.

Sharma and Tripathi (1988) reported that exchangeable acidity correlated positively only with amorphous Fe_2O_3 whereas pH dependent and total acidities of soils showed positive correlations with organic matter, amorphous and crystalline Al_2O_3 and amorphous Fe_2O_3. The relative contribution of various constituents in pH dependent component of soil acidity was rated as amorphous Al_2O_3 > total Al_2O_3 > organic matter > crystalline Al_2O_3 > amorphous Fe_2O_3 > crystalline Fe_2O_3.

Ananthanarayana *et al* (1974) and Patil (1986) studied the fertility status and lime requirement of acid soils of Karnataka and observed that total acidity or extractable acidity decreased with depth due to decrease in organic matter content. The total acidity and clay content of soils are related due to the buffering action. H^+ is the chief source of exchange acidity and not exchangeable Al^{3+}. The pH dependent acidity was positively correlated with organic matter content in the acid soils of Maharastra (Kodarekar *et al* 1981). Das *et al* (1992) studied the laterite soils of Orissa (Alfisols, Ultisols and Inceptisols) and observed that pH dependent acidity varied from 3.1 to 11.8 cmol(+)/kg which was mainly associated with the inorganic fractions of soil such as oxides of iron. aluminium and clay. pH dependent acidity at pH 8.0 was 3 to 4 times greater than at pH 7.0. Exchangeable Al and Al saturation (%) significantly and negatively correlated with soil pH.

2.4 Kinetics of Soil pH, Eh and nutrients due to submergence

2.4.1 Kinetics of Soil pH

Subramanyan (1937) reported increase in Soil pH due to submergance and attributed this mainly to the increase in the concentration of ammonium in the soil solution. Karunakar and Daniel (1950) working with a soil of initial pH 8.0 observed a decrease in pH to 7.3 with the progress of rice growth under submerged conditions and thought that the pH fluctuations were related to the growth stages of the rice crop.

Ponnamperuma (1955) suggested that submergence of acid soils leads to a gradual increase in pH, the magnitude of which depends on the initial pH, the organic matter content and duration of submergence.

The optimum pH (measured in the solution of submerged soil) for rice is about 6.6. At that pH microbial release of N and P is fast; the supply of Cu, Fe, Mn, Mo and Zn are adequate and the concentrations of substances that interfere with nutrient uptake such as Al, Fe, Mn, Co_2, organic acids and H_2S are below toxic levels. In the tropics, mineral soils with an organic matter content >2% attain this pH 2-4 weeks after flooding. Delaying transplanting until 2 weeks after submergence increased yield by 1 t/ha in the dry season and 0.8 t/ha in the wet season overplanting at submergence (IRRI annual report 1963).

According to Patrick (1964) an increase in pH was always accompanied by a decrease in redox potential and that at a low redox potential the ferric hydroxide was reduced to ferrous hydroxide according to the equation.
$Fe(OH)_3 + e^- \longrightarrow Fe(OH)_2 + OH^-$

Chakravarty and Kar (1970) and Mukherjee and Basu (1971) reported that flooding acid soils resulted in slight initial depression and then a gradual increase in soil pH to near neutrality, a gradual decrease in the redox potential and a decrease in Fe^{3+} during 30 days of flooding with a consequent increase in the water extractable P and Fe^{2+} which reached a peak in 10 days after submergence. Dev and Sharma (1971) in studies on 13 soils of Punjab obtained stabilisation of pH around neutrality, except in calcareous soils, in 15 days flooding and attributed this to increase in Fe^{2+} and Mn^{2+}. The pH, electrical conductivity and oxidisable organic matter of the surface flood water were found to be higher than those of the soils under study.

Mohanty and Patnaik (1975), in studies on 20 soils in the pH range 4.7 to 8.5, with varying clay and organic carbon content belonging to alluvial, red, laterite and black soils found that submergence resulted in stabilisation of pH of all the soils, in the range 6.5 to 7.5 duing the first 10 days; the pH remained more or less unchanged for the next 40 days; after which it decreased in those soils in which initially it was 6.5 or less. The increase of pH in acid soils and its decrease in calcareous soils were attributed to Fe^{3+} - Fe^{2+} and carbonate bicarbonate equilibria respectively. Flooding these soils also resulted in a decrease in the redox potential to negative values, the magnitude of decrease being more in soils having high organic carbon and active Fe content. Sharma *et al* (1977) found that flooding a silty clay loam soil of pH 8.3 increased Fe^{2+} and Mn^{2+} during the first 15 days but decreased the content of Na, K, Ca, Mg and Zn during the entire period of 60 days.

For most soils and sediments the fairly stable pH value obtained after several weeks of submergence is between 6.7 and 7.2 in the soil or 6.5 to 7.1 in the soil solution. Peat sediments and acid sulphate sediments have pH values of 5 even after prolonged submergence. The pH increase in iron deficient soils and sediments is small. Soils and sediments high in organic matter and in reducible iron attain a pH of 6.5 within a few weeks of water inundation. Low temperature retards the pH increase in acid soils and sediments. The increase in pH of most soils is largely due to the reduction of iron Fe^{+++} to Fe^{++} and can be described quantitatively by the equations.

$$Eh = 1.06 - 0.059 \log Fe^{2+} - 0.177 \text{ pH}$$

Although the increase in pH of acidic sediments is brought about by soil reduction, the fairly stable pH attained after a few weeks of submergence is regulated by the partial pressure of CO_2. For iron rich sediments the empirical relationship is $pH = 6.1 - 0.58 \log PCO_2$. The pH values of flooded calcareous and sodic sediments are lower than those of well drained soils because of CO_2 accumulation and the pH values are highly sensitive to PCO_2 as shown below :

Calcareous soils : $pH = 0.60 - 2/3 \log PCO_2$

Sodic soils : $pH = 7.85 + \log(\text{alkalinity}) - \log PCO_2$

The pH profoundly increases hydroxide, carbonate, sulphide, phosphate and silicate equilibria in the sediments and soils. These equilibria regulates the precipitation and dissociation of solids, the sorption and desorption of ions and concentration of such nutritionally significant elements or substances such as phosphorus, iron, aluminium, copper, zinc, hydrogen sulphide, carbonic acid and organic acids

Kabeerathumma and Patnaik (1978) studied the effect of submergence on the availability of toxic and deficient nutrients in acid sulphate soils of Kerala. They noted that flooding resulted in an increase in the pH. The exchangeable Fe content increased and reached a peak value in 30 days and then decreased. The amount of Fe released was dependent on the active Fe content of the soils. The course of change of exchangeable Mn was similar to that of Fe. The overall effect of submergence was towards an increased availability of Ca and K.

$$Fe(OH)_3 + e^- \longrightarrow Fe(OH)_2 + OH^-$$

Correlation studies indicated that pH had a significnt negative correlation with water soluble and exchangeable forms of iron while E.C., CEC and clay content had positive correlation. Total soluble salts and organic matter were positively correlated with iron. The pH attained peak value on the 20th day of submergence in lateritic alluvium, 30th day in *Karapadom* soil and 60th day in *Kayal, Kole* and *Pokkali* soils. *Kari* soils showed steady slow increase throughout the period of submergence. Lime application at full LR and half

LR levels increased the pH upto 5th day in all soils except in the *Kari* Soil after which it decreased with further period of submergence. In *Kari* soil a peak value could be noticed on the 20th day (Harikumar 1989).

Aitkeu and Moody (1991) observed that of the electrolytes used, pH measured in 0.02 M $CaCl_2$ gave the closest approximation to pH_{SS} (soil solution pH).

2.4.2 Redox potential (Eh mV)

Ponnamperuma (1972) found that the low potentials -0.2 to -0.4 V of submerged soils reflect reduced state and the high potentials 0.8 to 0.3 V reflect the oxidised condition. When an aerobic soil is submerged, its Eh decreases during the first few days and reaches a minimum, then it increases, attain a maximum and decreases again asymptotically to a value characteristic of the soil after 8-12 weeks of submergence. The rapid initial decrease of Eh is due to the release of reducing substances accompanying oxygen depletion before Mn (IV) and Fe (III) oxide hydrates can mobilize their buffer capacity. Soils high in nitrate (more than 275 ppm NO_3^-) have positive potentials for several weeks after submergence. Soils low in organic matter (less than 0.2%) maintain positive potentials even 6 months after submergence.

Ponnamperuma (1978 & 1982) found that the optimum Eh for wetland rice is 70-120mV at pH 7.0 in the soil solution. A low Eh increases the availability of P, Fe, Mn and Mo but decrease that of S and Zn.

Larsen *et al* (1991) studied flood induced chemical transformations in calcareous agricultural soils of South Florida found that within 2 days of flooding redox potential decreased to -150 mV and -300 mV and by day 21, it had stabilised at about -165 mV. The intial pH values was 7.9 and 7.5 but after 3 weeks of flodding the pH of both soils had stabilised at about 7.25. After 7 weeks of flooding extractable Mn and Fe increased 50 fold and 30 fold, extractable Mg and Ca and K increased, P decreased, NO_3^- decreased, NH_4^+ increased. Cogger *et al* (1992) in a study on measuring and interpreting redox potentials found that exchangeable Fe (II) was present at $\leq + 200$ mV (pH 5-7) indicating conditions suitable for Fe reduction and mottling. Wang *et al* (1993) studied soil redox and pH effects on methane production in a flooded rice soil and found that the critical soil Eh for initiation of methane production was -150 to -160 mV and the optimum pH was near neutrality.

2.4.3 Available nitrogen

De and Sarkar (1936) reported an increase in the ammonium-N in soil soon after flooding it reached a peak value in six weeks, remained unchanged for one month and then decreased.

Bomji (1938) obtained a higher content of ammoniacal nitrogen than of nitrate nitrogen in flooded rice fields.Mohanty and Patnaik (1975) working with 20 different soils reported that flooding resulted in an increase in the easily oxidisable organic matter and ammonium nitrogen, the peak values are reached in 10 to 30 days of flooding depending upon the soil type and its organic matter content. After this period both decreased, the former by oxidation to CO_2 and the latter either by nitrification followed by denitrification or by microbial immobilisation.

Abichandani and Patnaik (1958b) working on the mineralisation of soil nitrogen at varying moisture levels reported that under aerobic conditions, nitrification was active and ammoniacal nitrogen gradually decreased with time. Under anaerobic conditions ammonification was more active and nitrate nitrogen decreased till only traces were found.

Abichandani and Patnaik (1955, 1961) and Borthakur and Mazumdar (1968) obtained stimulation of mineralisation of native nitrogen in neutral soils under flooded conditions through application of lime which resulted in increased availability of nitrogen to the extent of 20-40 kg/ha with a consequent increase in rice response. Abichandani and Patnaik attributed it to a temporary rise in the soil pH by 1-2 units, which resulted in the dispersion of soil organic matter and made it more suitable for rapid decomposition by soil microorganisms.

Gupta (1955) observed rapid loss, to the extent of 10 per cent of the applied ammoniacal nitrogen, during the first three days and a total loss of 21.1 per cent in about 15 days largely due to volatilisation. Abichandani and Patnaik (1958b) reported that only 40 per cent of applied nitrogen could be recovered in 42 days submergence from surface applied ammonium sulphate in comparison with 88 per cent recovered when the fertilizer was incorporated in the reduced zone. These authors further reported that for growing rice under flooded soil conditions ammonia containing fertilizers be preferred to nitrates and that the fertilizer application be sub surface to get better results.

Bhattacharya (1971) was of the opinion that increase in ammoniacal nitrogen in soil on flooding might partly be due to expansion of clay lattice resulting in the release of the fixed ammonia.

Murty and Singh (1978) also studied ammoniacal nitrogen accumulation in soils on flooding, the amount dependent on the total C and N in soil and increased on addition of rice straw.

Pasricha and Singh (1977) found that the activity ratio of NH_4^+ increased with soil submergence, had linear relationship with the changes in exchangeable N and obeyed Schofield's ratio law.

2.4.4 Phosphorus

Basak and Bhattacharya (1962) obtained a decrease in Al-P, Fe-P and organic P during the period of rice growth with a consequent increase in available P to the extent of 64 per cent from transplanting to the pre flowering stage. This was attributed to reduction in P fixation, faster rate of P release than that of its absorption by rice roots, presence of continuous stream of water resulting in increased P availability due to hydrolytic dissolution of Al-P and reductive stabilisation of Fe-P.

Resubmergence of air dried or overdried acid laterite soils resulted in increased available P in light textured soils but not in clay soils because of higher contents of active Fe in the latter (Sawant *et al* 1970). Prabhakar *et al* (1974) reported increase in available P with increase in the water content or with the addition of organic materials such as compost or dried green leaf, the increase was more in sandy loams than in alluvial and black soils.

Pathak *et al* (1972) reported that the availability of P, Fe and Mn increased till 70 days after transplanting rice and then decreased. Mandal and Nandi (1971) found that addition of organic matter increased the intensity of soil reduction under submerged conditions as a result of which the available P, Fe and Mn increased.

Singh and Bahaman (1976) reported an increase in available P, Fe-P, Al-P and decrease in Ca-P in 20 days of flooding of acid soils. Data on isotopically exchangeable P indicated that a portion of the inorganic P in soil was converted into more labile forms under submerged soil conditions (Gupta and Singh 1975).

Singh and Ram (1977) observed an increase in available P in soil upto the tillering stage and then a decrease. This increase in acid soils was related to decrease in Fe-P and Ca-P; in alluvial soils it was related to decrease in Al-P and Ca-P. Mandal and Khan (1977) found that about 60-75 per cent of the P fertilizer added to rice crop remained fixed at harvest. Resubmergence of this soil for growing rice, after a 5 month fallow period, resulted in adequate supply of P during the initial growth stages mostly from the Fe-P fraction.

Diaz *et al* (1993) in a study on phosphorus mineralization from Histosols found that repetitive flooding increased the amounts of total P and soluble reactive P in leachates. Total P mineralised from flooded cultivated Histosols was upto 2 times greater than under drained cultivated conditions.

Release of phosphate ions occured from the exchange between organic anions and phosphate ions in Fe-P and Al-P compounds. P mobilisation results from an increased microbial activity in the presence of physiologically active rice roots and from the capacity of rice plants to reoxidise the rhizosphere during the later phase of the growing period. In soils poor in iron oxides under highly reduced conditions.

$Fe\ (PO_4)_2 + 3H_2S \longrightarrow 3\ FeS + 2H_3\ PO_4$ conversion increased the availability of P in flooded soils (Mandal 1979).

Organic acids released during anaerobic decomposition of organic matter under flooded soil can increase the solubilities of Ca-P compounds by complexing Ca^{2+} ions and thereby disturbing the solubility equilibria of Ca-P. Also attributed to observed lowering of fixation of applied P in the presence of added organic matter in flooded acidic lowland rice soils to the complexation of soil Fe and soil Al by decomposition products of organic matter. Welp *et al.* (1983) reported upto 70% of the total soluble phosphorus in flooded soil-solution was in organic combination.

Mathew Regi and Jose (1984) reported that flooding the soil resulted in an increase in the content of available P, Fe-P, Al-P and saloid-P, while the cocentration of reductant soluble P, occuluded P and Ca -P showed a gradual decrease.

The availability of phosphorus in soil increased upon submergence due to reduction of ferric compounds. The reduction of free hydrous oxides during flooding and the liberation of sorbed and co precipitated phosphorus as a result increased the levels of solution or extractable P in flooded acidic soil (Willet 1986). The subsequent release of occluded P forms within the structure of amorphous iron oxides has been proposed by De Datta *et al* (1989). The chemical equilibria of equations of the following types have been used to describe the activity of Fe^{2+} in solutions of flooded soils (Ponnamperuma 1967).

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

for reduction in the early stages of flooding

$$Fe_3(OH)_8 + 8H^+ + 2e^- \longrightarrow 3Fe^{2+} + 8\,H_2O$$

in soils after prolonged flooding. There is thus an increase of exchangeable Fe^{2+} in soils with a concomitant rise in soil pH and decline in Eh. High phosphorus availability also occur due to higher solubilities of $FePO_4 \cdot 2H_2O$ and $AlPO_4 \cdot 2H_2O$ from hydrolysis due to increased soil pH in acid and strongly acid soils.

Tomar and Tek Chand (1992) studied the effect of soil properties on the transformation of phosphorus in acid soils and found that the pH, CEC, clay, organic carbon and active Al and Fe contents individually had no significant effect on the transformation of added P into saloid P and Al-P. The clay and extractable Fe contents increased the transformation of added P into Fe-P. The available P increased with pH but decreased with organic carbon.

Ponnamperuma (1955) found that flooding the soil increases the availability of native and added P. Consequently the yield response of low land rice to fertilizer P are generally lower than those to nitrogen or even to phosphorus for upland crops grown on the same soil or under alternate wetting and drying conditions.

2.4.5 Potassium

Ramanathan and Krishnamoorthy (1973) reported that the black soils had higher available K than alluvial and red soils. The available K increased with the period of submergence, which was attributed to the release of K from the non exchangeable form.

Sreedevi and Aiyer (1974) studied potassium status of the acid rice soils of Kerala State and found comparatively high values of total, exchangeable, difficultly exchangeable and HCl soluble potassium in *Kari, Karapadom* and *Kayal* soils of Kuttanad region due to submergence in salt water from adjoining back waters and deposition of silt by flood waters. More than 88% of total K in illitic soils was in mineral phase which suggested that parent material was the origin of most of K. Ammonium ions with crystal radii of 0.143 nm would displace K^+ which has a similar crystalline radius (0.133 nm) from wedge zones or specific sites.

Murty and Singh (1975) reported an initial decrease in available K during the first week of flooding followed by a gradual increase. Mohanty and Patnaik (1977) reported that the transformation and availability of K, Ca and Mg were primarily governed by silt + clay content of the soil and this in turn determined the total amounts present and also the cation exchange sites. The availability of these three cations increased on flooding on account of their displacement by the action of water through hydration and hydrolysis, reached a peak in about 30 days and then decreased. The decrease in K might be due to lattice fixation and that of Ca and Mg precipitation as carbonates and carbonate apatites.

2.4.6 Magnesium

Pisharody and Mutunayagam (1966) in a study on the manganese status of rice soils of Kerala found that the availability of this micronutrient is much higher in soils in the submerged state.

Ponnamperuma (1972) and Van Breemen (1975 and 1976) demonstrated that although Ca and Mg are not directly involved in redox reactions in soils, their concentration in the water soluble fraction was found to increase following flooding. These increases have been attributed to exchange processes in which

Fe^{2+} brought into solution by reductions displaces Ca^{2+} and Mg^{2+} on the cation exchange complex. Van Breemen (1973) observed decreases in exchangeable Ca^{2+} and Mg^{2+} following artificial oxidation of pyritic sediments.

2.4.7 Sulphur

Ponnamperuma (1972) found that the reduction of sulphate due to submergence is brought about by a small group of obligate anaerobic bacteria of the genus Dcsulfovibrio which use SO_4^{2-} as the terminal electron acceptor in respiration. In neutral and alkaline soils concentrations as high as 1500 ppm SO_4^{2-} may be reduced to zero within 6 weeks of submergence. Acid soils first show an increase in water soluble SO_4^{2-} then a slow decrease spread over several months. The initial increase in SO_4^{2-} concentration is due to the release of SO_4^{2-} which is strongly sorbed at low pH by clay and hydrous oxides of iron and aluminium sulphate reduction proceeds slowly in submerged acid sulphate soils, lime accelerates reduction considerably. Although large amounts of H_2S are produced in submerged soils, the concentration of water soluble H_2S may be so small that it is chemically almost undetectable. The critical level of soil available sulphur was estimated to be 12 ppm. The critical level of plant total sulphur at panicle initiation stage was found to be 0.13 per cent (Bhuiyan, *et al* 1986).

2.4.8 Iron

The most important chemical change that takes place when a soil is submerged is the reduction of iron and accompanying increase in the solubility. Acid soils high in organic matter and iron build up concentrations as high as 600 ppm within 1-3 weeks of submergence. The increase in concentration of water soluble iron can, in most soils be related to the potential and pH of the $Fe(OH)_3$ - Fe^{2+} system. When a soil is submerged, Fe(III) compounds are directly and indirectly reduced to Fe (II) by microorganisms and large amounts of iron are brought into solution. During submergence the concentration of water soluble iron increases to a peak value and then declines or reaches a plateau. Acid soils high in organic matter and iron build up concentrations as high as 600 ppm within 1-3 weeks of submergence.

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

with $Eh = 1.06 - 0.059 \log Fe^{2+} - 0.177\ pH$

where Fe^{2+} denotes the activity of water soluble Fe(II) (Ponnamperuma ., 1966) .

Mutunayagam (1948) conducted laboratory studies on submergence and showed that the soluble iron content rose from 25 ppm in two days to 896 ppm in 12 days in *Kari* soils. The principal cause of crop failure in Kaipuzha areas of *Kari* soils was solubilization of iron to an exceedingly toxic concentration.

Savant and Kibe (1969) reported that the changes of Fe and Mn on submergence were both electrochemical and chemical. Jayaram and Nayar (1972) reported complete reduction of Fe and Mn in 15-30 days flooding in soils having low active Fe and Mn whereas in soils with high active Fe and Mn, the release of Mn was completed earlier than that of Fe. Mn preceded Fe in the order of reduction. The release of Fe however, was several times that of Mn in soils with high $CaCO_3$ content which resulted in a high Fe/Mn ratio in these soils especially under unpuddled condition.

The exchangeable iron content increased due to submergence (Kabeerathumma and Nair 1973).

Jaggi and Russel (1973) obtained high concentration of Fe^{2+} in flooded soils treated with Ipomoea leaves which attained a level of 2,000 ppm in 6 weeks and then decreased gradually to 1000 ppm.

Ghosh *et al* (1976), Bondyopadyay (1984) and Patnaik and Mohanty (1989) noticed increase in exchangeable iron content upto 30 days and there after a gradual decrease. Mandal and Mitra (1982) reported that the content of soluble and exchangeable iron were more in continuously waterlogged soils than in alternately water logged saturated soils. Harikumar (1989) studied the dynamics of the forms of soil iron in the acid soils of Kerala during submergence and found that submergence significantly increased pH and the contents of some of the forms of soil iron. Crystalline iron decreased with submergence. Active and free oxide forms of iron had no significant effect. The active iron neither increased nor decreased significantly due to the organic matter and lime treatments.Water soluble and exchangeable iron decreased significantly due to lime treatment. Lovley *et al* (1991) suggested that micro organisms enzymatically catalyse most of the Fe (III) reduction zone of aquatic sediments and aquifers.

2.4.9 Manganese

The main transformation of manganese in submerged soils are the reduction of Mn(IV) oxides to Mn(II), an increase in the concentration of water soluble Mn^{2+}, precipitation of manganous carbonate and reoxidation of Mn^{2+}

diffusing or moving by mass flow to oxygenated interfaces in the soil. Acid soils high in manganese and in organic matter build up water soluble Mn^{2+} concentrations as high as 90 ppm within a week or two of submergence, then show an equally rapid decline to a fairly stable level of about 10 ppm (Ponnamperuma 1972). The behaviour of manganese in paddy soils is similar to iron in many aspects. On flooding Mn(IV) and Mn (III) oxide hydrates were reduced to the much more soluble Mn (II) compounds. The rate of increase in concentration as well as the peak and the final stable concentration are determined mainly by the manganese and organic matter content of the soil. The release of water soluble Mn^{2+} precedes that of Fe^{2+} because Mn(IV) and Mn(III) oxides are reduced more easily than Fe (III) oxides. Paddy soils may contain 50 to 3000 ppm reduced manganese in the solid phase and 1 to 100 ppm Mn^{2+} in the solution phase. The concentration of water soluble Mn^{2+} is low in high pH soils that are low in organic matter and active manganese and is high in acid soils high in manganese and organic matter (Ponnamperuma 1977). Water soluble Mn^{2+} moves down the profile and is precipitated in a zone below the Fe(II) oxide layer (Kawaguchi and Kyuma 1969).

Moore and Patrick (1989) in a study on the manganese availability and uptake by rice in acid sulphate soils showed that Mn solid phases such as oxides, hydroxides, carbonates, phosphates or silicates were probably not controlling Mn solubility in these soils. Cation exchange was the dominant mechanism governing Mn^{2+} activities in these soils. Managanese uptake by rice was more closely related to the Mn^{2+}/Fe^{2+} activity ratio than to Mn^{2+} activity or exchangeable Mn, possibly due to Fe antagonism.

2.4.10 Zinc

When a soil is submerged, the concentration of water soluble zinc decreases and reaches values as low as 0.3 ppm despite desorption from Fe(III) and Mn (IV) oxide hydrates. In acid soils the decrease in zinc concentration may be due partly to the increase in pH following soil reduction because solubility of zinc in water decreases 100 times when pH increases by one unit (Thrierweiler and Lindsay 1969). But the concentration of zinc decreases in calcareous and sodic soils inspite of the decrease in pH brought about by the accumulation of CO_2.

Subrahmanyam and Mehta (1975) reported that zinc availability was highest in saturated soils, followed in descending order by flooding and field capacity. Katyal (1977) reported a decrease in zinc concentration in the soil solution of flooding. Haldar and Mandal (1979) observed a decrease in NH_4OAc (pH 7.0) extractable Zn and Cu in alluvial soils; the decrease was pronounced under continuous saturation followed by continuous waterlogging. Budheswar and Omanwar (1980) reported an increase in DTPA extractable Zn in flooded soils when compared with aerobic soils. Mandal and Haldar (1980) showed that application of P decreased the content of DTPA extractable Zn, Cu, Fe and Mn in waterlogged rice soils. The depressive effect of P on extractable Zn, was found to be more prominent with soil native Zn compared to applied Zn.

Singh *et al* (1993) conducted laboratory incubation experiments and observed that the magnitude of transformation of applied zinc to organically, amorphous Fe oxide and Mn oxide bound fractions was relatively higher under the continuously than under the alternately submerged conditions and results were reverse in respect of water soluble plus exchangeable and crystalline Fe-oxide bound fractions. Application of organic matter enhanced the transformation of applied Zn to Zn oxide, organically and amorphous Fe-oxide bound forms but it discourgaed such transformations to the water soluble plus exchangeable and crystalline Fe-oxide fractions.

Biswapati and Mandal (1992) studied the chemistry of zinc availability in submerged soils and found that precipitation of zinc as hydroxide, carbonate and sulphide and its adsorption into the surface of hydrated oxides of iron were partly responsible for the decrease in Zn on submergence. Water soluble plus exchangeable, organically complexed and amorphous sesquioxide forms were found to be of major importance in determining zinc concentration in rice plants. When zinc was applied to soil as fertilizer, much of it was found to be transformed into iron oxide bound forms. Reduction of Fe_2O_3 and subsequent formation of amorphous hydrated oxides of iron played the most significant role in controlling zinc availability in submerged soils. Keeping soil under submergence for 15 days before application and application of organic matter were found to be beneficial in maintaining higher proportion of applied zinc in active forms. zinc deficiency increased with increasing pH; total soluble salts and $CaCO_3$ and decreased with organic carbon content.

2.4.11 Copper

The concentration of water soluble copper in a soil decreases on flooding despite desorption from Fe(III) and Mn (IV) oxide hydrates. This may be due partly to pH increase, for the solubility of copper decreases 100 fold of each unit pH increase (Norwell and Lindsay 1969).

In reduced environments, copper may be present as Cu_2O, Cu, CuS or Cu_2S and adsorbed on soil minerals. It is also present as insoluble complexes with organic matter. But the concentration of copper in the solutions of flooded soils is several orders higher than those permitted by the solubility of CuS or Cu_2S (Agotade 1972).

Water soluble plus exchangeable copper had highly significant negative correlation with pH. At high pH values copper availability decreased due to precipitation of copper as hydroxide (Raghupathi and Vasuki 1991).

2.4.12 Silica

Sreenivasan (1936) obtained higher concentration of Si on flooding soils for extended periods Nair. and Aiyer (1968) working with 22 different soils obtained increased available Si on flooding, irrespective of pH and organic matter content. From studies on soils from fields freshly brought under rice cultivation, Rao and Venkateswaralu (1974) reported that in red sandy loam soils the available Si increased from 63 ppm to 127 ppm in three weeks of flooding after which the values remained more or less unchanged for eight weeks. Nair *et al.* (1977) found that in different soil types, flooding increased available Si which reached a peak in 20 days; there was either no change or a slight decrease in the next 40 days. Flooding resulted in an increase in extractable Si in soil accompanied by an increase in Fe and a decrease in Al. The higher availability of Si was due to hydrolysis of alumina silicates (allophanes) and reduction of ferri silicate (hisingerite).

Ponnamperuma (1972) observed that the concentration of silica in the solutions of submerged soils increases slightly after flooding and then decreases gradually and after several months of submergence the concentration may be lower than at the start. The increase in concentration after flooding may be due to the release of silica following reduction of hydrous oxides of Fe(III) sorbing silica and action of CO_2 on alumino silicates. The subsequent decrease may be the result of recombination with alumino silicates following the decrease in PCO_2.

2.5 Lime requirement

Padmaja and Varghese (1972) studied the effect of calcium, magnesium and silicon on soil reaction, nitrogen and phosphorus status of the red loam soils of Kerala and found that liming red loam soils of Kerala at the rate of 2.5 metric tonnes/ha of CaO raised the soil pH by 1 to 1.5 units. Liming with CaO and magnesium carbonate was more effective than liming with CaO alone. Availability of nitrogen in the soil was increased by the application of calcium or magnesium or both. Availability of P_2O_5 was increased by the application of silicon either alone or in combination with calcium or magnesium or both.

Kabeerathumma and Nair (1973) studied the effect of liming on exchangaeable cations and pH of acid soils of Kuttanad and found that full lime requirement was found to be the optimum dose for *Kari* while half lime requirement was sufficient for the *Karapadom* soil for equal effects. Ferrous iron content and exchangeable Al and exchangeable hydrogen were effectively reduced by lime application and high negative correlations of these elements with pH were noticed.

The amount of exchangeable aluminium can be used as the criterion to determine the amount of lime to apply in acid soils (Kamprath 1970). The amount of $CaCo_3$ required to neutralise specific quantity of KCl exchangeable Al is given by the equation

$CaCO_3$ tons/ha = cmol (1/3 Al^{-3}) kg^{-1} x factor (Kamprath 1984)

The factor for most ultisols and oxisols is in the range of 1.5 to 2.

Ahmad and Wilson (1992) found that the acid sulphate soils of Guyana and Trinidad, needed 50 tonnes per hectare of ground lime stone to appreciably reduce the effects of the high acidity which develops on draining. Where dilute sea water is available and its use can be controlled, repeated flooding and draining of acid sulphate soils have been used for reclamation.

Attanandana and Sorasith (1986) suggested leaching and drainage, submergence, liming addition of manganese dioxide, nitrogen, phosphorus and potassium including utilization of rock phosphate as phosphate source and use of resistant varieties as ameliorative measures for acid sulphate soils.

When an acid sulphate soil is kept submerged until the pH increases sufficiently, aluminium toxicity is eliminated and iron toxicity minimized (Ponnamperuma 1964) permitting rice to grow normally. Attanandana (1982) showed that grain yields were increased by 77% for three successive years in field experiment on an acid sulphate soil in Thailand by means of presubmergence for six weeks before planting. Several researchers have reported liming to be the simplest way of increasing the pH of the soil. The combination of leaching and liming had the greatest effect in rice production in acid sulphate soils. Another important effect of liming is the increased availability of most plant nutrients (Attanandana and Sorasith 1986).

Marykutty (1986) found that aluminium saturation of effective CEC is the best parameter for measurement of soil acidity. She found that *Kari* soils had highest percentage of aluminium saturation above 75.0. Liming the soil coupled with washing had been found to be significantly superior in raising the mean pH values and decreasing exchangeable hydrogen and aluminium content of the soils.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

In Kerala it is estimated that there are 6 lakh ha of wetlands comprising both natural and man made wet lands. The natural wet lands of Kerala are unique due to their nearness to sea and periodical inundation with salt water. Indigenous classifiction of wet lands of Kerala was mainly based on their geomorphology, hydrology, general characteristics and constraints of production.

3.1. Details of sample collection

To study the acidity generating factors in relation to nutrient availability, profile samples as well as surface samples were collected from twelve specific locations representing the natural and man made wet lands. The selection of locations were based on the occurrence of natural wet lands which had been reclaimed for cultivation and which have a natural water table at or near their surface and man made wet lands which had been brought under cultivation by man for rice culture in the recent past. Care was also taken to select soils which represent major rice growing tracts of the State. The profiles were dug at the twelve representative sites detailed on next page and Fig. 1.

Profile pits were dug in the above 12 locations upto a depth of >150 cm. Information on the site and profile description were made as per the guidelines suggested by FAO (1990). A total number of 77 samples were collected representing each horizon of the profiles under study.

Sl. No.	Site	Nature	Common name of soil type
1.	Vellayani	Natural/*Kayal*, fresh water	Acid hydromorphic
2.	Karamana	Manmade/valley bottom	Borwn hydromorphic
3.	Thakazhi	Natural/*Kari*	Acid sulphate
4.	Nedumudi	Natural/*Karapadom*	Acid hydromorphic
5.	D-Block	Natural/*Kayal*	Saline hydromorphic
6.	Njarakkal	Natural/*Pokkali*	Saline acid
7.	Anthikkadu	Natural/*Kole*	Saline acid
8.	Pazhayangadi	Natural/*Kaipad*	Saline acid
9.	Pattambi	Manmade/valley bottom	Brown hydromorphic
10.	Kattampalli	Natural swamp	Acid hydromorphic (reclaimed)
11.	Wyanad	Manmade/valley bottom	Brown hydromorphic
12.	Chittoor	Manmade/valley bottom	Non acid black soil

In addition to profile samples ten, composite surface samples were taken from a radial distance of 5 km of each of the above profile locations for soil characterisation and detailed laboratory investigations (Appendix -1).

3.2. Profile description

Description of the twelve profiles representing the major rice growing tracts of Kerala was done according to Soil Survey Staff 1975.

3.3. Laboratory investigations

The wet land profile samples as well as surface samples were taken along with field water as in the field condition and initial analyses for pH (H_2O), pH (KCl), pH ($CaCl_2$) and electrical conductivity were done.

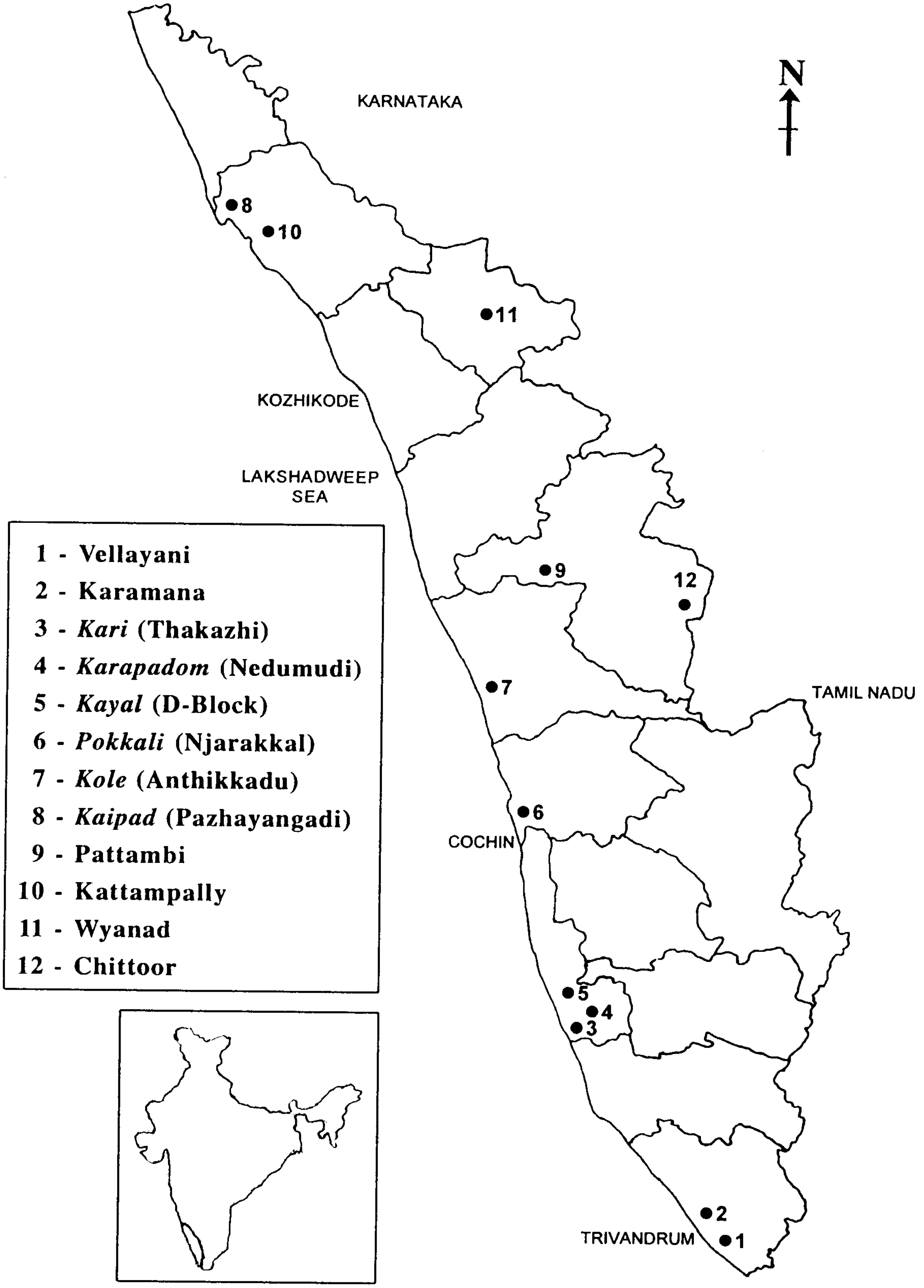

Fig. 1. Map of Kerala showing locations of pedons

The wet soil samples were air dried, powdered and sieved through 2mm IS sieve and stored in bottles. The sieved soil samples were subjected to physical, chemical and mineralogical analysis. A portion of all samples were kept separately in wet condition for specific determinations.

3.3.1. Chemical analysis

i) Measurement of pH

a) pH (H_2O)

Soil water ratio 1:1 and 1:2.5 were taken and pH measured in Biochem pH meter.

b) pH (KCl)

The soil was mixed with IM KCl in the ratio 1:1 and pH measured.

c) pH ($CaCl_2$)

Soil and 0.01 M $CaCl_2$ were taken in 1:2 ratio mixed thoroughly and pH measured.

ii) Total Soluble Salts

This was done in the 1:2.5 ratio soil water suspension. The electrical conductivity of the supernatent liquid was measured in a conductivity meter. (Jackson. 1973).

pH and electrical conductivity measurements were done both for wet field samples as well as dried samples.

iii) Study of the components of acidity

a) Active acidity

This is given by the concentration of H^+ in the soil solution. This was measured by pH determination.

b) Exchangeable acidity

Exchangeable acidity refers to exchangeable Al^{3+} plus H^+ adsorbed on the colloidol surface by electrostatic forces and extracted by a neutral unbuffered salt solution of IM KCl.

The sample was percolated with IM KCl solution. The acidity brought into solution from various sources in the soil was measured by titration with 0.025 M NaOH (Black. 1965).

In addition one of the sources of acidity namely exchangeable aluminium was measured separately by using Atomic Absorption Spectrophotometer.

c) Extractable acidity or potential acidity or maximal acidity or titratable acidity

This refers to the total H^+ in covalent bonds plus exchangeable Al^{3+} and H^+ extracted with a buffered salt solution of a given pH (Soil Survey Staff 1975).

This was extracted by $BaCl_2$ TEA buffer solution (pH 8.2). The sample was shaken with a $BaCl_2$-TEA buffer solution (pH 8.2) for 16 hours. After centrifugation an aliquot of the supernatent solution was titrated with acid to measure residual base (Black. 1965).

d) Non exchangeable acidity

It is the amount of the titratable acidity that still remains in the soil after the exchangeable acidity has been removed with a neutral unbuffered salt solution. This type of acidity is represented by H^+ in covalent bonds with organic and mineral soil fractions. This was measured by substracting exchangeable acidity from potential acidity.

iv) Organic carbon

Organic carbon was determined by the method of walkley and Black (1934) in which soil was digested with standard potassium dichromate and sulphuric acid and the excess chromic acid was back titrated against standard ferrous sulphate in the presence of orthophosphoric acid using diphenyl amine indicator.

v) Analysis of nutrients

All profile as well as surface samples were subjected to analysis of nutrients namely available nitrogen, phosphorous, potassium, calcium, magnesium, sodium, iron, manganese, zinc and copper.

a) Available Nitrogen

Available nitrogen was determined by alkaline permanganate method suggested by Subbiah and Asaija (1956). Here the amount of soil nitrogen released by alkaline permanganate solution (100 ml of 0.32 per cent potassium permanganate and 100 ml of 2.5 per cent sodium hydroxide) from 20 g of soil was estimated by distillation procedure. Care was taken to see that a fixed volume of distillate (30 ml) was collected in standard acid each time. The excess acid was then back titrated against standard alkali, using methyl red indicator.

b) Available Phosphorus

Available phosphorus was extracted by Bray No.1 extractant (0.03N Ammonium flouride in 0.025N HCl) and determined by stannous reduced molybdo phosphoric blue colour method using Klett-Summerson photo electric colorimeter at 660 nm (Jackson 1973).

c) Available Potassium

Extracted using neutral N ammonium acetate and read in Biochem flame photometer (Jackson 1973).

d) Available bases

Calcium, magnesium and sodium were also determined in the leachate collected by neutral N ammonium acetate extract. (Jackson, 1973).

e) Micronutrients

Iron, manganese, zinc, copper: 20g soil was mixed with 40 ml 0.05 M DTPA and shaken for 2 hours, filtered through Whatman NO.42 filter paper and read in GBC 902 Double Beam Atomic Absorption Spectrophotometer. (Lindsay and Norwell 1978).

vi) Cation exchange capacity

Cations were displaced by mixing soil with neutral N ammonium acetate and keeping overnight. Then the solution was leached and the excess ammonium acetate was removed by washing with alcohol. The soil was then distilled with magnesium oxide, the ammonia liberated being absorbed in a known excess of standard acid. The excess acid was then titrated with standard alkali and the cation exchange capacity was calculated. For samples which had E.C. > 0.5 mS were prewashed with 80% ethanol to remove excess and free salts. In the leachate the exchangeable bases were determined (Schollenberger and Dreibelbig, 1930). Effective CEC was determined by adding exchangeable bases and exchange acidity (Soil Survey Staff, 1992).

vii) Active Iron and Manganese

36 selected surface samples (3 samples from each wet land randomly selected) were subjected to more chemical analyses.

The samples were heated in a complexing buffer of sodium citrate/ bicarbonate to which solid sodium dithionite was added as a reducing agent. Iron and manganese were measured in the extract by AAS (Mehra and Jackson 1960).

viii) Total Sulphur

Total sulphur in selected 36 samples were determined as per the method described by FAO (1988). Weighed out 1g. of 0.15 mm sieved soil into a 100 ml flask and 5 ml of digestion mixture was added (Potassium dichromate + perchloric acid + nitric acid + bromine). The flask was then heated, cooled and made up the volume to 50 ml. Sulphur oxidised to sulphate was determined turbidimetrically.

ix) Available Sulphur

36 selected samples were analysed for available sulphur. Soil samples were extracted with 40 ml each of 0.5 M $NaHCO_3$ at pH 8.5 (1 hour shaking)

and sulphate was determined as barium sulphate and determined turbidimetrically according to the method of Chesnin and Yien (1951).

x) Available Silica

Available silica was extracted using N sodium acetate solution buffered at pH 4.0 Available silica in the extract was determined by reduced silico molybdate method (Imaizumi and Yoshida, 1958).

xi) Mechanical analysis

36 samples(3 each from each wet land)were selected randomly and textural class determined by International Pipette method (Piper 1942).

xii) Clay mineralogy

Clay fraction of 12 samples one each from each wet land were subjected to X-ray diffraction analysis and clay minerals identification done. (Kunze and Dixon, 1986 and Kim, 1982).

3.4. *In vitro* study on the kinetics of soil pH, Eh and nutrients due to submergence

36 samples(3 each from each wet land)were selected for submergence study. 500 g samples were taken in glass bottles covered with black paper on all sides and 5 cm water was maintained for 12 weeks. The initial as well as fornightly pH, Eh available N, P, K, Ca, Mg, Na, K, Fe, Mn, Zn, Cu, Al and Si were determined (Jackson 1973). Eh was determined using a platinum calomel electrode assembly.

3.5. Lime requirement of surface samples

Lime requirement was calculated employing different methods.

i) Exchangeable aluminium method

Lime requirement was computed by the method of (Kamprath 1970). Lime requirement = Exch. Al x 1.5 tonnes/ha

ii) Shoemaker method

Mixed 10g of soil with 20 ml of buffer solution and shook for 10 minutes. Read the pH of the suspension and estimated the lime requirement from the graph prepared from the data of Shoemaker (Shoemaker *et al* 1961).

iii) Base saturation elevation method

This method depends upon an ammonium acetate extraction of soil to measure cation exchange capacity and percent base saturation. The lime requirement was calculated as the calcium carbonate necessary to raise the base saturation to 60%; this was done using the monogram given by Metson (1961).

iv) Titration method

Lime requirement was also done by titration method for selected samples based on the principle that 10 ml of 0.1M NaOH is equivalent to 5 tonnes $CaCO_3$/ha. The quantity of 0.1 M NaOH required to reach pH 5.5 was determined and lime requirement calculated (Dent 1986).

3.6. Statistical analysis

Analysis of variance for all characters between wet lands was done. All possible correlations were worked out between the characters studied taking into consideration all soils and separately for each wet land. Regression equations were worked out for relevent characters by taking acidity parameters as dependent factor and acidity contributing factors as independent factor.

The data on submergence study was analysed by CRD split plot design. Linear and quadratic regressions were worked out based on the kinetics of nutrients and other soil parameters and the equations having more R value was taken. Multiple regressions were done by taking acidity as dependent factor and acidity related variables as independent factor. Path coefficient analysis was also done for dry pH, exchange acidity, non exchange acidity and potential acidity.

RESULTS

4. RESULTS

Detailed investigations have been carried out to characterise and quantify the components of acidity and acidity generating factors in the natural and manmade wet land rice soils of Kerala in relation to nutrient availability. An attempt has also been made to assess the most suitable method for determination of lime requirement for different wet land rice soils in the State. The results obtained from these investigations are presented.

4.1 Pedogenic environment of the different wet lands

Table 1 presents pedogenic environment and classification of the different wet lands subjected to detailed investigations. Out of the twelve geo-climatic locations studied, four represented man made wet lands and the rest natural. All the natural wet lands were below sea level ranging from 0.1 M to 1.0 M and the locations Nedumudi, D-Block and Thakazhi represented the natural wet lands of *Kuttanad* namely *Karapadom*, *Kayal* and *Kari* respectivley. Of these the D-Block representing the *Kayal* (lake) region is subjected to seasonal ingress of saline water from the sea and brackish backwaters. Lying as a contiguous geographic region these soil groups come under Aeric Tropaquepts (*Karapadom*), Typic Hydraquents (*Kayal*) and Typic Sulfaquents (*Kari*).

The locations Njarakkal (*Pokkali*), Anthikkad (*Kole*) and Pazhayangadi (*Kaipad*) represented the coastal natural wetlands which are saline-acid in nature subjected to seasonal inundation of saline and fresh water. According to Soil Taxonomy (1975) these three soil groups are classified as Sulfic Tropaquepts,

Table 1. Pedogenic environment of the locations of wet lands under study

Sl. No.	Location	Type	Local soil name	Latitude N	Longitude E	MSL	Natural vegetation	Land use	Soil TaxonomicClassiciation
1.	Vellayani	Natural/Fresh water kayal	Acid hydromorphic	8°26'3"	76°59'5"	- 0.1M	Marsh land grasses	Rice - Single crop	Fine, Kaolinitic, Isohyperthermic, Tropic Fluvaquent
2.	Karamana	Manmade/Valley	Brown hydromorphic	8°28'3"	76°57'50"	+ 7M	Grasses, weeds	Rice - double crop	Fine, Kaolinitic, Isohyperthermic, Typic Tropaquent
3.	Thakazhi	Natural/Kari	Acid sulphate	9°20'27"	76°25'30"	- 1M	Marsh land grassess and mangroves	Rice - double crop	Fine, Loamy - Mixed Isohyperthermic, Typic Sulfaquent
4.	Nedumudi	Natural/Karapadom	Acid hydromorphic	9°24'51"	76°25'13"	- 0.75M	Grasses and Weeds	Rice- Double crop	Fine, Mixed, Isohyperthermic, Aeric Tropaquept
5.	D-Block	Natural/Kayal	Saline hydromorphic	9°31'2"	76°24'45"	- 1M	Marsh land grasses mangroves	Rice - Single crop	Fine, Mixed, Isobyperthermic, Typic Hydraquent
6.	Njarakkal	Natural/Pokkali	Saline acid	10°3'5"	76°13'22"	- 1M	Grasses and weeds	Rice - single crop	Fine, Mixed Isohyperthermic, Sulfic Tropaquept.
7.	Anthikkadu	Natural/Kole	Saline acid	10°26'4"	76°8'52"	- 0.1M	Marsh land grasses	Rice - double crop	Fine, Mixed, Isohyperthermic, Typic Tropaquepts.
8.	Pazhayangadi	Natural/Kaipad	Saline acid	12°43'"	75°17'2"	- 1M	Grasses and weeds	Rice - double crop	Fine, Mixed, Isohyperthermic, Tropic Fluvaquent
9.	Pattambi	Manmade/Valley	Brown hydromorphic	10°48'51"	76°11'35"	+ 0.40M	Grasses and weeds	Rice - double crop	Fine, Kaolinitic, Isobyperthermic, Aeric Kandiaqult
10.	Kattampalli	Natural/Swamp reclaimed	Acid hydromorphic	11°36'48"	75°40'54"	- 1M	Marsh land grasses	Rice - double crop	Fine Loamy, Kaolinitic, Isohyperthermic, Tropic Fluvaquent
11.	Wyanad	Manmade/Valley	Brown hydromorphic	11°37'28"	76°14'16"	+ 800M	Grasses and weeds	Rice - double crop	Fine Loamy, Kaolinitic, Isohyperthermic, Typic Tropaquent
12.	Chittoor	Manmade/Valley	Non acid black soil	10°43'19"	76°46'42"	+98M	Grasses and weeds	Rice - double crop	Fine Loamy, Mixed, Isohyperthermic, Petrocalcic Calciusters

Typic Tropaquepts and Tropic Fluvaquents. The natural wet lands of Vellayani and Kattampally represented the acid hydromorphic soils. However the former is a fresh water lake and the latter a reclaimed swamp. Taxonomically both these soils belong to Tropic Fluvaquents. The manmade wet lands of Karamana, Pattambi and Wyanad represented the brown hydromorphic soils located in differing physiographic positions, namely coastal, mid land and high land. The soils of Karamana and Wyanad come under Typic Tropaquent and that of Pattambi under Aeric Kandiaqult. The man made wet land soil of Chittoor is a unique soil group in this study, being non-acid black soil coming under the sub group of Petrocalcic Calciusterts. Hence comparisons on the extent and severity of the acid characteristics of other soil groups can be made taking this as the standard.

4.2 Profile morphology of the major wetland rice soils

Table 2 presents the profile morphology of the twelve wet land rice soils of Kerala subjected to detailed investigations with respect to their acid characteristics. The nature of horizonisation and the profile characteristics of different wet lands show wide variation depending on their pedogenic environments. The pedons of Karamana, Vellayani, Thakazhi, D-Block, Pazhayangadi and Wyanad do not have a 'B' horizon where as Nedumudi, Njarakkal, Anthikkad and Pattambi have 'B' horizons with unique features. Gleying was noticed in the sub surface horizons of all the pedons except that of Chittoor, Pattambi and Anthikkad. The field pH of the surface and deeper horizons varied very much in the pedons of Karamana, Vellayani, Nedumudi, D-Block, Pazhayangadi and Kattampally whereas the variation in pH as a function of depth was not marked in the pedon of Thakazhi, Njarakkal, Anthikkad, Pattambi and Chittoor. The C horizon of Nedumudi, D-Block and Pazhayangadi have a field pH (wet) around 7.0. However the black soil from Chittoor recorded a field pH above 7.0 in all the horizons.

Table 2. Profile morphology of major wet land rice soils of Kerala

1. Vellayani	2. Karamana	3. Thakazhi	4. Nedumudi
2	1	4	3
Ap$_1$: 0-11 cm; Light olive brown 2.5 Y 5/6 moist and pale yellow 2.5 Y 7/4 dry; Sandy clay loam; moderate granular, weekly cemented; many fine medium continuous pores; fine and medium rice and weed roots; gradual wavy boundary pH 4.5 (Wet), 3.8 (dry). Ap$_2$: 11-16 cm; Greyish brown 2.5 Y 5/2 moist and light grey 2.5 y 7/2 dry ; Sandy clayloam, moderate granular sticky, weakly cemented; many fine medium continuous and discontinuous pores, clear smooth boundary pH 4.6 (Wet), 4.1 (dry). A2g: 16-28 cm; Light yellowish brown 2.5 y 5/4 moist and light grey 2.5 Y 7/0 dry; clay loam; moderate fine granular sticky plastic many continuous and discontinuous pores; gradual smooth boundary pH 4.9 (Wet) 4.0 (dry). Ac: 28-40 cm; Light olive brown 2.5 Y 5/4 moist and very pale brown 10 YR 8/3 dry; clay; massive sticky; plastic; many fine continuous pores; gradual smooth boundary pH 5.2 (wet), 4.5 (dry). C$_1$: 40-56 cm; Light brownish grey 2.5 Y 6/2 moist and pale yellow 2.5 Y 7/4 dry clay; massive, sticky, plastic; strong;	Ap$_1$: 0-17cm -Olive brown 2.5 Y 4/4 moist and Pale yellow 2.5 Y 7/4 dry; sandy clay loam, moderate fine granular, slightly sticky, slightly plastic; many fine vesicular and tubular pores many fine roots concentrated in the first 5cm, diffuse smooth boundary; pH 6.0 (wet) 4.5 (dry). Ap$_2$: 17-32 cm; Light olive brown 2.5 Y 5/6 moist and light Yellowish brown 2.5 Y 6/4 dry sandy clay; moderate fine granular; slightly sticky; slightly plastic; common vesicular and tubular pores, diffuse smooth boundary; pH 5.5 (wet), 5.0 (dry). Ac : 32-56 cm; Light olive brown 2.5 Y 5/6 moist and light yellowish brown 2.5 Y 6/4 dry clay; massive; sticky plastic common fine,imped pores; diffuse smooth boundary. pH 6.2 (wet), 5.0 (dry). C$_1$g : 56-90cm; Olive brown 2.5Y 4/4 moist and dark greyish brown 2.5 Y 4/2 dry, massive, plastic, fine irregular pores, diffuse smooth boundary; pH 6.0 (wet) 5.8 (dry) C$_2$: 90-111cm; Dark grey 2.5 Y N/4 moist and dark greyish brown 2.5 Y 4/2 dry; clay; massive; sticky, plastic, fine	Ap$_1$: 0-12 cm; Olive brown 2.5 Y 4/4 moist and light olive brown 2.5 Y 5/4 dry; sandy clay loam; moderate fine granular; slightly; sticky and slightly plastic, many five roots inside the peds, many five tubular pores; gradual smooth boundary pH 3.9 (wet), 3.0 (dry). Ap$_2$: 12-18 cm; Very dark greyish brown 2.5 Y 3/2 moist and grey ish brown 2.5 Y 5/2 dry; sandy clay; moderate fine granular, slightly sticky and slightly plastic, few roots many fine tubular pores; gradual smooth boundary; few fossilwoods well mixed. pH 4.0 (wet) 3.7 (dry). Ag: 18-30 cm; very dark greyish brown 2.5 Y 3/2 moist and dark greyish brown 2.5 Y 4/2 dry; Sandy clay; moderate course granular, sticky and plastic, roots nil; fine irregular pores; gradual smooth boundary; few fossil woods pH 4.4 (wet), 2.3 (dry). C$_1$: 30-54 cm, very dark grey 2.5 Y 3/N moist and very dark greyish brown in 2.5 Y 3/2 dry; clay; coarse granular sticky and plastic; roots nil, many fine tubular pores diffused smooth boundary; numerous soft fossil woods pH 5.5 (wet), 2.6 (dry).	Ap$_1$: 0-16 cm; Olive brown 2.5 Y4/4 moist light olive brown 2.5 Y 5/4 dry; sandy clay; coarse granular; many fine roots inside peds; many fine tubular pores; smooth diffuse boundary. pH 4.6 (wet) 4.1 (dry). Ap$_2$: 16-24 cm; Greyish brown 2.5 Y 5/2 moist and light olive brown 2.5 Y 5/4 dry clay; moderate fine granular; sticky; slighty plastic; roots few; fine irregular pores, gradual smooth boundary. pH 5.0 (wet) 5.0 (dry). B$_2$: 24-34 cm Dark greyish brown 2.5 Y 4/2 moist and olive brown 2.5 Y 5/4 dry; few five distinct dark reddish brown mottles, clay massive sticky, plastic strong, roots nil fine irregular pores; gradual smooth boundary. pH 5.6 (wet), 5.5 (dry). 2 C$_1$g: 34-52 cm; Dark greyish brown 2.5 Y 4/2 moist and dark grey 2.5 Y N/4 dry; few fine distinct dark reddish brown mottles, clay; masive; sticky; plastic; strong, roots nil, fine irregular pores; diffuse smooth boundary pH 5.8 (wet), 5.7 (dry). 2 C-2g: 52-69; very dark brown 2.5 Y 3/2 moist and dark grey 2.5 Y N/4 dry; few fine faint reddish brown mottles; clay;

Contd...

Table 2. (Contd....)

1	2	3	4
roots nil, fine many continuous pores, diffuse smooth boundary, wood fossils and remains of earlien mangrove vegetation pH 5.6 (wet), 4.9 (dry). C_2: 56-82 cm, very dark greyish brown 2.5 Y 3/2 moist and light grey 2.5 Y 7/2 dry; clay; massive; blocky; sticky; plastic roots nil, fine many continuous pores; diffuse smooth boundary wood fossils and remains of cerlier mangrove vegetation pH 5.6 (wet) 4.7 (dry). C_3: 82-150 cm; very dark greyish brown 2.5 Y 3/2 moist and light grey 2.5 Y 7/2 dry, clay; massive; blocky; strong; sticky; plastic; roots nil many fine continuous pores; diffuse boundary. pH 5.7 (wet), 4.6 (dry). C_4: 150-172 cm; very dark greyish brown 2.5 Y 3/2 moist and grey 2.5 Y N/6 dry; clay; massive strong, sticky; plastic; roots nil fine many continuous pores, and diffuse wavy boundary remaining of magrove vegetation. pH 6.0 (Wet), 4.8 (dry). C_5: 172-200 cm; Very dark greyish brown 2.5 Y 3/2 moist and grey 2.5 N/6 dry; Clay; fine granular; plastic, sticky; roots nil, pH 6.1 (Wet), 4.8 (dry).	irregular pores; diffuse smooth boundary pH 6.0 (Wet), 5.0 (dry) C_3: 111-140 cm; Olive brown 2.5 Y 4/4 moist and light grey 2.5 Y 7/2 dry; clay-massive; sticky; plastic; fine irregular pores, diffuse smooth boundary pH 6.0 (wet), 5.1 (dry). C_4: 140-210 cm; Dark grey 2.5 Y N/4 moist and brownish grey 2.5 Y 6/2 dry; clay; massive; sticky; plastic; fine irregular pores; diffuse Smooth boundary; pH 6.1 (Wet), 4.8 (dry).	C_2: 54-140 cm, Black 2.5 Y N/2 moist and very dark greyish brown 2.5 Y 3/2 dry; clay; mossive, sticky and plastic, roots nil; many tubular pores; few soft fossil woods; pH 5.0 (wet), 2.5 (dry).	massive; very sticky; plastic; strong; roots nil; fine irregular pores; diffuse smooth boundary; remains of mangrove vegetation. pH 6.2 (wet) 3.7 (dry). $2C_3g$: 69-164 cm; Very dark greyish brown 2.5 Y 3/2 moist and dark grey 2.5 Y N/4 dry; Clay; massive; very sticky; plastic; strong; roots nil; fine irregular pores; diffuse smooth boundary pH 6.8 (wet) 2.6 (dry).

Contd...

Table 2. (Contd....)

5. D-Block	6. Njarakkal	7. Anthikkadu	8. Pattambi
5	6	7	8
Ap$_1$; 0-10 cm, Dark greyish brown 2.5 Y 4/2 moist and light olive brown 2.5 Y 5/6 dry; Sandy clay; moderate granular, many fine roots; many fine pores, gradual smooth boundary; pH 5.5 (wet), 3.8 (dry). Ap$_2$; 10-18 cm, Dark greyish brown 2.5 Y 4/2 moist and light olive brown 2.5 Y 5/4 dry; clay; moderate granular, weak, slightly plastic, slightly sticky, roots few; many fine tubular pores; gradual smooth boundary; pH 5.6 (wet), 4.3 (dry). Clg; 18-22 cm; Olive brown 2.5 Y4/4 moist and dark greyish brown 2.5 4/2 dry; few fine faint mottles; Clay; massive; fossillified wood; many fine tubular pores; Clear smooth boundary; lime shell accumulation about 5% by weight pH 6.8 (wet), 6.9 (dry). C2g; 22-33 cm; Olive brown 2.5 Y4/4 moist and olive brown 2.5 Y 5/2 dry, clay, massive; sticky, plastic, strong; many fine irregular, pores; gradual smooth boundary; lime shell accumulation about 10% by weight; pH 6.8 (wet), 6.8 (dry). C3g: 33-41 cm; black 2.5 YN/2 dry; very dark greyish brown 2.5 Y 3/2 moist;	Ap$_1$; 0-8 cm; very dark gray 2.5 Y N/3 moist and very dark greyish brown 2.5 Y 4/2 dry; sandy clay; Weak fine granular; slightly sticky and slightly plastic; weak many fine tubular pores gradual smooth boundary; few fine roots. pH 4.2 (wet), 2.6 (dry). Ap$_2$; 8-20 cm; Black 2.5 Y N/2 moist and very dark brown 2.5 Y 3/2 dry; sandy clay; weak fine granular; slightly sticky and slightly plastic; Many fine tubular pores, gradual smooth boundary; few fine roots, pH 4.4 (wet) 2.6 (dry). B$_2$; 20-35 cm; Black 2.5 Y N/2 moist and very dark greyish brown 2.5 Y 4/2 dry; sandy clay; massive; sticky and plastic; strong many fine irregular pores; diffuse smooth boundary; roots nil. pH 4.9 (wet), 2.8 (dry). Cg; 35-75 cm; Black 2.5 Y N/2 moist and very dark greyish brown 2.5 Y 3/2 dry; clay; massive; highly sticky and plastic; strong irregular pores; diffuse wavy boundary; roots nil. pH 4.3 (wet), 2.8 (dry). C2g; 75-110 cm, Black 2.5 Y N/2 moist and very dark greyish brown 2.5 Y 3/2 dry; clay; massive; highly sticky and	Ap$_1$; 0-10 cm; Olive brown 2.5 Y 4/4 moist and pale yellow 2.5 Y 7/4 dry; Sandy clay loam; medium granular; sticky; plastic; weak; many fine roots, fine tubular pores, gradual smooth boundary. pH 4.4 (wet), 4.0 (dry). Ap$_2$; 10-20 cm; Olive brown 2.5 Y/4 moist and pale yellow 5.5 Y 7/4 dry; sandy clay; moderate. Fine granular; slightly sticky; plastic, weak, roots nil many tubular pores smooth gradual boundary pH 4.5 (wet), 4.2 (dry). B$_1$; 20-30 cm; dark grayish brown 2.5 Y 4/2 moist and olive brown 2.5 Y 4/4 dry sandy, fine granular, stricky, plastic, strong, roots nil, medium tubular pores, graual smooth boundary. pH 4.5 (wet), 4.2 (dry). B$_2$; 30-40 cm; Dark greyish 2.5 Y 4/2 moist and olive brown 2.5 Y 4/4 dry; clay; massive; sticky; slightly plastic; roots nil. medium tubular pores; gradual smooth boundary pH 4. 6 (wet), 4.1 (dry). C$_1$; 40-50 cm, very dark grey 2.5 Y N/3 moist and dark grey 2.5 Y N/4 dry; clay moderate; massive, slightly plastic; nonsticky; roots nil; tubular	Ap; 0-20 cm; olive brown 2.5 Y 4/4 moist and light yellowish brown 2.5 Y 6/4;clay loam; weak, fine granular; non sticky; slightly plastic; many micro discontinuous vertical pores; mony fiberous roots; clean smooth boundary pH 5.3 (wet), 4.5 (dry). B$_1$: 20-30 cm Light Olive brown 2.5 Y 5/4 moist and olive yellow 2.5 Y 6/6 dry; clay massive; slightly sticky, plastic cemented with Iron oxide; micro continuous vertical pores; medium roots gradual smooth boundary pH 5.3 (wet), 4.5 (dry). B$_2$; 30-46 cm; Olive brown 2.5 Y 4/4 moist and olive yellow 2.5 Y 6/6 dry; clay; sub angular blocky. Slightly sticky; non plastic, weakly cemented; vertical pores, roots absent; gradual smooth boundary; pH 5.2 (wet), 5.1 (dry). C$_1$; 46-56 cm; Olive brown 2.5 Y 4/4 moist and light yellowish brown 2.4 Y 6/4 dry; clay massive; non sticky; non plastic; weakly cemented; vertical pores; roots absent diffuse smooth boundary; pH 5.2 (wet), 5.1 dry C$_2$; 56-89 cm; Olive brown 2.5 Y 4/4 moist and light yellowish brown 2.4 Y 6/4 dry; clay massive; non sticky; non

Contd...

Table 2. (Contd....)

5	6	7	8
Fine distinct reddish and yellowish mottles, Clay, massive sticky; plastic; strong, many fine irregular pores, gradual boundary. pH 6.7 (wet), 3.8 (dry). C$_4$g; 41-97 cm, Black 2.5 Y N/2 moist and very dark grey 2.5 Y N/3 dry, few fine distinct mottles; clay; massive; sticky; plastic; strong; fine irregular pores; smooth boundary, peat wood occasional. pH 6.9 (wet), 2.3 (dry). C$_5$g; 97-103 cm; Black 2.5 Y N/2 moist and very dark grey 2.5 Y N/3 dry; clay; massive; plastic. Strong; fine irregular pores, clean smooth boundary; occasional lime shells. pH 7.2 (wet), 3.1 (dry). C$_6$g; 103-151 cm Black 25 Y N/2 moist and very dark greyish brown 2.5 Y 3/2 dry; clay; massive, sticky; plastic, strong. fine irregular pores diffuse smooth boundary; occassional peats. pH 7.4 (wet), 3.0 (dry).	plastic; strong irregular fine pores, diffuse wavy boundary; roots nil. pH 4.6 (wet); 2.82 dry). C$_3$g; 110 & below; Black 2.5 Y N/2 moist and very dark greyish brown 2.5 Y 3/2 dry; clay massive; highly sticky and plastic; strong irregular fine pores; roots nil. pH 4.7 (wet), 2.91 (dry).	pores; gradual smooth boundary pH 4.8 (wet) 4.1 (dry). C$_2$; 50-60 cm; Black 2.5 Y N/2 moist and very dark greyish brown 2.5 Y 3/2 dry; Clay; massive; sticky; Plastic; strong; roots nil; fine tubular pores; gradual smooth boundary pH 49 (wet), 4.1 (dry). C$_3$; 60-70 cm; Black 2.5 Y N/2 moist and very dark greyish brown 2.5 Y 3/2 dry; clay; massive; sticky; plastic, strong roots nil; fine tubular pores, gradual smooth boundary, pH 4.9 (wet), 3.9 (dry). C$_4$; 70-80 cm; Black 2.5 Y N/2 moist and very dark brown 10 Y 3/3 dry... clay; massive sticky, Plastic; strong roots nil; fine tubular poores; gradual smooth boundary. pH 4.9 (wet), 3.2 (dry).	plastic, weakly cemented; vertical pores; roots absent; diffuse smooth boundary. pH 5.3 (wet) 5.2 (dry). C$_3$; 89 cm and below; Olive brown 2.5 Y 4/4 moist and light yellowish brown 2.5 Y 6/4 dry; Clay; massive, non sticky, non plastic, weakly cemented; vertical irregular pores; roots absent; pH 5.3 (wet) 5.2(dry).

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Table 2. (Contd....)

9. Pazhayangadi	**10. Kattampally**	**11. Wyanad**	**12. Chittoor**
9	11	12	10
Ap_1; 0-9 cm; very dark greyish brown 2.5 Y 3/2 moist and dark greyish brown 2.5 Y 4/2 dry; sandy clay; moderate granular; slightly sticky slightly plastic; weak; many fine roots; tubular pores; gradual smooth boundary. pH 4.8 (wet), 4.5 (dry). Ap_2; 9-17 cm; Dark greyish brown 2.5 Y 4/2 moist greyish brown 2.5 Y 5/2 dry; clay; fine granular; sticky; plastic; weak; fine roots; tubular pores, gradual smooth boundary pH 6.4 (wet), 5.9 (dry). Cg_1; 17-26 cm. Dark grey, 2.5 Y 4/6 moist. Very dark greyish brown 2.5 Y 3/2 dry; few fine reddish and yellowish mottles; clay massive, slightly sticky; slightly plastic, weak roots nil, fine tubular pores; gradual smooth noundary. pH 6.9 (wet), 6.9 (dry). Cg_2; 26-45 cm; Dark grey 2.5 Y 4/6 moist dark grey 2.5 Y 3/0 dry; few fine distinct mottles; clay massive, sticky plastic; strong; roots nil; irregular pores diffuse wavy boundary. pH 7.1 (wet), 7.3 (dry). C_3; 45-59 cm; Black 2.5 Y N/2 moist and very dark greyish brown 2.5 Y 3/2 dry; clay, massive, sticky; plastic, strong	Ap; 0-26 cm Dark brown 10 YR 3/3 wet and brown 10 YR dry sandy clay loam, granular many fine roots, tubular pores smooth boundary pH 5.7 (wet) 5.3 (dry). Ac; 26-47 cm. Light yellowish brown 10 YR 6/4 wet and brownish yellow 10 YR 6/6 dry, sandy clay loam, fine granular reddish yellow streaks and mottles diffuse boundary, pH 6.9 (wet), 6.1 (dry). C_1; 47-76 cm. Pale brown 10 YR 6/3 wet and light yellowish brown 10 YR 6/4 dry sandy clay loam, mang tubular pores, reddish yellow streaks and mottles smooth boundary pH 6.7 (wet), 6.0 (dry). Cg_1; 76-100 cm light brownish grey 10 YR 6/2 wet and pale brown 10 YR 6/3 dry; sandy clayloam reddish yellow streaks and mottles, fine granular fine tubular pores, diffuse boundary. pH 6.4 (wet), 5.8 (dry). Cg_2; 100-150 cm light brownish gray 10 YR 6/2 wet and pale brown 10 YR 6/3 dry. Sand, clay loam fine tubular pores fine granular, reddish brown streaks and mottles, diffuse boundary pH 4.8 (wet), 4.2 (dry).	Ap_1; 0-36 cm dark greyish brown 10 YR 4/2 moist and brown 10 YR 4/3 dry sandy clay loam, many fine tubular pores, many fine roots, diffuse boundary pH 4.9 (wet), 4.4 (dry). Ap_2; 36-72 Brown 10 YR 5/3 moist and yellowish brown 10 YR 5/4 when dry, Sandy clay loam reddish brown streaks and mottles, fine granular fine tubular pores, fine roots diffuse boundary pH 5.0 (wet), 5.0 (dry). Cg_1; 72-112 cm. Yellowsih brown 10 YR 5/4 moist and brownish yellow 10 YR 6/6 dry, sandy clay loam, reddish brown, streaks and mottles, fine tubular pores, fine granular, roots nil, diffuse boundary pH 5.0 (wet), 5.2 (dry). Cg_2; 112-150 cm. Yellowsih brown 10 YR 5/4 moist and light yellowish brown, 10 YR 6/4 dry, silty clay loam, tubular pores, fine granular reddish brown streaks and mottles; roots nil pH 5.0 (wet), 4.8 (dry).	Ap; 0-25 cm. Black 10 YR 2/1 moist and very dark grayish brown. 10 YR 3/1 dry clay loam, fine granular sticky, and plastic, tubular pores, few fivne roots, way boundary pH 7.8 (wet), 7.8 (dry). ACk; 25-49 cm Very dark gray to 10 YR 3/1 moist and very dark grayish brown 10 YR 3/2 dry, clay, very fine granular clay massive, sticky, plastic, fine tubular pores; lime ($CaCO_3$) concretious, few fine roots, smooth boundary pH 7.9 (wet), 7.7 9dry). C_1kc; 49-65 cm Very dark gray 10 YR 3/1 moist and very dark grayish brown 10 YR 3/2 dry, Clay, Clay massive, sticky, plastic, few fine pores, Co CO_3 can cretious diffuse smooth boundary roots nil. pH 7.9 (wet), 7.0 (dry). C_2kc; 65-88 cm very dark grayish brown in 10 Y R 3/2 wwet, clay, very clay massive, sticky plastic, fine few pores CaCO3 concretious; diffuse wavy boundary pH 7.9 (wet), 7.9 (dry). Cgk; 88-150 cm. Very dark grayish brown 10 YR 3/2 wet, clay, clay massive, sticky plastic fine pores, roots nil $CaCO_3$ concretions pH 8.3 (wet), 8.2 (dry).

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Table 2. (Contd....)

9	10	11	12
roots nil fine irregular pores, diffuse smooth boundary pH 7.2 (wet), 7.2 (dry). C_4; 59-84; Black 2.5 Y N/2 moist and very dark greyish brown 2.5 Y 3/2 dry; clay; massive; sticky, plastic strong roots nil, fine irregular pores, diffuse smooth boundary pH 7.3 (wet), 7.0 (dry). C_5; 84-126 cm; Block 2.5Y N/2 moist and very dark grey brown 2.5 Y 3/2 dry, clay, massive; sticky; plastic; strong; roots oil; fine irregular pores, diffuse smooth boundary. pH 7.4 (wet) 3.33 (dry).	Cg_3; 150 cm and below very dark grey 10 YR 3/1 wet and very black grayish brown 10 YR 3/2 when dry, clay loam fine tubular pores, roots nil, diffuse smooth boundary. pH 3.4 (wet), 2.85 (dry).		

4.3 Components of soil acidity in major wet lands

4.3.1 Active acidity

Table 3 gives the components of acidity in profile samples of major wet land rice soils of Kerala. The horizon samples from twelve locations of the State numbering seventy seven were subjected for evaluation of the active acidity and the data presented therein. The aqueous pH of the dry samples (1:1) is presented in Column 1 in the Table. A perusal of the data indicates the high degree of variability of active acidity in different pedons under investigation. Of all the pedons the *Kari* soil of Thakazhi and *Pokkali* soil of Njarakkal recorded the highest active acidity and the black soil of Chittoor was in the alkaline range. The dry pH of the surface horizons of all the pedons except those of Kattampally and Chittoor showed a pH less than 4.5. However intrapedon variation of pH of different horizons was very marked in *Karapadom* of Nedumudi, *Kayal* of D-Block, *Kaipad* of Pazhayangadi and Kattampally swamp. There was a constancy of pH in the subsurface horizons of Vellayani (lake), Karamana, *Pokkali, Kole*, Pattambi, Wyanad and Chittoor. The third layer (18-30cm) of *Kari* and the sixth layer (41-97cm) of *Kayal* recorded the lowest pH of 2.3 followed by the two surface horizons (0-8 cm and 8-20 cm) of *Pokkali* registering a pH of 2.6. However the inter horizonal variation was very marked in the pedon of *Kayal*, the range being 2.3 to 6.9.

The range and mean values of components of acidity in surface samples of the twelve wetlands are presented in Table 4. The data on statistical analysis revealed significant variation between wetlands for all components of acidity. In the case of surface samples, maximum mean dry soil pH was recorded by the Chittoor soils (6.99) where as the minimum was registered by the *Pokkali* soils (3.18) followed by *Kari* soils (3.20). Between locations within wetland, the maximum variation in pH was found in *Kayal* lands (3.3 units) and the minimum variation (0.8 unit) in Vellayani and *Kole* lands.

Table 3. Components of acidity in profile samples of major wetlands

Sl. No.	Location & depth (cm)	Active Acidity Dry pH 1 : 1 (H_2O)	Exch. acidity	Non-exch. acidity	Potential acidity
			cmol(+)/kg		
Vellayani - Tropic Fluvaquent					
1	0-11	3.8	1.10	15.90	17.0
2	11-16	4.1	0.60	18.40	19.0
3	16-28	4.0	0.90	12.10	13.0
4	28-40	4.5	0.25	6.80	7.0
5	40-56	4.9	0.30	17.70	18.0
6	56-82	4.7	0.50	6.50	7.0
7	82-150	4.6	0.79	10.31	11.0
8	150-172	4.8	0.40	12.60	13.0
9	172-200	4.8	0.50	18.50	19.0
	Mean	4.46	0.59	13.20	13.78
Karamana - Typic Tropaquent					
10	0-17	4.5	0.7	21.3	22.0
11	17-32	5.0	0.3	12.7	13.0
12	32-56	5.0	0.2	6.8	7.0
13	56-90	5.8	0.1	6.9	7.0
14	90-111	5.0	0.3	9.7	10.0
15	111-140	5.1	0.4	7.6	8.0
16	140-200	4.8	1.0	15.0	16.0
	Mean	5.0	0.43	11.43	11.86
Kari (Thakazhi) - Typic Sulfaquent					
17	0-12	3.0	16.1	41.9	58.0
18	12-18	3.7	4.1	33.9	38.0
19	18-30	2.3	87.9	77.1	165.0
20	30-54	2.6	20.7	17.3	38.0
21	54-134	2.5	36.6	48.1	85.0
	Mean	2.82	33.08	43.66	76.8
Karapadom (Nedumudi) - Aeric Tropaquept					
22	0-16	4.1	3.2	25.8	29.0
23	16-24	5.0	0.4	17.6	18.0
24	24-34	5.5	0.1	24.9	25.0
25	34-52	5.7	0.1	23.9	24.0
26	52-69	3.7	3.6	47.4	51.0
27	69-164	2.6	34.4	43.6	78.0
	Mean	4.43	6.97	30.5	37.5

Contd...

Table 3. Contd...

Sl. No.	Location & depth (cm)	Active acidity Dry pH 1 : 1 (H_2O)	Exch. acidity	Non-exch. acidity	Potential acidity
			cmol(+)/kg		
Kayal (D Block) - Typic Hydraquent					
28	0-10	3.8	2.3	27.7	30.0
29	10-18	4.3	0.5	22.5	23.0
30	18-22	6.9	0.2	9.8	11.0
31	22-33	6.8	0.1	10.9	11.0
32	33-41	3.8	15.0	5.0	20.0
33	41-97	2.3	53.1	34.1	87.2
34	97-103	3.1	14.5	62.5	77.0
35	103-151	3.0	13.3	55.7	69.0
	Mean	4.25	12.37	28.52	41.02
Pokkali (Njarakkal) - Sulfic Tropaquept					
36	0-8	2.6	9.8	85.2	95.0
37	8-20	2.6	33.1	43.9	77.0
38	20-35	2.8	27.6	42.4	70.0
39	35-75	2.8	10.5	21.5	32.0
40	75-110	2.8	16.1	9.9	26.0
41	110 & below	2.9	13.7	15.3	29.0
	Mean	2.75	18.46	36.36	54.83
Kole (Anthikkad) - Typic Tropaquept					
42	0-10	4.0	4.0	30.0	34.0
43	10-20	4.2	3.4	26.6	30.0
44	20-30	4.2	3.1	18.9	22.0
45	30-40	4.1	2.9	15.1	18.0
46	40-50	4.1	2.1	13.9	16.0
47	50-60	4.1	3.0	13.0	16.0
48	60-70	3.9	14.0	35.9	30.0
49	70-100	3.2	9.3	32.7	42.0
	Mean	3.97	5.22	23.26	26.0
Kaipad - (Pazhayangadi) - Tropic Fluvaquent					
65	0-9	4.5	0.1	15.9	16.0
66	9-17	5.9	0.2	6.8	7.0
67	17-26	6.9	0.1	9.9	10.0
68	26-45	7.3	0.1	9.9	10.0
69	45-59	7.2	0.1	10.95	11.0
70	59-84	7.0	0.2	21.8	22.0
71	84-126	3.3	3.0	6.0	9.0
	Mean	6.02	0.54	11.61	12.14

Contd...

Table 3. Contd...

Sl. No.	Location & depth (cm)	Active acidity Dry pH 1 : 1 (H_2O)	Exch. acidity	Non-exch. acidity	Potential acidity
			cmol(+)/kg		
Pattambi - Aeric Kandiaqult					
50	0-20	4.5	1.0	19.0	20.0
51	20-30	4.5	0.4	18.6	19.0
52	30-46	5.1	0.1	10.9	11.0
53	46-56	5.1	0.1	11.9	12.0
54	56-89	5.2	0.1	6.9	7.0
55	89 & below	5.2	0.1	5.9	6.0
	Mean	4.93	0.3	12.2	12.5
Kattampally - Tropic Fluvaquent					
72	0-26	5.3	0.05	5.95	6.0
73	26-47	6.1	0.05	9.95	1.0
74	47-76	6.0	0.1	8.9	9.0
75	76-100	5.8	0.05	12.95	13.0
76	100-150	4.2	0.9	17.1	18.0
77	150 & below	2.8	22.0	10.0	32.0
	Mean	5.03	3.86	10.81	13.17
Wyanad - Typic Tropaquent					
61	0-36	4.4	0.8	14.2	14.0
62	36-72	5.0	0.7	55.3	56.0
63	72-112	5.2	0.4	11.6	12.0
64	112-150	4.8	0.3	2.7	3.0
	Mean	4.85	0.55	20.95	21.25
Chittoor - Petro Calcic Calciustert					
56	0-25	7.8	0.1	11.9	12.0
57	25-49	7.7	0.1	10.9	11.0
58	49-65	7.0	0.1	26.9	27.0
59	65-88	7.9	0.05	20.95	21.0
60	88-150	8.2	0.1	13.9	14.0
	Mean	7.72	0.09	16.91	17.0

Table 4. Components of acidity in surface soil samples of major wet lands

Name of wet land		Active acidity dry pH 1:1 (H_2O)	Exchange acidity	Non exchange acidity	Potential acidity
			├────	cmol(+)/kg	────┤
L1	Vellayani	4.0 - 4.8 (4.35)	0.6 - 3.7 (1.580)	8.1 - 31.3 (17.42)	7.0 - 35.0 (19.00)
L2	Karamana	4.8 - 5.8 (5.28)	0.3 - 0.7 (0.409)	7.4 - 17.3 (13.59)	7.0 - 35.0 (13.80)
L3	*Kari*	2.2 - 4.2 (3.20)	1.2 - 53.9 (16.40)	13.0 - 263.6 (113.65)	15.0 - 317.5 (129.95)
L4	*Karapadom*	3.5 - 5.0 (4.31)	0.3 - 8.8 (3.310)	16.7 - 60.8 (32.59)	21.0 - 68.0 (32.30)
L5	*Kayal*	3.1 - 6.4 (4.44)	0.2 - 12.8 (4.930)	15.8 - 59.2 (36.67)	16.0 - 72.0 (41.60)
L6	*Pokkali*	2.8 - 3.8 (3.18)	5.0 - 16.7 (8.030)	22.6 - 48.2 (33.17)	31.0 - 55.0 (41.20)
L7	*Kole*	4.2 - 5.0 (4.63)	0.6 - 2.8 (1.380)	13.6 - 40.0 (28.62)	15.0 - 41.0 (30.00)
L8	*Kaipad*	4.0 - 6.0 (5.27)	0.15 - 5.1 (0.695)	1.8 - 34.9 (15.00)	2.0 - 30.0 (14.70)
L9	Pattambi	4.5 - 5.6 (4.93)	0.2 - 1.0 (0.490)	9.8 - 27.3 (18.81)	10.0 - 28.0 (19.30)
L10	Kattampally	4.6 - 6.1 (5.46)	0.15 - 0.20 (0.165)	10.85 - 24.8 (19.63)	11.0 - 25.0 (19.30)
L11	Wyanad	4.2 - 5.4 (4.83)	0.15 - 0.6 (0.340)	5.8 - 19.5 (12.86)	6.0 - 20.0 (13.20)
L12	Chittoor	5.7 - 7.8 (6.99)	0.10 - 0.2 (0.125)	4.4 - 25.9 (19.13)	4.6 - 28.0 (19.26)
	CD	0.5043	4.785	25.464	29.600
	SE	0.1805	1.713	9.116	10.599

Values in paranthesis indicate mean values

4.3.2 Exchange acidity

Exchange acidity (Table 3) was <1.0 cmol(+)/kg in all the horizons of Vellayani, Karamana, Pattambi, Wyanad and Chittoor. In Chittoor profile, the values for this component were very low (0.1 - 0.05 cmol(+)/kg) when compared to other pedons and the values were more or less uniform throughout the pedon. Maximum exchange acidity was noticed in the 18-30 cm horizon of *Kari* profile (87.9 cmol (+)/kg). In *Kari* and *Pokkali* pedons, throughout the profile a high exchange acidity was noticed. In *Karapadom*, *Kole*, *Kaipad* and Kattampally pedons, the exchange acidity was found to be high in lower layers. But in *Kayal* profile this component was found to be increasing from 33 cm to lower layers. The intra pedon variation was minimum in Vellayani, Karamana, Pattambi, Wyanad and Chittoor whereas it was maximum in *Kari*, *Karapadom*, *Kayal*, *Pokkali*, Kattampally, *Kole* and *Kaipad.*

Comparing the surface samples (Table 4), it was found that the maximum mean exchange acidity was noticed in *Kari* samples (16.4 cmols) followed by *Pokkali* soils (8.03 cmols) and the minimum in Chittoor soils (0.125 cmols). The soils that gave exchange acidity values <1 .0 cmols were *Kaipad* (0.695 cmols), Pattambi (0.49 cmols), Karamana (0.409 cmols), Wyanad (0.34), Kattampally (0.165) and Chittoor (0.125). The minimum exchange acidity was noticed in Chittoor soils.

4.3.3 Non exchange acidity

From this study (Table 3) we could infer that major part of potential acidity is constituted by non exchange acidity. As per Table 3, inter horizonal variation in non exchangeable acidity was high in all profiles. The maximum non exchange acidity was recorded in the 0-8 cm horizon of *Pokkali* profile followed by the 18-30 cm layer of *Kari* profile. The maximum mean value for this component was noticed in the profile of *Kari* (43.66 cmols) followed by *Pokkali* pedon (36.36 cmols) and the mean minimum in Kattampally profile (10.81 cmols). The profiles Vellayani, Karamana, Pattambi, *Kaipad*, Chittoor and Kattampally registered mean values of < 20.0 cmols.

With regard to surface samples (Table 4), all the wetlands differed significantly. Highest mean and lowest mean were recorded by *Kari* soil (113.65 cmols) and Wyanad soil (12.86 cmols) respectively. Within wetland, variation was found to be high in all the soils studied. In wetlands of Vellayani, Karamana, *Kaipad*, Pattambi, Kattampally, Wyanad and Chittoor the mean value for this component was < 20.0 cmols.

4.3.4 Potential acidity

A scan through the observations revealed that the intrapedon variation for potential acidity was high for all wetlands (Table 3). The highest value obtained for this component was 165 cmols for the 18-30 cm layer of *Kari* soil. Of this 46.73 per cent was non exchangeable. In Vellayani, *Karapadom*, *Kayal*, *Kole* and Kattampally the lowest horizons registered the highest potential acidity. *Pokkali* profile had maximum potential acidity in the surface layers (95 and 77 cmols). More than 70 per cent of this component was non exchangeable in these layers. In Wyanad, the second horizon recorded 56 cmols potential acidity, but out of which 55.3 cmols was non exchangeable. The mean values of potential acidity for Vellayani, Karamana, Pattambi, Chittoor, *Kaipad* and Kattampally profiles were <20.0 cmols. The maximum mean value (76.8 cmols) was recorded by *Kari* profile followed by *Pokkali* profile (54.83 cmols) and the minimum mean (12.14 cmols) by *Kaipad* profile.

Data of surface samples on statistical analysis revealed significant difference between wetlands with respect to potential acidity. The highest mean value was recorded by *Kari* soils (129.95 cmols) and the lowest mean by Wyanad soils (13.2 cmols). The highest variation within wetland was also observed in *Kari* surface samples and the lowest variation in Kattampally and Wyanad soils.

4.4 Acidity generating factors

The acidity generating factors in the profile samples of wet lands are presented in Table 5 and that of surface samples of twelve wet lands in Table 6.

4.4.1 Exchangeable aluminium

In Vellayani pedon, the exchangeable aluminium ranged between 0.01 to 0.89 cmols. Here high values were observed in the surface horizons but towards lower depths it decreased drastically. In Karamana profile it ranged from 0.08 to 0.45 cmols. In the lowest horizon maximum exchangeable aluminium was noticed. In *Kari* soil of Thakazhi the highest value of 23.58 cmols was recorded by the third layer (18-30 cm) and the lowest value of 2.94 in the layer just above this. Inter horizonal variation was very high in *Kari* soil with respect to exchangeable aluminium. The profile from *Karapadom* soil also showed wide variation in exchangeable aluminium content ranging from 0.05 cmols to 8.83 cmols. The exchangeable aluminium concentration in the case of *Kayal* land of D-Block was maximum in the sixth layer (14.57 cmols) which decreased to 3.71 cmols in the lowest layer. The surface horizons of *Kayal* soil had comparatively lower concentration for this factor. In *Pokkali* pedon from Njarakkal, high exchangeable aluminium was noticed throughout the profile and the values ranged from 7.77 to 12.73 cmols. *Kole* lands of

Anthikkad had shown more or less uniform values ranging from 2.51 to 4.13 cmols Pattambi and Wyanad pedons registered only very low values for exchangeable aluminium. In *Kaipad* and Kattampally profiles the surface horizons contained only low amounts of exchangeable aluminium but the lowest layers recorded appreciable quantities. Eventhough *Kari* and *Pokkali* pedons registered high quantities of exchangeable aluminium, the intra pedon variation was prominent only in *Kari*. In *Kole* pedon also the interhorizonal variation was not at all conspicuous. The maximum mean for this factor was observed in Thakazhi profile (11.75 cmols) representing *Kari* soil followed by Njarakkal pedon (10.37 cmols) representing *Pokkali* and the minimum mean (0.17 cmols) was registered by Pattambi profile. In the profile from Chittoor only traces of exchangeable aluminium and that too in the undetectable range were observed. By scanning the mean values of pedons we could group Vellayani, Karamana, Pattambi, Wyanad and *Kaipad* as soils having low exchangeable aluminium, apart from black soils of Chittoor.

Surface samples taken from radial distances of 5km around the profile pits had shown very low values (mean) ranging from 0.0 to 5.72 cmols. The highest value recorded was for *Kari* (5.72 cmols) followed by *Pokkali* (3.93 cmols), *Kayal* (2.93 cmols), *Karapadom* (1.99 cmols), Vellayani (1.11 cmols), *Kole* (0.82 cmols), *Kaipad* (0.48 cmols), Pattambi (0.35 cmols), Karamana (0.26 cmols), Wyanad (0.24 cmols) and Kattampally (0.13 cmols). Exchangeable aluminium content of Calciusterts of Chittoor was below the readable range.

4.4.2 Organic matter

In Vellayani pedon the surface and lower horizons had comparatively higher values for organic matter (Table 5). The range varied from 0.73 to 2.38

per cent. Organic matter of Karamana profile decreased drastically with depth from 2.06 per cent for the surface to 0.10 per cent for the lowest layer. *Kari* soils of Thakazhi recorded the highest organic matter content among the profiles studied ranging from 0.9 to 8.79 per cent. Here the organic matter content was low in the surface layer and maximum in the third layer (8.79 per cent). In the case of *Karapadom*, the organic matter content decreased gradually upto third layer and then registered an increase; the variation observed was from 1.75 to 4.49 per cent. *Kayal* lands of D-Block also had shown wide variation in organic matter content from 0.72 to 7.41 per cent. No definite pattern of accumulation could be observed here. *Pokkali* lands of Njarakkal showed a clear decline in organic matter content with depth ranging from 4.15 to 1.64 per cent. In *Kole* lands of Anthikkadu the values decreased gradually with depth upto the sixth layer and then increased subsequently to 4.17 per cent in the lower most layer. Distribution of organic matter in the profile of Pattambi also recorded a clear decrease with depth ranging from 0.17 and 1.93 per cent. The *Kaipad* profile from Pazhayangadi had values for organic matter content ranging from 0.28 to 1.21 per cent, the highest being on the surface. Kattampally profile recorded the highest organic matter content in the lowest layer (1.66 per cent) and the lowest content was recorded in the third layer (0.16 per cent). Profile taken from Wyanad showed a marked decrease in organic matter content with depth. The pedon from Chittoor also showed a decrease in organic matter content with depth, the highest being 1.79 per cent and lowest 0.26 per cent. Interhorizonal variation was high in all pedons. Comparing the means of organic matter we could observe that all profiles studied were rich in organic matter except Karamana, Pattambi, Chittoor, Wyanad, *Kaipad* and Kattampally which recorded low status.

Table 5. Soil acidity contributing factors in profile samples of major wetlands

Location & depth (cm)	Exch. Al. cmol(+)/kg	Org. matter %	Exch. H cmol(+)/kg	DTPA Fe ppm	DTPA Mn ppm	CEC cmol (+)/kg	Total soluble salts dSm^{-1}
L1 Vellayani							
0-11	0.77	2.16	0.33	256.0	13.8	12.0	0.1
11-16	0.89	1.58	0.073	313.4	27.2	11.9	0.1
16-28	0.59	0.95	0.31	194.4	13.6	5.6	<0.05
28-40	0.11	1.03	0.04	201.4	10.0	4.9	<0.05
40-56	0.16	0.73	0.14	88.0	15.2	5.2	<0.05
56-82	0.26	1.14	0.24	184.2	32.0	6.2	<0.05
82-150	0.06	2.38	0.63	274.8	19.8	7.0	0.1
150-172	0.01	1.16	0.39	248.4	32.2	9.4	0.25
172-200	0.01	1.86	0.49	337.4	37.8	12.6	0.6
Mean	0.32	1.44	0.29	233.11	22.4	8.31	0.15
L2 Karamana							
0-17	0.24	2.06	0.46	447.0	20.40	9.76	<0.05
17-32	0.14	2.01	0.16	265.8	28.40	14.5	<0.05
32-56	0.10	0.60	0.10	89.2	14.20	10.5	<0.05
56-90	0.08	0.46	0.02	59.6	28.40	5.9	<0.05
90-111	0.11	0.20	0.19	156.8	20.40	6.5	<0.05
111-140	0.17	0.20	0.23	200.6	19.80	3.2	<0.05
140-200	0.45	0.10	0.55	302.6	16.60	13.3	<0.05
Mean	0.18	0.80	0.24	217.37	21.17	9.09	<0.15
L3 *Kari* - (Thakazhi)							
0-12	9.10	5.43	7.0	247.8	31.2	28.9	2.8
12-18	2.94	4.34	1.16	422.6	17.2	20.3	1.0
18-30	23.58	8.79	64.32	201.6	32.2	33.5	8.0
30-54	9.44	0.90	11.26	230.2	34.8	7.9	3.1
54-134	13.68	4.55	22.92	259.4	80.6	18.1	4.8
Mean	11.75	4.80	21.33	272.22	39.2	21.74	3.94
L4 *Karapadam* - (Nedumudi)							
0-16	2.84	3.04	0.36	380.4	25.8	15.8	0.2
16-24	0.10	1.86	0.30	227.6	39.0	13.9	0.1
24-34	0.05	1.75	0.05	169.2	38.6	17.1	0.1
34-52	0.06	4.13	0.04	98.0	51.0	18.3	0.3
52-69	1.52	4.49	2.08	209.2	45.6	23.0	2.3
69-164	8.83	4.33	25.57	167.8	299.0	29.2	6.0
Mean	2.23	3.26	4.73	208.7	83.17	19.55	1.5

Contd...

Table 5. (Contd....)

Location & depth (cm)	Exch. Al. cmol(+)/kg	Org. matter %	Exch. H cmol(+)/kg	DTPA Fe ppm	DTPA Mn ppm	CEC cmol (+)/kg	Total soluble salts dSm^{-1}
L5 *Kayal* - (D block)							
0-10	1.37	3.38	0.93	264.4	46.4	15.9	1.6
10-18	0.18	1.34	0.32	388.4	25.0	14.0	0.9
18-22	0.03	1.88	0.17	131.4	39.6	13.7	1.3
22.33	0.02	0.72	0.08	29.0	247.0	12.5	0.8
33-41	0.02	3.48	0.08	169.2	184.6	15.2	0.6
41-97	14.57	7.41	38.53	284.8	160.4	31.7	8.3
97-103	3.11	5.86	11.39	300.0	203.8	38.8	6.0
103-151	3.71	5.97	9.59	136.2	27.2	37.3	6.0
Mean	2.81	3.75	7.64	212.92	116.75	22.38	3.19
L6 *Pokkali* - (Njarakkal)							
0-8	8.82	4.15	0.98	302.2	41.0	24.2	12.1
8-20	13.5	3.05	19.6	256.6	40.8	22.2	9.1
20-35	12.73	3.0	14.87	225.4	30.61	19.8	6.5
35-75	10.34	2.33	0.16	203.0	23.0	10.2	4.3
4.75-110	9.08	1.74	9.08	284.0	28.4	9.3	4.5
110 & below	7.77	1.64	5.93	145.0	58.8	8.1	4.5
Mean	10.37	2.65	8.44	236.03	37.10	15.63	6.83
L7 *Kole* - (Anthikkad)							
0-10	3.12	2.83	0.88	121.4	16.8	15.1	0.3
10-20	2.55	0.91	0.85	58.8	8.2	12.3	0.07
20-30	2.52	0.86	0.58	48.8	14.6	9.55	0.07
30-40	2.52	0.86	0.38	43.8	8.4	8.3	<0.05
40-50	2.58	0.78	0.32	146.4	41.0	8.4	<0.05
50-60	2.51	0.71	0.49	160.8	20.8	7.7	<0.05
60-70	3.43	2.07	0.67	424.4	8.0	11.8	0.1
70-100	4.13	4.17	5.17	331.6	9.2	20.2	0.8
Mean	2.92	1.65	1.17	167.0	15.87	11.67	0.18
L8 Pattambi							
0-20	0.76	1.93	0.24	347.4	31.0	6.6	<0.05
20-30	0.14	1.40	0.26	201.8	22.2	6.8	<0.05
30-46	0.04	0.86	0.06	64.4	14.4	5.4	<0.05
46-56	0.04	0.36	0.06	65.4	10.6	4.9	<0.05
56-89	0.04	0.34	0.06	110.4	15.0	4.7	<0.05
89 & below	0.04	0.17	0.06	134.6	16.0	4.0	<0.05
Mean	0.17	0.84	0.12	154.0	18.2	5.4	<0.05

Contd...

Table 5. (Contd...)

Location & depth (cm)	Exch. Al . cmol(+)/kg	Org. matter %	Exch. H cmol(+)/kg	DTPA Fe ppm	DTPA Mn ppm	CEC cmol (+)/kg	Total soluble salts dSm^{-1}
L9 Chittoor							
0-25	traces	1.79	0.10	77.4	22.4	22.08	<0.05
25-49	traces	0.84	0.10	72.8	16.0	22.08	<0.05
49-65	traces	0.69	0.10	47.4	11.8	27.48	<0.05
65-88	traces	0.29	0.05	90.2	30.8	23.88	<0.05
88-150	traces	0.26	0.10	95.0	33.6	28.68	<0.05
Mean		0.77	0.09	76.56	22.92	24.84	<0.05
L10 Wyanad							
0-36	0.34	1.16	0.46	214.2	16.4	5.7	<0.05
36-72	0.44	0.55	0.26	231.0	13.8	5.2	<0.05
72-112	0.10	0.40	0.30	66.6	14.2	4.2	<0.05
112-150	0.08	0.31	0.22	93.6	14.2	4.7	<0.05
Mean	0.24	0.61	0.31	151.35	14.65	4.95	<0.05
L11 *Kaipad* - (Pazhayangadi)							
0-9	0.06	1.21	0.03	33.0	24.8	9.1	7.2
9-17	0.02	0.91	0.18	101.8	9.2	10.4	4.9
17-26	0.02	0.57	0.08	78.6	16.8	19.0	3.8
26-45	0.02	0.52	0.08	80.0	11.6	16.04	2.8
45-59	0.02	0.28	0.03	61.6	17.2	12.1	3.3
59-84	0.02	0.57	0.18	71.6	18.8	15.8	4.4
84-126	1.26	0.86	1.74	71.6	18.8	17.7	5.5
Mean	0.20	0.70	0.33	71.17	16.74	14.30	4.56
L12 Kattampally							
0-26	0.02	0.90	0.03	92.6	26.2	7.0	<0.05
26-47	0.02	0.29	0.03	36.4	13.2	5.8	<0.05
47-76	0.04	0.16	0.06	39.2	10.6	6.8	<0.05
76-100	0.02	0.45	0.03	63.4	13.8	6.7	<0.05
100-150	0.46	0.29	0.44	167.2	19.2	8.9	0.075
150 & below	10.05	1.66	11.95	246.6	10.4	8.6	2.4
Mean	1.77	0.62	2.09	107.56	15.56	7.3	0.44

Table 6. Acidity contributing factors in surface samples of wetlands

Name of wetlands	Exch. Al. cmol(+)/kg	Org. matter %	Exch. H cmol(+)/kg	DTPA Fe (ppm)	DTPA Mn (ppm)	CEC cmol(+)/kg	EC dSm^{-1}	Clay (%)	Total S (ppm)	Avail. S (ppm)	Active Fe (ppm)	Active Mn (ppm)
Vellayani	1.11	2.77	0.46	431.68	33.60	7.860	0.175	60.90	1823.51	1496.50	4761.66	276.66
Karamana	0.26	1.77	0.15	238.30	20.86	7.126	0.070	35.98	1011.94	590.98	2815.00	115.00
Kari	5.72	10.55	10.67	2399.66	31.52	40.990	3.005	66.43	12914.64	4026.36	3948.33	68.33
Karapadam	1.99	4.66	1.31	416.08	27.44	13.730	0.840	55.86	4517.46	2517.00	3743.33	153.33
Kayal	2.93	5.00	1.99	381.60	31.66	19.970	1.125	66.43	8078.29	1249.99	2918.33	293.33
Pokkali	3.93	3.02	4.09	455.00	13.56	23.830	6.910	63.91	15359.36	3260.92	2831.66	151.66
Kole	0.82	2.00	0.56	299.83	46.36	11.710	0.170	61.17	7759.41	1937.22	871.66	440.00
Pattambi	0.35	1.061	0.13	291.80	30.60	6.360	0.065	49.89	891.13	365.5	1020.00	311.66
Chittoor	0.0	2.604	0.125	263.14	18.80	21.730	0.135	36.46	10416.75	204.00	4275.00	406.66
Wyanad	0.24	1.832	0.125	88.70	20.62	6.620	0.050	29.43	647.15	216.75	2865.00	396.66
Kaipad	0.48	0.288	0.21	163.60	4.64	4.260	0.570	36.20	6483.91	420.75	1711.66	306.66
Kattampally	0.13	0.636	0.03	143.20	36.36	7.300	0.205	30.85	6909.06	467.5	1825.00	490.00
CD	1.6880	1.7326	3.35	950.9413	NS	7.66	0.813	29.24	5463.08	1379.78	2432.99	337.28
SE	0.6043	0.6023	1.19	340.4643		2.74	0.291	10.02	1871.60	472.69	833.52	115.55

In the case of surface samples of wet lands, the highest mean value for organic matter was noted in the *Kari* soils (10.55%) followed by *Kayal* (5.0%) and *Karapadom* (4.6%). Data on statistical analysis revealed significant difference between wet lands.

4.4.3 Exchangeable hydrogen

The concentration of exchangeable hydrogen taken as an index of proton source and thus hydrogen ion activity, is presented in Table 5 Column 3. In the case of pedon from Vellayani all the values recorded were less than 1.0 cmol. Profile from Karamana also showed more or less similar trend as that of Vellayani and the higher values recorded were in the first (0.46 cmols) and last (0.55 cmols) horizons respectively. Sulfaquents of *Kari* lands recorded the highest exchangeable hydrogen content (64.32 cmols) among the profiles investigated. The value increased with depth upto the third layer and then decreased to 22.92 cmols in the lowest layer. In the profiles representing *Karapadom*, *Kole*, *Kaipad* and Kattampally the exchangeable hydrogen increased with depth. Among these, the Kattampally profile recorded the highest value of 11.95 cmols. Contrary to this, the profile sample from Wyanad registered a decrease in exchangeable hydrogen content with depth, the highest value recorded was 0.46 cmols in the first layer. *Kayal* lands of D-Block registered comparatively higher value (38.53 cmols) in the sixth layer which decreased to 9.59 cmols in the lowest layer. Surface horizons in this profile generally had lower values ranging from 0.08 to 0.93 cmols. *Pokkali* profile of Njarakkal registered the highest values in the second horizon (19.6 cmols) followed by third horizon (14.87 cmols). The value decreased to 5.93 cmols in the lowest layer. In the case of Pattambi profile, the values for exchangeable hydrogen was highest in the second layer (0.26 cmols) followed by 0.24 cmols for the surface layer. Values recorded for the lowest layers were negligible.

Values for exchangeable hydrogen was very low for the profile from Chittoor and it decreased with depth. The values ranged from 0.05 to 0.1 cmols. The interhorizonal variation was high in the profiles of *Kari*, *Karapadom*, *Kayal* and *Pokkali*. The mean values for exchangeable hydrogen was below 1.0 cmols in the pedons of Vellayani, Karamana, Pattambi, *Kaipad* and Chittoor. The highest exchangeable hydrogen was noticed in the *Kari* profile followed by *Pokkali* pedon.

Exchangeable hydrogen content of surface samples collected from different locations indicated wide variations (Table 6). Maximum mean values were registered by samples taken from *Kari* lands (10.67 cmols) followed by *Pokkali* (4.09 cmols), *Kayal* (1.99 cmols), *Karapadom* (1.31 cmols), *Kole* (0.56 cmols) and Vellayani (0.46 cmols). In the case of other locations values recorded were extremely low.

4.4.4 DTPA extractable iron

Iron content of the profile and surface samples as indicated by DTPA extractable - Fe is presented in Table 5 and 6. The data indicated wide variation in DTPA extractable iron within the profiles studied. Profile from Vellayani representing Tropic Fluvaquent registered the highest iron content in the lowest layer of the profile (337.4 ppm). First, second and seventh layers also had comparatively higher values ie. 256, 313 and 274 ppm respectively. In the case of Tropaquents of Karamana highest value was observed in the surface (447 ppm) followed by the lowest layer (302. 6 ppm) and second layer (265.8 ppm). *Kari* soils represented by Thakazhi pedon registered the highest iron content in the second layer (422.6 ppm) and the lowest (201.6 ppm) in the third layer. Samples of *Karapadom* soils from Nedumudi showed a decrease in iron content with depth upto the fourth layer which increased subsequently in the fifth layer and decreased further in last layer. The range of variation was from 98.0 to 380 ppm.

The hydraquents of D-Block reported highest iron content in the second layer (388 ppm) and the lowest value was reported in the fourth layer (29.0 ppm) *Pokkali* pedon of Njarakkal showed a decrease in iron content with depth upto the fourth layer and increased subsequently with a decrease towards the last layer, the values ranged from 145.0 to 302.2 ppm. The profile from Anthikkad representing *Kole* lands showed comparatively lowest values for the surface layers but the last two layers registered high values (424 and 331 ppm). The Kandiaqult of Pattambi registered a decrease in the iron content with depth for the first three layers but the values increased subsequently for the last three layers. The surface two layers registered comparatively higher iron content. Iron content of the profile ranged from 64.4 to 347.4 ppm *Kaipad* pedon from Pazhayangadi recorded low values throughout the profile ranging from 33 to 101.8 ppm. Much variation has not been observed for the last five layers. Fluvaquent of Kattampally showed highest iron content in the lowest layer (246 ppm). Surface soil recorded 92 ppm of DTPA iron which decreased subsequently with depth upto the third layer. Again it increased to 63.4 and 167.2 ppm in the fourth and fifth layers respectively. The highest iron content in profile of Wyanad was in the second layer. Surface horizon showed 214.2 ppm of DTPA iron followed by 66.6 ppm in the third and 93.6 ppm in the last layer. Petrocalcic Calciusterts of Chittoor registered more or less uniform values except for the third layer. DTPA - Fe content ranged for the whole profile from 47.4 to 95.0 ppm. Comparing the means of profiles we could find that *Kari*, *Pokkali*, Vellayani, Karamana, *Kayal* and *Karapadom* recorded high DTPA extractable iron.

The surface samples also showed considerable variation in this factor. The highest value among these samples were recorded by *Kari* lands (2399 ppm) followed by *Pokkali* (455 ppm), Vellayani (431 ppm), *Karapadom* (416 ppm), *Kayal* (381 ppm), Pattambi (291 ppm), Chittoor (263 ppm), Karamana (238 ppm), *Kaipad* (163 ppm), Kattampally (43 ppm) and Wyanad (88 ppm).

4.4.5 DTPA extractable Manganese

Interhorizonal variation in DTPA extractable manganese was not prominent in most of the profiles except *Kari*, *Karapadom* and *Kayal*. In *Kari* and *Karapadom* profiles the lowest horizons registered higher available manganese while in *Kayal* pedon the middle horizons recorded higher values. The maximum manganese (299 ppm) availability was noticed in the lower most layer of *Karapadom* profile from Nedumudi and the minimum (8.0 ppm) in the (60-70 cm) horizon of *Kole* profile from Anthikkad. Considering the mean values of profiles the *Kayal* pedon from D-Block ranked first recording a value of 116 ppm manganese followed by Karapadaom (83 ppm) and *Kari* (39 ppm). All other profiles registered lower values for DTPA extractable manganese.

With respect to manganese availability of surface samples there was no significant variation between wetlands. The highest value was recorded by *Kole* lands (46.36 ppm) and the lowest by *Kaipad* lands (4.64 ppm).

4.4.6 Cation exchange capacity

Vellayani profile representing the Tropic Fluvaquents showed wide variation in cation exchange capacity within the profile ranging from 4.9 cmols to 12.6 cmols. (Table 5). The surface two horizons as well as the lowest horizon registered comparatively high values for cation exchange capacity. In the Typic Tropaquents of Karamana also the same trend could be observed. The values ranged between 3.2 cmols to 14.5 cmols.

Kari profile from Thakazhi (Sulphaqents) recorded wide variation in CEC within the profile, the values ranged from 7.9 cmols to 33.5 cmols. The surface three horizons registered high values followed by a sudden decrease in the fourth layer (7.9 cmols) and then increased to 18.1 cmols in the lower most horizon. In *Karapadom* proffile comparatively high cation exchange capacity values were registered throughout the profile. The highest value (29.2 cmols) was recorded in the lower most horizon and the lowest (13.9 cmols) in the second horizon . Hydraquents of *Kayal* represented by D-Block pedon showed a decrease in cation exchange capacity from surface to the fourth layer and then increased drastically to 38.8 cmols in the seventh layer. The lower most three horizons registered high exchange values ranging from 31.7 cmols to 38.8 cmols. *Pokkali* lands represented by Njarakkal profile had shown a gradual decrease in CEC with depth. The highest CEC (24.2 cmols) was observed in the surface horizon and the lowest (8.1 cmols) in the lower most horizon . In the *Kole* profile cation exchange capacity values ranged from 7.7 cmols to 20.2 cmols. The surface as well as lowest horizons recorded comparatively higher values for cation exchange capacity and the highest value being observed in the lower most horizon (20.2 cmols). Pattambi pedon representing Aeric Kandiaqult registered low values for this property and the values ranged from 4.0 cmols to 6.8 cmols. The CEC decreased from surface to lower layers. The Pazhayangadi profile representing *Kaipad* lands registered increase in CEC with depth upto third layer then it decreased and then increased and reached 17.7 cmols in the lower most horizon. The lowest value (9.1 cmols) was observed in the surface layer and the highest (19.0 cmols) in the third layer. The cation exchange capacity of the Kattampally pedon was low and the values ranged from 5.8 to 8.9 cmols. Wyanad profile also registered low values ranging from 4.2 to 5.7 cmols. The Petrocalcic Calciusterts of Chittoor registered higher values for cation exchange capacity throughout the profile ranging from 22.08 cmols to 28.68 cmols.

The cation exchange capacity values representing the surface samples of major wetlands showed wide variation. The highest mean CEC (40.99 cmols) was found in *Kari* samples and lowest mean (4.26 cmols) in *Kaipad* soils. The soils differed significantly with respect to this factor.

4.4.7 Total soluble salts

As a measure of total soluble salts, electrical conductivity (dSm^{-1}) was taken and presented in Table 5. Vellayani and Karamana profiles contained only very little soluble salts. In *Kari* profile 18-30 cm horizon recorded an electrical conductivity of 8 dSm^{-1}. In *Karapadom* soils the lowest horizon (69-164 cm) recorded highest soluble salts (6 dSm^{-1}). In *Kayal* pedon the lower horizons had more soluble salts than the surface layers. The 41-97 cm layer of *Kayal* profile recorded high electrical conductivity (8.3 dSm^{-1}). In the *Pokkali* profile from Njarakkal the surface layers (0-8 cm and 8-20 cm) recorded, high soluble salt concentrations (12.1 and 9.1 dSm^{-1}). In Pattambi, Wyanad and Chittoor profiles only very little soluble salts was noticed (< 0.05 dSm^{-1}). In *Kaipad* pedon, the high electrical conductivity (7.2 dSm^{-1}) was noticed in the first horizon (0-9 cm). The horizons which recorded high soluble salts also registered high acidity in the profiles studied.

Analysis of the surface samples showed significant variation between wetlands studied. The highest mean soluble salts was recorded by *Pokkali* soils (6.2 dSm^{-1}) which is highly above the tolerance limit for rice.

4.4.8 Content and nature of clay

All the wetlands contained more than 35 per cent clay except Kattampally and Wyanad soils. (Table 6). The highest mean clay content (66.43 per cent) was observed in the surface samples of *Kari* soil and the lowest (29.4 per cent) in Wyanad soils. Clay content of wetlands differed significantly from one another.

X-ray diffraction data of the clay samples of the twelve wetlands is presented in Table 7 and figures 2 to 13. From the XRD analysis we could observe that in all the wet lands of Kerala Kaolinite was the predominant clay mineral except Chittoor where smectite was found to be the major clay mineral.

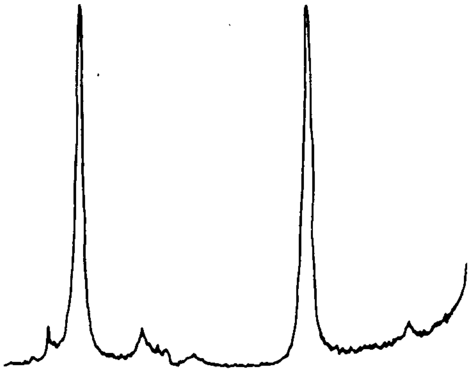

Fig. 2. X-ray diffraction pattern of the <2 μm fraction of surface samples of major wetlands of Kerala – VELLAYANI

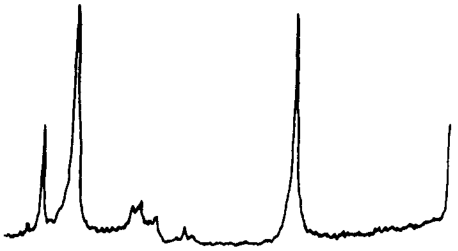

Fig. 3. X-ray diffraction pattern of the <2 μm fraction of surface samples of major wetlands of Kerala – KARAMANA

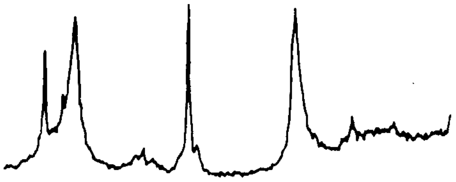

Fig. 4. X-ray diffraction pattern of the <2 μm fraction of surface samples of major wetlands of Kerala – *KARAPADOM*

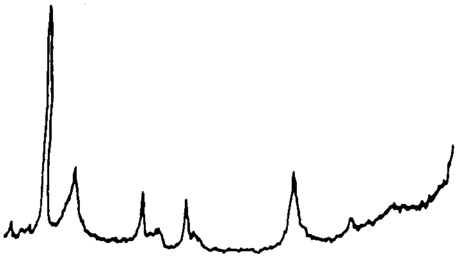

Fig. 5. X-ray diffraction pattern of the <2 μm fraction of surface samples of major wetlands of Kerala – *KARI*

Fig. 6. X-ray diffraction pattern of the <2 µm fraction of surface samples of major wetlands of Kerala – *KAYAL*

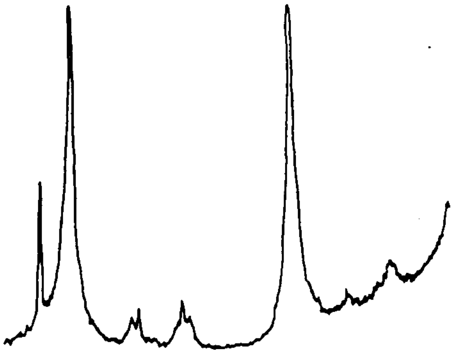

Fig. 7. X-ray diffraction pattern of the <2 µm fraction of surface samples of major wetlands of Kerala – *KOLE*

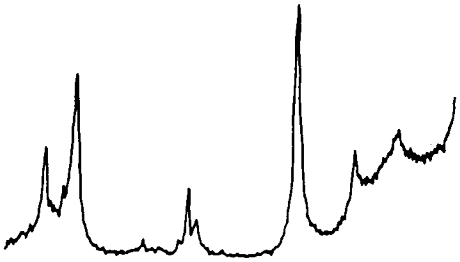

Fig. 8. X-ray diffraction pattern of the <2 µm fraction of surface samples of major wetlands of Kerala – *KAIPAD*

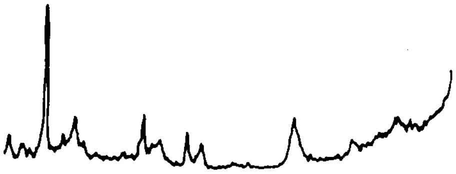

Fig. 9. X-ray diffraction pattern of the <2 µm fraction of surface samples of major wetlands of Kerala – *POKKALI*

Fig. 10. X-ray diffraction pattern of the <2 µm fraction of surface samples of major wetlands of Kerala – PATTAMBI

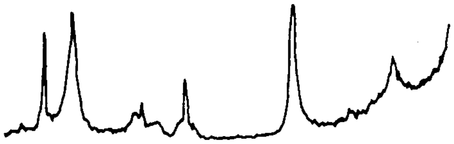

Fig. 11. X-ray diffraction pattern of the <2 µm fraction of surface samples of major wetlands of Kerala – KATTAMPALLY

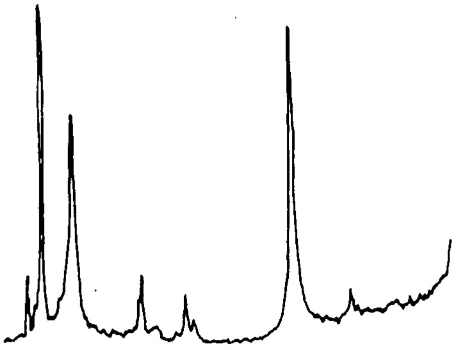

Fig. 12. X-ray diffraction pattern of the <2 μm fraction of surface samples of major wetlands of Kerala – WYANAD

Fig. 13. X-ray diffraction pattern of the <2 μm fraction of surface samples of major wetlands of Kerala – CHITTOOR

4.4.9 Total sulphur

Total sulphur in the surface samples of the wetlands showed wide variation. The highest mean value (15359 ppm) was observed in the *Pokkali* surface samples followed by *Kari* (12914 ppm). The lowest total sulphur was recorded in the Wyanad surface samples (647 ppm).

4.4.10 Available sulphur

The surface samples of wetlands varied significantly with respect to available sulphur content. The highest available sulphur was noticed in *Kari* samples (4026 ppm) followed by *Pokkali* soils (3260 ppm). The lowest available sulphur was noticed in Chittoor samples (204 ppm).

4.4.11 Active iron

The maximum active iron content (4761 ppm) was observed in the surface samples of Vellayani and the minimum was recorded by *Kole* soils (871 ppm). Active iron content varied significantly between wetlands studied.

Table 7. XRD data of fine clay fraction of major wetlands

Sl. No.	Name of wetland	d spacing A° intensity	Relative intensity	Mineral identified
1	Vellayani	7.3296	10	Kaolinite
		3.3274	1.3	Quartz
		4.1405	1.2	Goethite
		14.320	1.4	Chlorite/Vermiculite
2	Karamana	7.3918	6.8	Kaolinite
		3.3332	3.4	Quartz
		4.1463	1.2	Goethite
		4.8278	0.7	Gibbsite
		13.0995	0.8	Chlorite/Vermiculite
3	*Kari*	7.3161	2.5	Kaolinite
		4.2121	1.9	Quartz
		4.7916	1.7	Gibbsite
		4.9287	0.8	Illite
		3.1005	0.9	Feldspar
		14.4845	1.7	Smectite
4	*Karapadam*	7.3981	5.1	Kaolinite
		4.3272	5.2	Gibbsite
		3.3287	3.75	Quartz
		4.1512	0.8	Geothite
		10.4398	1.95	Illite
		14.6667	0.8	mixed
5	*Kayal*	7.3292	2.1	Kaolinite
		4.7925	2.0	Gibbsite
		4.1219	1.7	Goethite
		3.3175	1.65	Quartz
		14.9544	1.8	Smectite
6	*Pokkali*	10.3754	1.1	Illite
		15.1202	1.8	Smectite
		7.3204	1.7	Kaolinite
		4.7942	1.3	Gibbsite
		3.3182	4.8	Quartz
		3.1729	1.1	Feldspars

Contd...

Table 7 (Contd...)

Sl. No.	Name of wetland	d spacing A° intensity	Relative intensity	Mineral identified
7	*Kole*	7.2547	10	Kaolinite
		3.3050	5	Quartz
		4.1142	1.2	Goethite
		4.7656	1.7	Gibbsite
		10.15	1.9	Illite
		14.6410	2.7	Smectite + Chlorite/Vermiculite
8	Pattambi	7.3465	2.8	Kaolinite
		4.8077	0.7	Gibbsite
		4.1275	1.4	Goethite
		3.3213	2.0	Quartz
9	Chittoor	15.261	6.7	Smectite
		7.3755	2.3	Kaolinite
		4.1950	0.8	Goethite
		3.3125	3.2	Quartz
		3.2130	1.4	Feldspars
10	Wyanad	10.2690	1.7	Illite
		7.2717	8.9	Kaolinite
		4.9188	0.8	Illite
		4.7907	1.5	Gibbsite
		3.3129	9.8	Quartz
		3.2146	2.1	Feldspars
11	*Kaipad*	7.3053	7.4	Kaolinite
		3.3127	3.3	Quartz
		10.3241	3.3	Illite
		14.5508	3.9	Smectite + Chlorite/Vermiculate
		4.7936	2.2	Gibbsite
		3.2219	1.1	Feldspars
12	Kattampally	14.6849	2.5	Smectite
		10.3050	1.1	Illite
		7.2745	4.0	Kaolinite
		4.7891	1.0	Gibbsite
		4.1207	1.0	Goethite
		3.3126	3.2	Quartz
		3.1659	0.7	Feldspars

4.4.12 Active manganese

Soils showed wide variation in active manganese concentration. The highest mean (490 ppm) being observed in Kattampally samples and the lowest (68.33) in *Kari* samples.

4.5 Other physico-chemical properties of wetlands

Other physico-chemical properties of profile samples and surface samples of wet lands are presented in Table 8a and 8b.

4.5.1 Effective cation exchange capacity

Effective CEC in the Tropic Fluvaquent of Vellayani registered 9.88 cmols in the second layer and it decreased and reached 4.09 cmols in the fourth layer. Again it increased to 12.12 cmols in the lower most horizon. In the Typic Tropaquent of Karamana also the highest ECEC was noticed in the lower most horizon. In Thakazhi, the typic sulphaquent the highest effective CEC (100 cmols) was recorded in the 18-30 cm horizon. The Aeric Tropaquept of Nedumudi registered a gradual increase in ECEC with depth and the highest value (62.23 cmols) was found in the lower most horizon. In the Typic Hydraquent of *Kayal* represented by D-Block the highest effective CEC was found in the 41-97 cm horizon. From the surface to lower depths there was an increase in ECEC. The second and third horizon of Njarakkal profile recorded high effective CEC values (53.61 cmols and 46.27 cmols) when compared to other horizons. In the *Kole* lands of Thrissur represented by Anthikkad profile the surface as well as lower most layer had comparatively high ECEC compared to other horizons. The effective CEC decreased with depth in the Kandiaqult of Pattambi and reached 4.0 cmols in the lower most horizon.

Table 8a. Other chemical properties of profile samples of major wetlands

Location & depth	ECEC cmol(+)/kg	Avail. N ppm	Avail. P ppm	Avail. K ppm	Avail. Fe ppm	Avail. Mn ppm	Avail. Zn ppm	Avail. Cu ppm	Avail. Ca ppm	Avail. Mg ppm	Avail. Na ppm
L1 Vellayani											
0-11	8.82	161	18.61	52	256.0	13.8	3.82	1.52	1048.0	160.00	232
11-16	9.88	150	20.37	36	313.4	27.2	5.70	17.93	915.2	337.60	316
16-28	5.52	105	25.37	28	194.4	13.6	2.28	1.42	468.8	126.40	264
28-40	4.09	115	15.28	28	201.4	10.0	1.70	1.19	435.2	94.08	208
40-56	4.73	95	14.50	52	88.0	15.2	7.86	1.22	451.2	112.64	288
56-82	5.99	122	10.19	92	184.2	32.0	2.06	1.66	580.8	127.36	296
82-150	6.07	206	19.78	108	274.8	19.8	10.0	2.68	492.8	149.12	320
150-172	8.01	136	8.81	76	248.4	32.2	1.84	2.94	713.6	286.40	336
172-200	12.12	424	11.95	144	337.4	37.8	6.60	3.47	1065.6	475.20	452
Mean	7.25	168.22	16.09	68.44	233.11	22.4	4.65	3.78	685.68	207.64	301.33
L2 Karamana											
0-17	6.09	214	20.57	80	447.0	20.40	8.36	9.97	798.40	132.96	480
17-32	6.48	203	17.63	68	265.8	28.40	5.10	8.37	768.00	126.88	256
32-56	6.78	189	19.98	48	89.2	14.20	1.24	3.01	798.40	159.84	260
56-90	5.18	189	24.49	60	59.6	28.40	5.22	4.08	868.8	396.00	256
90-111	5.46	178	19.78	64	156.8	20.40	2.92	2.39	536.08	157.28	232
111-140	2.29	178	15.87	64	200.6	19.80	7.02	2.24	94.40	37.28	216
140-200	8.50	182	13.71	112	302.6	16.60	6.70	7.25	588.80	457.60	312
Mean	5.82	190.4	18.86	70.85	217.37	21.17	5.22	5.33	636.12	195.40	287.42

Table 8a. (Contd...)

Location & depth	ECEC cmol(+)/kg	Avail. N ppm	Avail. P ppm	Avail. K ppm	Avail. Fe ppm	Avail. Mn ppm	Avail. Zn ppm	Avail. Cu ppm	Avail. Ca ppm	Avail. Mg ppm	Avail. Na ppm
L3 *Kari* (Thakazhi)											
0-12	43.85	256	10.97	60	247.8	31.2	2.68	0.33	3003.0	1345.6	316
12-18	17.22	21	7.05	196	422.6	17.2	2.54	3.90	899.2	722.0	388
18.30	100.97	283	18.02	100	201.6	32.2	12.00	0.37	1577.6	468.8	232
30.54	28.07	122	4.00	44	230.2	34.8	4.82	0.46	1024.0	202.4	104
54-134	42.13	77	4.00	24	259.4	80.6	12.84	0.69	772.8	164.32	56
Mean	46.45	171.8	8.81	84.8	272.32	39.2	6.97	1.15	1455.32	580.62	219.2
L4 *Karapadam* (Nedumudi)											
0-16	13.94	242	6.85	72	380.4	25.8	7.46	6.59	1032	472.0	344
16-24	12.91	210	15.87	200	227.6	39.0	7.38	6.66	1072	819.2	416
24-34	17.06	203	7.84	228	169.2	38.6	11.04	8.25	1416	1222.4	484
34-52	15.96	189	15.47	224	98.0	51.0	11.0	9.06	2536	1496.0	492
52-69	22.62	189	6.27	268	209.2	45.6	6.20	3.36	3217	1926.4	504
69-164	62.23	186	16.25	32	167.8	299.0	11.16	0.48	6584	2451.2	92
Mean	24.12	203.16	11.42	170.66	208.7	83.16	9.04	5.73	2642.83	1397.86	388.66

Contd...

Table 8a. (Contd...)

Location & depth	ECEC cmol(+)/kg	Avail. N ppm	Avail. P ppm	Avail. K ppm	Avail. Fe ppm	Avail. Mn ppm	Avail. Zn ppm	Avail. Cu ppm	Avail. Ca ppm	Avail. Mg ppm	Avail. Na ppm
L5 *Kayal* (D-Block)											
0-10	12.50	333	7.83	208	264.4	46.4	4.90	2.88	1536.0	80.10	304
10-18	13.06	241	8.23	160	388.4	25.0	6.66	2.42	2550.0	65.40	196
18-22	13.59	259	13.71	260	131.4	39.6	4.32	1.52	9580.8	20.16	380
22-23	11.34	199	16.65	168	29.0	247.0	6.96	1.30	2417.6	81.60	240
33-41	13.41	276	12.85	89	169.2	184.6	6.28	0.83	2526.2	200.20	180
41-97	65.88	294	7.25	64	244.8	160.4	6.68	0.60	4814.4	945.60	156
97-103	44.82	199	15.67	32	300.0	203.8	5.26	0.30	10030.4	1200.00	1400
103-151	48.37	200	22.33	60	136.2	27.2	4.72	0.38	10734.4	7664.00	1120
Mean	27.87	250.12	13.06	130.12	207.92	116.75	6.09	1.28	5523.72	1282.13	497
L6 *Pokkali* (Njarakkal)											
0-8	33.04	500	57.20	24	3022	41.0	16.94	1.38	2153.6	582.40	2660
8-20	53.61	346	36.24	4	256.6	40.8	14.82	1.40	1739.2	635.20	1960
20-35	46.27	315	33.69	248	225.4	30.61	11.58	1.57	1611.2	512.00	1316
25-75	18.38	283	34.67	4	203.0	23.0	3.58	1.54	1028.8	196.80	252
75-110	24.13	185	23.90	12	284.0	28.4	4.24	1.65	1064.0	160.00	312
110 & below	21.31	137	38.40	52	145.0	58.8	4.10	1.77	910.4	201.60	288
Mean	32.79	294.33	37.35	57.33	236.03	37.10	9.21	1.55	1417.86	381.33	1131.33

Contd....

Table 8a. (Contd...)

Location & depth	ECEC cmol(+)/kg	Avail. N ppm	Avail. P ppm	Avail. K ppm	Avail. Fe ppm	Avail. Mn ppm	Avail. Zn ppm	Avail. Cu ppm	Avail. Ca ppm	Avail. Mg ppm	Avail. Na ppm
L7 *Kole* (Anthikkad)											
0-10	17.04	200	11.56	144	121.4	16.8	6.00	3.78	1800	670.4	252
10-20	11.72	140	12.93	88	58.8	8.2	6.04	1.29	1414.4	102.4	268
20-30	9.39	136	15.87	68	48.8	14.6	2.06	1.65	1310.4	81.6	204
30-40	8.31	129	18.02	52	43.8	8.4	5.30	1.44	656.0	166.8	140
40-50	8.53	122	14.89	64	146.4	41.0	2.06	1.65	708.8	143.6	168
50-60	7.19	101	4.36	60	160.8	20.8	7.64	2.01	484.8	121.7	140
60-70	9.46	101	4.70	100	424.4	8.0	7.88	2.71	592.0	165.6	176
70-100	15.18	105	6.46	80	331.6	9.2	4.16	4.13	790.4	145.7	116
Mean	10.85	129.25	11.09	82	167.0	15.87	5.14	2.33	969.6	199.72	183
L8 Pattambi											
0-20	4.34	241	5.92	120	347.4	31.0	2.92	7.13	376.0	96.32	80
20-34	4.90	178	5.42	264	201.8	22.2	3.10	5.55	465.6	104.0	144
34-46	4.92	140	6.43	72	64.4	14.4	3.30	3.41	793.6	149.6	96
46-56	4.93	119	4.22	140	65.4	10.6	1.14	5.99	1070.4	67.2	132
56-89	4.6	119	6.43	52	110.4	15.0	1.82	1.71	942.4	180.4	120
89 & below	4.0	112	4.22	28	134.6	16.0	4.06	1.52	547.2	154.8	300
Mean	4.61	151.5	5.44	112.66	154.0	18.2	2.72	4.21	699.2	125.38	145.33

Contd...

Table 8a. (Contd...)

Location & depth	ECEC cmol(+)/kg	Avail. N ppm	Avail. P ppm	Avail. K ppm	Avail. Fe ppm	Avail. Mn ppm	Avail. Zn ppm	Avail. Cu ppm	Avail. Ca ppm	Avail. Mg ppm	Avail. Na ppm
L9 Chittoor											
0-25	21.05	172	23.12	48	77.4	22.4	1.02	4.94	4472.0	278.4	300
25-49	19.44	129	27.23	44	72.8	16.0	2.96	4.03	2617.6	643.2	264
49-65	20.81	179	38.20	8	47.4	11.8	2.98	5.39	2772.8	704.0	180
65-88	23.50	98	45.06	44	90.2	30.8	1.24	2.23	4992.0	406.4	220
88-150	28.47	84	43.49	28	95.0	33.6	1.64	1.66	13144.0	1089.4	228
Mean	22.65	132.4	35.42	34.4	76.56	22.92	1.96	3.65	5599.68	624.28	238.4
L10 Wyanad											
0-36	4.23	301	32.71	180	214.2	16.4	7.10	1.77	518.4	86.56	152
36-72	3.57	144	20.96	24	231.0	13.8	8.24	1.57	433.6	82.72	220
72-112	3.93	116	19.20	28	66.6	14.2	6.28	3.22	800.0	88.48	168
112-150	4.24	105	15.67	8	93.6	14.2	8.30	1.76	676.8	61.76	52
Mean	3.99	166.5	22.13	60	151.35	14.65	7.48	2.08	60.72	79.88	148

Contd...

Table 8a. (Contd...)

Location & depth	ECEC cmol(+)/kg	Avail. N ppm	Avail. P ppm	Avail. K ppm	Avail. Fe ppm	Avail. Mn ppm	Avail. Zn ppm	Avail. Cu ppm	Avail. Ca ppm	Avail. Mg ppm	Avail. Na ppm
L11 *Kaipad* (Pazhayangadi)											
0-9	11.35	182	5.88	592	33.0	24.8	5.12	2.41	1187.2	169.6	548
9-17	10.47	164	11.36	524	101.8	9.2	2.18	2.17	771.2	203.2	1008
17-26	19.04	143	23.51	776	78.6	16.8	1.92	2.18	1000.0	484.8	1820
26-45	15.58	136	50.93	560	80.0	11.6	2.56	2.11	1001.6	342.4	1652
45-59	11.59	122	50.93	392	61.6	17.2	3.76	1.32	852.8	288.0	1120
59-84	15.42	126	55.63	560	71.6	18.8	7.60	2.69	1504.0	419.0	1596
84-126	17.00	126	55.63	44	71.6	18.8	7.60	2.69	1504.0	347.2	1260
Mean	14.35	142.71	36.26	492.57	71.17	16.74	4.39	2.22	1117.25	322.02	1286.28
L12 Kattampally											
0-26	5.93	112	15.28	33	92.6	26.2	4.10	7.93	10999.2	76.8	116
26-47	5.29	74	16.85	20	36.4	13.2	6.32	1.83	2398.4	187.2	148
47-76	6.73	70	16.96	20	39.2	10.6	1.58	1.74	1372.8	248.0	264
76-100	6.64	84	16.65	28	63.4	13.8	3.72	1.42	1347.2	281.6	192
100-150	9.13	74	17.24	44	167.2	19.2	6.12	1.84	1464.0	179.2	300
150 & below	30.12	182	6.07	4	246.6	10.4	4.20	0.88	1800.0	300.8	140
Mean	10.64	99.33	14.84	24.66	107.56	15.56	4.34	2.60	3230.26	212.26	193.33

Table 8b. Other physico-chemical properties of surface samples of major wetlands (Mean values)

Name of Wetland	Sand %	Silt %	Clay %	Eh mv	ECEC Cmol(+)/kg	Available nutrients (ppm)										
						N	P	K	Fe	Mn	Zn	Cu	Ca	Mg	Na	Si
Vellayani	31.50	7.62	60.90	496.00	5.56	187.2	21.77	57.5	431.68	33.6	3.48	4.198	621.6	118.57	217.2	75.11
Karamana	58.96	7.39	35.98	441.00	4.25	143.6	12.11	80.7	238.30	20.86	3.18	6.207	648.64	106.76	233.2	86.27
Kari	12.88	20.67	66.43	564.00	25.78	254.5	18.17	124	2399.66	31.52	89.28	1.28	1246.2	373.28	452.0	101.07
Karapadam	32.66	11.44	55.86	450.00	8.08	231.0	21.48	241.6	416.08	27.44	3.22	5.706	456.32	202.84	314.6	174.65
Kayal	17.89	17.62	64.45	513.00	14.66	197.5	29.29	354.8	381.6	31.66	3.63	3.091	1219.84	33.28	416.0	131.97
Pokkali	32.66	3.73	63.91	546.00	23.54	185.8	19.46	181.2	455.0	13.56	27.20	2.115	1724.18	567.36	2782.0	190.86
Kole	22.85	15.98	61.17	501.00	9.00	192.4	15.45	83.6	299.83	46.36	5.26	8.45	1072.8	133.6	221.6	136.60
Pattambi	41.57	8.53	49.89	457.00	4.64	162.8	9.71	54.0	291.80	30.6	2.27	10.20	707.36	133.57	108.0	157.18
Chittoor	56.26	7.26	36.46	421.00	16.75	155.5	25.34	70.0	263.14	18.80	9.33	7.34	4852.0	122.72	129.6	171.62
Wyanad	65.18	5.37	29.43	438.00	4.55	153.4	11.96	43.0	88.70	20.62	3.86	2.97	673.92	119.66	100.8	109.15
Kaipad	31.47	32.31	36.20	452.00	4.01	121.2	19.39	28.0	163.60	4.640	1.28	2.68	403.36	77.58	157.2	123.50
Kattampally	61.88	7.26	30.85	445.00	5.91	125.8	9.27	83.2	143.20	36.36	2.466	5.63	875.54	222.08	209.2	157.18
CD	28.38	12.72	29.24	44.09	5.76	54.39	9.40	80.24	950.94	NS	NS	2.46	849.27	104.59	208.59	82.91
SE	9.72	4.36	10.02	15.11	2.06	19.47	3.36	28.72	340.46			0.88	304.06	37.44	74.68	28.40

The highest ECEC (19.04 cmols) was recorded by the 17-26 cm horizon of Pazhayangadi profile representing the Tropic Fluvaquent. In Kattampally pedon the effective CEC increased with depth and the maximum value was recorded by the lower most layer (30.12 cmols). In Wyanad profile the values ranged from 3.93 cmols to 4.24 cmols. In Chittoor pedon, the ECEC ranged from 19.44 cmols to 28.47 cmols, the highest value being recorded by the lowest layer. The intrapedon variation was high in *Kari*, *Karapadom*, *Kayal*, *Pokkali* and Kattampally profiles. Considering the mean values of profiles the *Kari* pedon recorded maximum value (46.45 cmols) and Wyanad pedon the minimum (3.99 cmols).

Effective CEC of surface samples showed significant variation between wetlands. The highest mean ECEC (25.78 cmols) was noticed in *Kari* surface samples followed by *Pokkali* soil (23.54 cmols) and the lowest (4.01 cmols) in the *Kaipad* soil.

4.5.2 Available nutrients

4.5.2.1 Available nitrogen

In all the profiles studied there was a decrease in available nitrogen towards lower depths except in Vellayani and Kattampally profile where an inverse relationship was observed. The highest value for available nitrogen was recorded by the surface horizon of Njarakkal (500 ppm) pedon and the lowest by the third horizon of Kattampally profile (70 ppm).

Comparing the mean values of surface samples of wet lands it was observed that *Kari* soils recorded the highest value for available nitrogen (254 ppm) and the *Kaipad* land the lowest (121 ppm). All the wetlands differed significantly with respect to available nitrogen.

4.5.2.2 Available phosphorus

No definite pattern of increase or decrease of available phosphorus in the profiles of these wetlands could be observed. A high status of available phosphorus (25 ppm) was found in the third horizon of Vellayani Tropic Fluvaquent. In Karamana the values ranged from 13 ppm to 24 ppm, the highest being observed in the third layer. In Thakazhi representing Typic Sulphaquent registered 18 ppm in the third layer and the values ranged from 4 ppm to 18 ppm. In the *Karapadom* profile the highest available phosphorus (16 ppm) was found in the lower most horizon. In Typic Hydraquent of D-Block the values ranged between 7 ppm to 22 ppm. The highest value was observed in the lower most horizon. In *Pokkali* pedon from Njarakkal, the status was high (57 ppm) in the surface horizon and it decreased with depth upto fifth layer and then increaesed. High available phosphorus status was maintained throughout the profile. In Anthikkad pedon of *Kole* lands the availability of this nutrient was medium in the surface five horizons followed by a sharp decline in the lower horizons. In Pattambi pedon low values were observed throughout the profile (4 ppm to 6 ppm). In Pazhayangadi profile representing *Kaipad* lands there was a noticeable variation in available phosphorus content ranging from 5 ppm to 55 ppm from the top to bottom. The availability of phosphorus was found to be medium in status in the Kattampally profile except the lower most horizon. In the Typic Tropaquent of Wyanad a high available phosphorus (32 ppm) status was noticed in the surface layer and it decreased almost half the value in the lower most layer. In Chittoor profile high values were observed throughout the depth of the profile, the highest (43 ppm) being observed in the lower most horizon. When the mean values of profiles were compared the *Pokkali*, Wyanad and Chittoor pedons recorded high availability of this nutrient and among the surface samples *Kayal* and Chittoor soils registered the highest values.

4.5.2.3 Available Potassium

From the observations it was noticed that potassium availability increased with depth in Vellayani pedon, the highest value (144 ppm) being observed in the lower most horizon. In Vellayani and Karamana, maximum values were observed in the lower most horizons. In Karamana pedon the values ranged from 48 ppm to 112 ppm. The values were between 24 ppm and 196 ppm for *Kari* pedon and the values decreased with depth. In Nedumudi representing *Karapadom* soils the values were comparatively high, the highest being observed in the fifth layer (268 ppm). The available Potassium values decreased with depth in *Kayal* profiles and the values ranged between 32 ppm and 208 ppm. In the *Pokkali* profile from Njarakkal the third layer recorded 248 ppm, all the other horizons recorded low values. The *Kole* profile from Anthikkad registered 144 ppm available potassium in the surface horizon and it decreased with depth. A wide variation was noticed in profile from Pattambi the values being between 28 ppm and 264 ppm. The second layer (20-30 cm) recorded highest value here. *Kaipad* pedon registered high values throughout the depth of the profile except the lower most horizon. The values were very low for Kattampally pedon ranging from 4 ppm to 44 ppm. In Wyanad the surface layer registered 180 ppm and the values decreased with depth. In Chittoor also the values were low ranging from 8 to 48 ppm. The highest mean available potassium was recorded by *Kaipad* profile and the lowest by Kattampally profile.

Comparing the means of surface samples we could observe that *Kayal* samples registered highest value (354.8 ppm) followed by *Karapadom* soils (241.6 ppm) and the lowest being observed in the *Kaipad* soils.

4.5.2.4 Micronutrients

The available iron and manganese are dealt under 4.4. The surface sample (0-8cm) of *Pokkali* profile registered the highest available zinc (16 ppm), while the surface layer of Chittoor pedon (0-25 cm) recorded lowest value (1 ppm). Comparing the mean values of profiles also *Pokkali* pedon registered the maximum value (9 ppm) and Chittoor pedon the minimum value (1.96 ppm). Available zinc increased with depth in Vellayani, *Kari*, *Karapadom*, *Kayal*, *Kole*, Pattambi, Chittoor and Wyanad profiles but it decreased in other profiles.

The maximum copper availability (17 ppm) was noticed in the 11-16 cm layer of Vellayani profile and the minimum (0.30 ppm) in the 97-103 cm layer of *Kayal* profile. Copper availability increased with depth in Vellayani, *Kari*, *Pokkali*, *Kole* and Wyanad pedons. Considering the mean values of pedons the highest available copper (5 ppm) was found in *Karapadom* profile from Nedumudi and the lowest (1 ppm in the *Kari* profile from Thakazhi. The mean values of surface samples showed significant variation between wet lands. The highest mean copper avaialbility (10 ppm) was noticed in Pattambi surface samples and the lowest (1 ppm) in *Kari* samples.

4.5.2.5 Available Bases

Available calcium increased with depth in Vellayani, *Karapadom*, *Kayal*, Pattambi, Chittor, Wyanad and *Kaipad* where as in Karamana, *Kari*, *Pokkali*, *Kole* and Kattampally it decreased with depth. Of the profiles the highest available calcium (1314 ppm) was noticed in the lower most layer of Chittoor and the lowest (94.40 ppm) in the 111-140 cm layer of Karamana. Comparing the mean values of profiles the maximum calcium (5597 ppm) availability was observed in the Chittoor profile followed by *Kayal* profile (5523 ppm). The lowest mean was observed in the Wyanad pedon (607 ppm). Interhorizonal variation was high in all the profiles. Low values for available calcium was observed in profiles like Vellayani, Karamana, Pattambi and Wyanad. The surface samples of wetlands showed significant variation in available calcium. The highest available calcium (4852 ppm) was observed in Chittoor soils while the lowest value (403 ppm) was found in *Kaipad* soils.

Mean available magnesium values were high for profiles like *Karapadom* and *Kayal*. The highest mean (1397 ppm) was noticed in *Karapadom* profile and the lowest (79 ppm) in the Wyanad profile. In all the profiles studied the interhorizonal variation was high except in Wyanad profile. The highest available magnesium value (2451 ppm) was observed in the 69-164 cm horizon of *Karapadom* profile while the lowest value (37.28 ppm) was noticed in the 111-140 cm layer of Karamana pedon. The highest mean value (567 ppm) for surface samples was noticed in *Pokkali* soils but the lowest value (33 ppm) was observed in *Kayal* soils. All the wet lands differed significantly with respect to available magnesium.

The highest mean available sodium was noticed in the profiles from Pazhayangadi representing *Kaipad* lands (1286 ppm) and Njarakkal profile representing *Pokkali* lands (1131.33ppm). But low values were observed in the profiles of Pattambi and Wyanad. Considering the surface samples of wetlands the highest mean available sodium was found in *Pokkali* samples (2782 ppm) and the lowest in Wyanad samples (100.8 ppm). All the wetlands differed significantly with respect to available sodium.

The highest mean available sodium was noticed in the surface samples of *Pokkali* (2782 ppm). *Kari* and *Kayal* soils also recorded high values when compared to the surface samples of other wetlands. The lowest value was found in Wyanad soils. The soils differed significantly with respect to this nutrient.

4.5.2.6 Available Silicon

The highest silicon availability was observed in *Pokkali* surface samples and lowest in the Vellayani samples. All the wetlands differed significantly for this factor.

4.5.2.7 Redox potential

The maximum positive Eh (+564) was noticed in *Kari* surface samples followed by *Pokkali* (+546), *Kayal* (+513) *Kole* (+501) and Vellayani (+496). Karamana, *Karapadom*, Pattambi, *Kaipad*, Kattampally, Wyanad and Chittoor soils did not show much variation in redox potential, the values being +421 mv to +457 mv.

4.5.3 Texture

The clay content of the surface samples were dealt under Table 4.4.8. The maximum sand percentage was observed in Wyanad soils, followed by Kattampally and the minimum in the *Kari* samples. In *Kaipad* soils silt percentage was found to be maximum.

4.6 Parameters for assessment of soil acidity

Parameters for assessment of soil acidity viz. pH under field condition, ΔpH under dry condition, exchangeable aluminium, ΔpH and percentage base saturation are presented in Table 9 and 10.

Table 9. Parameters for assessment of soil acidity in profile samples of wetlands

Location & depth (cm)	pH										
	Wet				Dry						
	1:1 H_2O	1:2.5 H_2O	1:1 KCl	1:2 $CaCl_2$	1:1 H_2O	1:2.5 H_2O	1:1 KCl	1:2 $CaCl_2$	Exch. Al. cmol(+)/kg	ΔpH	% Base saturation
L1 Vellayani											
0-11	4.5	4.5	3.9	4.2	3.8	3.9	3.5	3.6	0.77	0.3	64.29
11-16	4.6	5.0	4.0	4.2	4.1	4.3	3.6	3.9	0.89	0.5	74.40
16-28	4.9	4.9	4.3	4.6	4.0	4.2	3.4	3.6	0.59	0.6	82.44
28-40	5.2	5.2	4.3	4.7	4.5	4.6	4.2	4.4	0.11	0.3	80.32
40-56	5.6	5.6	4.5	4.9	4.9	5.0	4.1	4.5	0.16	0.8	88.07
56-82	5.6	5.6	4.5	4.9	4.7	4.8	4.0	4.3	0.26	0.7	88.52
82-150	5.7	5.8	4.5	4.9	4.6	4.8	4.1	4.5	0.06	0.5	76.78
150-172	6.0	6.1	4.6	5.0	4.8	4.9	4.3	4.7	0.01	0.5	80.97
172-200	6.1	6.1	5.0	5.3	4.8	5.0	4.4	4.7	0.01	0.4	84.30
L2 Karamana											
0-17	6.0	6.1	4.2	4.8	4.5	4.6	3.9	4.3	0.24	0.6	55.24
17-32	5.5	5.6	4.3	4.6	5.0	5.0	4.2	4.5	0.14	0.8	42.65
32-56	6.2	6.3	4.6	5.2	5.0	5.1	4.7	5.0	0.10	0.3	62.64
56-90	6.0	6.2	4.6	5.0	5.8	5.9	5.0	5.3	0.08	0.8	86.07
90-111	6.0	6.2	5.4	5.7	5.0	5.1	4.2	4.5	0.11	0.8	79.45
111-140	6.0	6.2	5.3	5.6	5.1	5.2	4.1	4.3	0.17	1.0	58.94
140-200	6.1	6.3	5.1	5.2	4.8	4.9	3.7	3.9	0.45	1.1	63.16

Contd...

Location & depth (cm)	pH										
	Wet				Dry						
	1:1 H_2O	1:2.5 H_2O	1:1 KCl	1:2 $CaCl_2$	1:1 H_2O	1:2.5 H_2O	1:1 KCl	1:2 $CaCl_2$	Exch. Al. cmol(+)/kg	ΔpH	% Base saturation
L3 *Kari* (Thakazhi)											
0-12	3.9	3.9	3.2	3.5	3.0	3.1	2.7	3.0	9.10	0.3	96.00
12-18	4.0	4.2	3.3	3.6	3.7	3.8	3.3	3.7	2.94	0.4	64.42
18-30	4.4	4.4	4.0	4.2	2.3	2.4	2.0	2.3	23.58	0.3	38.98
30-54	5.5	5.8	4.9	5.2	2.6	2.7	2.3	2.6	9.44	0.3	93.29
54-134	5.0	6.0	4.5	4.8	2.5	2.6	2.1	2.4	13.68	0.4	30.59
L4 *Karapadam* (Nedumudi)											
0-16	4.6	4.7	3.7	4.0	4.1	4.2	3.6	3.9	2.84	0.5	68.18
16-24	5.0	5.0	4.2	4.5	5.0	5.0	4.2	4.7	0.10	0.8	89.99
24-34	5.6	5.8	4.5	4.8	5.5	5.6	4.6	5.3	0.05	0.9	99.16
34-52	5.8	5.8	5.0	5.3	5.7	5.8	5.1	5.6	0.06	0.6	86.67
52-69	6.2	6.3	5.5	5.8	3.7	3.8	3.2	3.6	1.52	0.5	82.67
69-164	6.8	6.8	5.0	5.4	2.6	2.8	2.5	2.6	8.83	0.1	95.28
L5 *Kayal* (D Block)											
0-10	5.5	5.6	5.0	5.2	3.8	4.0	3.6	3.9	1.37	0.2	64.17
10-18	5.6	5.6	4.8	5.1	4.3	4.4	4.0	4.3	0.18	0.3	89.69
18-22	6.8	7.1	6.7	6.8	6.9	7.1	6.7	6.9	0.03	0.2	97.71
22-33	6.8	6.9	6.6	6.7	6.8	6.9	6.6	6.8	0.02	0.2	89.93
33-41	6.7	6.7	5.8	6.1	3.8	4.0	3.4	3.6	0.02	0.4	87.33
41-97	6.9	7.0	5.8	6.1	2.3	2.6	2.2	2.5	14.57	0.1	71.91
97-103	7.2	7.5	6.1	6.4	3.1	3.4	2.8	3.3	3.11	0.3	93.61
103-151	7.4	7.6	6.6	6.9	3.0	3.3	2.8	3.2	3.71	0.2	94.04

Contd...

Location & depth (cm)	pH										
	Wet				Dry						
	1:1 H_2O	1:2.5 H_2O	1:1 KCl	1:2 $CaCl_2$	1:1 H_2O	1:2.5 H_2O	1:1 KCl	1:2 $CaCl_2$	Exch. Al. cmol(+)/kg	ΔpH	% Base saturation
L6 *Pokkali* (Njarakkal)											
0-8	4.2	4.3	3.2	3.6	2.6	2.9	2.5	2.8	8.82	0.1	96.06
8-20	4.4	4.6	3.3	3.7	2.6	2.8	2.5	2.8	13.5	0.1	92.43
20-35	4.9	5.0	3.4	3.9	2.8	3.0	2.6	2.9	12.73	0.2	94.34
35-75	4.3	4.4	3.5	3.8	2.8	3.5	2.7	2.9	10.34	0.1	77.35
75-110	4.6	4.8	3.6	4.0	2.8	3.1	2.7	3.0	9.08	0.1	86.45
110 & below	4.7	4.9	3.9	4.3	2.9	3.1	2.8	2.9	7.77	0.1	92.39
L7 *Kole* (Anthikkad)											
0-10	4.4	4.7	3.9	4.2	4.0	4.0	3.4	3.8	3.12	0.6	93.04
10-20	4.5	4.6	3.9	4.2	4.2	4.3	3.5	4.0	2.55	0.7	67.61
20-30	4.5	4.6	4.1	4.3	4.2	4.3	3.5	3.9	2.52	0.7	96.81
30-40	4.6	4.6	4.2	4.4	4.1	4.2	3.5	3.8	2.52	0.6	85.92
40-50	4.8	4.9	4.2	4.5	4.1	4.2	3.5	3.8	2.58	0.6	88.04
50-60	4.9	5.1	4.2	4.5	4.1	4.3	3.5	3.6	2.51	0.6	73.72
60-70	4.9	5.1	4.3	4.6	3.9	4.0	3.4	3.6	3.43	0.5	45.4
70-100	4.9	5.3	4.2	4.5	3.2	3.3	2.9	3.1	4.13	0.3	29.09

Contd...

Location & depth (cm)	pH										
	Wet				Dry						
	1:1 H_2O	1:2.5 H_2O	1:1 KCl	1:2 $CaCl_2$	1:1 H_2O	1:2.5 H_2O	1:1 KCl	1:2 $CaCl_2$	Exch. Al. cmol(+)/kg	ΔpH	% Base saturation
L8 Pattambi											
0-20	5.3	5.7	5.0	5.2	4.5	4.6	3.8	4.1	0.76	0.7	50.66
20-30	5.3	5.7	5.0	5.2	4.5	4.5	4.1	4.2	0.14	0.4	66.15
30-46	5.2	5.6	5.0	5.1	5.1	5.4	5.1	5.1	0.04	0.0	89.20
46-56	5.2	5.4	5.1	5.1	5.1	5.3	4.5	4.7	0.04	0.6	98.87
56-89	5.3	5.6	5.1	5.2	5.2	5.3	4.8	4.9	0.04	0.4	99.40
89 & below	5.3	5.9	5.3	5.3	5.2	5.5	5.2	5.2	0.04	0.0	98.81
L9 Chittoor											
0-25	7.8	8.0	6.7	7.3	7.8	8.0	6.8	7.4	—	1.0	94.88
25-49	7.9	8.0	6.5	7.3	7.7	7.9	6.6	7.2	—	1.1	87.61
49-65	7.9	8.0	6.3	7.1	7.0	7.3	6.0	6.8	—	1.0	75.37
65-88	7.9	8.2	7.0	7.7	7.9	8.2	6.6	7.4	—	1.3	98.19
88-150	8.3	8.6	7.1	7.8	8.2	8.5	6.8	7.6	—	1.4	98.92
L10 Wyanad											
0-36	4.9	5.0	3.9	4.3	4.4	4.5	3.8	4.1	0.34	0.6	60.28
36-72	5.0	5.1	3.8	4.1	5.0	5.2	3.9	4.2	0.44	1.1	55.29
72-112	5.0	5.2	3.9	4.3	5.2	5.3	4.3	4.4	0.10	0.9	64.26
112-150	5.1	5.2	3.9	4.3	4.8	4.9	4.1	4.3	0.08	0.7	45.65

Contd...

Location & depth (cm)	pH								Exch. Al. cmol(+)/kg	ΔpH	% Base saturation
	Wet				Dry						
	1:1 H_2O	1:2.5 H_2O	1:1 KCl	1:2 $CaCl_2$	1:1 H_2O	1:2.5 H_2O	1:1 KCl	1:2 $CaCl_2$			
L11 *Kaipad* (Pazhayangadi)											
0-9	4.8	5.3	4.5	4.6	4.5	4.8	4.2	4.7	0.06	0.3	99.45
9-17	6.4	6.8	6	6.2	5.9	6.1	5.4	5.9	0.02	0.5	96.88
17-26	6.9	7.0	6.2	6.5	6.9	7.2	6.2	6.9	0.02	0.7	99.68
26-45	7.3	7.4	6.8	7.0	7.3	7.6	6.6	7.2	0.02	0.7	91.37
45-59	7.2	7.6	6.8	7.0	7.2	7.4	6.5	7.2	0.02	0.7	95.35
59-84	7.3	7.6	6.4	6.8	7.0	7.4	6.5	7.2	0.02	0.5	96.32
84-126	7.4	7.5	6.0	6.5	3.3	3.6	2.8	3.4	1.26	0.5	79.11
L12 Kattampally											
0-26	5.7	6.0	5.1	5.3	5.3	5.4	4.6	5.0	0.02	0.7	83.72
26-47	6.9	6.8	5.8	6.4	6.1	6.2	5.1	6.0	0.02	1.0	93.67
47-76	6.7	6.5	5.5	6.4	6.0	6.1	4.9	6.0	0.04	1.1	97.5
76-100	6.4	6.6	5.5	6.0	5.8	5.9	4.8	5.0	0.02	1.0	98.35
100-150	4.8	5.0	3.3	3.7	4.2	4.3	3.5	3.9	0.46	0.7	92.47
150 & below	3.4	3.7	3.1	3.3	2.8	3.0	2.5	2.6	10.05	0.3	94.48

Table 10. Parameters for assessment of soil acidity in surface samples of wetlands

Name of Wetland		pH under field condition			pH under dry condition			Exch. Al. cmol(+)/kg	ΔpH [water pH - KCl pH]	% Base saturation
		1:1 H_2O	1:1 KCl	1:2 $CaCl_2$	1:1 H_2O	1:1 KCl	1:2 $CaCl_2$			
L1	Vellayani	4.2-6.1	3.5-5.6	3.4-5.2	4.0-4.8	3.3-3.9	3.7-4.3	0.3-2.5	0.3-1.0	39.3-56.5
		(5.09)	(4.70)	(4.50)	(4.35)	(3.65)	(4.03)	(1.11)	(0.69)	(50.84)
L2	Karamana	4.8-5.9	4.2-4.9	4.3-5.2	4.8-5.8	3.9-4.8	4.4-4.9	0.2-0.5	0-7-1.5	48.8-57.8
		(5.33)	(4.50)	(4.65)	(5.28)	(4.22)	(4.65)	(0.26)	(1.06)	(53.88)
L3	*Kari*	3.5-5.5	3.2-5.1	3.4-5.3	2.2-4.2	2.35-3.5	2.1-3.9	0.8-16.8	0.1-0.9	13.6-65.2
		(5.02)	(4.59)	(4.85)	(3.20)	(2.82)	(3.07)	(5.72)	(0.40)	(36.42)
L4	*Karapadam*	4.5-5.4	3.7-5.0	3.9-5.1	3.5-5.0	3.2-4.1	3.6-4.5	0.2-5.5	0.3-0.9	19.9-55.5
		(4.86)	(4.42)	(4.71)	(4.31)	(3.69)	(4.16)	(1.99)	(0.61)	(37.28)
L5	*Kayal*	3.6-6.4	3.3-5.8	3.5-5.8	3.1-6.4	2.78-5.76	3.18-6.2	0.1-7.4	0.3-1.18	23.4-56.5
		(5.07)	(4.60)	(4.87)	(4.44)	(3.79)	(4.24)	(2.93)	(0.64)	(48.82)
L6	*Pokkali*	4.7-6.5	3.4-5.7	4.8-6.4	2.8-3.8	2.5-3.3	2.8-3.5	0.9-9.3	0.0-0.60	54.4-76.8
		(5.58)	(4.38)	(5.45)	(3.18)	(2.82)	(3.11)	(3.94)	(0.34)	(66.56)
L7	*Kole*	4.5-5.5	3.7-5.2	4.1-4.9	4.2-5.0	3.5-4.0	3.7-4.5	0.1-1.9	0.5-1.0	42.6-76.7
		(4.90)	(4.26)	(4.50)	(4.63)	(3.79)	(4.20)	(0.82)	(0.83)	(65.83)
L8	Pattambi	5.2-6.1	4.5-5.4	4.8-5.8	4.5-5.6	3.6-5.5	3.7-6.0	0.2-0.7	0.3-1.0	40.7-84.0
		(5.64)	(4.99)	(5.25)	(4.93)	(4.19)	(4.42)	(0.35)	(0.74)	(60.97)
L9	Chittoor	6.9-8.0	5.8-7.0	6.5-7.7	5.7-7.8	4.6-7.0	5.0-7.6		0.5-1.3	62.1-85.1
		(7.43)	(6.54)	(7.04)	(6.99)	(6.05)	(6.63)	(0.00)	(0.94)	(74.02)
L10	Wyanad	5.1-6.5	4.1-5.7	4.2-5.8	4.2-5.4	3.8-4.2	3.8-4.5	0.1-0.4	0.1-1.4	43.5-89.8
		(5.92)	(5.00)	(5.14)	(4.83)	(3.99)	(4.24)	(0.24)	(0.84)	(62.17)
L11	*Kaipad*	4.2-6.2	4.1-5.4	4.0-5.9	4.0-6.0	3.4-5.0	3.5-5.8	0.1-3.6	0.4-1.2	54.6-96.5
		(5.58)	(4.74)	(4.72)	(5.27)	(4.45)	(4.76)	(0.48)	(0.81)	(81.44)
L12	Kattampally	5.1-6.4	4.0-5.7	4.8-5.8	4.6-6.1	4.0-5.1	4.5-5.7	0.1-0.2	0.5-1.3	63.1-89.6
		(5.77)	(4.88)	(5.38)	(5.46)	(4.61)	(5.07)	(0.13)	(0.85)	(76.30)
	CD	0.4643	0.4613	0.4375	0.5043	0.468	0.527	1.6880	0.216	11.9619
	SE	0.1662	0.1651	0.1566	0.1805	0.167	0.188	0.6043	0.077	4.2611

Values of parenthesis indicate mean

4.6.1 pH

A scan through the wet pH measurements of the profile samples revealed that there was an increase in pH towards lower depths in Vellayani, Karamana, Thakazhi, Nedumudi, D-Block, Njarakkal, Anthikkad. Pazhayangadi, Wyanad and Chittoor profiles. The only exception was Kattampally profile where upto 76 cm depth there was an increase in pH (6.7) which decreased to 3.4 at 150 cm and below. The pH (KCl) and pH ($CaCl_2$) also followed the same trend. But the values registered were low. This picture completely differed when the pH measurement was done after air drying the soil samples and it was dealt under 4.3.1. The trend observed for dry pH (H_2O) was more or less followed in the case of pH (KCl) and pH ($CaCl_2$) in all profiles studied. But the pH (KCl) and pH ($CaCl_2$) values were lower than dry pH (H_2O) values. The highest mean pH (H_2O) was noticed in Chittoor surface soils (7.4) and the lowest for *Karapadom* soils (4.8) under field wet condition. The maximum KCl pH was observed in Chittoor soils (6.54) and the minimum was for *Kole* Soils (4.26). In the case of $CaCl_2$ pH also Chittoor had the highest value (7.4) and Vellayani soils had the lowest value (4.5). Chittoor soil was taken as the standard for comparison and it had an alkaline pH and all the other soils were acidic in reaction. From the analysis of variance of the data it was found that all the soils differed significantly with respect to pH. The pH (H_2O) under dry condition was dealt under 4.3.1.

4.6.2. Exchangeable Aluminium

Exchangeable aluminium of profile samples as well as surface samples were presented under 4.4.1.

4.6.3 ΔpH

ΔpH (pH water - pH KCl) calculated in general increased from surface to lower depths in profiles selected from Karamana and Vellayani with values around 1.0 unit. Sulphaquents of Thakazhi showed more or less the same value throughout the profile whereas the values decreased with depth in the case of *Kayal* and *Kole* pedons. The maximum value for ΔpH (1.4) was noticed in the lowest horizon of Petrocalcic Calciusterts of Chittoor. Profiles from Kattampally and Wyanad recorded lowest ΔpH for the lowest horizons.

Surface samples collected from radial distances around profile pits also showed considerable variation in ΔpH. The difference was significant between soils. The highest mean ΔpH of 1.06 was noticed in Karamana surface samples where as the lowest value recorded was 0.34 for *Pokkali* samples.

4.6.4 Percentage base saturation

The percentage base saturation ranged from 64 to 88 per cent in Vellayani pedon. It increased with depth. But in Karamana profile it ranged between 42 and 86 per cent. Percentage base saturation increased with depth in this profile also. In *Kari* profile from Thakazhi high percentage base saturation (96 per cent) was noticed in the surface layer. In *Karapadom* pedon it increased with depth and 99 per cent saturation was noticed in the third layer. In *Kayal* profile from D-Block base saturation increased with depth and it ranged between 64 to 97 per cent. In the profile from Njarakkal representing *Pokkali* lands the values for this factor ranged between 77 and 96 per cent, the highest being observed in the surface layer. The profile from Anthikkadu registered 96 percentage base saturation in the third layer and it decreased to 29 percentage in the lower most horizon. In Pattambi pedon though low values for this factor was registered in the surface two layers it increased to high values in the lower layers. Throughout the entire depth of profile high values were registered in the profiles from Pazhayangadi and Kattampally. Low values ranging from 45 percentage to 64 percentage was noticed in the pedon from Pattambi. In the Petrocalcic Calciusterts of Chittoor high values were registered throughout the depth of the pedon ranging from 75 to 99 percentage. The mean values for this factor was highest in the surface samples from *Kaipad* lands and lowest for *Kari* samples.

4.7 Evaluation of acidity generating factors

Correlations and regressions were worked out between components of acidity with acidity generating factors and available nutrients in the surface samples (120) taking into consideration all wet lands together are presented in Table 11. The regression equations computed are also given in the Table.

4.7.1 pH and acidity contributing factors

From the correlations it was found that field water pH (1:1) had got positive significant correlations with available calcium ($r = 0.5859^{**}$), ΔpH ($r = 0.3000^{**}$) and base saturation ($r = 0.4463^{**}$). It had got negative significant correlations with exchangeable aluminium ($r = -0.3199^{**}$), organic matter percentage ($r = -0.2067^{*}$), available nitrogen ($r = -0.2579^{**}$) and exchangeable hydrogen ($r = -0.1943^{*}$). Of these the most influencial factors towards active acidity were exchangeable aluminium, organic matter, nitrogen and exchangeable hydrogen,10 per cent of variation in active acidity at field wet condition was accounted by exchangeable aluminium. Variations in soil reaction at field condition was mainly accounted by the avaialble calcium to about 34 per cent.

Table 11. Relationship between components of acidity with acidity generating factors and available nutrients in the surface soil samples of wetlands (n = 120)

y	x	r	R^2	Regression equation
Field condition				
Water pH				
1:1	Exch.Al	–0.3199**	0.1023	y = 5.6767 – 0.01064 X
	Org. matter %	–0.2067*	0.0427	y = 5.6778 – 0.0532 X
	ΔpH	0.30003**	0.0377	y = 4.9167 + 0.8200 X
	Exch.H	–0.1943*	0.0377	y = 5.5749 – 0.0029 X
	% Base saturation	0.4463**	0.1991	y = 4.3420 + 0.0197 X
	Available N	–0.2579**	0.0665	y = 6.0586 – 0.0034 X
	Available Ca	0.5859**	0.3433	y = 5.1156 + 0.0003 X
	Exch. Ca	0.5385**	0.2900	y = 5.0475 + 0.1121 X
	Available K	–0.1853*	0.0343	y = 5.6600 – 0.0012 X
	Exch.K	–0.1809*	0.0326	y = 5.6566 – 0.4795 X
KCl pH 1:1	Exch Al	–0.2729**	0.0744	y = 4.9240 – 0.0821 X
	ΔpH	0.2273*	0.516	y = 4.3892 + 0.5621 X
	% Base saturation	0.2981**	0.0888	y = 4.0907 + 0.01192 X
	Avaialble Ca	0.5899**	0.3480	y = 4.4351 + 0.0003 X
	Avalable Na	–0.2196*	0.0482	y = 4.9003 – 0.0002 X
	Exch Ca	0.5662**	0.3205	y = 4.3542 + 0.1067 X
	Exch.Na	–0.2113*	0.0446	y = 4.9356 – 0.0947 X
$CaCl_2$ pH				
1:2	Effective CEC	0.2290*	0.0524	y =4.8850 + 0.0192 X
	% Base saturation	0.3566**	0.1271	y = 4.1728 + 0.0153 X
	Available Ca	0.6675**	0.4455	y = 4.6426 + 0.0003 X
	Exch.Ca	0.6425**	0.4128	y = 4.5423 + 0.1305 X
Electrial conductivity				
	Exch.Al	0.2884**	0.0831	y = 0.5445 + 0.2043 X
	Available K	0.2325*	0.0540	y = 0.4690 + 0.0032 X
	Available Cu	–0.2181*	0.0475	y = 1.3711 – 0.1041 X
	Available Mg	0.6772**	0.4586	y = –0.5566 + 0.0067 X
	Available Na	0.9229**	0.8518	y = - 0.1328 + 0.0021 X
	CEC	0.2380**	0.0566	y = 0.3911 + 0.0322 X
	Exch. Mg	0.6576**	0.4324	y = - 0.8291 + 1.0901 X
	Exch Na	0.9034**	0.8163	y = 0.5065 + 0.9540 X
	Exch.K	-0.24043*	0.0578	y = 0.4555 + 1.3587 X
	ΔpH	-0.4075**	0.1660	y = 2.5883 - 2.3129 X
	ECEC	0.4094**	0.1676	Y = 0.0558 + 0.0752 X

y	x	r	R^2	Regression equation
Dry condition				
Water pH				
1:1	Exch.Al	−0.6929**	0.4801	y = 5.2021 − 0.3080 X
	Org.matter	−0.5023**	0.2523	y = 5.2619 − 0.1730 X
	Available N	−0.4429**	0.1960	y = 5.9825 − 0.0070 X
	Available K	−0.2267*	0.0514	y = 4.9737 − 0.0020 X
	DTPA Fe	−0.3559**	0.1267	y = 4.8961 − 0.0003 X
	Available Zn	−0.2719**	0.0739	y = 4.7993 − 0.0046 X
	Available Cu	0.3382**	0.1144	y = 4.2338 + 0.1013 X
	Available Ca	0.4329**	0.1874	y = 4.3434 + 0.0003 X
	Avaialble Mg	−0.5276**	0.2784	y = 5.4281 − 0.0032 X
	Avaialble Na	−0.4890**	0.2391	y = 5.0670 − 0.0007 X
	CEC	0.3928**	0.1543	Y = 5.2162 − 0.0334 x
	Exch.Ca	0.3735**	0.1395	y = 4.3045 + 0.1040 X
	Exch.Mg	−0.5654**	0.3197	y = 5,6464 − 0.5881 X
	Exch.Na	−0.5293**	0.2802	y = 5.2390 − 0.3507 X
	Exch.K	−0.2043*	0.0417	y = 4.9508 − 0.7246 X
	ΔpH	0.6054**	0.3665	y = 3.1206 + 2.2118 X
	Exch.H	−0.5253**	0.2759	y = 4.9489 − 0.1261 X
	ECEC	−0.4091**	0.1673	y = 5.2384 − 0.0471 X
	% Base saturation	0.4770**	0.2275	y = 3.0610 − 0.0281 X
KCl pH				
1:1	Exch Al	−0.6038**	0.3646	y = 4.3537 − 0.2295 X
	Org. matter %	−0.4123**	0.1700	y = 4.3757 − 0.1214 X
	Available N	−0.3828**	0.1465	y = 4.9282 − 0.0052 X
	Available K	−0.1924*	0.0370	y = 4.1789 − 0.0014 X
	DTPA Fe	−0.2736**	0.0748	y = 4.1118 −0.0002 X
	Available Cu	0.2742**	0.0752	y = 3.6582 − 0.0703 X
	Available Ca	0.5237**	0.2780	y = 3.5961 + 0.0003 X
	Available Mg	−0.4282**	0.1834	y = 4.4869 − 0.0022 X
	Available Na	−0.4249**	0.1805	y = 4.2523 − 0.0005 X
	CEC	−0.2637**	0.0695	y = 4.2826 − 0.0191 X
	Exch.Ca	0.4537**	0.2058	y = 3.5568 + 0.1080 X
	Exch. Mg	−0.4578**	0.2096	y = 4.6370 − 0.4073 X
	Exch.Na	−0.4536**	0.2057	y = 4.3750 − 0.2571 X
	ΔpH	0.3980**	0.1584	y = 3.0985 + 1.2438 X
	Exch.H	−0.4205**	0.1768	y = 4.1522 − −0.0863 X
	Effective CEC	−0.2784**	0.0775	y = 4.2994 − 0.0274 X
	% Base saturation	0.4725**	0.2232	y = 2.5867 + 0.0238 X

y	x	r	R^2	Regression equation
CaCl$_2$ pH				
1:2	Exch.Al	– 0.6206**	0.3851	y = 4.7726 – 0.2589 X
	Org. matter %	– 0.4201**	0.1765	y = 4.7938 – 0.1358 X
	Available N	– 0.3925**	0.1540	y = 5.4180 – 0.0058 X
	DTPA Fe	– 0.3324**	0.1105	y = 4.5210 – 0.00029 X
	Available Zn	– 0.2541**	0.0646	y = 4.4362 – 0.0040 X
	Available Cu	0.2816**	0.0793	y = 3.9888 + 0.0792 X
	Available Ca	0.5283**	0.2791	y = 3.9299 + 0.0003 X
	Available Mg	– 0.4189**	0.1754	y = 4.8968 – 0.0024 X
	Available Na	– 0.4161**	0.1732	y = 4.6453 – 0.0005 X
	CEC	– 0.2893**	0.0837	y = 4.7133 – 0.0231 X
	Exch.Ca	0.4630**	0.2144	y = 3.877 + 0.1210 X
	Exch.Mg	– 0.4522**	0.2045	y = 5.0645 – 0.4414 X
	Exch.Na	−0.4430**	0.1962	y = 4.7761 – 0.2754 X
	ΔpH	0.4138**	0.1712	y = 3.3453 + 1.4189 X
	Exch.H	– 0.4746**	0.2252	y = 4.5612 + 0.1069 X
	ECEC	−0.3024**	0.0914	Y = 4.7299 – 0.0327 X
	% Base saturation	0.4757**	0.2263	y = 2.8127 + 0.0263 X
Electrical conductivity				
	Exch.Al	0.6752**	0.4559	y = 2.87 + 0.5720 X
	Org. matter %	0.4318**	0.1865	y = 0.2117 + 0.2835 X
	Available N	0.3342**	0.1117	y = −0.7210 + 0.0101 X
	Available K	0.2012*	0.404	y = 0.6717 + 0.0033 X
	DTPA Fe	0.4231**	0.1790	y = 0.7133 + 0.0007 X
	Available Zn	0.4179**	0.1747	y = 0.8930 + 0.0135 X
	Available Cu	−0.3915**	0.1532	y = 2.1836 – 0.2236 X
	Available Mg	0.7746**	0.6001	y = −0.5887 + 0.0092 X
	Available Na	0.8770**	0.7691	y = −0.0511 + 0.0024 X
	Exch.Mg	0.7855**	0.6171	y = 1.3333 + 1.5574 X
	Exch.Na	0.8802**	0.7749	y = −0.5148 + 1.1117 X
	ΔpH	−0.5393**	0.2909	y = 3.8171 – 3.7562 X
	Exch.H	0.6190**	0.3832	y = 0.5978 + 0.2833 X
	ECEC	0.7569**	0.5730	y = – 0.6911 + 0.1664 X
Exchange acidity				
	Exch.Al	0.9319**	0.8684	y = −0.6876 + 2.5603 X
	Org. matter %	0.7705**	0.5938	y = −1.7955 + 1.6405 X
	Available N	0.5789**	0.3351	y = 6.8889 + 0.0571 X
	DTPA Fe	0.8456**	0.3351	y = 0.860784 + 0.0049 X
	Available Mn	0.2444**	0.0597	y = 1.5124 + 0.0623 X
	Available Zn	0.5910**	0.3493	y = 2.3558 + 0.0620 X
	Available Cu	−0.3690**	0.1361	y = 6.5666 – 0.6836 X

y	x	r	R^2	Regression equation
	Available Mg	0.4767**	0.2272	y = 0.6888 + 0.01838 X
	Available Na	0.2921**	0.0853	y = 1.9464 + 0.0027 X
	CEC	0.8285**	0.6864	y = –3.0541 + 0.4355 X
	Exch.Mg	0.5230**	0.2736	y = –2.0286 + 3.3628 X
	Exch.Na	0.3372**	0.1137	y = 1.1893 + 1.3809 X
	ΔpH	–0.4802**	0.2306	y = 11.0944 – 10.4855 X
	Exch.H	0.9805**	0.9615	y = 0.7434 + 1.4554 X
	ECEC	0.8600**	0.7397	Y = –3.3237 + 0.6131 X
	% Base saturation	–0.4597**	0.21138	y = 13.1554 – 0.1679 X
Non exch acidity				
	Exch Al	0.7574**	0.5737	y = 12.9008 + 11.4582 X
	Org. matter %	0.8539**	0.7292	y = –0.1092 + 10.0102 X
	Available N	0.6322**	0.3997	y = –30.2973 + 0.3433 X
	DTPA Fe	0.8290**	0.6873	y = 17.7139 + 0.02666 X
	Available Mn	0.3402**	0.1157	y = 17.5112 + 0.4778 X
	Available Zn	0.6426**	0.4130	y = 25.3139 + 0.3713 X
	Available Cu	–0.2472**	0.06113	y = 42.6832 – 2.5319 X
	Available Mg	0.3646**	0.1329	y = 13.9089 + 0.07735 X
	CEC	0.8814**	0.7770	y = –6.2773 + 2.5516 X
	Exch.Ca	0.1900*	0.03612	y = 22.5574 + 1.8013 X
	Exch.Mg	0.4477**	0.2005	y = 5.6634 + 15.8514 X
	ΔpH	–0.3572**	0.1275	y = 62.61106 – 44.4146 X
	Exch H	0.9277**	0.8607	y = 17.5350 + 7.5823 X
	ECEC	0.7591**	0.5763	y = –1.3912 + 2.9801 X
	% Base saturation	–0.4983**	0.2483	y = 89.7800 – 1.0020 X
Potential acidity				
	Exch.Al	0.7928**	0.6286	y = 12.2021 + 13.9762 X
	Org. matter %	0.8538**	0.7289	y = –2.0143 + 11.6623 X
	Available N	0.6316**	0.3989	y = –37.1320 + 0.3997 X
	DTPA Fe	0.4830**	0.7170	Y = 18.5042 + 0.0315 X
	Available Mn	0.3315**	0.1099	y = 18.8856 + 0.5426 X
	Available Zn	0.6437**	0.4143	y = 27.5947 + 0.4334 X
	Available Cu	–0.2694**	0.0726	y = 49.1601 – 3.2025 X
	Available Mg	0.3876**	0.1503	y = 13.1228 + 0.0958 X
	CEC	0.8861**	0.7853	y = –9.4329 + 2.9890 X
	Exch.Ca	0.1841**	0.0341	y = 24.6394 + 2.0398 X
	Exch.Mg	0.4661**	0.2172	y = 3.5415 + 19.2263 X
	Exch.Na	0.1984*	0.0393	y = 25.7538 + 5.211548 X
	ΔpH	–0.3810**	0.1451	y = 73.5898 – 55.20413 X
	Exch H	0.9481**	0.8989	y = 18.2182 + 9.0291 X
	ECEC	0.7849**	0.6161	y = –4.7593 + 3.5904 X
	% Base saturation	–0.5016**	0.2516	y = 103.1906 – 1.1754 X

* Significant at 5% level ** Significant at 1% level

Under dry condition 48 per cent of variation in active acidity was contributed by exchangeable aluminium, organic matter accounted for 25 per cent, exchangeable hydrogen for 28 per cent. Dry pH (H_2O) 1:1 had negative significant correlations with exchangeable aluminium ($r = -0.69^{**}$), organic matter ($r = -0.50^{**}$), Nitrogen ($r = -0.44^{**}$), Iron ($r = -0.36^{**}$), CEC ($r = -0.39^{**}$), exchangeable hydrogen ($r = -0.53^{**}$). Though 28 per cent of variation in pH could be accounted by percentage base saturation only calcium had a positive influence on it.

4.7.2 Exchange acidity and acidity contributing factors

Exchange acidity had positive significant correlations with exchangeable aluminium ($r = 0.93^{**}$), organic matter ($r = 0.77^{**}$), nitrogen ($r = 0.58^{**}$), iron ($r = 0.85^{**}$), manganese ($r = 0.24^{**}$), CEC ($r = 0.83^{**}$), ECEC ($r = 0.86^{**}$) and exchangeable hydrogen ($r = 0.98^{**}$). 86 per cent of variation in exchange acidity was accounted by exchangeable aluminium ($R^2 = 0.86$). Organic matter had a coefficient of determination 0.59 and cation exchange capacity 0.68, exchangeable hydrogen 0.96 and effective cation exchange capacity 0.73.

4.7.3 Non-exchange acidity and acidity contributing factors

Non exchange acidity was mainly governed by exchangeable hydrogen ($r = 0.93^{**}$), CEC ($r = 0.88^{**}$), organic matter ($r = 0.85^{**}$), effective CEC ($r=0.76^{**}$), exchangeable aluminium ($r = 0.76^{**}$) and nitrogen ($r = 0.63^{**}$). 86 per cent of variation of this component was accounted by exchangeable hydrogen ($R^2 = 0.86$). Cation exchange capacity and organic matter determined about 77 per cent and 73 per cent of variation in non exchange acidity respectively.

4.7.4. Potential acidity and acidity contributing factors

The coefficient of determination (R^2) for exchangeable hydrogen, cation exchange capacity, organic matter, exchangeable aluminium, iron and nitrogen were 0.90, 0.79, 0.73, 0.63, 0.72, and 0.39 respectively. In wetland soils of Kerala exchangeable hydrogen, organic matter and cation exchange capacity determined the extent of potential acidity.

4.7.5. Correlations between components of acidity and acidity contributing factors in selected samples

The parameters that could not be analysed for 120 samples are dealt here. The regressions are presented in Table 12. From the correlations it was found that when available sulphur in the soil increases there was a decrease in pH ($r = -0.36^{**}$). Redox potential had negative significant correlation with pH under field condition ($r = -0.43^{**}$). Under dry condition redox potential accounted for 69 per cent of variation in active acidity. Dry soil pH had negative correlations with total sulphur ($r = -0.35^{**}$), available sulphur ($r = -0.59^{**}$), redox potential ($r = -0.83^{**}$) and clay content ($r = -0.55^{**}$). Total sulphur accounted for 13 per cent, available sulphur 35 per cent and clay content 30 per cent of variation in active acidity.

The main contributors towards exchange acidity among the factors studied in 36 samples were total sulphur ($R^2 = 0.51$), redox potential ($R^2 = 0.66$), available sulphur ($R^2 = 0.37$) and clay content ($R^2 = 0.26$).

Non-exchange acidity was positively and significantly influenced by total sulphur ($r = 0.59^{**}$), available sulphur ($r = 0.71^{**}$), Eh ($r = 0.69^{**}$) and clay content ($r = 0.56^{**}$).

Table 12. Regression equations between acidity components and acidity generating factors in selected 36 surface samples

y	x	r	R^2	Regression equation
Field condition				
Water pH 1:1	Available S	−0.3568*	0.1273	y = 5.8421 − 1.8836 X
	Eh	−0.4329**	0.1874	y = 8.7071 − 0.0065 X
Water pH 1:2.5	Available S	−0.3756*	0.1411	y = 6.0739 − 0.0001 X
	Eh	−0.4221*	0.1782	y = 8.7622 − 0.0062 X
KCl pH 1:1	Available S	−0.3673*	0.1349	y = 5.1197 − 0.0001 X
	Eh	−0.3942*	0.1554	y = 7.4100 − 0.0053 X
Electrical conductivity 1:2.5	Total S	0.4785**	0.2290	y = 0.1106 − 0.0004 X
	Available S	0.3884*	0.1508	y = 0.1981 − 0.0004 X
	Eh	0.3679*	0.1354	y = −5.1324 + 0.0125 X
Dry Condition				
Water pH 1:1	Total S	−0.3535*	0.1250	y = 5.1083 − 0.00006 X
	Available S	−0.5886**	0.3464	y = 5.2696 − 0.0004 X
	Eh	−0.8280**	0.6857	y = 12.6803 −0.0167 X
	Sand%	0.4674**	0.2184	y = 3.8704 + 0.0211 X
	Clay%	−0.5489**	0.3013	y = 6.0426 − 0.0274 X
Water pH 1:2.5	Total S	−0.3736*	0.1396	y = 5.2566 − 0.00007 X
	Available S	−0.6217**	0.3865	y = 5.432 − 0.0004 X
	Eh	−0.8318**	0.6919	y = 13.0721 − 0.0173 X
	Sand%	0.4782**	0.2287	y = 3.9369 + 0.0222 X
	Clay%	−0.5635	0.3175	y = 6.2317 − 0.0290 X

y	x	r	R^2	Regression equation
KCl pH				
	Available S	−0.5345**	0.2856	y = 4.3643 − 0.0032 X
	Eh	−0.7913**	0.6262	y = 10.1965 − 0.013 X
	Sand%	0.4817**	0.2320	y = 3.2396 + 0.0178 X
	Clay%	−0.5361**	0.2875	y = 5.0163 − 0.0219 X
CaCl$_2$ pH				
1:2	Available S	−0.4913**	0.2414	y = 4.7964 − 0.0003 X
	Eh	−0.7742**	0.5994	y = 11.2337 − 0.0180 X
CaCl$_2$ pH				
1:2.5	Sand %	0.4337**	0.1881	y = 3.6499 − 0.0180 X
	Clay %	−0.4861**	0.2363	y = 5.4540 − 0.0223 X
E.C 1:2.5	Total S	0.6956**	0.4839	y = −0.5209 + 0.0002 X
	Available S	0.5898**	0.3479	y = 0.0926 + 0.0007 X
	Eh	0.6262**	0.3921	y = −9.7580 + 0.0224 X
	Clay %	0.3519*	0.1238	y = −0.5995 + 0.0311 X
Δ pH				
	Total S	−0.38061*	0.1448	y = 0.8786 − 0.000018 X
	Available S	−0.5577**	0.3111	y = 0.9052 − 0.0001 X
	Eh	0.6646**	0.4417	y = 2.4837 − 0.0036
	Clay %	−0.4053*	0.1643	y = 1.0262 − 0.0054 X
Exch. acidity	Total S	0.7116**	0.5064	y = −1.2192 + 0.00059 X
	Available S	0.6101**	0.3722	y = −0.1368 + 0.00193 X
	Eh	0.8132**	0.6614	y = −32.6798 + 0.0738 X
	Sand %	−0.4602**	0.211861	y = 6.18501 − 0.0933 X
	Clay %	0.5066**	0.2566	y = −3.0447 + 0.1136 X
Non-exch. acidity				
	Total S	0.5897**	0.3478	y = 8.1073 + 0.0030 X
	Available S	0.70970**	0.5036	y =8.0751 + 0.0139 X
	Eh	0.6926**	0.4798	y = −159.0397 + 0.3909 X
	Sand %	−0.5282**	0.2790	y = 53.4476 − 0.6664 X
	Clay %	0.5633**	0.3173	y = 11.1668 + 0.7859 X
Potential acidity				
	Total S	0.6269**	0.3930	y = 6.8847 + 0.0036 X
	Available S	0.7217**	0.5209	y = 7.8587 + 0.0159 X
	Eh	0.7318**	0.5356	y = −191.8368 + 0.4654 X
	Sand %	−0.5408**	0.2921	y = 60.0001 − 0.7678 X
	Clay %	0.5777**	0.3337	y = −14.5551 + 0.9076 X

* Significant at 5% level ** Significant at 1% level

The variation in potential acidity was mainly accounted by total sulphur (39%), available sulphur (52%), redox potential (53%) and clay content (33%).

4.8 Correlation between soil acidity components and available nutrients in surface samples of major wet lands

Correlations and regressions between acidity components and available nutrients are presented in Table 11 and appendix 4&5. Available nitrogen, available potassium, magnesium, sodium, iron and zinc had got negative significant correlations with pH (1:1) under dry condition. Available calcium and copper had got positive significant correlations with pH.

Exchange acidity recorded positive significant correlations with available nitrogen, magnesium, sodium, iron, manganese and zinc but negative significant correlation was found with copper.

Non-exchange acidity registered positive significant correlation with available nitrogen, calcium, magnesium, manganese and zinc whereas available copper recorded negative significant value.

Positive significant correlations were observed between potential acidity and available nitrogen, calcium, magnesium, sodium, iron, manganese and zinc while available copper recorded a negative significant value.

4.9. Relationship between soil acidity components and acidity generating factors within wet lands

From the analysis of variance it was found that almost all the soil characters studied varied significantly between the wetlands. Since correlations and regressions were worked out separately for each wet land. The correlations within wetlands and regressions taking acidity components as dependent factor and acidity contributing factors as independent factor is given in Table 13.

Comparing the pH under field and dry conditions, it was found that dry pH has got more significant correlations with the soil characters studied since all the determinations were made with dry soil. In Vellayani surface samples it was observed that variation in pH under dry condition was mainly accounted by exchangeable aluminium ($R^2 = 0.49$) and exchangeable hydrogen ($R^2 = 0.51$). pH (KCl) had got negative significant correlations with exchangeable aluminium ($r = -0.98^{**}$), organic matter ($r = -0.79^{**}$), nitrogen ($r = -0.91^{**}$), CEC ($r = -0.75^{*}$), exchangeable hydrogen ($r = -0.86^{*}$) and ECEC ($r = -0.91^{**}$). When the content of these factors increased in soil there was a decrease in pH. 98 per cent of variation in exchange acidity in Vellayani surface soils was contributed by exchangeable aluminium ($R^2 = 0.98$). Other major contributors were exchangeable hydrogen ($R^2 = 0.85$), nitrogen ($R^2 = 0.73$), ECEC ($R^2 = 0.68$) etc. The main soil character that accounted towards potential acidity were exchangeable aluminium ($R^2 = 0.65$), organic matter ($R^2 = 0.49$), and exchangeable hydrogen ($R^2 = 0.61$).

In Karamana soils about 52 per cent variation in pH was accounted by organic matter ($R^2 = 0.52$). The coefficient of determination (R^2) for ΔpH and iron were 53 and 40 per cent respectively. Exchange acidity was mainly accounted by exchangeable aluminium ($R^2 = 0.82$) and organic matter ($R^2 = 0.80$).

Under *Karapadom* conditions the variation in field water pH 1:1 was mainly accounted by available magnesium ($R^2 = 0.49$). KCl pH under field condition was controlled by available iron concentration ($R^2 = 0.45$). Variation in active acidity under dry condition was accounted by ECEC exchangeable aluminium, exchangeable hydrogen and ΔpH. The coefficient of determination for exchangeable aluminium, exchangeable hydrogen and ECEC towards pH in KCl solution were 0.73, 0.74 and 0.74 respectively. The main soil characters that controlled exchange acidity in *Karapadom* soils were exchangeable aluminium ($R^2 = 0.99$) and exchangeable hydrogen (R^2 0.99). Potential acidity was mainly controlled by the organic matter status of soil ($R^2 = 0.67$).

In *Kayal* surface samples 40 per cent variation in pH under field wet condition was accounted by available calcium ($R^2 = 0.40$). Under dry condition exchangeable aluminium, exchangeable hydrogen, manganese, iron and ECEC controlled active acidity. Exchange acidity in *Kayal* soils was mainly contributed by exchangeable aluminium ($R^2 = 0.99$), exchangeable hydrogen ($R^2 = 0.99$), available manganese ($R^2 = 0.67$) and CEC ($R^2 = 0.39$). Effective CEC, exchangeable hydrogen, exchangeable aluminium and cation exchange capacity determined the variations in potential acidity in these soils. The coefficient of determination (R^2) for these factors were 0.84, 0.77, 0.77 and 0.52 respectively.

The main soil parameters that accounted for the variation in pH in *Kari* soils were CEC ($R^2 = 0.78$), exchangeable hydrogen ($R^2 = 0.71$), organic matter ($R^2 = 0.68$), ECEC ($R^2 = 0.67$), nitrogen ($R^2 = 0.66$) exchangeable aluminium ($R^2 = 0.61$) manganese ($R^2 = 0.62$) and iron ($R^2 = 0.50$). Exchange acidity was mainly controlled by exchangeable aluminium ($r = 0.94^{**}$), iron ($r = 0.91^{**}$), CEC ($r = 0.87^{**}$) and available manganese ($r = 0.84^{**}$). Cation exchange capacity ($R^2 = 0.95$), exchangeable hydrogen ($R^2 = 0.95$), nitrogen ($R^2 = 0.90$), organic matter ($R^2 = 0.85$), iron ($R^2 = 0.70$) and manganese ($R^2 = 0.70$) were the determining soil factors towards potential acidity.

Table 13. Regressions between components of acidity with acidity generating factors and available nutrients within the surface samples of wetlands (n = 10)

y	x	r	R^2	Regression equation
I. Vellayani				
Field condition				
Water pH				
1:1	Av. Copper	0.82**	0.66	y = 3.64 + 0.34 X
	Av. Magnesium	0.71*	0.50	y = 3.73 + 0.01 X
KCl pH 1:1	Av. Copper	0.84**	0.71	y = 3.14 + 0.37 X
	Av. Magnesium	0.77**	0.60	y = 3.15 + 0.01 X
Dry condition				
Water pH	Exch. Al.	−0.70*	0.49	y = 4.60 − 0.22 X
1:1	Exch. H	−0.72*	0.51	y = 4.62 − 0.58 X
KCl pH 1:1	Exch. Al.	−0.98**	0.96	y = 3.96 − 0.27 X
	Org. Matter	−0.79**	0.62	y = 4.01 + 0.13 X
	Av. N	−0.91**	0.83	y = 4.15 − 0.002 X
	Av. Zn	−0.70*	0.49	y = 3.90 − 0.07 X
	Av. Mg	−0.86**	0.73	y = 4.19 − 0.004 X
	CEC	−0.75*	0.56	y = 4.26 − 0.08 X
	Exch. H	−0.86**	0.74	y = 3.94 − 0.60 X
	ECEC	−0.91**	0.83	y = 4.25 − 0.11 X
Exchange acidity				
	Exch. Al	0.98**	0.98	y = 0.09 + 1.34 X
	Org. Matter	0.68*	0.47	y = 0.06 + 0.55 X
	Av. N	0.85**	0.73	y = −0.69 + 0.01 X
	Av. Zn	0.79**	0.62	y = 0.25 + 0.38 X
	Av. Mg	0.79**	0.62	y = −0.84 + 0.02 X
	Exch. H	0.92**	0.85	y = 0.11 + 3.16 X
	ECEC	0.83**	0.68	y = −1.05 + 0.47 X
Potential acidity				
	Exch. Al	0.81**	0.65	y = 8.14 + 9.73 X
	Org. matter	0.70*	0.49	y = 5.19 + 4.97 X
	Av. N	0.79**	0.62	y = 0.35 + 0.09 X
	Av. Mg	0.73*	0.53	y = −0.96 + 0.17 X
	Exch. H	0.78**	0.61	y = 7.88 + 23.92 X
	ECEC	0.73*	0.54	y = −1.82 + 3.74 X

y	x	r	R^2	Regression equation
2. Karamana				
Dry condition				
Water pH				
1 : 1	Org. matter	−0.72*	0.52	y = 5.96 − 0.39 X
	DTPA Fe	−0.64*	0.40	y = 5.76 − 0.002 X
	Δ pH	0.73*	0.53	y = 4.10 + 1.11 X
KCl pH 1 : 1	Exch. Al	−0.52	0.27	y = 4.57 − 1.34 X
	Org. matter	−0.58	0.34	y = 4.60 − 0.21 X
Exch. acidity	Exch. Al	0.91**	0.82	y = 0.08 + 1.24 X
	Org. matter	0.89**	0.80	y = 0.09 + 0.18 X
	Av. N	0.64*	0.41	y = −0.38 + 0.005 X
	Av. K	0.78**	0.60	y = 0.32 + 0.001 X
	DTPA Fe	0.69*	0.47	y = 0.22 + 0.008 X
	Av. Mn	0.68**	0.46	y = 0.22 + 0.008 X
	Exch. H	0.74*	0.54	y = 0.16 + 1.66 X
3. *Karapadom*				
Field condition				
Water pH				
1 : 1	Av. Mg	0.70*	0.49	y = 4.59 + 0.001 X
KCl pH 1 : 1	DTPA Fe	−0.67*	0.45	y = 3.62 + 0.002 X
Dry condition				
Water pH	Exch. Al	−0.82**	0.68	y = 4.67 − 0.18 X
	Av. Mn	0.63*	0.40	y = 4.03 + 0.01 X
	Av. Cu	0.82**	0.68	y = 3.75 + 0.09 X
	Av. Na	−0.68*	0.46	y = 5.02 − 0.002 X
	Δ pH	−0.81**	0.66	y = 3.16 + 1.86 X
	Exch. H	−0.81**	0.66	y = 4.71 − 0.30 X
	ECEC	−0.87**	0.75	y = 5.17 − 0.11 X
KCl pH 1 : 1	Exch. Al	−0.86**	0.73	y = 3.96 − 0.13 X
	Av. Mn	0.72*	0.60	y = 3.47 + 0.008 X
	Av. Cu	0.93**	0.86	y = 3.26 + 0.08 X
	Av. Na	−0.65*	0.42	y = 4.17 − 0.001
	Exch. H	−0.86**	0.74	y = 3.99 − 0.22 X
	ECEC	−0.86**	0.74	y = 4.29 − 0.07 X

y	x	r	R^2	Regression equation
Exch. acidity				
	Exch. Al	0.998**	0.997	y = 0.14 + 1.58 X
	Org. matter	0.69*	0.48	y = −3.22 + 1.40 X
	Av. N	0.66*	0.44	y = −4.88 + 0.03 X
	Av. Cu	−0.72*	0.51	y = 6.78 − 0.61 X
	CEC	0.65*	0.43	y = −4.33 + 0.56 X
	Exch. H	0.99**	0.99	y = −0.19 + 2.67 X
	ECEC	0.91**	0.83	y = −3.13 + 0.80 X
Potential acidity				
	Org. matter	0.82**	0.67	y = −1.73 + 8.15 X
	Av. N	0.75**	0.57	y = −9.82 + 0.20 X
	Exch. H	0.64*	0.41	y = 25.16 + 8.49 X
4. *Kayal*				
Field condition				
Water pH				
1:1	Av. Ca	0.64*	0.40	y = 4.10 + 7.91 X
	% Base Saturation	0.66*	0.44	y = 1.99 − 0.06 X
KCl pH 1:1	Av. Ca	0.70*	0.50	y = 3.70 + 0.0007 X
Dry condition				
Water pH				
1:1	Exch. Al	−0.88**	0.77	y = 5.52 − 0.37 X
	DTPA Fe	−0.64*	0.41	y = 6.22 − 0.005 X
	Av. Mn	0.85**	0.73	y = 3.28 + 0.04 X
	Av. Cu	0.72*	0.53	y = 3.16 + 0.41 X
	Exch. H	−0.87**	0.76	y = 5.48 − 0.52 X
	ECEC	−0.75*	0.57	y = 6.92 − 0.17 X
KCl pH 1:1	Exch. Al	−0.82**	0.66	y = 4.69 − 0.30 X
	DTPA Fe	−0.75*	0.56	y = 5.66 − 0.004 X
	Av. Mn	0.82**	0.67	y = 2.81 + 3.10 X
	Av. Cu	0.63*	0.40	y = 2.75 + 0.0008 X
	Exch. H	−0.80**	0.63	y = 4.64 − 0.42 X
	ECEC	−0.72*	0.51	y = 5.89 − 0.41 X

y	x	r	R^2	Regression equation
Exch. acidity				
	Exch. Al	0.997**	0.99	y = –0.03 + 1.69 X
	Av. Mn	–0.82**	0.67	y = 9.42 – 0.14 X
	Av. Cu	–0.87**	0.76	y = 11.13 – 2.0 X
	CEC	0.62*	0.39	y = –6.0 + 0.55 X
	Δ pH	–0.70*	0.49	y = 13.07 – 12.65 X
	Exch. H	0.99**	0.99	y = 0.14 + 2.40 X
	ECEC	0.91**	0.83	y = –7.17 + 0.82 X
Pot acidity				
	Exch. Al	0.88**	0.77	y = 27.51 + 4.79 X
	Av. Mn	–0.64*	0.41	y = 52.90 – 0.35 X
	Av. Cu	–0.71*	0.50	y = 57.91 – 5.27 X
	CEC	0.72*	0.52	y = 0.85 + 2.04 X
	Exch. H	0.87**	0.77	y = 28.01 + 6.82 X
	ECEC	0.92**	0.84	y = 2.26 + 2.68 X
5. *Karl*				
Field condition				
Water pH				
1:1	Av. Cu	–0.73*	0.54	y = 5.37 – 0.27 X
Dry condition				
Water pH				
1:1	Exch. Al	–0.78**	0.61	y = 3.78 – 0.10 X
	Org. matter	–0.83**	0.68	y = 4.22 – 0.09 X
	Av. N	–0.81**	0.66	y = 4.42 – 0.005 X
	Av. K	0.85**	0.73	y = 2.53 + 0.005 X
	DTPA Fe	–0.71*	0.50	y = 3.50 – 0.0001 X
	Av. Mn	–0.79**	0.62	y = 3.53 – 0.01 X
	Av. Zn	–0.65*	0.42	y = 3.37 – 0.002 X
	CEC	–0.88**	0.78	y = 4.06 – 0.02 X
	Exch. H	–0.84**	0.71	y = 3.65 – 0.04 X
	ECEC	–0.82**	0.67	y = 3.89 – 0.03 X
	% Base saturation	0.77**	0.60	y = 2.33 + 0.02 X
KCl pH 1:1	Av. K	0.65*	0.43	y = 2.51 + 0.002 X
	Δ pH	0.70*	0.48	y = 2.43 + 0.97 X

y	x	r	R^2	Regression equation
Exch. acidity				
	Exch. Al	0.94**	0.87	y = −2.47 + 3.29 X
	Org. matter	0.79**	0.62	y = −10.00 + 2.50 X
	Av.N	0.84**	0.70	y = −17.45 + 0.13 X
	Av.K	−0.75*	0.56	y = 32.35 − 0.13 X
	Av.Fe	0.91**	0.82	y = 6.25 + 0.004 X
	Av.Mn	0.84**	0.70	y = 6.95 + 0.30 X
	CEC	0.87**	0.77	y = −6.45 + 0.56
	Exch Ca	0.72*	0.52	y = −11.73 + 4.99 X
Pot acidity				
	Exch. Al	0.84**	0.70	y = 20.57 + 19.11 X
	Org. matter	0.92**	0.85	y = −69.41 + 18.89 X
	Av.N	0.95**	0.90	y = −118.71 + 0.98 X
	Av.K	−0.77**	0.59	y = 236.41 − 0.86 X
	Av.Fe	0.84**	0.70	y = 69.34 + 0.02 X
	Av.Mn	0.84**	0.70	y = 68.91 + 1.94 X
	Av.Zn	0.64*	0.40	y = 101.25 + 0.32 X
	CEC	0.97**	0.95	y = −35.35 + 4.03 X
	Exch. Ca	0.73*	0.54	y = −55.77 + 32.98 X
	Exch. H	0.95**	0.91	y = 40.90 + 8.34 X
	ECEC	0.89**	0.80	y = −1.29 + 5.09 X
	% Base saturation	−0.82**	0.68	y = 29.27 − 4.48 X
6. *Pokkali*				
Field condition				
Water pH	Exch.Al	−0.47	0.22	y = 6.00 − 0.11 X
	Org matter %	0.43	0.18	y = 4.52 + 0.35 X
	Av.Ca	0.45	0.20	y = 5.08 + 0.0003 X
Dry condition				
Water pH				
1:1	ExchAl	−0.84**	0.71	y = 3.64 − 0.12 X
	Exch H	−0.90**	0.81	y = 3.82 − 0.15 X
	ECEC	−0.83**	0.68	y = 4.50 − 0.06 X
KCl pH 1:1	Exch Al	−0.73*	0.54	y = 3.15 − 0.08 X
	Av.Cu	0.84**	0.71	y = 2.55 + 0.13 X
	Exch H	−0.85**	0.73	y = 3.32 − 0.12 X
	ECEC	−0.69*	0.48	y = 3.78 − 0.04 X

y	x	r	R^2	Regression equation
Exch acidity	Exch Al	0.98**	0.97	y = 1,21 +1.73 X
	Av.Cu	−0.78**	0.61	y = 12.19 − 1.97 X
	Exch.H	0.98**	0.95	y = −0.85 + 2.07 X
	ECEC	0.89**	0.78	y = −11.39 + 0.82 X
Pot acidity	Org.matter	0.76*	0.57	y = 6.67 +11.44 X
	Av.N	0.81**	0.66	y = −11.72 + 0.28X
	DTPA Fe	−0.83**	0.68	y = 97.99 − 0.12 X
	Av.Ca	0.90**	0.81	y = 22.72 +0.01 X
	CEC	0.75*	0.56	y = −1.05 + 1.81 X
	Exch.Mg	0.73*	0.53	y = 3.59 + 10.08 X
	Exch.H	0.75*	0.57	y = 24.99 + 3.96 X
	ECEC	0.87**	0.75	y = −3.73 + 1.90 X
7. ***Kole***				
Filed condition				
Water pH				
1:1	Av.Mg	0.70*	0.48	y = 5.73 − 0.006 X
Dry condition				
Water pH				
1:1	Av.Ca	0.65*	0.42	y = 4.28 + 0.04 X
	ΔpH	0.70*	0.46	y = 3.63 + 1.19 X
KCl pH 1:1	Exch.Al	−0.71*	0.51	y = 4.02 − 0.27 X
Exch. acidity	Exch.Al	0.97**	0.94	y = 0.42 + 1.17 X
	Exch H	0.71**	0.50	y = −0.04 + 2.53 X
Pot.acidity	Org. matter	0.75*	0.56	y = 0.44 + 14.74 X
	Av.N	0.80**	0.64	y = −11.63 + 0.22 X
	CEC	0.75*	0.57	y = 9.55 + 1.74 X
	Δ pH	0.81**	0.66	y = −2.52 + 38.95 X
8. ***Kaipad***				
Field condition				
Water pH				
1:1	ExchAl	−0.78**	0.61	y = 5.80 − 0.45 X
	Av.K	−0.87**	0.75	y = 5.92 − 0.01 X
	Av.Na	−0.74*	0.54	y = 6.58 − 0.006 X
	ExchH	−0.74*	0.54	y = 5.80 − 1.01 X
	ECEC	−0.66*	0.44	y = 6.39 − 0.20 X

y	x	r	R^2	Regression equation
Dry condition				
Water pH				
1:1	ExchAl	−0.76**	0.59	y = 5.47 − 0.42 X
	Org. matter	−0.74*	0.55	y = 5.68 − 1.42 X
	Av.K	−0.83**	0.68	y = 5.57 − 0.01 X
	Av.Zn	−0.71*	0.51	y = 5.93 − 0.52 X
	Av.Na	−0.75*	0.56	y = 6.24 − 0.006 X
	CEC	−0.65*	0.42	y = 6.74 − 0.34 X
	Exch. H	−0.78**	0.60	y = 5.48 − 1.01 X
	ECEC	−0.69*	0.48	y = 6.07 − 0.20 X
KCl pH 1:1	Exch Al	−0.71*	0.50	y = 4.62 − 0.35 X
	Av.K	−0.76*	0.57	y = 4.70 − 0.009 X
	Av.Na	−0.69*	0.47	y = 4.70 − 0.009 X
	CEC	−0.70*	0.49	y = 5.88 − 0.33 X
	Exch.H	−0.74*	0.56	y = 4.64 − 0.87 X
	ECEC	−0.68	0.47	y = 5.17 − 0.18 X
Exch.acidity				
	Exch.Al	0.999**	0.99	y = 0.01 + 1.41 X
	Org. matter	0.94**	0.88	y = −0.65 + 4.67 X
	Av. P	0.67*	0.45	y = 0.87 + 0.08 X
	Av. K	0.97**	0.94	y = 0.23 + 0.03 X
	Av. Zn	0.68*	0.47	y = 0.97 + 1.20 X
	Av. Cu	0.64*	0.40	y = 0.84 + 0.57 X
	Exch. H	0.99*	0.99	y = − 0.02 + 3.37 X
	ECEC	0.93**	0.86	y = − 2.10 + 0.69 X
9. Pattambi				
Field condition				
Water pH				
1:1	Av.Ca	0.66*	0.43	y = 5.16 + 0.0007 X
	Av.Mg	0.65*	0.42	y = 4.91 + 0.006 X
	CEC	0.76*	0.58	y = 4.37 + 0.20 X
	Exch.Ca	0.78**	0.61	y = 5.00 + 0.31 X
	ECEC	0.80**	0.64	y = 4.79 + 0.18 X

y	x	r	R^2	Regression equation
Dry condition				
Water pH				
1 : 1	Exch Al	–0.67*	0.45	y = 5.37 – 1.24 X
	Org. matter	–0.86**	0.74	y = 5.73 – 0.75 X
	Av.N	–0.66*	0.45	y = 6.18 – 0.007 X
	DTPA Fe	–0.76**	0.58	y = 5.47 – 0.002 X
	Av.Cu	–0.72*	0.52	y = 5.54 – 0.06 X
	Av.Ca	0.70*	0.48	y = 4.30 + 0.0009 X
	Exch H	–0.64	0.42	y = 5.27 – 2.52 X
KCl pH 1 : 1	Exch. Al	–0.76*	0.58	y = 4.83 – 1.81 X
	Org. matter %	–0.93**	0.86	y = 5.3 – 1.04 X
	Av.N	–0.71*	0.50	y = 5.90 –0.01 X
	DTPA. Fe	–0.87**	0.75	y = 4.98 – 0.002 X
	Av.Cu	–0.79**	0.63	y = 5.06 – 0.08 X
	Av.Na	0.69*	0.47	y = 3.69 – 0.005 X
	ΔpH	–0.67*	0.44	y = 5.29 – 1.48 X
	Exch H	–0.75*	0.56	y = 4.71 – 3.77 X
Exch.acidity				
	Exch. Al	0.99**	0.98	y = – 0.01 + 1.43 X
	Org. matter	0.71*	0.51	y = 0.03 + 0.49 X
	DTPA. Fe	0.83**	0.69	y = 0.03 + 0.001 X
	Av.Cu	0.70*	0.49	y = 0.04 + 0.04 X
	Exch. H	0.96**	0.92	y = 0.09 + 2.92 X
	% Base saturation	–0.74*	0.55	y = – 1.47 – 0.01 X
Potential acidity				
	Exch. Al	0.68*	0.47	y = 12.83 + 18.31 X
	DTPA Fe	0.63*	0.40	y = 12.81 + 0.02 X
	ΔpH	0.80**	0.64	y = 4.50 + 20.00 X
	Exch. H	0.76**	0.58	y = 13.42 + 42.91 X
10. Kattampally				
Field condition				
Water pH	DTPA Fe	–0.79**	0.63	y = 6.61 – 0.005 X
	Av.Zn	0.72*	0.52	y = 5.51 + 0.009 X
	Av. Mg	0.65*	0.42	y = 5.45 + 0.002 X
Dry condition				
Water pH				
1 : 1	Av.Zn	0.66*	0.44	y = 5.21 + 0.009 X
	DTPA. Fe	-0.60	0.36	y = 6.13 - 0.004 X
	Av.Mg	0.60	0.35	y = 5.14 + 0.002 X

y	x	r	R^2	Regression equation
KCl pH 1:1	DTPA Fe	−0.69*	0.47	y = 5.28 − 0.004 X
Exch.acidity				
	Exch. Al	0.99**	0.99	y = 0.0000008 + 1.25 X
	Exch. H	0.99**	0.99	y = 0.0000008 + 5.0 X
Pot acidity				
	Av.K	0.69*	0.47	y = 15.99 + 0.04 X
	Exch.Ca	−0.64*	0.40	y = 21.66 − 0.42 X
	% Base saturation	0.74*	0.55	y = 4.82 + 2.53 X
11. Wyanad				
Field condition				
Water pH 1:1	DTPA. Fe	0.63*	0.40	y = 4.90 + 0.01 X
	Av. Na	0.66*	0.43	y = 5.14 + 0.007 X
Dry condition				
Water pH 1:1	ΔpH	0.89**	0.79	y = 4.10 + 0.87 X
Exch.acidity	Exch.H	0.94**	0.88	y = 0.11 + 1.85 X
12. Chittoor				
Field condition				
Water pH 1:1	Av. Cu	− 0.69*	0.47	y = 8.09 − 0.09 X
Dry condition				
Water pH	Av. Ca	0.66*	0.43	y = 9.01 − 2.14 X
	ΔpH	−0.65*	0.42	y = 9.01 − 2.14 X
	% Base saturation	0.71*	0.50	y = 1.79 + 0.07 X
KCl pH 1:1	Av. Ca	0.73*	0.54	y = 4.77 + 0.0002 X
	Av. Mg	0.69*	0.48	y = 3.52 + 0.02 X
	ΔpH	−0.78**	0.61	y = 9.01 − 3.15 X
	% Base saturation	0.71*	0.50	y = −0.30 + 0.08 X
Exch acidity	% Base saturation	0.69*	0.47	y = − 0.13 + 0.003 X
Pot acidity	Av.P	0.75*	0.56	y = 2.12 + 0.67 X
	Exch. H	−0.73*	0.53	y = 33.91 − 117.23 X

Under *Pokkali* conditions variation in active acidity was accounted by exchangeable hydrogen (81 per cent), exchangeable aluminium (97 per cent) and effective CEC (68 per cent). Exchange acidity was controlled by exchangeable aluminium ($R^2 = 0.97$), exchangeable hydrogen ($R^2 = 0.95$) and ECEC ($R^2 = 0.78$) respectively. Potential acidity was determined by ECEC ($r = 0.87^{**}$), CEC ($r = 0.75^{**}$), nitrogen ($r = 0.81^{**}$), organic matter ($r = 0.76^{**}$) and exchangeable hydrogen ($r = 0.75^{**}$).

In *Kole* soils, available magnesium (R^2 0.48) determined the pH under field wet condition. pH under dry condition was influenced by available calcium ($R^2 = 0.42$) and ΔpH ($R^2 = 0.46$). pH (KCl) was determined by exchangeable aluminium ($R^2 = 0.51$). 94 per cent variation in exchange acidity was accounted by exchangeable aluminium. The variation in potential acidity was contributed by ΔpH ($R^2 = 0.66$), nitrogen ($R^2 = 0.64$), cation exchange capacity ($R^2 = 0.57$) and organic matter ($R^2 = 0.56$).

In *Kaipad* surface samples, the pH under field wet condition was accounted by exchangeable aluminium ($r = -0.78^{**}$), exchangeable hydrogen ($r = -0.74^{*}$) and effective CEC ($r = -0.66^{**}$). 60 per cent of variation in pH under dry condition was accounted by exchangeable hydrogen ($R^2 = 0.60$). Exchangeable aluminium accounted for 59 per cent of variation in pH. Exchange acidity in these soils were contributed by exchangeable aluminium ($R^2 = 0.99$) and exchangeable hydrogen ($R^2 = 0.99$). No significant correlations were obtained between potential acidity and the acidity contributing factors studied.

In Pattambi soils effective CEC, CEC, exchangeable calcium and available magnesium determined the reaction of the soil under field wet condition. pH in the dried samples were correlated with organic matter

($r = -0.86^{**}$), iron ($r = -0.76^{**}$), available calcium ($r = 0.70^{*}$) and exchangeable aluminium ($r = -0.67^{*}$). Exchange acidity was mainly accounted by exchangeable aluminium ($R^2 = 0.98$), exchangeable hydrogen ($R^2 = 0.92$), iron ($R^2 = 0.69$) and organic matter ($R^2 = 0.51$). ΔpH ($R^2 = 0.64$), exchangeable hydrogen ($R^2 = 0.58$) exchangeable aluminium ($R^2 = 0.47$) and available iron ($R^2 = 0.40$) accounted for the variation in potential acidity in Pattambi soils.

Available iron accounted for 63 per cent of variation in active acidity in Kattampally soils. Under dry condition also iron was the most important factor that contributed towards lowering of pH ($R^2 = 0.36$). Exchange acidity was contributed by exchangeable aluminium and exchangeable hydrogen. Potential acidity was mainly controlled by exchangeable calcium ($r = -0.64^{*}$).

In Wyanad soils, field pH was mainly determined by the available sodium status of soil ($R^2 = 0.43$). The reaction under dry condition was influenced by ΔpH ($R^2 = 0.79$). The exchange acidity was mainly contributed by exchangeable hydrogen ($R^2 = 0.88$).

In Chittoor alkaline soils the pH under dry and wet conditions were determined by available calcium and percentage base saturation. 47 per cent variation in exchange acidity was accounted by percentage base saturation ($R^2 = 0.47$). Potential acidity in these soils were determined by exchangeable hydrogen ($R^2 = 0.53$).

4.10 Multiple regressions between components of acidity and acidity contributing factors in surface samples of wetlands

The multiple regression equations are presented in Table 14 & 15.

Table 14. Multiple regression equations between components of acidity and acidity contributting factors in surface samples of wet lands (n = 120)

Field condition

pH (H_2O) = $4.4813 - 0.1547\ X_1 + 0.0700\ X_2 - 0.0022\ X_3 + 0002\ X_4 + 0.0000\ X_5 + 0.000\ X_6 - 0.0010\ X_7 + 0.0000\ X_8 - 0.0004\ X_9 - 0.0035\ X_{10} + 0.6522\ X_{11} + 0.0352\ X_{12} + 0.0088\ X_{13}$

F for regression = 8.5016
$R^2 = 0.5690$

pH (KCl) = $4.241 - 0.137\ X_1 + 0.1586\ X_2 - 0.0028\ X_3 + 0.0002\ X_4 + 0.0000\ X_5 + 0.000\ X_6 - 0.0005\ X_7 + 0.0000\ X_8 - 0.0004\ X_9 - 0.0280\ X_{10} + 0.2129\ X_{11} + 0.0409\ X_{12} + 0.0057\ X_{13}$

F for regression = 7.2080
$R^2 = 0.5282$

pH ($CaCl_2$) = $4.0386 - 0.1720\ X_1 + 0.1020\ X_2 - 0.0026\ X_3 + 0.002\ X_4 + 0.0001\ X_5 + 0.000\ X_6 - 0.0004\ X_7 - 0.001\ X_8 - 0.0008\ X_9 - 0.0126\ X_{10} + 0.4441\ X_{11} + 0.0681\ X_{12} + 0.0071\ X_{13}$

F for regression = 8.1566
$R^2 = 0.5588$

Dry condition

pH (H_2O) = $4.2049 - 0.2163\ X_1 - 0.0884\ X_2 + 0.001\ X_3 + 0.0003\ X_4 - 0.0001\ X_5 - 0.0005\ X_6 - 0.0002\ X_7 + 0.0001\ X_8 + 0.0012\ X_9 + 0.0081\ X_{10} + 0.8708\ X_{11} + 0.0186\ X_{12} + + 0.0027\ X_{13}$

F for regression = 38.5616
$R^2 = 0.8569$

pH (KCl) = $4.0827 - 0.2124\ X_1 - 0.1139\ X_2 + 0.0006\ X_3 + 0.0003\ X_4 + 0.0001\ X_5 - 0.0005\ X_6 - 0.0002\ X_7 + 0.001\ X_8 + 0.0015\ X_9 - 0.0137\ X_{10} - 0.0488\ X_{11} + 0.0148\ X_{12} + 0.0023\ X_{13}$

F for regression = 23.7598
$R^2 = 0.7868$

Contd...

Table 14. (Contd....)

pH ($CaCl_2$) = $4.3271 - 0.2358\ X_1 - 0.0818\ X_2 - 0.000\ X_3 + 0.0004\ X_4 - 0.0001\ X_5 - 0.005\ X_6 + 0.0002\ X_7 + 0.0001\ X_8 + 0.0024\ X_9 + 0.1241\ X_{10} + 0.0851\ X_{11} - 0.0616\ X_{12} + 0.0107\ X_{13}$

F for regression = 1045.85
$R^2 = 0.9938$

Exchange acidity = $-1.6080 + 1.6215\ X_1 - 0.065\ X_2 - 0.0006\ X_3 - 0.0002\ X_4 + 0.0025\ X_5 - 0.0000\ X_6 - 0.0034\ X_7 + 0.0023\ X_8 + 0.0038\ X_9 + 0.1241\ X_{10} + 0.1738\ X_{11} - 0.0616\ X_{12} + 0.0107\ X_{13}$

F for regressian = 1045.85
$R^2 = 0.9938$

Potential acidity = $-17.0145 + 3.944\ X_1 + 0.6646\ X_2 + 0.0128\ X_3 - 0.0051\ X_4 + 0.0242\ X_5 - 0.0055\ X_6 - 0.0215\ X_7 + 0.0134\ X_8 + 0.0813\ X_9 + 2.6775\ X_{10} + 3.9088\ X_{11} - 1.2211\ X_{12} + 0.1954\ X_{13}$

F for regression = 153.8816
$R^2 = 0.9598$

X1 = Exch. Al
X4 = Ca,
X7 = K,
X13 = % Base saturation
X10 = CEC
X2 = Organic matter %
X5 = Mg,
X8 = Fe,
X11 = ΔpH
X3 = Nitrogen
X6 = Na,
X9 = Mn,
X12 = ECEC.

Table 15. Multiple regression between components of acidity and acidity contributing factors in selected surface samples (n = 36)

Field conditions

Water pH 1:1 = $10.1052 - 0.0004\ X_1 + 0.0001\ X_2 + 0.0001\ X_3 - 0.0002\ X_4 - 0.0106\ X_5 + 0.0068\ X_6$
F. for regression = 2.4297 $R^2 = 0.3778$

KCl pH 1:1 = $7.8823 - 0.0003\ X_1 + 0.0001\ X_2 + 0.0000\ X_3 - 0.0002\ X_4 - 0.0075\ X_5 + 0.0093\ X_6$
F. for regression = 2.0413 $R^2 = 0.3378$

$CaCl_2$ pH 1:2 = $8.0836 + 0.0001\ X_1 + 0.0001\ X_2 + 0.0001\ X_3 - 0.0001\ X_4 - 0.0082\ X_5 + 0.0047\ X_6$
F. for regression = 3.0075 $R^2 = 0.4291$

Dry condition

Water pH 1:1 = $14.1226 - 0.0002\ X_1 + 0.0000\ X_2 + 0.0001\ X_3 - 0.0001\ X_4 - 0.0205\ X_5 + 0.0039 X_6$
F. for regression = 11.6167 $R^2 = 0.7438$

KCl pH = $10.8927 - 0.0000\ X_1 + 0.000\ X_2 + 0.000\ X_3 - 0.0001\ X_4 - 0.0158\ X_5 + 0.0026\ X_6$
F. for regression = 9.1501 $R^2 = 0.6958$

$CaCl_2$ pH = $12.6978 - 0.0001\ X_1 + 0.0001\ X_2 + 0.0001\ X_3 - 0.000\ X_4 - 0.0192\ X_5 + 0.0060\ X_6$
F. for regression = 8.6025 $R^2 = 0.6826$

Exchange acidity = $31.2055 - 0.0005\ X_1 + 0.0003\ X_2 + 0.0002\ X_3 - 0.0002\ X_4 + 0.0644\ X_5 - 0.0057\ X_6$
F. for regression = 12.1569 $R^2 = 0.7524$

Potential acidity = $74.3645 + 0.0153\ X_1 + 0.0009\ X_2 + 0.0014\ X_3 + 0{+}0085\ X_4 + 0.1509\ X_5 + 0.2128\ X_6$
F. for regression = 7.8892 $R^2 = 0.6635$

X_1 = Active Mn; X_2 = Active Fe; X_3 = Total S; X_4 = Available S; X_5 = Eh; X_6 = Clay %.

Multiple regressions were computed using exchangeable aluminium, organic matter, nitrogen, iron, manganese, calcium, magnesium, sodium, potassium, cation exchange capacity, ΔpH, effective CEC and base saturation percentage as factors. 56 per cent of variation in active acidity in terms of pH could be accounted by these factors taken together under field wet condition. But under dry condition 85 percentage of variation could be accounted by these factors in surface samples. 99 percentage of variation in exchange acidity was determined by these factors. But in the case of potential acidity 96 percentage of variation could be determined by these factors.

Multiple regressions were also worked out in selected 36 surface samples using components of acidity and acidity contributing factors like active manganese, active iron, total sulphur, available sulphur, redox potential (mV) and clay percentage. Under field wet condition only 38 percentage of variation in pH could be accounted by these factors. But under dry condition, 74 percentage of variation in pH was found to be determined by these factors. 75 percentage of variation in exchange acidity and 66 percentage of variation in potential acidity could be decided by these factors in the selected 36 surface samples.

4.11 Direct and indirect effect of acidity contributing factors towards acidity

The data are presented in Table 16, 17, 18 & 19.

Exchangeable aluminium (-2.52) had got maximum direct effect in controlling pH. The factor was followed by exchangeable hydrogen (1.42), cation exchange capacity (1.42) and available sulphur (-1.12).

Table 16 (a). Direct and indirect effects of acidity contributing factors on dry water pH 1:1

	Exch. Al.	Org. matter	Exch. H	DTPA Fe.	DTPA Mn.	Active Fe.	Active Mn.	Total S	Availabe S	CEC	EC	% Clay	Correlation coefficient	Residue
Exch. Al	**-2.5233**	-0.5311	1.3327	-0.2606	0.0162	0.1337	-0.0665	-0.2727	-0.6487	0.8934	0.8085	0.3912	-0.7274**	
Org. Matter	-0.1506	**-0.1646**	0.8800	-0.2959	0.0131	0.2138	-0.0939	-0.1586	-0.7175	1.1726	0.4623	0.3635	-0.4759**	
Exch. H $^{+}$	-2.3596	-0.7191	**1.4252**	-0.3115	0.0189	0.1114	-0.0900	-0.3015	-0.7484	1.1037	0.7864	0.4082	-0.6761**	
DTPA. Fe	-1.3096	-0.6864	0.8843	**-0.5021**	0.0187	0.0989	0.1190	-0.1824	-0.6761	0.7307	0.4084	0.4571	-0.6395**	
DTPA. Mn	0.4015	0.1498	-0.2655	0.0925	**-0.1016**	0.1264	0.0927	-0.0915	-0.0199	-0.1411	-0.1499	0.0395	0.1328	
Active. Fe	-0.3921	-0.2893	0.1846	-0.0577	-0.0149	**0.8605**	-0.0379	-0.0270	-0.5660	0.2156	0.1197	-0.0257	-0.0302	
Active. Mn	0.5037	0.3283	-0.3849	-0.1794	-0.0283	-0.0980	**-0.3331**	0.0543	0.4894	-0.2737	-0.2457	-0.3062	0.1925	0.0481
Total S	-1.6364	-0.4393	1.0216	-0.2178	-0.0221	0.0552	-0.0430	**-0.4206**	-0.6378	0.9766	0.7304	0.2796	-0.3536*	
Available S	-1.4587	-0.7444	0.9502	-0.3024	-0.0018	0.4339	-0.1452	-0.2390	**-1.1225**	0.9583	0.6193	0.4637	-0.5886**	
CEC	-1.5894	-0.9629	1.1091	0.2587	0.0101	0.1308	-0.0643	-0.2896	-0.7585	**1.4183**	0.4623	0.3855	-0.4073*	
EC	-1.9432	-0.5128	1.0676	-0.1953	0.0145	0.0981	-0.0779	-0.2926	-0.6622	0.6245	**1.0499**	0.2680	-0.5664**	
% Clay	-1.2965	-0.5560	0.7640	-0.3014	-0.0053	-0.0290	-0.1340	-0.1544	-0.6836	0.7181	0.3695	**0.7614**	-0.5470**	

Table 16 (b). Direct and indirect effect of acdity contributing factors on dry pH (H_2O)

	Direct effect	Max +ve indirect effect	Max -ve indirect effect	Total +ve indirect effect	Total -ve indirect
Exch Al	-2,5233	1.3327	-0.6487	3.5757	-1.7796
O.M	-0.1646	1,1726	-0,7175	3.1053	-1.4165
Exch. H	1.4252	1.1037	-2.3596	2.4286	-4.5301
DTPA - Fe	-0.5021	0.8843	-1.3096	2.7171	-2.8545
DTPA - Mn	-0.1016	0.4015	-0.2655	0.9024	-0.6679
Active Fe	0.8605	0.2156	-0.5660	1.1878	-1.4106
Active Mn	-0.3331	0.5037	-0.3849	1.3757	-2.8919
Total S	-0.4206	1.0216	-1.6364	3.0634	-2.9964
Available S	-1.1225	0.9583	-1.4587	3.4254	-2.8915
CEC	1.4183	1.1091	-1.5894	2.3565	-3.6647
EC	1.0499	1.0676	-1.9432	2.0727	-3.6840
% Clay	0.7614	0.7640	-1.2965	1.8516	-3.1602

Table 17 (a). Direct and indirect effects of acidity contributing factors on exchange acidity

	Exch. Al.	Org. matter	Exch. H	DTPA Fe.	DTPA Mn.	Active Fe.	Active Mn.	Total S	Availabe S	CEC	EC	% Clay	Correlation coefficient	Residue
Exch. Al	**1.7720**	0.3176	-0.7877	0.2063	0.0004	0.0286	0.0788	0.4655	0.0323	-0.3538	-0.5811	-0.2287	0.9130**	
Org. Matter	0.8080	**0.6966**	-0.5202	0.2343	0.0003	-0.0457	0.1114	0.2708	0.0357	-0.4644	-0.3208	-0.2125	0.5934**	
Exch. H	1.6590	0.4301	**-0.8424**	0.2466	0.0005	-0.0238	0.1067	0.5145	0.0372	-0.4371	-0.5458	-0.2386	0.9049**	
DTPA. Fe	0.9197	0.4106	-0.5227	**0.3975**	0.0005	-0.0211	-0.1411	0.3114	0.0336	-0.2894	-0.2834	-0.2672	0.5482**	
DTPA. Mn	-0.2819	-0.0896	0.1569	-0.0732	**-0.0025**	-0.0270	-0.1099	0.1561	0.0010	0.0559	0.1041	-0.0231	-0.1332	
Active. Fe	0.2754	0.1730	-0.1091	0.0457	-0.0004	**-0.1840**	0.0450	0.0460	0.0281	-0.0854	-0.0831	0.0150	0.1663	
Active. Mn	-0.3537	-0.1964	0.2275	0.1420	-0.0007	0.0210	**-0.3950**	-0.0927	-0.0243	0.1084	0.1705	0.179	-0.2144	0.1613
Total S	1.1491	0.2628	-0.6038	0.1724	-0.0005	-0.0118	0.0510	**0.7178**	0.0317	-0.3868	-0.5069	-0.1634	0.7116**	
Available S	1.0244	0.4453	-0.5616	0.2394	-0.000	-0.0928	0.1722	0.4079	**0.0558**	-0.3796	-0.4298	-0.2710	0.6101**	
CEC	1.1162	0.5759	-0.6555	0.2048	0.0002	-0.0280	0.0762	0.4943	0.0377	**-0.5617**	-0.3208	-0.2253	0.7140**	
EC	1.3646	0.3067	-0.6310	0.1546	0.0004	-0.0210	0.0924	0.4994	0.0329	-0.2473	**-0.7286**	-0.1567	0.6664**	
% Clay	0.9104	0.3326	-0.4516	0.2386	-0.0001	0.0062	0.1589	0.2636	0.0340	-0.2844	-0.2565	**-0.4451**	0.5066**	

Table 17 (b) **Direct and indirect effects of acidity contributing factors on exchange acidity**

	Direct effect	Max +ve indirect effect	Max -ve indirect effect	Total +ve indirect effect	Total -ve indirect
Exch. Al	1.7720	0.4655	-0.7877	1.1295	-1.9513
Org. matter	0.6966	0.8080	-0.5202	1.4605	-1.5636
Exch. H	-0.8424	1.6590	-0.5484	2.9946	-1.2453
DTPA - Fe	0.3975	0.9197	-0.5227	1.6758	-1.5249
DTPA - Mn	-0.0025	0.1569	-0.2819	0.4740	-0.6047
Active - Fe	-0.1840	0.2754	-0.1091	0.6282	-0.278
Active - Mn	-0.3950	0.2275	-0.3537	0.8484	-0.6678
Total S	0.7178	1.1491	-0.6038	1.667	-1.6732
Available S	0.0558	1.0244	-0.5616	2.2892	-1.7348
CEC	-0.5617	1.1162	-0.6555	2.5053	-1.2296
EC	-0.7286	1.3646	-0.6310	2.451	-1.0560
% Clay	-0.4451	0.9104	-0.4516	1.9443	-0.9926

Table 18 (a). Direct and indirect effects of acidity contributing factors on non exchange acidity

	Exch. Al	Org. Matter	Exch. H	DTPA Fe	Total S	Available S	% Clay	CEC	Correlation coefficient	Residue
Exch. Al	**-0.3647**	0.1158	0.5269	0.0280	-0.0115	0.0350	0.0379	0.2373	0.6048**	
Org. Matter	-0.1663	**0.2540**	0.3480	0.0318	-0.0067	0.0387	0.0353	0.3114	0.8462**	
Exch. H	-0.3410	0.1569	**0.5635**	0.0334	-0.0127	0.0404	0.0396	0.2931	0.7732**	
DTPA. Fe	-0.1893	0.1497	0.3497	**0.0539**	-0.0077	0.0365	0.0443	0.1941	0.6312**	
Total S	-0.2365	0.0958	0.4039	0.0234	**-0.0178**	0.0344	0.0271	0.2594	0.598**	0.3559
Available S	-0.2108	0.1624	0.3757	0.0325	-0.0101	**0.0606**	0.0450	0.2545	0.7097**	
% Clay	-0.1874	0.1213	0.3021	0.0324	-0.0065	0.0369	**0.0739**	0.1907	0.5633**	
CEC	-0.2297	0.2100	0.4385	0.0278	-0.0122	0.0409	0.0374	**0.3767**	0.8894**	

Table 18 (b). Direct and indirect effect of acdity contributing factors on non-exchange acidity

	Direct effect	Max +ve indirect effect	Max -ve indirect effect	Total +ve indirect effect	Total -ve indirect
Exch Al	-0.3647	0.5269	-0.0115	0.9809	-0.0115
Org. matter	0.2540	0.3480	-0.1663	0.7652	-0.1730
Exch. H	0.5635	0.2931	-0.3410	0.5634	-0.3537
DTPA - Fe	0.0539	0.3497	-0.1893	0.7743	-0.1970
Total S	-0.0178	0.4039	-0.2365	0.8440	-0.2365
Available S	0.0606	0.3757	-0.2108	0.8701	-0.2209
% Clay	0.0739	0.3021	-0.1874	0.6834	-0.1939
CEC	0.3767	0.4385	-0.2297	0.7546	-0.2419

Table 19 (a). Direct and indirect effects of acidity Contributing factors on Potential acidity

	Exch. Al	Org. matter	Nitrogen	DTPA-Fe	CEC	ECEC	Exch.H	Δ pH	% Base saturation	Correlation coefficient	Residue
Exch. Al	**0.0183**	0.0761	0.0255	-0.0315	0.3652	-0.3444	0.7423	-0.0159	-0.0246	0.7929**	
Ong. matter	0.0132	**0.1050**	0.0354	-0.0310	0.4305	-0.2935	0.6623	-0.0116	-0.0326	0.8539**	
Nitrogen	0.0106	0.0844	**0.0440**	-0.0229	0.3117	-0.222	0.4802	-0.0088	-0.0283	0.6317**	
DTPA - Fe	0.0115	0.0647	0.0200	**-0.0502**	0.3411	-0.2839	0.8069	-0.0061	-0.0194	0.8431**	0.1861
CEC	0.0134	0.0910	0.0276	-0.0345	**0.4964**	-0.3755	0.7329	-0.0126	-0.0229	0.8862**	
ECEC	0.0150	0.0736	0.0234	-0.0341	0.4455	**-0.4184**	0.7326	-0.0136	-0.0127	0.7850**	
Exch. H	0.0054	0.0789	0.0240	-0.0460	0.4130	-0.3480	**0.8809**	-0.0113	-0.0222	0.9481**	
Δ pH	-0.0114	-0.0438	-0.0139	0.0111	-0.2136	0.2046	-0.3579	**0.0279**	0.0093	-0.3810**	
% Base saturation	-0.0086	-0.0657	-0.0239	0.0187	-0.2183	0.1024	-0.3763	0.0050	**0.0520**	-0.5017**	

Table 19 (b). Direct and Indirect effect of acidity contributing factors towards Potential acidity

	Direct effect	Max. positive indirect effect	Max. negative indirect effect	Total positive indirect effect	Total negative indirect effect
Exch. Al.	0.0183	0.7423	-0.3444	1.2091	-0.4347
Org. matter	0.1050	0.6623	-0.0326	1.2464	-0.3926
Nitrogen	0.0440	0.4802	-0.0283	0.9309	-0.2984
Iron	-0.0502	0.8069	-0.0502	1.2442	-0.4011
CEC	0.4964	0.7329	-0.3755	1.3613	-0.4758
ECEC	-0.4184	0.7326	-0.4184	1.2901	-0.5051
Exch. H	0.8809	0.4130	-0.0460	1.4122	-0.4641
Δ pH	0.0279	0.2046	-0.3579	0.2586	-0.6396
% Base saturation	0.0520	0.1024	-0.3763	0.1913	-0.6928

Maximum positive indirect effect was also exchangeable aluminium (1.33) followed by organic matter (1.17), exchangeable hydrogen (1.10) and cation exchange capacity (1.10). Maximum negative indirect effect on pH was for exchangeable hydrogen (-2.35) followed by total soluble salts represented by EC (-1.94), total sulphur (-1.63), CEC (-1.58) and available sulphur (-1.45).

Exchange acidity was directly affected by exchangeable aluminium (1.77) and exchangeable hydrogen (-0.84). Maximum positive indirect effect towards exchange acidity was for exchangeable hydrogen (1.65) and maximum negative indirect effect was for exchangeable aluminium (0.78). Total positive indirect effect was recorded by exchangeable hydrogen and total negative indirect effect by exchangeable aluminium.

Exchangeable hydrogen, cation exchange capacity, organic matter and exchangeable aluminium directly influenced non exchange acidity. Maximum positive indirect effects were recorded by exchangeable aluminium followed by cation exchange capacity, total sulphur, available sulphur, organic matter and clay content. Maximum negative indirect effects were observed for exchangeable hydrogen, total sulphur and cation exchange capacity. Total positive indirect effect was maximum for exchangeable aluminium, followed by sulphur, iron, organic matter and CEC. Total negative indirect effect was recorded by exchangeable hydrogen.

Potential acidity was directly influenced by exchangeable hydrogen (0.88), Cation exchange capacity (0.49) and organic matter (0.105). Apart from this exchangeable hydrogen decided the extent of potential acidity through its indirect positive effects through CEC and organic matter. Maximum positive indirect effect was for iron (0.81), exchangeable aluminium (0.74), ECEC

(0.73), CEC (0.73) and organic matter (0.66). Maximum negative indirect effect was for effective CEC (-0.418). Total positive indirect effect was maximum for exchangeable hydrogen (1.41) followed by CEC (1.36), ECEC (1.29), organic matter (1.24) and iron (1.24). Total negative indirect effect was maximum for percentage base saturation (-0.69).

4.12 Kinetics of pH, Eh and available nutrients due to submergence in the wetlands

Kinetics of pH, Eh and available nutrients are given in Table 20-35.

Quadratic and linear regressions were worked out relating available nutrients and period of submergence and the relationships having more R^2 values had been taken for computing regression equations. The regression equations for pH, Eh and available nutrients are presented in Table 36. Almost all the relationships in all soils followed quadratic pattern than linear model.

4.12.1 Kinetics of pH

Changes in pH followed a linear trend in Vellayani soils. The maximum pH reached due to twelve weeks submergenc was 6.4. 17 per cent of variation in pH could be accounted by the period of submergence in vellayani soils. In all soils except *Kari, Pokkali, Kayal, Karapadom* and *Kole* the pH was above 5.5 after 2 weeks submergence. At first there occurred a slight decrease in pH; then it increased to maximum. *Pokkali* soils recorded the lowest pH (4.3) after 3 months. When models were fitted Kayal, *Kari, Kole, Kaipad* and Chittoor soils followed a quadratic pattern than linear model. In *Kari* soils maximum pH was obtained only after 88 days. In *Kari* soils 25 per cent of variation in pH could be accounted by the period of submergence. Chittoor soils reached the maximum point after 6 weeks (pH 7.2).

Table 20. Kinetics of pH due to submergence in wet land soils

Soils	Period of submergence										
	Initial	2 days	1 week	2 weeks	3 weeks	4	6	8	10	12	Mean
Vellayani	4.33	4.15	5.33	5.53	6.00	6.20	6.28	6.34	6.44	6.46	5.71
Karamana	5.30	4.84	6.22	6.50	6.63	6.56	6.56	6.57	6.65	6.68	6.25
Karapadom	4.56	4.39	5.57	5.26	5.56	5.90	6.10	6.30	6.25	6.26	5.62
Kari	3.53	3.43	4.07	4.35	5.00	5.16	5.30	5.35	5.46	5.58	4.73
Kayal	4.26	4.09	4.26	4.43	4.70	4.58	4.91	5.00	5.01	5.04	4.66
Kole	4.50	4.46	4.54	4.60	5.80	5.86	5.90	5.92	6.13	6.21	5.39
Kaipad	5.53	5.65	6.00	6.33	6.36	6.33	6.33	6.33	6.26	6.31	6.15
Pokkali	3.36	3.40	3.28	3.26	4.13	4.16	4.13	4.10	4.30	4.31	3.85
Pattambi	4.73	4.81	5.82	6.06	6.46	6.50	6.50	6.57	6.36	6.18	6.00
Kattampally	5.20	5.51	5.74	6.23	6.06	6.16	6.20	6.30	6.13	6.02	5.96
Wyanad	4.70	5.12	6.09	6.40	6.70	6.80	6.86	6.96	6.83	6.76	6.33
Chittoor	6.63	6.13	6.59	7.20	7.15	7.13	7.18	7.26	7.20	7.26	6.98
Mean	4.72	4.67	5.30	5.51	5.88	5.97	6.02	6.09	6.09	6.09	

CD	Soil x Period	=	0.47	SE	S x P	=	0.17
CD	Periods	=	0.14	SE	P	=	0.05
CD	Soils	=	1.13	SE	S	=	0.39

Table 21. Kinetics of redox potential due to submergence in wet land soils at 5 cm depth (mV)

Soils	Period of submergence							
	Initial	2 weeks	4	6	8	10	12	Mean
Vellayani	496.33	135.66	99.66	95.00	92.00	88.33	86.00	156.14
Karamana	441.00	66.33	46.33	43.00	41.00	38.66	36.66	101.86
Karappadom	450.33	221.33	113.00	104.00	96.33	88.33	84.66	165.43
Kayal	513.00	271.33	176.00	163.66	151.33	142.00	138.33	222.24
Kari	564.66	265.66	217.33	178.33	148.33	126.66	114.33	230.76
Pokkali	546.00	327.33	270.66	250.00	232.00	224.66	219.66	295.76
Kole	501.66	144.00	121.66	118.66	114.66	111.66	109.66	174.57
Kaipad	452.66	192.00	138.33	131.33	125.33	120.00	118.33	182.57
Pattambi	457.00	146.66	101.66	96.33	91.66	87.33	85.33	152.29
Kattampally	445.00	233.33	212.33	206.66	204.00	201.66	200.33	243.33
Wynad	438.66	140.00	111.00	103.33	97.66	93.33	91.66	153.66
Chittur	421.33	115.33	87.00	80.66	75.33	64.33	69.66	130.52
Mean	477.31	188.25	141.25	130.92	122.47	115.58	112.89	

CD Soil x Period = 52.47 SE S x P = 18.93

CD Periods = 15.15 SE P = 5.46

CD Soils = 87.80 SE S = 30.08

Table 22. Kinetics of redox potential (Eh) at 8 cm depth in wet land soils (mV)

	Period of submergence							
Soils	Initial	2 weeks	4	6	8	10	12	Mean
Vellayani	494.00	110.66	77.33	74.66	72.33	70.66	69.00	138.38
Karamana	438.66	43.00	33.00	30.33	28.00	26.00	25.00	89.19
Karapadom	448.33	181.66	78.00	76.66	75.33	75.00	74.33	144.19
Kari	561.66	240.00	198.66	160.33	133.33	100.00	91.00	212.14
Kayal	510.33	239.00	149.66	140.00	131.00	124.33	122.66	202.43
Kole	499.66	129.66	107.33	104.33	101.33	99.00	97.33	162.66
Kaipad	450.66	162.66	110.00	107.00	106.33	104.00	102.66	163.33
Pokkali	543.66	298.00	250.33	237.33	221.66	209.66	207.33	281.14
Pattambi	455.00	105.00	75.66	72.66	69.33	68.00	66.66	130.33
Kattampally	442.66	212.66	200.66	196.00	192.00	188.66	187.33	231.43
Wyanad	436.66	94.00	94.66	90.33	85.33	78.66	76.00	136.58
Chittoor	419.33	85.33	59.66	57.33	56.33	61.33	55.00	113.48
Mean	475.06	158.47	119.61	112.25	106.02	100.44	97.86	

CD	Soil x Period	=	55.97	SE	S x P	=	20.19
CD	Periods	=	16.16	SE	P	=	5.83
CD	Soils	=	26.60	SE	S	=	29.67

Table 23. Kinetics of available nitrogen due to submergence in wetland soils ppm.

	Period of submergence							
Soils	Initial	2 weeks	4	6	8	10	12	Mean
Vellayani	218.66	575.83	611.66	651.00	682.00	702.33	712.00	593.29
Karamana	157.66	357.00	372.00	385.00	398.66	409.66	415.33	356.48
Karapadom	177.33	427.33	492.66	553.66	590.66	624.00	642.66	501.19
Kari	238.33	579.33	638.66	673.33	716.33	738.66	748.33	417.23
Kayal	140.33	327.00	363.33	393.00	411.00	430.00	440.00	357.81
Kole	204.33	505.33	536.66	564.66	580.33	592.33	599.66	511.91
Kaipad	119.00	139.66	180.00	217.33	239.66	254.66	263.66	202.00
Pokkali	176.33	410.00	435.66	458.66	471.66	480.00	488.33	417.23
Pattambi	179.66	279.00	342.00	398.66	436.66	455.66	466.33	365.43
Kattampally	128.66	203.66	259.33	278.66	290.33	296.66	302.00	255.62
Wyanad	96.66	472.00	536.00	582.66	610.66	629.33	638.66	509.43
Chittoor	128.66	233.66	259.33	278.66	290.33	296.66	302.00	255.62
Mean	163.81	375.78	415.44	448.75	471.92	487.83	496.94	

CD Soil x Period = 116.57 SE S x P = 42.05

CD Periods = 33.65 SE P = 12.14

CD Soils = NS

Table 24. Kinetics of available Phosphorus due to submergence ppm.

	Period of submergence							
Soils	Initial	2 weeks	4	6	8	10	12	Mean
Vellayani	32.48	187.74	210.29	231.69	251.87	269.63	277.55	208.73
Karamana	53.48	174.79	181.10	174.11	178.50	182.80	187.13	161.71
Karapadom	18.62	194.62	197.18	196.56	208.48	213.14	220.30	178.42
Kari	47.56	276.05	211.22	147.39	97.88	101.32	104.38	140.83
Kayal	29.29	201.42	164.76	120.09	85.35	89.10	91.94	111.71
Kole	13.32	117.47	109.64	100.06	101.89	104.58	106.74	93.39
Kaipad	13.00	89.58	78.61	63.64	58.00	60.82	63.36	61.01
Pokkali	12.51	229.38	174.64	117.59	97.79	102.34	100.93	119.32
Pattambi	18.02	105.73	83.96	61.32	44.77	50.08	51.92	59.40
Kattampally	9.22	160.69	123.89	89.53	55.57	59.78	62.28	80.14
Wyanad	12.88	161.23	127.26	87.20	58.43	62.54	64.49	82.01
Chittoor	27.50	118.14	101.45	83.08	73.94	77.69	77.66	79.93
Mean	23.98	168.07	147.00	122.69	109.38	114.49	117.39	

CD Soil x Period = 49.89 SE S x P = 17.99

CD Periods = 14.40 SE P = 5.20

CD Soils = 60.51 SE S = 20.73

Table 25. Kinetics of Potassium due to submergence in wetland soils ppm

	Period of submergence							
Soils	Initial	2 weeks	4	6	8	10	12	Mean
Vellayani	45.33	41.35	52.11	62.00	69.66	65.69	61.63	56.83
Karamana	134.33	22.10	33.38	44.18	51.48	41.43	31.01	51.13
Karapadom	226.66	58.41	66.67	73.89	81.26	76.64	73.28	93.76
Kari	164.00	66.31	108.46	129.30	151.09	158.92	152.68	32.97
Kayal	406.66	100.31	129.79	153.76	175.06	170.78	162.65	85.58
Kole	100.00	50.17	61.38	71.89	77.91	72.70	63.84	71.13
Kaipad	13.33	13.15	32.02	45.61	56.34	35.86	22.40	31.25
Pokkali	260.00	98.83	136.43	172.28	199.13	196.60	191.26	79.22
Pattambi	57.33	38.03	39.87	41.33	42.28	40.57	38.67	42.58
Kattampally	38.66	66.73	60.84	48.84	42.51	35.77	24.15	59.65
Wyanad	41.33	25.95	34.37	43.58	51.93	51.43	54.28	43.27
Chittoor	48.00	25.21	28.04	30.48	31.89	33.05	33.80	32.93
Mean	136.31	50.55	65.28	76.39	85.88	81.62	75.80	

CD Soil x Period = 136.31 CD Soils = 97.05 SE S x P = 24.59

CD Periods = 19.68 SE P = 7.09

Table 26. Kinetics of available Calcium due to submergence in wetland soils ppm.

	Period of submergence							
Soils	Initial	2 weeks	4	6	8	10	12	Mean
Vellayani	469.33	517.74	600.89	694.22	733.56	867.00	939.36	688.88
Karamana	786.13	402.82	409.39	422.32	425.33	459.74	489.93	485.09
Karapadom	426.13	637.97	677.89	709.23	732.40	814.40	871.28	695.62
Kari	1014.26	786.27	892.45	968.99	997.21	1096.24	1131.43	983.84
Kayal	994.66	1206.80	1340.71	1428.09	1492.38	1696.95	1777.30	1419.56
Kole	1310.40	1188.61	1294.63	1396.21	1458.88	1513.48	1549.47	1387.38
Kaipad	424.53	246.16	267.05	284.61	296.36	320.44	341.43	311.52
Pokkali	1316.26	785.96	796.15	807.99	808.09	904.53	943.62	908.94
Pattambi	416.00	285.91	287.52	258.24	292.14	384.18	454.10	339.73
Kattampally	897.60	365.90	382.47	398.02	408.85	487.50	545.07	497.92
Wyanad	899.73	692.66	736.14	751.60	779.24	881.85	933.34	810.65
Chittoor	2245.33	2141.57	2306.11	2446.91	2514.65	2522.45	2530.05	2386.73
Mean	933.37	771.53	832.62	880.54	911.59	995.73	1042.20	

SE

CD Soil x Period = 312.28 SE S x P = 112.66

CD Periods = 90.15 SE P = 32.52

CD Soils = 812.14 SE S = 278.23

Table 27. Kinetics of available Magnesium due to submergence ppm.

	Period of submergence							
Soils	Initial	2 weeks	4	6	8	10	12	Mean
Vellayani	138.40	89.29	103.72	114.13	121.75	136.15	147.41	121.55
Karamana	97.17	41.88	43.84	45.93	47.73	46.48	44.57	52.52
Karapadom	223.25	239.76	267.78	293.70	310.37	298.15	290.17	274.74
Kari	287.46	296.25	355.85	407.91	435.38	424.13	416.64	374.81
Kayal	393.06	358.26	437.07	511.67	555.67	551.12	550.80	479.67
Kole	171.93	288.22	307.65	322.80	336.32	327.62	319.81	296.31
Kaipad	66.89	56.70	60.50	63.59	66.51	62.03	57.33	61.51
Pokkali	572.26	401.93	469.11	539.17	572.49	536.26	310.86	514.59
Pattambi	87.62	45.63	45.37	45.36	45.32	24.96	61.99	55.18
Kattampally	274.13	197.71	226.92	246.62	262.21	266.58	274.73	249.85
Wyanad	140.80	93.06	108.17	114.85	121.49	129.08	132.23	119.96
Chittoor	90.02	302.83	319.63	327.61	337.06	349.57	357.86	297.80
Mean	211.65	200.96	228.80	252.78	267.70	265.18	263.70	

CD	Soil x Period	=	81.04	SE	S x P	=	29.24
CD	Periods	=	23.40	SE	P	=	8.44
CD	Soils	=	157.49	SE	S	=	53.95

Table 28. Kinetics of available Sodium due to submergence ppm.

Soils	Period of submergence Initial	2 weeks	4	6	8	10	12	Mean
Vellayani	180.00	337.33	458.66	568.00	645.33	614.33	576.00	482.81
Karamana	193.33	298.66	373.33	432.66	480.00	455.33	404.00	376.76
Karapadom	317.33	529.33	663.33	804.66	889.33	914.00	933.33	721.62
Kari	364.00	1073.33	1298.66	1564.66	1726.66	1732.66	1745.33	1357.91
Kayal	452.00	1676.66	1833.33	1982.66	2101.33	2186.00	2240.00	1781.71
Kole	281.33	1150.66	1271.33	1378.66	1468.00	1345.33	1213.33	1158.38
Kaipad	126.66	230.66	247.33	258.66	268.00	285.33	300.00	245.24
Pokkali	2374.66	3466.66	4652.00	5664.66	6244.66	5927.33	5642.00	4853.43
Pattambi	46.66	358.66	371.33	386.00	394.66	467.33	517.33	363.14
Kattampally	332.00	1932.33	1648.00	1324.66	942.66	728.66	634.33	1077.67
Wyanad	85.33	326.66	322.66	315.33	306.66	332.66	361.00	292.91
Chittoor	78.66	496.00	582.66	684.66	760.00	757.33	744.00	586.19
Mean	402.67	989.83	1143.56	1280.45	1352.28	1312.20	1276.06	

CD Soil x Period = 857.32 SE S x P = 309.29
CD Periods = 247.49 SE P = 89.30
CD Soils = 1414.33 SE S = 484.54

Table 29. Kinetics of available Iron due to submergence ppm.

	Period of submergence							
Soils	Initial	2 weeks	4	6	8	10	12	Mean
Vellayani	400.20	465.03	439.62	404.23	397.84	492.22	592.05	455.89
Karamana	240.06	320.05	311.24	300.82	290.49	368.46	435.39	323.79
Karapadom	483.20	393.79	388.90	381.41	369.40	455.38	512.62	426.39
Kari	691.06	401.55	453.04	500.24	534.22	526.50	527.56	519.17
Kayal	339.80	363.60	326.34	272.11	218.13	298.04	342.88	308.71
Kole	265.43	394.27	375.10	360.50	348.27	345.46	343.24	347.47
Kaipad	185.33	180.37	186.99	187.72	197.66	188.52	178.75	186.48
Pokkali	460.66	342.97	367.00	385.36	400.43	369.17	328.48	379.16
Pattambi	363.33	340.26	351.88	365.76	378.72	357.27	341.61	356.98
Kattampally	198.66	161.97	136.50	115.85	106.35	137.92	165.52	146.11
Wyanad	75.60	328.74	382.78	442.50	492.17	220.72	133.26	296.54
Chittoor	192.46	159.35	166.10	175.80	182.78	165.41	153.76	170.81
Mean	324.65	321.00	323.79	324.36	326.38	327.09	337.93	

CD	Soil x Period	= 39.21	SE	S x P	=	39.21
CD	Periods	= NS	SE	Soils	=	45.08
CD	Soils	= 45.09				

Table 30. Kinetics of available Manganese due to submergence ppm.

Soils	Period of submergence							
	Initial	2 weeks	4	6	8	10	12	Mean
Vellayani	57.93	38.73	38.75	39.09	38.74	37.24	37.82	41.19
Karamana	24.13	19.16	18.44	17.41	17.04	13.44	10.27	17.13
Karapadom	37.46	15.69	17.25	18.27	18.96	17.88	17.53	20.45
Kari	7.66	7.40	8.31	9.28	10.13	17.50	21.74	11.72
Kayal	34.46	13.15	32.86	34.47	38.28	40.41	42.36	32.29
Kole	45.96	40.37	34.90	30.63	28.30	29.97	30.43	34.37
Kaipad	6.13	5.59	5.20	4.86	4.50	4.74	4.81	5.12
Pokkali	13.13	10.86	8.49	7.12	6.18	13.68	18.84	11.18
Pattambi	15.00	10.39	10.26	10.71	11.20	9.35	7.78	10.67
Kattampally	32.86	31.98	28.75	25.72	24.89	12.75	6.81	23.43
Wyanad	15.26	21.73	19.88	18.86	18.27	41.33	50.61	25.57
Chittoor	20.80	49.00	40.74	34.22	30.99	27.21	23.27	32.32
Mean	25.90	22.01	21.16	20.92	20.63	22.13	22.69	

CD Soil x Period = NS

CD Periods = NS

CD Soils = NS

Table 31. Kinetics of available Zinc due to submergence ppm.

	Period of submergence							
Soils	Initial	2 weeks	4	6	8	10	12	Mean
Vellayani	4.89	6.58	5.56	4.67	4.22	3.31	1.38	4.38
Karamana	1.74	3.42	3.15	2.39	1.74	1.60	1.27	2.19
Karapadom	3.87	4.96	4.70	3.82	3.05	2.20	1.43	3.44
Kari	2.72	4.30	3.72	2.61	1.53	1.02	0.69	2.37
Kayal	1.87	3.20	2.63	1.79	1.63	1.06	0.60	1.83
Kole	9.55	6.17	3.45	2.59	1.85	0.95	0.54	3.59
Kaipad	1.35	1.94	1.58	1.08	0.72	0.43	0.30	1.06
Pokkali	4.79	7.81	6.96	6.77	6.12	3.33	2.05	5.41
Pattambi	3.16	4.19	3.20	2.10	1.31	0.60	0.39	2.14
Kattampally	1.83	2.74	2.20	1.32	0.68	0.48	0.25	1.36
Wyanad	7.28	4.88	4.24	2.61	1.99	1.32	0.75	3.30
Chittoor	7.10	4.27	3.92	3.63	3.42	3.07	2.84	4.04
Mean	4.18	4.54	3.78	2.95	2.36	1.62	1.05	

CD Soil x Period = NS SE · P = 0.28

CD Periods = 0.79 CD Soils = NS

Table 32. Kinetics of available Copper due to submergence ppm.

	Period of submergence							
Soils	Initial	2 weeks	4	6	8	10	12	Mean
Vellayani	4.37	1.03	1.04	0.78	0.82	0.90	0.94	1.42
Karamana	6.27	1.81	1.67	1.46	1.45	1.41	1.35	2.21
Karapadom	8.20	2.39	1.86	1.32	1.36	1.46	1.52	2.59
Kari	0.86	0.22	0.38	0.56	0.18	0.44	0.41	0.44
Kayal	2.05	0.95	0.63	0.34	0.35	0.42	0.37	0.74
Kole	6.06	4.06	2.22	1.66	1.70	1.53	1.32	2.66
Kaipad	2.48	0.89	0.96	0.99	0.89	0.78	0.73	1.11
Pokkali	2.10	0.11	0.12	0.14	0.08	0.04	0.02	0.37
Pattambi	11.66	2.75	2.30	2.05	2.29	2.41	2.49	3.71
Kattampally	5.44	1.04	1.45	1.65	1.10	0.67	0.44	1.69
Wyanad	2.97	0.48	0.83	0.62	0.60	0.59	0.59	0.96
Chittoor	6.25	1.80	1.47	1.20	1.02	0.93	0.50	1.86
Mean	4.90	1.47	1.25	1.07	0.99	0.97	0.89	

CD	Soil x Period	=	1.59	SE	S x P	=	0.58
CD	Periods	=	0.46	SE	P	=	0.17
CD	Soils	=	1.20	SE	S	=	0.41

Table 33. Kinetics of available Sulphur due to submergence ppm.

		Period of submergence						
Soils	Initial	2 weeks	4	6	8	10	12	Mean
Vellayani	1496.59	924.32	311.83	150.80	33.53	20.96	11.09	421.31
Karamana	590.98	365.35	218.11	119.74	20.96	12.49	8.48	190.88
Karapadom	2517.00	1413.62	422.01	216.73	44.34	21.32	10.24	663.61
Kari	4026.36	3919.47	3823.43	450.78	55.68	29.82	26.09	1761.76
Kayal	1249.99	1451.56	1887.80	1031.17	196.37	52.33	20.79	841.43
Kole	1937.22	1019.83	438.20	219.82	47.07	24.23	15.10	528.79
Kaipad	420.75	259.13	188.35	86.88	18.36	10.04	3.59	141.02
Pokkali	3261.05	2170.22	1884.86	848.44	184.53	87.77	29.36	1209.47
Pattambi	365.50	286.14	220.81	114.44	22.17	10.95	3.76	146.26
Kattampally	467.50	279.04	171.51	86.87	19.48	9.57	3.74	148.25
Wyanad	216.75	192.36	166.35	73.64	15.52	8.94	3.56	96.74
Chittoor	204.00	154.42	120.03	53.91	9.48	4.66	2.43	78.42
Mean	1396.14	1036.29	821.11	287.77	55.63	24.43	11.52	

CD Soil x Period = 816.55 SE S x P = 294.59

CD Periods = 235.72 SE P = 85.04

CD Soils = 660.98 SE S = 226.44

Table 34. Kinetics of available Silica due to submergence ppm.

	Period of submergence							
Soils	Initial	2 weeks	4	6	8	10	12	Mean
Vellayani	75.22	94.44	117.54	143.16	167.85	154.41	149.80	128.92
Karamana	86.27	85.73	88.38	92.33	94.83	91.69	89.99	89.89
Karapadom	174.65	166.24	149.45	138.66	132.19	141.22	151.78	150.60
Kari	101.67	141.09	169.42	193.87	212.14	208.10	199.85	175.17
Kayal	131.97	169.74	198.55	231.97	251.57	240.40	216.61	205.83
Kole	136.60	101.88	171.00	194.76	206.32	213.16	217.99	184.53
Kaipad	123.50	111.88	93.21	75.28	64.59	77.89	90.17	90.93
Pokkali	190.86	217.31	255.84	263.24	273.93	282.16	282.92	252.33
Pattambi	157.18	161.79	147.94	138.30	130.79	132.86	131.60	142.93
Kattampally	157.19	149.92	135.65	122.00	112.72	128.04	137.22	134.68
Wyanad	109.15	153.80	208.35	236.38	282.80	280.05	231.24	214.54
Chittoor	171.62	174.55	175.71	174.33	178.47	185.16	191.19	178.72
Mean	134.66	148.20	159.26	167.03	175.69	177.93	174.20	

CD Soil x Period = 65.33 SE S x P = 23.57

CD Periods = 18.86 SE P = 6.80

CD Soils = NS

Table 35. Kinetics of available Aluminium due to submergence ppm.

	Period of submergence							
Soils	Initial	2 weeks	4	6	8	10	12	Mean
Vellayani	137.24	16.50	7.90	5.27	3.99	2.41	1.54	24.98
Karamana	28.50	3.58	2.68	1.81	1.53	1.19	0.81	5.73
Karapadom	54.30	8.44	6.88	4.52	3.92	2.58	1.88	11.76
Kari	326.10	123.08	100.55	81.02	59.73	48.26	35.06	110.54
Kayal	375.30	203.30	161.41	136.19	113.86	93.32	52.06	162.21
Kole	89.13	74.72	16.42	11.10	7.83	5.65	2.80	29.67
Kaipad	13.51	8.10	6.52	5.39	4.20	3.22	1.93	6.13
Pokkali	356.70	304.91	287.48	252.41	187.04	135.35	91.95	230.84
Pattambi	46.2	20.34	13.12	9.80	7.52	4.62	2.66	14.90
Kattampally	12.00	5.86	4.30	3.74	3.04	2.54	1.48	4.71
Wyanad	13.20	6.84	5.24	3.65	2.74	2.00	1.38	5.01
Chittoor	Traces	Traces	Traces	Traces	Traces	Traces	Traces	
Mean	121.02	64.64	51.04	42.91	32.94	25.94	16.13	

CD Soil x Period = 78.61 SE S x P = 28.36

CD Periods = 22.69 SE P = 8.19

CD Soils = NS

4.12.2 Kinetics of Eh (at 5cm depth)

Redox potential decreased from 496 mV to 86 mV after 12 weeks submergence in Vellayani soil. The maximum initial Eh (564 mV) was recorded by *Kari* soils and reached 114 mV, after 90 days. The minimum Eh change was for *Pokkali* soils (327 mV). The maximum change occurred was within the first two weeks in all soils. Chittoor soils recorded an Eh value of 69 mV after 90 days at 5 cm depth.

Redox potential at 8 cm depth reached 25 mV in Karamana Soils after 3 months and 207 mV was recorded by *Pokkali* soils at this depth.

4.12.3 Kinetics of available nitrogen

All the soils recorded an increase in available nitrogen due to submergence. Vellayani soils had 494 ppm increase in available nitrogen after 3 months. During the first two weeks there was sudden increase and from there a slow increase was observed in all soils. The maximum increase was noticed in Kattampally soils 542 ppm. When quadratic regression model was fitted for nitrogen Vellayani, Karamana, *Pokkali*, *Kole* and Wyanad soils showed maximum nitrogen availability in about 8 weeks

4.12.4 Kinetics of available phosphorus

Available phosphorus increased in all soils due to submergence. In *Kayal, Kari, Pokkali, Kole, Kaipad*, Pattambi, Wyanad and Chittoor soils showed an increase in available phosphorus during the first two weeks from there it decreased and then increased to constant value. The maximum increase was observed for Vellayani soils. All the soils followed a quadratic model

Kayal, Kari, Pokkali, Pattambi, Kattampally and Wyanad soils reached at their maximum phosphorus availability condition in about 5 weeks.

4.12.5 Kinetics of available potassium

Available potassium increased due to submergence in Vellayani soil but it decreased in all other wetlands. *Kaipad* soils had got the minimum available potassium. Maximum decrease in available potassium occurred during first two weeks submergence. In all soils there was a decrease in the available potassium upto 4th week then it increased and again decreased. Soils followed a quadratic model. Vellayani and Kattampally soils took 10 weeks to reach the maximum available potassium level. About 88 per cent of variation in the availability of this element could be accounted by period of submergence in Kattampally soils.

4.12.6 Kinetics of available calcium

Available calcium increased in Vellayani, *Karapadom*, *Kayal, Kari, Kole*, Pattambi, Wyanad and Chittoor soils due to water logging. In *Kari* Soils first there was a decline in calcium then increased and reached a value of 1131 ppm. The available calcium decreased in *Pokkali, Kaipad* and Kattampally soils. In others it decreased at first and then increased. The maximum calcium availability was noticed in *Kayal* soils. According to the quadratic regression model fitted *Kari* soils attained maximum K availability stage within four weeks.

4.12.7 Kinetics of available magnesium

In Vellayani soils first there was a decrease and then increased. Karamana soils showed a decreasing trend throughout the period of submergence.

Karapadom, Kayal, Kari, Kole and Chittoor had a constant increase in available magnesium. In *Pokkali, Kaipad*, Pattambi and Wyanad during the first two weeks there was a decline in available magnesium then it increased. All the soils followed a quadratic trend.

4.12.8 Kinetics of available sodium

In all soils available sodium increased due to submergence. In Vellayani and Karamana soils there was a constant increase upto 8 weeks then it decreased. In *Karapadom, Kayal, Kari, Pokkali, Kole* and *Kattampally* there was a sudden increase during the first two weeks then it increased at a slow rate. All the soils followed a quadratic pattern during the kinetics. The regression equations are presented in Table 36.

4.12.9 Kinetics of available iron

Available iron increased in Vellayani, Karamana, *Karapadom, Kayal, Kole* and Wyanad soils. It decreased in *Kari, Pokkali, Kaipad*, Pattambi, Katampally and Chittoor soils. The maximum available iron was recorded by Vellayani soil (592 ppm). Soils followed a quadratic pattern of change for this element and regression equations are also computed.

4.12.10 Kinetics of available manganese

Manganese showed a decreasing trend in Vellayani, Karamana, *Karapadom, Kole, Kaipad, Pattambi, Kattampally* soils. But in *Kari*, Pokkali, Wyanad and Chittoor a slight increase due to submergence was observed. Changes in available manganese followed a quadratic trend in all soils.

Table 36. Regressions relating kinetics of available nutrients, pH and Eh with period of submergence in surface soils of wet lands

Name of wetland	Regression equations		F	R^2	Optinum t weeks
Available nitrogen					
Vellayani	Y = 290.94 + 97.64t	-5.45T	14.2191*	0.8767	8.9552
Karamana	Y = 200.76 + 51.41t	-2.94T	10.4667*	0.8396	8.7508
Karapadom	Y = 217.75 + 82.44t	-4.06T	43.4091**	0.9560	10.1490
Kari	Y = 303.94 + 99.62t	-5.44T	18.9733**	0.9046	9.1621
Kayal	Y = 175.18 + 56.06t	-2.96T	23.160**	0.9205	9.4812
Kole	Y = 266.89 + 81.84t	-4.73T	12.2182*	0.8593	8.6496
Kaipad	Y = 111.67 + 20.60t	-0.64T	163.6981**	0.9879	16.0976
Pokkali	Y = 224.68 + 63.90t	-3.67T	12.6712*	0.8637	8.7049
Pattambi	Y = 183.58 + 48.38t	-2.09T	1595.1550**	0.9987	11.6004
Kattampally	Y = 143.15 + 22.02t	-1.17T	20.1979**	0.9099	9.3963
Wyanad	Y = 168.86 + 110.77t	-6.23T	18.0020**	0.9000	8.8873
Chittoor	Y = 146.75 + 33.89t	-1.82T	30.1194**	0.9377	9.3277
Available Phosphorus					
Vellayani	Y = 62.43 + 44.09t	-2.27T	20.1810*	0.9098	9.6956
Karamana	Y = 83.25 + 27.84t	-1.70T	5.3388	0.7275	8.1725
Karapadom	Y = 60.28 + 40.55t	-2.41T	6.2998*	0.7590	8.4243
Kari	Y = 127.08 + 21.82t	-2.25T	0.7360	0.2690	4.8418
Kayal	Y = 86.98 + 20.23t	-1.86T	0.7219	0.2652	5.4422
Kole	Y = 41.09 + 19.92t	-1.29T	2.7178	0.5761	7.7035
Kaipad	Y = 36.36 + 11.40t	-0.84T	0.9871	0.3304	6.7747
Pokkali	Y = 83.46 + 24.56t	-2.14T	0.5935	0.2288	5.7267
Pattambi	Y = 47.86 + 9.19t	-0.84T	0.5432	0.2136	5.4809
Kattampally	Y = 59.94 + 17.27t	-1.60T	0.7115	0.2624	5.3825
Wyanad	Y = 63.05 + 16.55t	-1.54T	0.6808	0.2538	5.3562
Chittoor	Y = 55.62 + 12.63t	-0.99T	0.8281	0.2920	6.3794
Available Potassium					
Vellayani	Y = 39.82 + 4.86t	-0.23T	7.7998**	0.7959	10.4002
Karamana	Y = 101.80 - 18.64t	+1.18T	1.8542	0.4811	7.9214
Karapadom	Y = 182.97 - 34.53t	+2.27T	3.2104	0.6162	7.6099
Kari	Y = 129.31 - 6.81t	+0.86T	0.9155	0.3140	3.9768
Kayal	Y = 322.45 - 56.78t	+3.92T	2.0971	0.5119	7.2433
Kole	Y = 82.92 - 4.90t	+0.34T	0.3759	0.1582	7.2364
Kaipad	Y = 4.86 + 11.33t	-0.80T	6.1643	0.7550	7.0817
Pokkali	Y = 207.01 - 19.09t	+1.67T	0.6464	0.2442	5.7215
Pattambi	Y = 51.84 - 3.30t	+0.20T	2.1924	0.5229	8.1316
Kattampally	Y = 123.42 - 18.59t	+0.92T	15.2874**	0.8843	10.1186
Wyanad	Y = 34.44 + 0.32t	+0.13T	4.1454	0.6746	-1.1817
Chittoor	Y = 47.79 - 4.24t	+0.32T	1.9248	0.4904	6.6459

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Table 36 (Contd...)

Name of wetland	Regression equations	F	R^2	Optinum t weeks
Available Calcium				
Vellayani	Y = 464.41 + 30.62t +0.78T	241.1145**	0.9918	-19.5429
Karamana	Y = 696.57 - 91.65t +6.51T	4.5851	0.6963	7.0410
Karapadom	Y = 474.32 + 51.86t -1.73T	21.9041**	0.9163	15.0028
Kari	Y = 938.98 - 23.65t +3.52T	4.6265	0.6982	3.2719
Kayal	Y = 1025.77 + 74.71t -1.65T	103.8134**	0.9811	35.6716
Kole	Y = 1250.35 + 11.13t +1.35T	11.3291	0.8500	-4.1184
Kaipad	Y = 378.76 - 37.03t +2.98T	2.7424	0.5783	6.2140
Pokkali	Y = 1195.77 - 131.76t +9.69T	4.9161	0.7108	6.8008
Pattambi	Y = 399.89 - 50.74t +4.70T	30.4370**	0.9383	5.4005
Kattampally	Y = 775.64 - 130.05t +9.66T	4.6868	0.7009	6.7280
Wyanad	Y = 850.69 - 48.27t +4.80T	7.2077*	0.7828	5.0284
Chittoor	Y = 2169.05 + 45.90t -1.11T	9.6391*	0.8282	20.6729
Available Magnesium				
Vellayani	Y = 124.31 - 8.10t +0.88T	4.0869	0.6714	4.5939
Karamana	Y = 82.92 - 11.52t +0.74T	3.4959	0.6361	7.7348
Karapadom	Y = 215.79 + 18.65t -1.02T	38.5194**	0.9506	9.1580
Kari	Y = 268.50 + 30.22t -1.44T	26.0193**	0.9286	10.4728
Kayal	Y = 356.74 + 28.37t -0.91T	12.1909*	0.8591	15.5967
Kole	Y = 191.64 + 37.19t -2.28T	20.9457**	0.9128	8.1626
Kaipad	Y = 60.09 + 0.99t -0.09T	0.3177	0.1371	5.6911
Pokkali	Y = 502.45 - 1.44t +0.40T	0.1401	0.0654	1.7986
Pattambi	Y = 78.96 - 11.56t +0.88T	7.0831*	0.7798	6.5935
Kattampally	Y = 248.40 - 7.25t +0.86T	1.4972	0.4281	4.1940
Wyanad	Y = 126.47 - 6.68t +0.65T	1.5735	0.4403	5.1743
Chittoor	Y = 137.86 + 53.51t -3.10t	8.8876*	0.8163	8.6349
Available Sodium				
Vellayani	Y = 168.79 + 98.87t -5.37t	228.3821**	0.9913	9.2073
Karamana	Y = 186.43 + 65.36t -3.88T	173.8949**	0.9886	8.4202
Karapadom	Y = 320.35 + 108.75t -4.83T	1122.8710**	0.9982	11.2546
Kari	Y = 441.76 + 276.19t -14.25T	102.7932**	0.9809	9.6909
Kayal	Y = 695.65 + 342.86t -18.67T	16.4232*	0.8914	9.1798
Kole	Y = 423.44 + 283.94t -18.63T	19.5573**	0.9072	7.6209
Kaipad	Y = 148.97 + 27.58t -1.33T	16.5666*	0.8923	10.3591
Pokkali	Y = 2196.58 + 836.30t -45.40T	126.1563**	0.9844	9.2098
Pattambi	Y = 125.24 + 66.01t -3.04T	8.3288*	0.8064	10.8513
Kattampally	Y = 823.78 + 254.83t -24.52T	1.9092	0.4884	5.1961
Wyanad	Y = 150.01 + 47.47t -2.73T	3.8430	0.6577	8.6905
Chittoor	Y = 139.40 + 142.90t -7.90T	41.8017**	0.9543	9.0482

Contd...

Table 36 (Contd...)

Name of wetland	Regression equations		F	R^2	Optinum t weeks
Available Iron					
Vellayani	Y = 442.39 - 19.21t	+2.48T	4.7059	0.7018	3.8790
Karamana	Y = 274.81 - 1.35t	+1.10T	5.7629	0.7424	0.6142
Karapadom	Y = 475.97 - 38.66t	+3.51T	25.6627**	0.9277	5.5114
Kari	Y = 603.54 - 43.22t	+3.36T	0.9968	0.3326	6.4321
Kayal	Y = 374.52 - 28.81t	+2.06T	2.0136	0.5017	6.9982
Kole	Y = 301.94 + 22.26t	-1.69T	1.5264	0.4328	6.5749
Kaipad	Y = 180.68 + 3.14t	-0.25T	1.2150	0.3779	6.2575
Pokkali	Y = 418.52 - 9.19t	+0.30T	0.9293	0.3172	15.1411
Pattambi	Y = 349.69 + 4.57t	-0.39T	0.4354	0.1788	5.9006
Kattampally	Y = 202.59 - 25.64t	+1.87T	55.8034**	0.9654	6.8475
Wyanad	Y = 90.00 + 120.85t	-9.97T	17.2970*	0.8964	0.0594
Chittoor	Y = 179.05 - 0.89t	-0.06t	0.6629	0.2489	-7.9913
Available Manganese					
Vellayani	Y = 53.32 - 4.34t	+0.27T	5.3066	0.7263	8.1124
Karamana	Y = 22.72 - 0.83t	-0.01T	22.0153**	0.9167	-34.0554
Karapadom	Y = 31.73 - 4.28t	+0.28T	2.9740	0.5979	7.7357
Kari	Y = 8.09 - 0.80t	+0.16T	59.3672**	0.9674	2.4703
Kayal	Y = 26.00 - 0.57t	+0.19T	2.3389	0.5391	1.5266
Kole	Y = 46.45 - 3.81t	+0.21T	183.1852**	0.9892	9.1782
Kaipad	Y = 6.17 - 0.33t	+0.02T	85.1124**	0.9770	9.0749
Pokkali	Y = 14.20 - 2.76t	+0.26T	18.0096**	0.9000	5.2980
Pattambi	Y = 13.51 - 0.65t	+0.02T	3.7226	0.6505	16.2061
Kattampally	Y = 32.39 + 0.21t	-0.20T	62.1986**	0.9688	0.5448
Wyanad	Y = 19.48 - 2.42t	+0.42T	12.7578	0.8645	2.9108
Chittoor	Y = 29.40 + 3.89t	-0.39T	1.7997	0.4736	4.9548
Available Zinc					
Vellayani	Y = 5.36 + 0.26t	-0.05T	23.1494**	0.9205	2.6768
Karamana	Y = 2.34 + 0.21t	-0.03T	3.1853	0.6143	3.8966
Karapadom	Y = 4.28 + 0.17t	-0.34T	25.4698**	0.9272	2.3795
Kari	Y = 3.42 + 0.06t	-0.03T	7.9422*	0.7988	1.1372
Kayal	Y = 2.35 + 0.11t	-0.02T	7.0618*	0.7793	2.4158
Kole	Y = 9.21 - 1.65t	+0.07T	121.2187**	0.9838	10.8400
Kaipad	Y = 1.64 - 0.02t	-0.01T	10.8205*	0.8440	-1.1235
Pokkali	Y = 5.43 + 0.82t	-0.10T	18.0446**	0.9002	4.3161
Pattambi	Y = 3.75 - 0.16t	-0.01T	14.7334*	0.8805	-6.5595
Kattampally	Y = 2.30 - 0.17t	-0.01T	8.5751*	0.8109	-3.1254
Wyanad	Y = 7.06 - 0.91t	+0.03T	144.8987**	0.9864	13.8509
Chittoor	Y = 6.51 - 0.75t	+0.04T	14.2334*	0.8768	9.5740

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Table 36 (Contd...)

Name of wetland	Regression equations	F	R^2	Optinum t weeks
Available Copper				
Vellayani	$Y = 3.64 - 0.83t + 0.05T$	6.8011	0.7728	7.8104
Karamana	$Y = 5.26 - 1.10t + 0.07T$	7.0409^{*}	0.7788	8.0675
Karapadom	$Y = 6.99 - 1.60t + 0.10T$	10.1356^{*}	0.8352	7.9914
Kari	$Y = 0.70 - 0.11t + 0.01T$	1.1845	0.3720	7.3748
Kayal	$Y = 1.88 - 0.39t + 0.02T$	29.6128^{**}	0.9367	8.4654
Kole	$Y = 5.88 - 1.02t + 0.06T$	57.6121^{**}	0.9664	9.2037
Kaipad	$Y = 2.09 - 0.33t + 0.02T$	4.8821	0.7094	8.5335
Pokkali	$Y = 1.62 - 0.45t + 0.03T$	5.2702	0.7249	8.0343
Pattambi	$Y = 9.64 - 2.25t + 0.15T$	6.5412	0.7658	7.7325
Kattampally	$Y = 4.31 - 0.83t + 0.04T$	4.3419	0.6846	9.1952
Wyanad	$Y = 2.38 - 0.52t + 0.03T$	4.2889	0.6820	7.9381
Chittoor	$Y = 5.25 - 1.11t + 0.06T$	8.8355^{**}	0.8154	8.7141
Available Sulphur				
Vellayani	$Y = 1473.32 - 327.50t + 17.56T$	126.1665^{**}	0.9844	9.3267
Karamana	$Y = 582.06 - 111.66t + 5.36T$	728.9230^{**}	0.9973	10.4144
Karapadom	$Y = 2425.45 - 561.13t + 30.86T$	87.3031^{**}	0.9776	9.0903
Kari	$Y = 4690.71 - 664.13t + 20.30T$	9.4281^{*}	0.8250	16.3556
Kayal	$Y = 1478.11 - 2.34t - 11.97T$	6.4417	0.7631	-0.0977
Kole	$Y = 1843.91 - 410.74t + 22.10T$	118.9240^{**}	0.9835	9.2917
Kaipad	$Y = 415.39 - 75.49t + 3.43T$	296.7355^{**}	0.9933	10.9902
Pokkali	$Y = 3284.39 - 522.51t + 20.39T$	86.028^{**}	0.9773	12.8146
Pattambi	$Y = 382.04 - 56.31t + 1.96T$	87.0813^{**}	0.9775	14.3429
Kattampally	$Y = 456.81 - 88.46t + 4.27T$	558.0740^{**}	0.9964	10.3509
Wyanad	$Y = 236.20 - 30.00t + 0.78T$	29.7373^{**}	0.9370	19.2828
Chittoor	$Y = 212.62 - 33.40t + 1.27T$	87.7782^{**}	0.9777	13.1133
Available Silica				
Vellayani	$Y = 68.63 + 17.88t - 0.90T$	36.4779^{**}	0.9480	9.8918
Karamana	$Y = 84.49 + 1.87t - 0.11T$	5.2652	0.7247	8.3540
Karapadom	$Y = 179.01 - 10.73t + 0.69T$	28.4854^{**}	0.9344	7.7527
Kari	$Y = 100.11 + 23.15t - 1.23T$	413.5951^{**}	0.9952	9.4268
Kayal	$Y = 125.54 + 27.12t - 1.59T$	68.4538^{**}	0.9716	8.5123
Kole	$Y = 133.24 + 12.11t - 0.41T$	183.9761^{**}	0.9892	14.7373
Kaipad	$Y = 129.49 - 14.00t + 0.87T$	23.3457^{**}	0.9211	8.0074
Pokkali	$Y = 190.63 + 17.33t - 0.81T$	122.6394^{**}	0.9840	10.6521
Pattambi	$Y = 162.43 - 4.66t + 0.16T$	13.7560^{*}	0.8731	14.3430
Kattampally	$Y = 162.46 - 10.79t + 0.71T$	13.8008^{*}	0.8734	7.5893
Wyanad	$Y = 97.59 + 37.99t - 2.13T$	36.9978^{**}	0.9487	8.9002
Chittoor	$Y = 173.09 - 0.46t + 0.16T$	39.9556^{**}	0.9523	1.4208

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Table 36 (Contd...)

Name of wetland	Regression equations	F	R^2	Optinum t weeks
Exch. Aluminium				
Vellayani	Y = 109.96 - 30.60t +1.90T	7.4838*	0.7891	8.0680
Karamana	Y = 22.80 - 6.11t +0.38T	6.9515*	0.7766	8.1073
Karapadom	Y = 43.95 - 11.32t +0.69T	7.5272*	0.7901	8.2358
Kari	Y = 284.08 - 54.74 t +2.98T	14.0934*	0.8757	9.1879
Kayal	Y = 340.37 - 49.46t +2.28T	23.1276**	0.9204	10.8443
Kole	Y = 93.53 - 19.48t +1.02T	24.8324**	0.9255	9.5541
Kaipad	Y = 12.54 - 1.68t +0.07T	42.0493**	0.9546	11.9779
Pokkali	Y = 351.72 - 15.25t -0.57T	206.5099**	0.9904	-13.4834
Pattambi	Y = 41.38 - 8.11t +0.43T	24.8587**	0.9255	9.5144
Kattampally	Y = 10.75 - 1.79t +0.09T	19.3289**	0.9062	9.8934
Wyanad	Y = 12.16 - 2.08t +0.10T	41.1785**	0.9537	10.1629
Chittoor				
Redox potential (5cm depth)				
Vellayani	Y = 415.47 - 93.69t +5.82T	7.8924*	0.7978	8.0443
Karamana	Y = 354.63 - 92.54t +5.82T	6.5932	0.7673	7.9551
Karapadom	Y = 410.33 - 82.89t +4.85T	23.7021**	0.9222	8.5377
Kari	Y = 507.02 - 86.92t +4.72T	19.0367**	0.9049	9.2146
Kayal	Y = 469.45 - 82.99t +4.82T	22.5396**	0.9185	8.6062
Kole	Y = 419.74 - 89.17t +5.57T	6.8928	0.7751	7.9984
Kaipad	Y = 398.44 - 75.67t +4.58T	12.0074*	0.8572	8.2617
Pokkali	Y = 505.39 - 68.99t +3.93T	20.9580	0.9129	8.7788
Pattambi	Y = 389.48 - 84.58t +5.20T	9.4347*	0.8251	8.1365
Kattampally	Y = 398.17 - 55.49t +3.43T	8.1492*	0.8080	8.0999
Wyanad	Y = 372.60 - 78.08t +4.80T	8.4783*	0.8091	8.1354
Chittoor	Y = 353.67 - 79.63t +4.90T	8.3917	0.8075	8.1308
Redox potential (8cm depth)				
Vellayani	Y = 407.15 - 98.12t +6.15T	7.3443*	0.7860	7.9736
Karamana	Y = 346.19 - 94.76t +5.99T	5.9450	0.7483	7.9081
Karapadom	Y = 397.47 - 89.85t +5.50T	16.4337*	0.8915	8.1736
Kari	Y = 497.21 - 89.45t +4.84T	16.1995*	0.8901	9.2423
Kayal	Y = 458.55 - 88.16t +5.25T	17.6062*	0.8980	8.4010
Kole	Y = 414.78 - 92.10t +5.78T	6.7847	0.7723	7.9689
Kaipad	Y = 388.73 - 81.15t +5.03T	9.9538*	0.8327	8.0685
Pokkali	Y = 493.97 - 71.32t +4.14T	14.3954	0.8780	8.6215
Pattambi	Y = 375.83 - 89.48t +5.60T	7.3813*	0.7868	7.9844
Kattampally	Y = 390.29 - 57.12T +3.54t	7.1071*	0.7804	8.0774
Wyanad	Y = 355.67 - 79.39t +4.95T	5.6477	0.7385	8.0253
Chittoor	Y = 342.89 - 84.52t +5.34T	6.8918	0.7751	7.9132

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Table 36 (Contd...)

Name of wetland	Regression equations	F	r	R^2	Optinum 't' in days
pH					
Vellayani	pH = 5.39 + 0.0271t -0.00T		0.4167*	0.17	
Karamana	pH = 6.28 - 0.01t +0.0002T	1.25		0.08	30.10
Karapadom	pH = 5.25 + 0.035t -0.00T		0.5261*	0.28	
Kari	pH = 5.55 - 0.04t +0.0002T	31.12*		0.70	51.12
Kayal	pH = 6.57- 0.13t +0.0013T	4.47**		0.25	87.78
Kole	pH = 5.38 -0.05t +0.0004T		0.7122**	0.51	
Kaipad	pH = 6.82 -0.006t -0.00T	4.23*		0.24	27.90
Pokkali	pH = 3.28 + 0.05t -0.00T		0.26	0.07	
Pattambi	pH = 6.08 - 0.02t +0.0003T	1.28		0.09	32.69
Kattampally	pH = 6.05 - 0.008t 0.0001T	0.38		0.03	43.00
Wyanad	pH= 6.10 + 0.007t -0.000T	0.88		0.06	683.29
Chittoor	pH = 7.37 - 0.03t +0.0004T	3.83*		0.22	45.72

t = Number of weeks submergence T = t x t

4.12.11 Kinetics of available zinc

Available Zinc followed a decreasing pattern in all the wet lands studied. The regression models were of a quadratic pattern for all wet lands.

4.12.12 Kinetics of available copper

Available copper decreased in all soils due to submergence. The soils followed a quadratic pattern and regression equations computed.

4.12.13 Kinetics of available sulphur

Although the initial available sulphur was high in all soils, it decreased to very low concentrations due to submergence.

The highest initial available sulphur was noticed in *Kari* Soils (4026 ppm) and it decreased to 26 ppm after twelve weeks of submergence. In *Pokkali* it reduced from 3261 ppm to 29 ppm. Available sulphur followed a quadratic pattern in all soils.

4.12.14 Kinetics of available silica

Available silica increased in all soils except in *Kaipad, Pattambi* and *Kattampally* soils. It increased from 75 ppm to 149 ppm in Vellayani surface soils. When regression models were fitted all the soils followed a quadratic trend.

4.12.15 Kinetics of exchangeable aluminium

Exchangeable aluminium decreased in all soils due to submergence. A sudden decrease occurred in all soils during the first two weeks afterwards it decreased slowly. In *Kayal, Kari and Pokkali* soils the initial exchangeable aluminium was high and after twelve weeks also there was toxic amounts of this element in the soil.

4.13 Comparison of lime requirement methods for different wetlands

Lime requirement had been calculated for all the wetlands using three methods namely exchangeable aluminium method, shoemaker method and base saturation elevation method. All the three methods could not be applied for all the soils. Exchangeable aluminium method was applicable to all soils. Shoemaker method was only applicable to soils which recorded buffer solution pH values between 4.8 and 6.9. Base saturation elevation method of calculating lime requirement was applicable only for soils having percentage base saturation below 60 percentage. The titration method of determining lime requirement was also adopted for all soils for comparison. The means of lime requirement of the wetlands are given in Table 37. According to the exchangeable aluminium method *Kari* soils required the highest amount of lime ie. 8.59 tonnes ha^{-1} followed by *Pokkali* 5.91 tonnes ha^{-1}. Based on shoe maker method *Kari* soils required 8 tonnes ha^{-1} (based on two observations) and *Pokkali* soils needed 11.5 tonnes ha^{-1} (based on one observation). According to base saturation elevation method *Kari* soils needed about 23.33 tonnes ha^{-1} of lime to neutralise the acidity. Based on titration method the requirement of lime were Vellayani- 2.8 tonnes ha^{-1}, *Karapadom* - 3.34 tonnes ha^{-1}, *Kayal*- 4.58 tonnes ha^{-1}, *Kari*- 20.65 tonnes ha^{-1} and *Pokkali*-5.53 tonnes ha^{-1}.

Table 37. Lime requirement of major wetlands (t/ha)

Name of wetland	Exch. Al method	Shoemaker method	Base saturation method	Titration method
Vellayani	1.67	7.20	1.99	2.80
Karamana	0.39	3.55	0.51	0.52
Karapadom	3.00	7.67	3.72	3.34
Kari	8.59	8.00	23.22	20.65
Kayal	4.41	6.75	2.85	4.58
Kole	1.23	8.75	1.84	1.52
Kaipad	0.72	5.00	0.37	0.84
Pokkali	5.91	11.5	1.28	5.53
Pattambi	0.54	4.69	0.84	0.72
Kattampalli	0.20	2.58	—	0.52
Wyanad	0.37	2.94	0.61	0.50
Chittoor	—	—	—	—

Table 38. Comparison of lime requirement methods

y	x	r	R^2	Regression equation
Dry water pH 1:1				
1. Vellayani				
	Exch. Al. method	−0.70*	0.49	$y = 4.60 - 0.22X$
	Base saturation method	−0.52	0.27	$y = 4.62 - 0.03X$
	Shoemaker method	−0.67*	0.45	$y = 4.62 - 0.03X$
2. Karamana				
	Exch. Al. method	−0.62	0.39	$y = 5.88 - 2.31X$
	Base saturation method	0.015	0.0002	—
	Shoemaker method	−0.007	0.005	—
3. *Karapadom*				
	Exch.Al. method	−0.82*	0.68	$y = 4.67 - 0.018X$
	Base saturation method	−0.25	−0.06	$y = 4.45 - 0.04X$
	Shoemaker method	0.73*	0.53	$y = 3.93 + 0.07X$
4. *Kayal*				
	Exch. Al. method	−0.88**	0.77	$y = 5.52 - 0.37X$
	Base saturation method	−0.43	0.18	$y = 4.81 - 0.13X$
	Shoemaker method	0.38	0.14	$y = 4.10 + 0.09X$
5. *Kari*				
	Exch. Al. method	−0.78**	0.61	$y = 3.78 - 0.10X$
	Base saturation method	−0.85**	0.73	$y = 3.74 + 0.03X$
	Shoemaker method	0.45	0.20	$y = 3.07 + 0.08X$
6. *Pokkali*				
	Exch. Al. method	−0.84**	0.71	$y = 3.64 - 0.11X$
	Base saturation method	−0.45	0.20	$y = 3.26 - 0.22X$
	Shoemaker method	0.64*	0.40	$y = 3.11 - 0.06X$
7. *Kole*				
	Exch. Al. method	−0.46	0.21	$y = 4.82 - 0.24X$
	Base saturation method	−0.23	0.05	$y = 4.65 - 0.06X$
	Shoemaker method	0.21	0.04	$y = 4.45 + 0.02X$
8. *Kaipad*				
	Exch. Al. method	−0.76**	0.59	$y = 5.47 - 0.41X$
	Base saturation method	−0.16	0.002	$y = 5.30 - 0.81X$
	Shoemaker method	−0.70*	0.49	$y = 5.44 - 0.11X$

y	x	r	R^2	Regression equation
9.	Pattambi			
	Exch. Al. method	0.67*	0.45	y = 5.40 – 1.24X
	Base saturation method	–0.48	0.23	y = 5.11 – 0.43X
	Shoemaker method	–0.18	0.03	y = 5.06 – 0.003X
10.	Kattampally			
	Exch. Al. method	–0.20	0.04	y = 6.06 – 4.52X
	Base saturation method	–0.45	0.21	y = 5.69 – 1.09X
	Shoemaker method			
11	Wyanad			
	Exch. Al. method	–0.40	0.16	y = 5.16 – 1.37X
	Base saturation method	0.16	0.03	y = 4.81 + 0.004X
	Shoemaker method	–0.24	0.06	y = 4.92 – 0.035X
Dry KCl pH				
1.	Vellayani			
	Exh. Al. method	–0.98**	0.96	y = 3.96 – 0.27X
	Base saturation method	–0.62	0.38	y = 3.72 – 0.03X
	Shoemaker method	–0.90**	0.80	y = 3.97 – 0.04X
2.	Karamana			
	Exch. Al. method	–0.86**	0.74	y = 3.96 – 0.13X
	Base saturation method	–0.37	0.14	y = 3.84 – 0.04X
	Shoemaker method	0.80**	0.64	y = 3.40 + 0.06X
3.	*Karapadom*			
	Exch. Al. method	–0.82**	0.68	y = 4.67 – 0.018X
	Base saturation method	–0.25	–0.06	y = 4.45 – 0.04X
	Shoemaker method	0.73*	0.53	y = 3.93 + 0.07X
4.	*Kayal*			
	Exch. Al. method	–0.82**	0.66	y = 4.69 – 0.30X
	Base saturation method	–0.37	–0.14	y = 4.08 – 0.099X
	Shoemaker method	0.41	0.17	y = 3.16 + 0.09X
5.	*Kari*			
	Exch. Al. method	–0.52	0.27	y = 3.05 – 0.04X
	Base saturation method	–0.32	0.10	y = 2.94 – 0.007X
	Shoemaker method	–0.17	0.03	y = 2.85 + 0.018X
6.	*Pokkali*			
	Exch. Al. method	–0.73*	0.54	y = 3.15 – 0.08X
	Base saturation method	–0.57	0.32	y = 2.92 – 0.22X
	Shoemaker method	0.66	0.44	y = 2.78 – 0.05X

y	x	r	R^2	Regression equation
8.	*Kaipad*			
	Exch. Al. method	-0.71^{*}	0.51	y = 4.62 = 0.35X
	Base saturation method	-0.23	0.05	y = 4.49 - 1.07X
	Shoemaker method	-0.62	0.38	y = 4.59 - 0.09X
9.	Pattambi			
	Exch. Al. method	-0.76^{**}	0.58	y = 4.83 - 1.81X
	Base saturation	-0.50	0.25	y = 4.43 - 0.56X
	Shoemaker method	-0.43	0.19	y = 4.59 - 0.10X
10.	Kattampally			
	Exch. Al. method	-0.44	0.19	y = 5.76 - 8.69X
11.	Wyanad			
	No significant correlation			
	Chittoor	Nil		
Exch. acidity				
1.	Vellayani			
	Exh. Al. method	0.99^{*}	0.97	y = 0.08 + 1.34X
	Base saturation method	0.76^{*}	0.57	y = 1.21 + 0.19X
	Shoemaker method	0.86^{**}	0.73	y = 0.09 + 0.21X
2.	Karamana			
	Exch. Al. method	0.91^{**}	0.82	y = 0.08 + 1.25X
	Base saturation method	-0.06	0.003	
	Shoemaker method	0.32	0.10	
3.	*Karapadom*			
	Exch. Al. method	0.99^{**}	0.99	y = 0.14 + 1.58X
	Base saturation method	0.57	0.33	y = 0.98 + 0.63X
	Shoemaker method	-0.69	0.48	y = 5.57 - 0.52X
4.	*Kayal*			
	Exch. Al. method	0.99^{**}	0.99	y = 0.03 + 1.69X
	Base saturation method	0.51	0.25	y = 3.20 + 0.61X
	Shoemaker method	-0.38	0.15	y = 6.33 - 0.38X

y	x	r	R^2	Regression equation
5.	*Kari*			
	Exch. Al. method	0.94**	0.87	y = –2.47 + 3.30X
	Base saturation method	0.88**	0.78	y = 1.32 + 0.93X
	Shoemaker method	–0.45	0.20	y = 20.1 –2.31X
6.	*Pokkali*			
	Exch. Al. method	0.98**	0.97	y = 1.21 + 1.73X
	Base saturation method	0.40	0.16	y = 7.05 + 2.55X
	Shoemaker method	–0.49	0.24	y = 8.71 – 0.59X
7.	*Kole*			
	Exch. Al. method	0.97**	0.94	y = 0.42 + 1.17X
	Base saturation method	0.86**	0.74	y = 1.18 + 0.54X
	Shoemaker method	0.50	0.25	y = 0.38 + 0.11X
8.	*Kaipad*			
	Exch. Al. method	0.99**	0.99	y = 0.013 + 1.41X
	Base saturation method	–0.11	0.012	
	Shoemaker method	0.98**	0.96	y = 0.98 + 0.40X
9.	Pattambi			
	Exch. Al. method	0.99**	0.98	y = –0.01 + 1.43X
	Base saturation method	0.73*	0.53	y = 0.27 + 0.51X
	Shoemaker method	0.108	0.01	
10.	Kattampally			
	Exch. Al. method	0.99**	0.99	y = 0.0000008 + 1.25X
	Base saturation method	Not significant		
	Shoemaker method	Not significant		
11.	Wyanad			
	Exch. Al. method	0.61	0.38	y = 0.09 + 1.01X
	Base saturation method	0.32	0.10	
	Shoemaker method	–0.27	0.07	
Pot acidity				
1.	Vellayani			
	Exh. Al. method	0.81**	0.65	y = 8.14 + 9.73X
	Base saturation method	0.66*	0.44	y = 16.12 + 1.45X
	Shoemaker method	0.88**	0.78	y = 5.32 + 1.90X
2.	Karamana			
	Exch. Al. method	–0.14	0.02	—
	Base saturation method	0.20	0.04	
	Shoemaker method	–0.63	0.39	y = 24.62 – 3.05X

y	x	r	R^2	Regression equation
3. Karapadom				
	Exch. Al. method	0.59	0.35	y = 27.04 + 4.63X
	Base saturation method	0.44	0.19	
	Shoemaker method	0.19	0.03	
4. *Kayal*				
	Exch. Al. method	0.88^{**}	0.77	y = 27.51 + 4.79X
	Base saturation method	0.35	0.12	
	Shoemaker method	–0.59	0.35	y = 48.56 + 1.91X
5. *Kari*				
	Exch. Al. method	0.84^{**}	0.70	y = 20.57 + 19.11X
	Base saturation method	0.98^{**}	0.96	y = 21.65 + 6.66X
	Shoemaker method	–0.53	0.28	y = 158.06 – 17.5X
6. *Pokkali*				
	Exch. Al. method	0.55	0.31	y = 32.14 + 2.30X
	Base saturation method	0.38	0.14	y = 39.04 + 5.65X
	Shoemaker method	–0.35	0.12	y = 42.33 – 0.98X
7. *Kole*				
	Exch. Al. method	0.25	0.06	
	Base saturation method	0.27	0.07	
	Shoemaker method	0.88^{**}	0.78	y = 9.46 + 2.35X
8. *Kaipad*				
	Exch. Al. method	0.58	0.34	y = 12.37 + 4.83X
	Base saturation method	–0.45	0.20	y = 16 – 35.13X
	Shoemaker method	0.58	0.33	y = 12.59 + 1.40X
9. Pattambi				
	Exch. Al. method	0.68^{*}	0.47	y = 12.83 + 18.31X
	Base saturation method	0.36	0.13	y = 17.35 + 4.65X
	Shoemaker method	0.49	0.25	y = 14.17 + 1.36X
10. Kattampally				
	Exch. Al. method	0.36	0.13	
	Base saturation method	0.68^{*}	0.47	y = 15.99 + 17.86X
	Shoemaker method	—	—	—
11. Wyanad				
	Exch. Al. method	0.36	0.13	—
	Base saturation method	0.48	0.23	y = 12.44 + 0.02X
	Shoemaker method	0.39	0.15	

Comparison of three lime requirement methods are given in Table 38. Correlation and regression analyses done using the first three methods and components of acidity gave the indication that exchangeable aluminium method could be adopted for all the wet lands. Significant negative correlations had been obtained between exchangeable aluminium and dry pH. Exchange acidity and potential acidity values also gave positive significant correlations with exchangeable aluminium in almost all soils. For Vellayani and *Kole* for ameliorating potential acidity shoemaker method of lime requirement was found to be best and for *Kari* and Kattampally soils base saturation elevation method can be adopted.

DISCUSSION

5. DISCUSSION

Rice is the principal crop that can be grown under submerged condition. Soil acidity is one of the major constraints that retards production of rice in many parts of the World. In Kerala most of the rice lands are acidic in reaction except in black soils of Chittoor. Soil acidity is a comprehensive reflection of many chemical properties of the soil and in turn it exerts profound influence on a series of other properties relating to soil fertility. The acidity of rice soils is characterised by a periodical change induced by alternate submergence and drainage and the rate and extent of such changes are far greater than those occurring in upland soils.

Attempts to unveil the nature, extent and severity of the problem of acidity, its contributing factors, interrelationship with other fertility parameters and suitable management practices to be adopted for achieving maximum rice production in wet lands of Kerala are discussed here under.

Twelve profiles and 120 surface samples were analysed representing the major rice growing tracts of the State. The components of acidity, acidity contributing factors and available nutrients were determined vertically (depth wise in profile samples) and horizontally (surface samples).

5.1. Acidity contributing factors in wet land soils of Kerala

Organic matter

Distribution of organic matter in profiles and surface samples of wetlands are given in Fig 14 and 15.

Though a highly significant negative relationship was observed between pH (dry) and organic matter in all the soils investigated, only 25 percent of variability in active acidity could be accounted by this factor. Perusal of the data also indicates the pronounced effect of organic matter in suppressing the pH of horizons of all the profiles studied. Contribution of organic matter towards active and potential acidity and electrical charges of soil colloids are investigated thoroughly by many workers (Bolt, 1976; Huduall, 1989; Zhong *et al.*, 1991 and Rajendran, 1992). The proton donating functional groups of humus and well decomposed organic matter viz. carboxyl, phenolic, hydroxyl, amino hydroxyl etc and their interaction with organomineral complexes of the soil play an important role in deciding the net pH of the system. The amphoteric behaviour of organic matter in this respect is well studied (Cang Dong quing, 1981) in soil systems particularly due to the zwitter ionic behaviour of organic colloids. The capacity of organic colloids to act as proton sink as well as proton source can be attributed to this behaviour. Thus the general effect of organic soils and soils rich in organic matter is mainly to enhance the acidity of the system.

An appraisal of the data clearly indicates that there is positive significant relationship between organic matter and exchangeable acidity ($r = 0.77^{**}$). Fifty nine per cent of variation in exchange acidity could be accounted by this factor when all the wetlands were taken together. This figure varies with individual

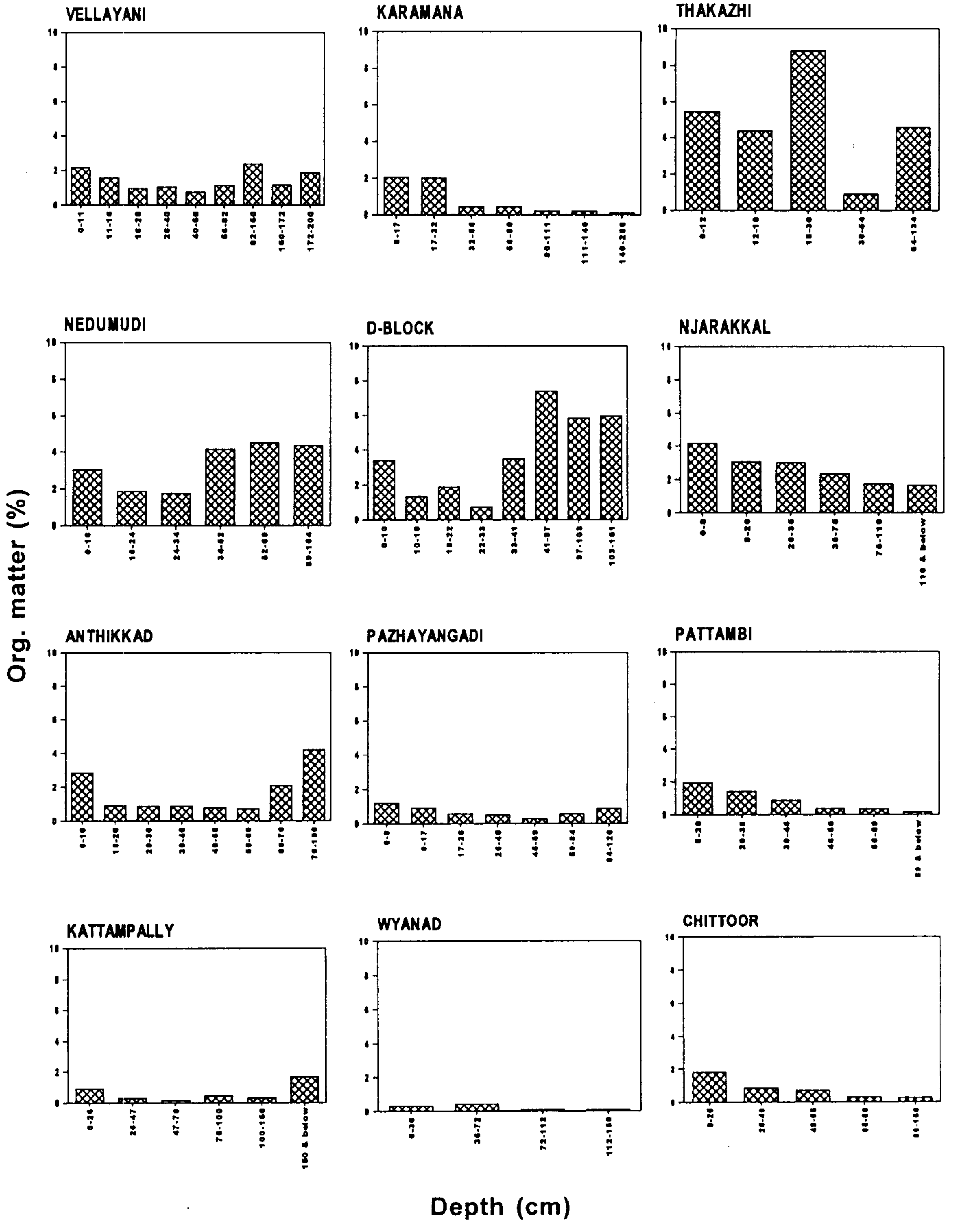

Fig. 14. Depthwise distribution of organic matter (%) in profiles of major wetlands

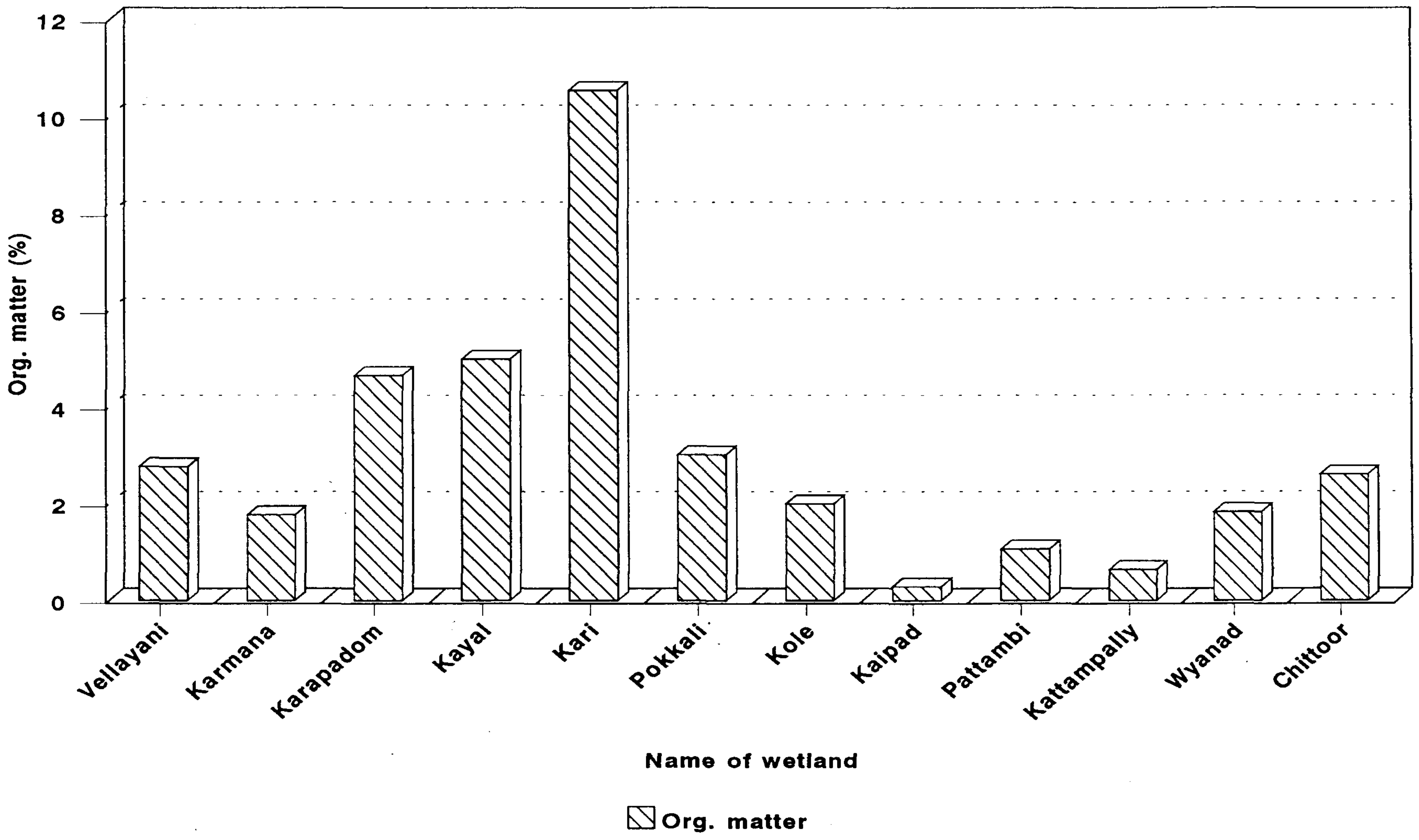

Fig. 15. Distrubution of organic matter in surface samples of major wetlands

soils based on the indirect effects of the other contributing factors. Wild (1988) also stated that the organic matter is predominantly acid in nature with the acidic properties being determined mostly by carboxyl groups below pH 7.0 and phenolic and enolic OH$^-$ at higher pH values. Van Raij (1969) in a study of the Brazilian soils also reported that the average contribution of organic matter to exchange properties of the soils was 74 per cent in surface soil and 35 per cent for subsoils. The mean CEC of 1g of carbon was found to be 3.36 me. The charge density of humic substances averages 300 me/100 g at pH 7.0 which is 30 times that of kaolinite. The cation exchange properties of soils are mainly determined by organic matter. In this study also a high positive significant correlation between CEC and organic matter was obtained ($r = 0.87^{**}$). CEC and exchange acidity were also highly correlated ($r = 0.83^{**}$). The exchange properties of soils are mainly determined by organic matter rather than clay minerals. The exchange acidity which is referred as the measure of exchangeable aluminium and exchangeable hydrogen in soils is determined by exchange properties of soil. So they are highly correlated.

Non exchange acidity was also found to be highly correlated to organic matter. About 73 per cent of variation in non exchange acidity could be accounted by organic matter. Iron and aluminium ions react with humus to form complexes which may undergo hydrolysis to yield hydrogen ions (Huduall, 1989). Several authors have observed a close relationship between the organic matter and pyrite contents (Berner, 1970) and suggested that the supply of organic matter commonly limits the amount of pyrite produced. The organic compounds contain acidic groups that are highly selective for association with protons. The adsorbed H$^+$ ions are considered part of the group or surface. Bolt et al (1976) considered them more difficultly exchangeable against other cations. They will dissociate releasing H$^+$ ions depending on the dissociation constant related to CEC, exchangeable hydrogen and aluminium in the soil, this relationship is self explanatory. High clay content thus generally leads to a high exchangeable hydrogen.

Cation exchange capacity

The pattern of cation exchange capacity of profile samples and surface soils are shown in figures 16 and 17.

Cation exchange capacity of the soils studied generally had a significant negative relationship with active acidity (pH) in the case of surface samples ($r = -0.39^{**}$) and profile samples. The relationship observed was significant and negative in the case of surfazce samples of *Kari* and *Kaipad* lands. With respect to active acidity CEC is a capacity factor which ultimately determines the hydrogen ion concentration in the soil solution in equilibrium with H^+ ions in the exchange complex of the colloids. Thus it is evident that increase in cation exchange capacity increases the H^+ ion concentration in the soil solution. This equilibrium of H^+ ion concentration between the soil solution and exchange complex is mostly dependent on the cation exchange capacity in all soils. The present study is thus in conformity with many reports (Marykutty, 1986 and G rove *et al.,* 1981).

Cation exchange capacity had positive significant correlations with exchange acidity ($r = 0.83^{**}$), non exchange acidity ($r = 0.88^{**}$) and potential acidity ($r = 0.88^{**}$). But when we take individual wetlands, CEC of *Kari* soils had highest significant correlations with pH ($r = -0.84^{**}$), exchange acidity ($r = 0.87^{**}$) and potential acidity ($r = 0.97^{**}$). Though CEC had a negative significant correlation with pH, the path coefficient analysis showed direct

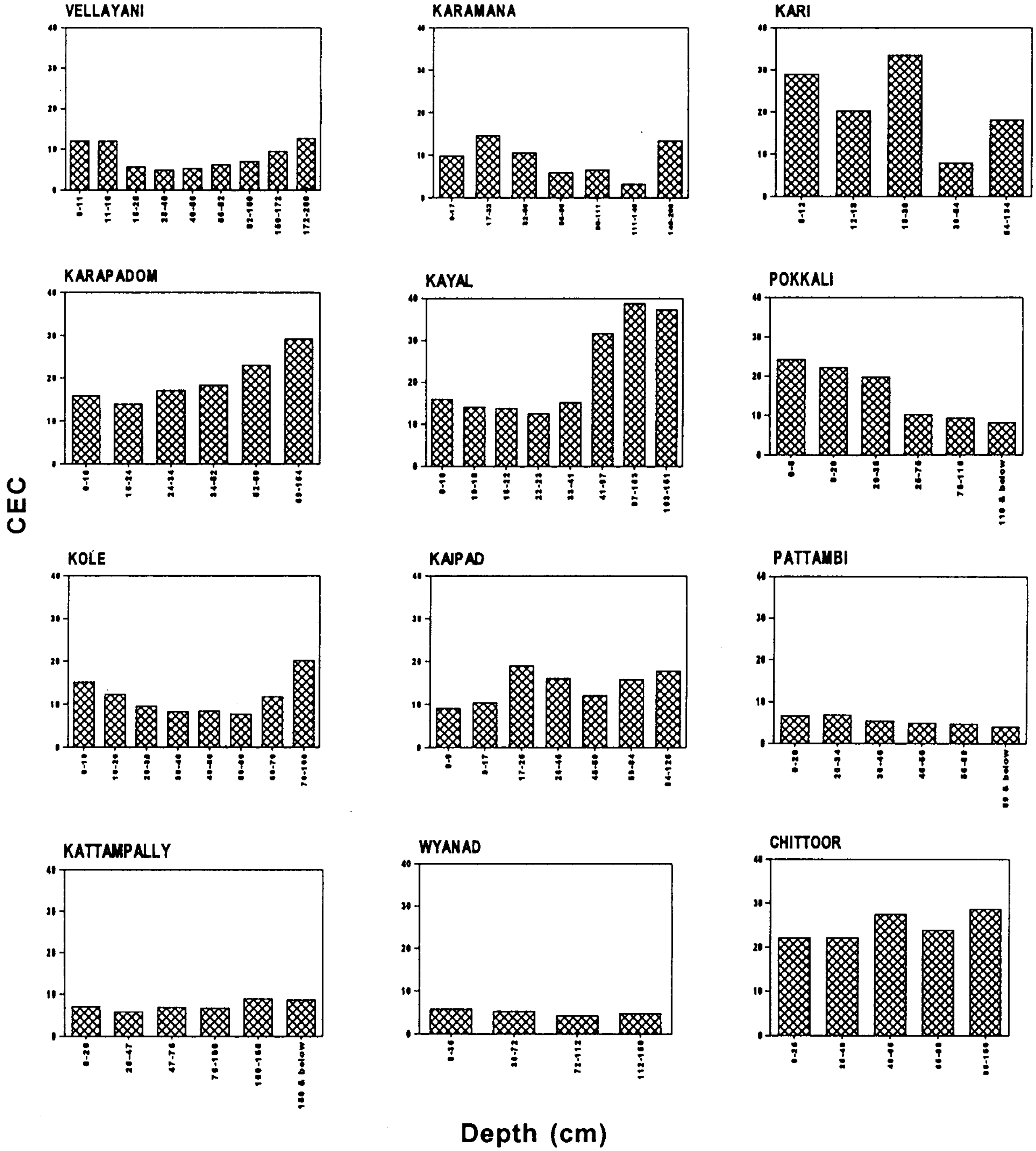

Fig. 16. Depthwise distribution of cation exchange capacity (cmol(+)/kg) in profiles of major wetlands

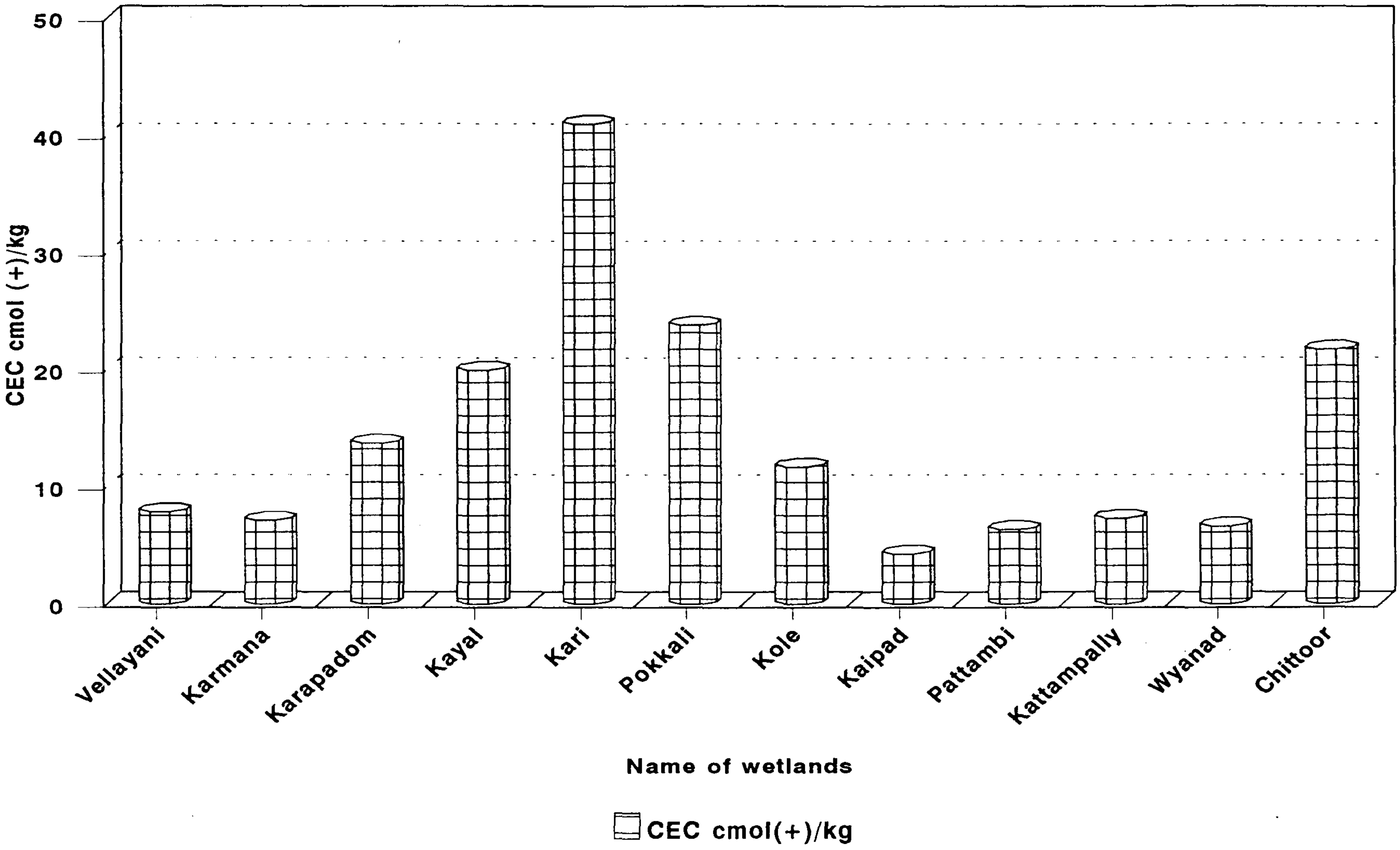

Fig. 17. Distribution of cation exchange capacity in surface samples of major wetlands

positive effect through the negative indirect effects of exchangeable aluminium, organic matter, active manganese, total sulphur and available sulphur. Total positive indirect effect is 2.35 and total negative indirect effect is -3.66. Hence the net effect is negative. CEC influenced exchange acidity negatively through the positive indirect effects of exchangeable aluminium, organic matter, DTPA - Fe, active manganese, total sulphur and available sulphur. Path coefficient analysis revealed a positive direct effect on non exchange acidity through the indirect effects of organic matter, exchangeable hydrogen, DTPA - Fe, available sulphur and percentage clay. Van Breemen's (1987) finding that clay and humic fractions are the seat of cation exchange and these creats potential and active acidity are in confirmity with the present finding.

Exchangeable hydrogen

A critical study of the data on exchangeable hydrogen revealed a significant negative relationship between exchangeable hydrogen and pH (dry). The correlation coefficient obtained was $r = -0.52^{**}$.

As exchangeable acidity is theoretically the sum of exchangeable hydrogen and exchangeable aluminium the behaviour of exchangeable hydrogen in mineral soils closely follows the pattern of the latter. As organic matter and clay minerals are the major sources of exchangeable hydrogen in soil colloids, CEC of the soil can also be considered as an index of exchangeable hydrogen. This relationship is closely evidenced from the highly positive correlation coefficient ($r = 0.82^{**}$) obtained between exchangeable hydrogen and CEC. Thus soils with high organic matter and CEC are likely to contribute more acidity through exchangeable hydrogen. This observation is corroborated in the present study.

Exchange acidity is significantly and positively influenced by exchangeable hydrogen ($r = 0.98^{**}$). Ninety six per cent of variation in exchange acidity could be accounted by exchangeable hydrogen. Path coefficient analysis revealed that though exchangeable hydrogen had a negative direct effect on exchange acidity, the positive effects of other contributing factors far exceeds the negative effects. Thus a net positive effect could be observed (Table 17). Non exchange acidity was positively and significantly correlated with exchangeable hydrogen ($r = 0.93^{**}$). Eighty six per cent of variation in non exchange acidity could be accounted by exchangeable hydrogen. Exchangeable hydrogen directly influenced non exchange acidity through the indirect positive effects of cation exchange capacity and organic matter.

Eighty nine per cent variation in potential acidity could be accounted by exchangeable hydrogen. Exchangeable hydrogen directly and positively influenced potential acidity through the indirect positive effects of cation exchange capacity, organic matter and exchangeable aluminium.

Exchangeable aluminium

The distribution of exchangeable aluminium in profile and surface samples of wetlands are presented in Fig 18 and 19.

A close scrutiny of the data clearly indicated a significant negative relationship between exchangeable aluminium and pH (dry) as evidenced from a high correlation coefficient ($r = -0.69^{**}$) Table 11. Van Breemen (1973, 1976) has shown that Al^{3+} activity is inversely related to pH, increasing roughly 10 fold per unit pH decrease. The contribution of exchangeable aluminium to the proton pool of soil systems in ferruginous and allitic soils have been studied in

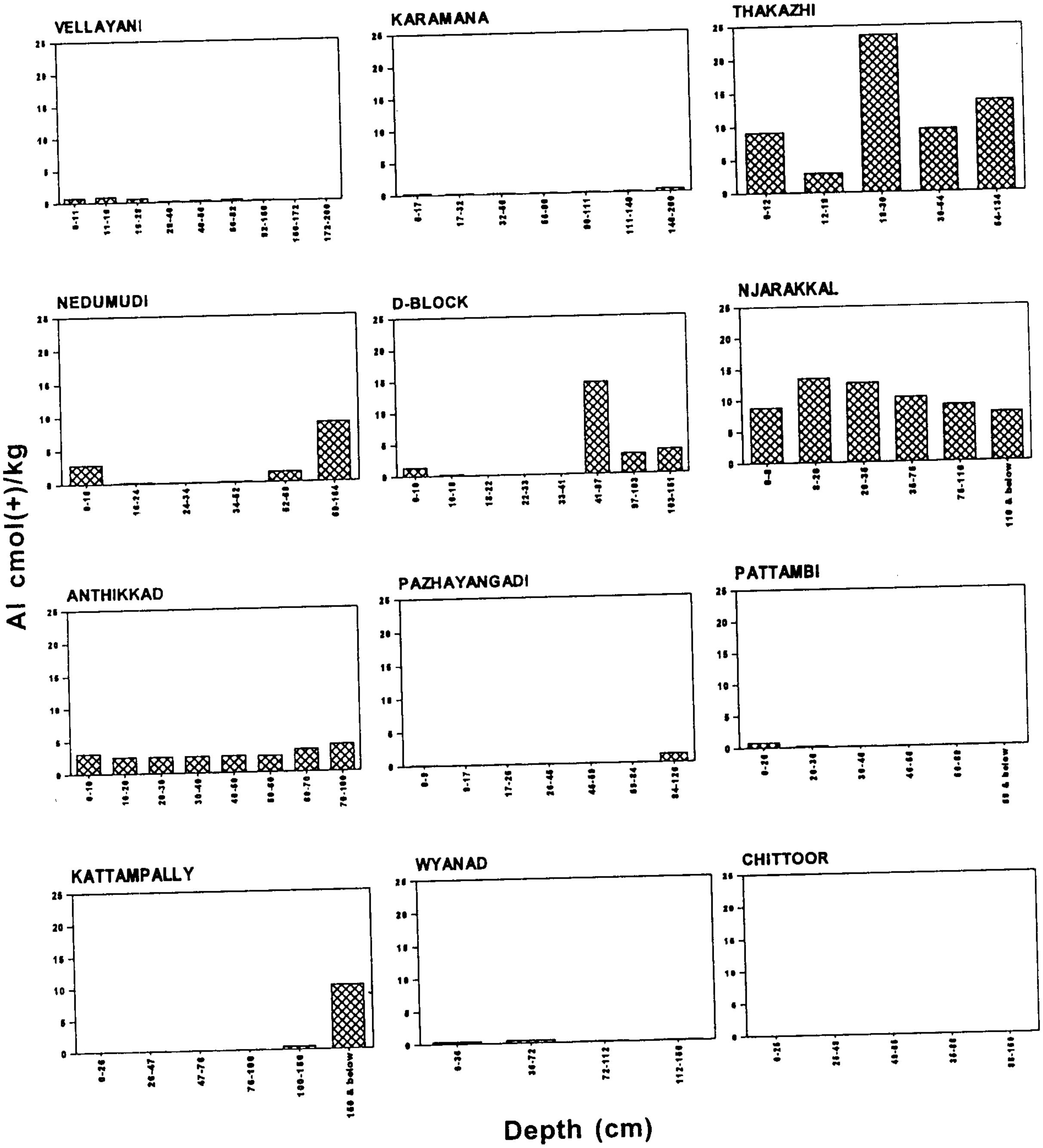

Fig. 18. Depthwise distribution of exchangeable aluminium (cmol(+)/kg) in profiles of major wetlands

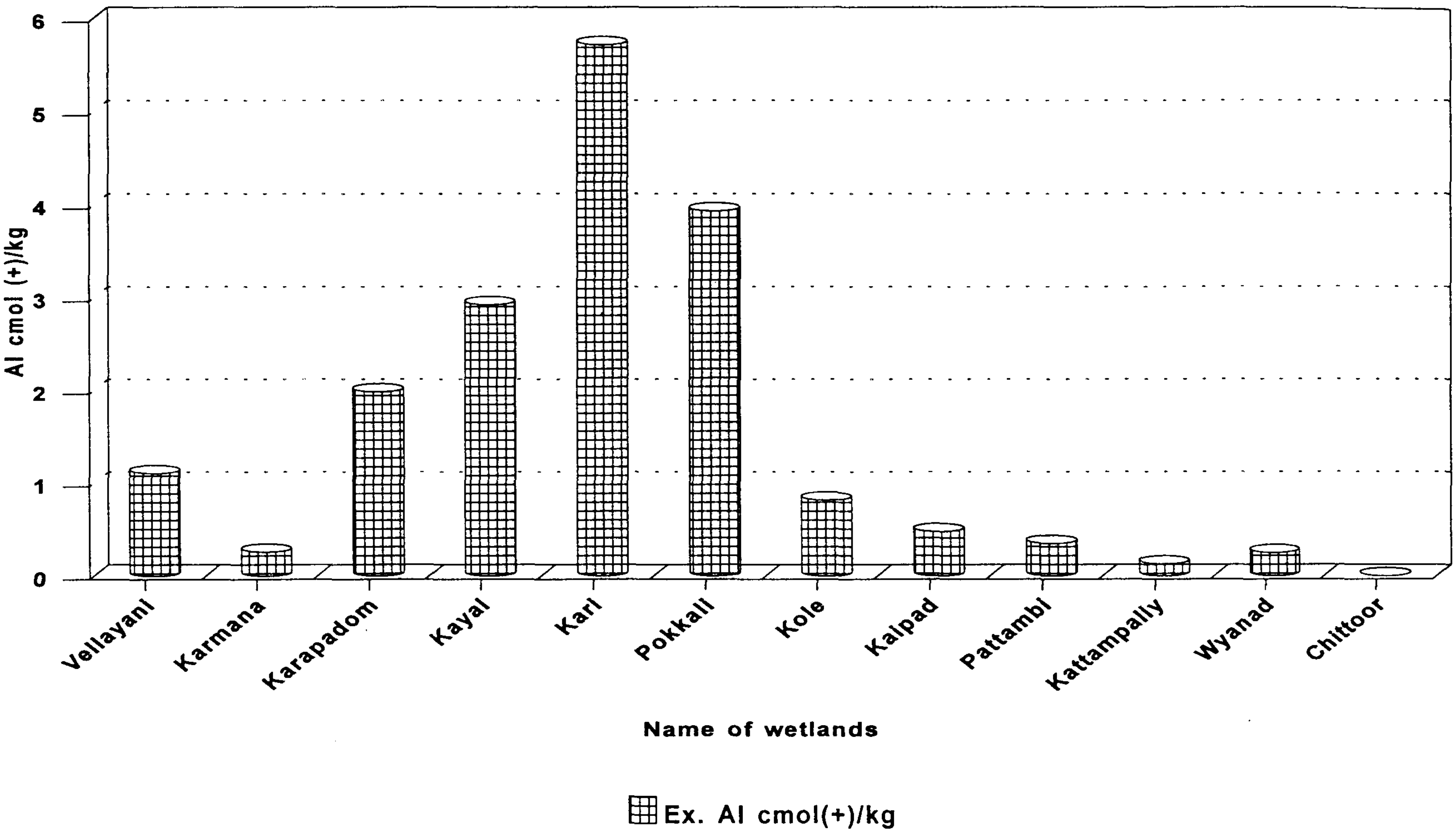

Fig. 19. Distribution of exchangeable aluminium in surface samples of major wetlands

detail by many workers. (Das *et al.,* 1992; Korovkin, 1958, Sanches, 1976, Kamprath, 1970). The stepwise hydrolysis of aluminium leading to the release of hydrogen ions, the major proton source in soil systems, plays a significant role in this case also in deciding the soil reaction. A consistent relationship throughout the profile to substantiate this has been observed. The highest amount of exchangeable aluminium reported in the seventh layer of Typic Tropaquent of Karamana (0.45 cmols) followed by the first layer (0.24 cmols) has given pH values 4.8 and 4.5 respectively (1:1 dry H_2O). Intermediate values of exchangeable aluminium had given pH values well within the range to accommodate the variation. Tropic Fluvaquent of Vellayani also gave the same relationship between pH and exchangeable aluminium with a highly significant relationship. Surface layers with high exchangeable aluminium generally registered lower pH values. This clearly indicated the role of exchangeable aluminium in the development of acidity. Exactly similar relationship was observed in the Aeric Tropaquept of Nedumudi, Typic Sulphaquent of Thakazhi and Typic Hydraquent of D-Block. No marked variation from this trend was observed in the case of the Typic Tropaquept of Anthikkad, Aeric Kandiaqult of Pattambi, Tropic Fluvaquent of Pazhayangadi and Sulphic Tropaquept of Njarakkal. Petrocalcic Calciusterts of Chittoor with no exchangeable aluminium had given high pH values above 7.0 for all the samples. Van Breemen (1976) and Moore and Patrick (1991) had reported that in neutral to alkaline soils most of the aluminium hydroxy ions will be converted to gibbsite ($Al(OH)_3$) which is insoluble. This could be the reason for the very low exchangeable aluminium in Chittoor samples. The significance of exchangeable aluminium in generating acidity as evidenced by pH values is thus well explained. The flux of pH changes closely approximates the exchangeable aluminium content of all the pedons under investigation. The Tropic Fluvaquent of Kattampally and

Typic Tropaquent of Wyanad also are not exceptions for the above statement. Thus the present study is in conformity with reports of Cate and Sukhai (1964) Mc Lean *et al* (1965), which explained the chemistry of exchangeable aluminium in soil acidity development. When we take individual wetlands there is variation in the extent of influence of exchangeable aluminium in deciding active acidity. This is due to the effect of other contributing factors like iron, manganese, organic matter and sulphur compounds. From path coefficient analysis, it was observed that exchangeable aluminium directly influence pH through the indirect negative effects of sulphur, organic matter, iron and manganese. Marykutty (1986) also observed the same type of relationship for the acidic rice soils of Kerala.

A scan through the data on exchange acidity and exchangeable aluminium of profile samples revealed a significant positive correlation between them. For surface samples of wetlands also a highly positive significant correlation ($r = 0.93^{**}$) was observed between exchange acidity and exchangeable aluminium. Under acidic soil conditions much aluminium becomes soluble and is either tightly bound by organic matter or is present in the form of aluminium or aluminium hydroxy cations. The exchangeable ions are adsorbed in preference to the cations by the negative sides of colloids. The adsorbed aluminium is in equilibrium with the aluminium ions in the soil solution and aluminium ions contributed to soil acidity through their tendency to hydrolyse. The extent of influence the exchangeable aluminium exerts on exchangeable acidity varies with soil. It could be attributed to the indirect effects of organic matter iron, manganese and sulphur.

From the correlation worked out, it could also be observed that non exchangeable acidity, which can be called pH dependent acidity had a positive significant correlation with exchangeable aluminium ($r = 0.76^{**}$). The aluminium hydroxy ions as well as iron hydroxy ions move into the inter layer space of the crystal units of clay minerals and become vary tightly adsorbed preventing inter crystal expansion and blocking some of the exchange sites. Raising the soil pH results in the removal of these ions and the release of exchange sites. Thus aluminium and iron hydroxy ions are partly responsible for the pH dependent acidity of soils. Moore and Patrick (1991) were also of the opinion that most of the pH dependent CEC sites were due to organic matter which complex with aluminium.

Potential acidity, which is the sum of exchangeable and non exchangeable acidity is directly and positively influenced by exchangeable aluminium through the indirect effects of organic matter, CEC and exchangeable hydrogen. But aluminium toxicity is not pronounced in soils containing enough sulphate because of complexation or coating of sulphate over aluminium.

Iron

Negative non significant relationship was observed between active iron and active acidity in the case of all the samples investigated. Though active iron represents easily reducible, water soluble and exchangeable iron, the most important fraction is the easily reducible form which is less significant as a proton source under the normal rice farming situations of Kerala. Further the reversible oxidation-reduction system operating in the field finally define the role of iron in acidity development. As the samples were collected during dry season a substantial amount of water soluble iron would have been converted to iron oxides. This is further evident from the highly significant negative correlation obtained between active acidity (pH) and DTPA iron. This is quite obvious from the low values obtained for DTPA iron in soils even though the active iron content was high.

A negative significant relationship ($r = -0.35^{**}$) was observed between active acidity (pH) and DTPA extractable iron. The relationship was highly significant and positive in the case of exchangeable, non exchangeable and potential acidity. This is obviously due to the reversible oxidation-reduction status existing for iron under the wetland rice system. As the active acidity was computed based on dry soil pH values, a drastic reduction in the DTPA extractable iron could be expected during drying of the sample. The mechanism involved in the ferrolysis process as outlined by Brinkman (1970) clearly explains this process of reversible oxidation reaction. Though the DTPA extractable iron represents water soluble and exchangeable fractions, the efficacy of DTPA in extracting completely the ferric form from a dry soil is doubtful and needs elaboration. Thus the chemistry of iron transformations in submerged soils upon drying and rewetting totally upset the equilibrium and its contribution to the total proton pool of the soil water system. In the case of surface samples of individual wet lands, though the relationship observed was negative between DTPA - Fe and pH, it was not significant in many cases. This may be due to variations in absolute content of iron and its interaction with other soil components, thus alleviating the effect of iron.

The results of the present study is in conformity with general relationship between iron and acidity in wetland soils. The pH taken as an index of active acidity decreases with increase in iron content. Thus ferruginous soils and soils rich in active iron and DTPA iron generally tend to contribute towards acidity development under all conditions of hydrological situations. Marykutty (1986) also found negative significant correlation between pH and sesquioxides in *Kole*, *Kari*, *Kayal*, *Karapadom* and *Pokkali* soils.

Exchange acidity, non exchangeable acidity and potential acidity increased with increase in DTPA - Fe content in the surface samples of wetlands. Thiry three per cent of variation in exchange acidity was accounted by DTPA iron, 69 per cent variation in non exchange acidity was accounted by DTPA - Fe and 72 per cent of variation in potential acidity could be accounted by this factor. Path coefficient analysis revealed that DTPA - Fe had negative direct effect on pH through the indirect negative effects of exchangeable aluminium, organic matter, total sulphur and available sulphur.

DTPA - Fe influenced exchange acidity through the indirect effects of organic matter, exchangeable aluminium and sulphur. Non exchange acidity was also directly influenced by DTPA - Fe through the indirect effects of exchangeable hydrogen, organic matter, CEC, clay and sulphur. Though DTPA - Fe and potential acidity had a positive significant correlation coefficient ($r = 0.84^{**}$), the path coefficient analysis showed a negative direct effect through the positive direct effects of exchangeable H^+, CEC, organic matter and exchangeable aluminium. Iron can contribute towards the acidity of a soil by hydrolysis. In the clay fraction iron occurs in the form of oxides and also complexes with organic substances and these may act as potential sources of H^+. DTPA - Fe plays a significant role in deciding active acidity, exchange acidity and potential acidity in *Kari* soils which also recorded highest value for this factor.

Manganese

For active manganese which is the easily reducible form no significant relationship was noticed. This may be due to the low absolute content of this element and substantial amount may be in oxidisable form due to drying. Due to partial pressure of CO_2, soluble manganese may be converted to manganese carbonate. Hence the flux of manganese concentration in rice soils of Kerala has less significance in acidity development except *Kari* soils.

Manganese contributes to soil acidity through hydrolysis. DTPA extractable had recorded positive significant correlation with exchange acidity ($r = 0.24^{**}$), non exchange acidity ($r = 0.34^{**}$) and potential acidity ($r = 0.33^{**}$). But when we take individual wetlands, *Kari* soils showed a decrease in pH with increase in DTPA extractable manganese ($r = -0.79^{**}$). The exchange acidity and potential acidity also increased with increase in available manganese.

Sulphur

Distribution of sulphur in surface samples of wetlands are given in Fig 20.

Significant negative correlation as expected was observed between pH and total sulphur ($r = -0.37^{**}$). The effect of sulphur and sulphur rich sediments in controlling the dynamics of soil pH has been investigated by many workers in wetland rice soils (Krairapanand *et al.*, 1991; Pons, 1972; Van Breemen, 1987 and Satawathananont *et al.*, 1991). Oxidation of sulphur rich sediments to free sulphate and sulpuric acid in acid sulphate soils producing extremely low pH values has been reported by many workers. Hence the contribution of sulphur to active, exchangeable, non exchangeable and potential

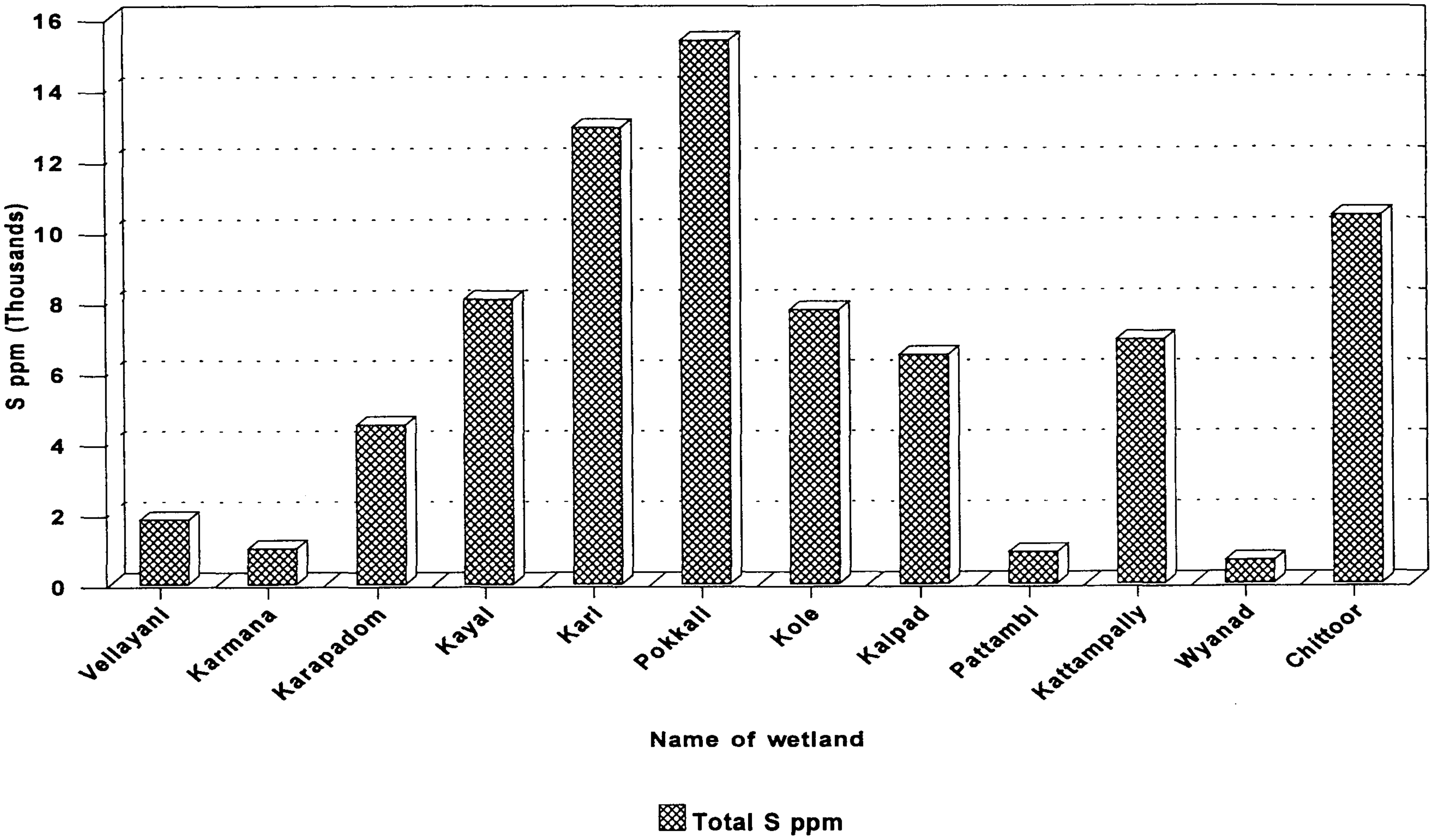

Fig. 20. Distrubution of total sulphur in surface samples of major wetlands

sources of acidity is well explained by its direct contribution to the proton source in soil systems.

The behaviour of available sulphur in relation to active acidity follows more or less the same pattern as that of total sulphur. Sulphur rich soils, mainly *Kari* and *Pokkali* also showed a direct positive relationship between available sulphur and total sulphur. Thus the contribution of available sulphur to acidity and its negative relationship with pH are well explained. However minor variations observed from the above trend in some of the samples might be due to variations in the hydrological situations and thus the aerobisity of the soils at the time of sampling.

Total soluble salts

Total soluble salt concentration measured as electical conductivity (d Sm^{-1}) showed a negative significant correlation with pH ($r = -0.6284^{**}$) and positive significant correlation with exchange acidity ($r = 0.6630^{**}$), non exchange acidity ($r = 0.52877^{**}$). All the acidity contributing factors showed positive significant correlation with electrical conductivity. Nair and Money (1972) also reported the same type of relationshop in the salt affected rice soils of Kerela because the cations of salts will displace adsorbed aluminium, H^+ etc. and cause an increase in acidity.

5.2 Nature, extent and management of acidity in wetland soils of Kerala

5.2.1 Vellayani - Fine Kaolinitic Isohyperthermic Tropic Fluvaquents

From the distribution of acidity in this pedon, we could see an increase in pH towards lower depths (Fig 21). This low active acidity in lower depths

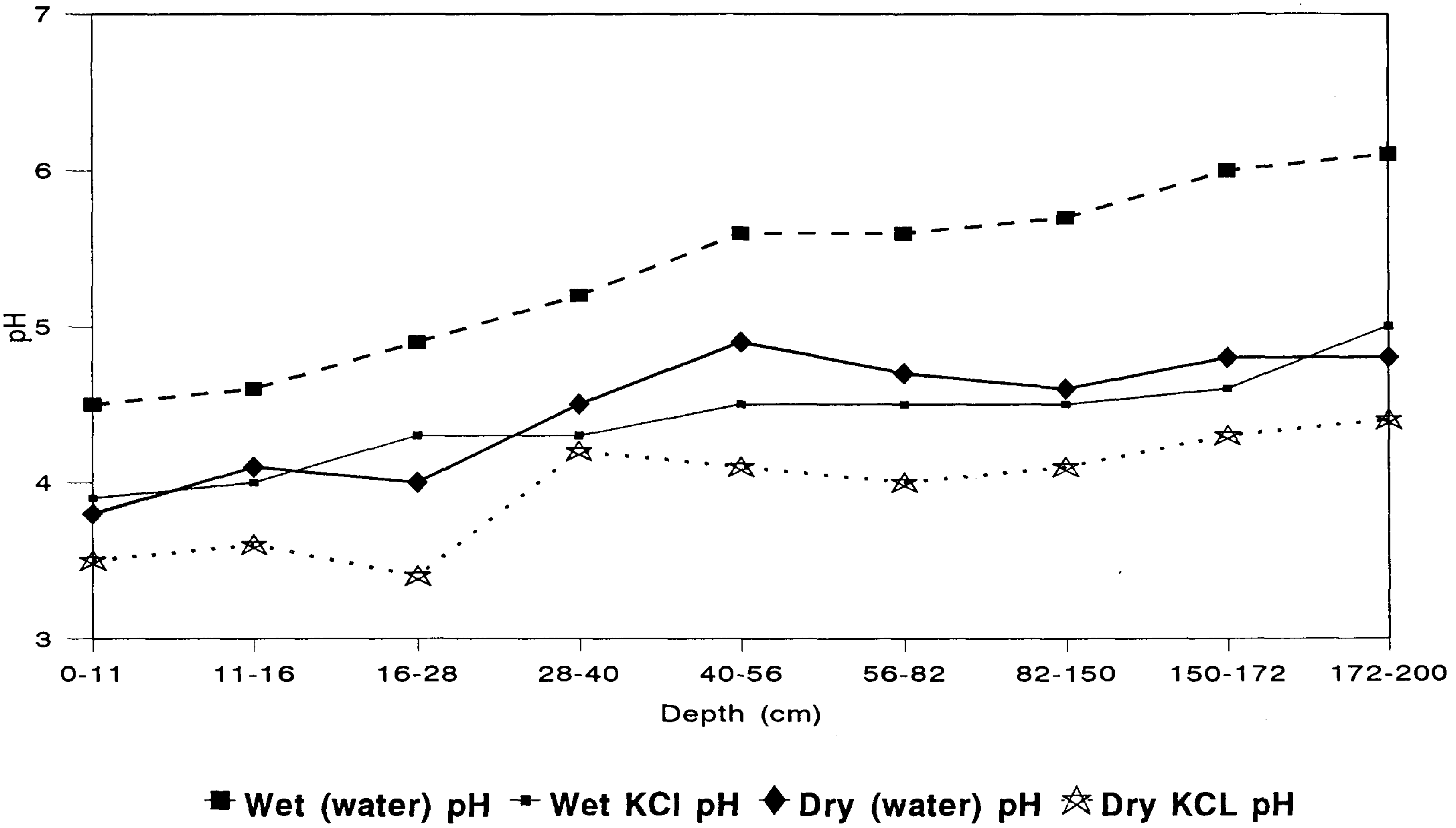

Fig. 21. Depth wise distribution of active acidity in profile samples of Veliayani - Tropic Fluvaquent

could be attributed to the presence of very small quantities of exchangeable aluminium. Exchange acidity also decreased in the lower horizon (Fig. 22) due to the presence of low aluminium. Non exchange acidity was more in surface layers, but it decreased in the middle portion and then it increased. Potential acidity also followed the same trend. In the surface layers, the organic matter was high, then it decreased and then an increase in the lower layers was observed. The acidity contributing factors like nitrogen, manganese, cation exchange capacity and effective CEC also were of the same distribution pattern. Since these factors are more in the surface layer and deeper layers, this pattern of distribution of acidity occurred in this profile. Decomposition of organic matter will result in the formation of CO_2 which combines with water to form carbonic acid. Dissociation of this week acid into H^+ and HCO_3^- provide another source of H^+ for soil acidification. Patil (1986) also observed a decrease in potential acidity due to decrease in organic matter content. Nitrification by Nitrosomonas and Nitrobacter release H^+ into soil solution. Hydrolysis of iron and manganese release H^+ into soil solution and this in turn reduced the pH. High CEC was found to be usually associated with high potential acidity. High CEC in soils is mainly due to high organic matter content and high clay content. When CEC is high, more exchangeable Fe, Al and Mn will be there in the exchange complex and this in turn on hydrolysis yield H^+ ions.

Vellayani surface samples (0-30 cm depth) had got 5.09 field wet pH and 4.35 dry pH. The drop in pH was 0.74. The surface samples of Vellayani had high aluminium, organic matter, iron, manganese and low base saturation. The action of these acidity contributing factors in the Vellayani surface soils resulted in a low pH. The exchange acidity of 1.58 cmol(+)/kg in these soils was mainly contributed by exchangeable aluminium rather than exchangeable

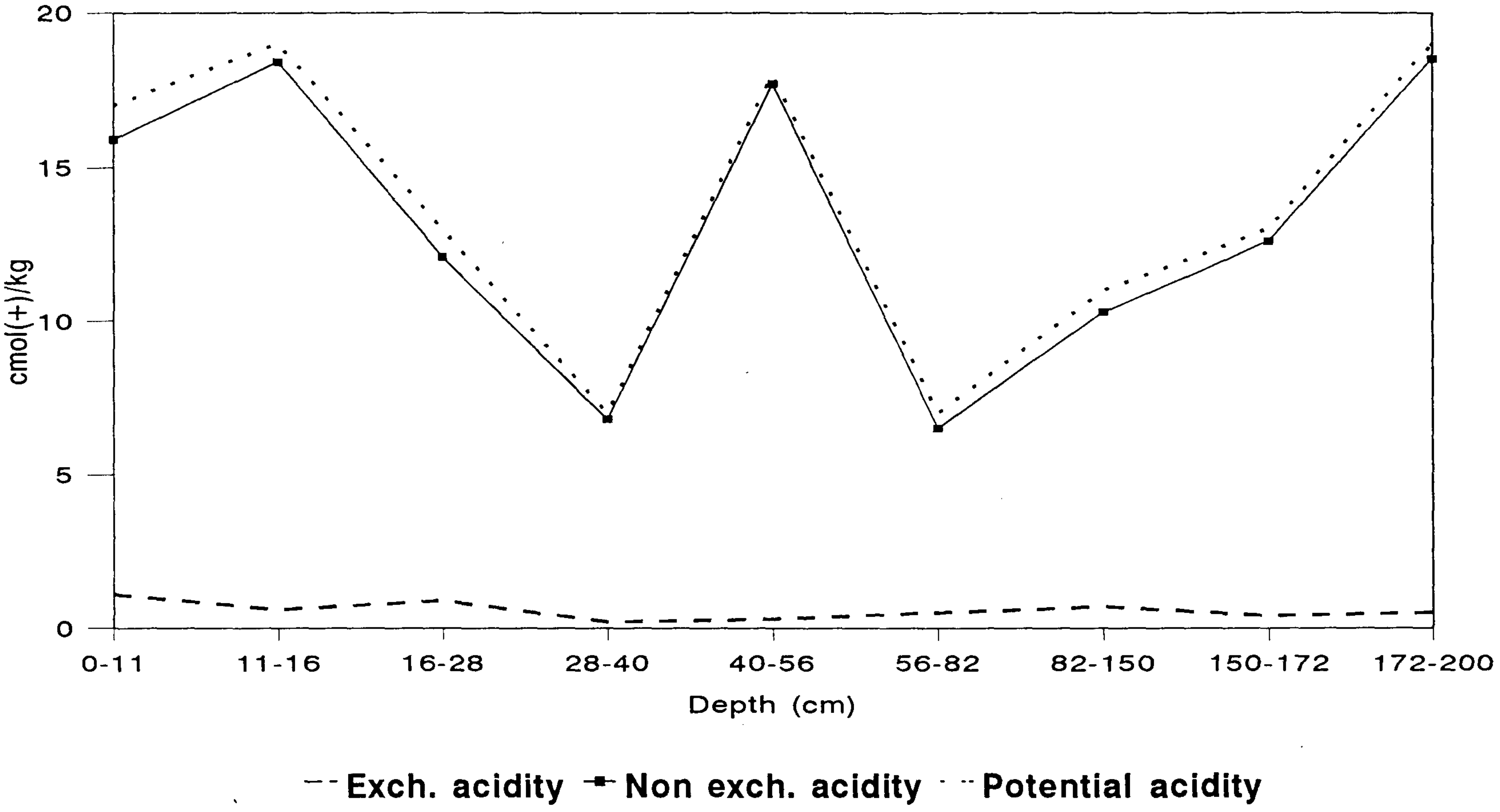

Fig. 22. Depth wise distribution of exchange acidity, non exchange acidity and potential acidity in profile samples of Vellayani - Tropic Fluvaquent

hydrogen. Of the potential acidity (19 cmol(+)/kg soil), 92 per cent was nonexchangeable because H^+ in covalent bonds with organic and mineral fractions were high in these soils. Clay content of these surface samples was also high (mean 61 per cent).

The relationship between components of acidity and other soil parameters revealed that under dry condition pH was directly correlated with exchangeable aluminium and exchangeable hydrogen. Exchangeable acidity in these soils are mainly contributed by exchangeable aluminium, exchangeable hydrogen, nitrogen compounds etc. The soils are medium in N, P, K and not deficient in micronutrients.

Kinetics of pH due to submergence showed a rise in pH to 5.5 within 2 weeks and followed a linear pattern of change in pH by submergence (Fig. 23).

Comparison of lime requirement calculated on the basis of three methods showed that for Vellayani soils, exchangeable aluminium method was the best. The value was 1.67 tonnes ha^{-1}. Even without liming, Vellayani soils can attain a pH favourable for rice within two weeks. Padmaja and Varghese (1972) also found that liming red loam soils of Kerala at the rate of 2.5 metric tonnes ha^{-1} raised the soil pH by 1 to 1.5 units. Reports from IRRI (1964) showed that delaying transplanting until 2 weeks after submergence increased yield by 1 tonne ha^{-1} in dry season and by 0.8 tonne ha^{-1} in the wet season.

5.2.2. Karamana-Fine Kaolinitic Isohyperthermic Typic Tropaquent

Distribution of active acidity in terms of pH, exchange acidity, non exchange acidity are presented in Fig 24 and 25.

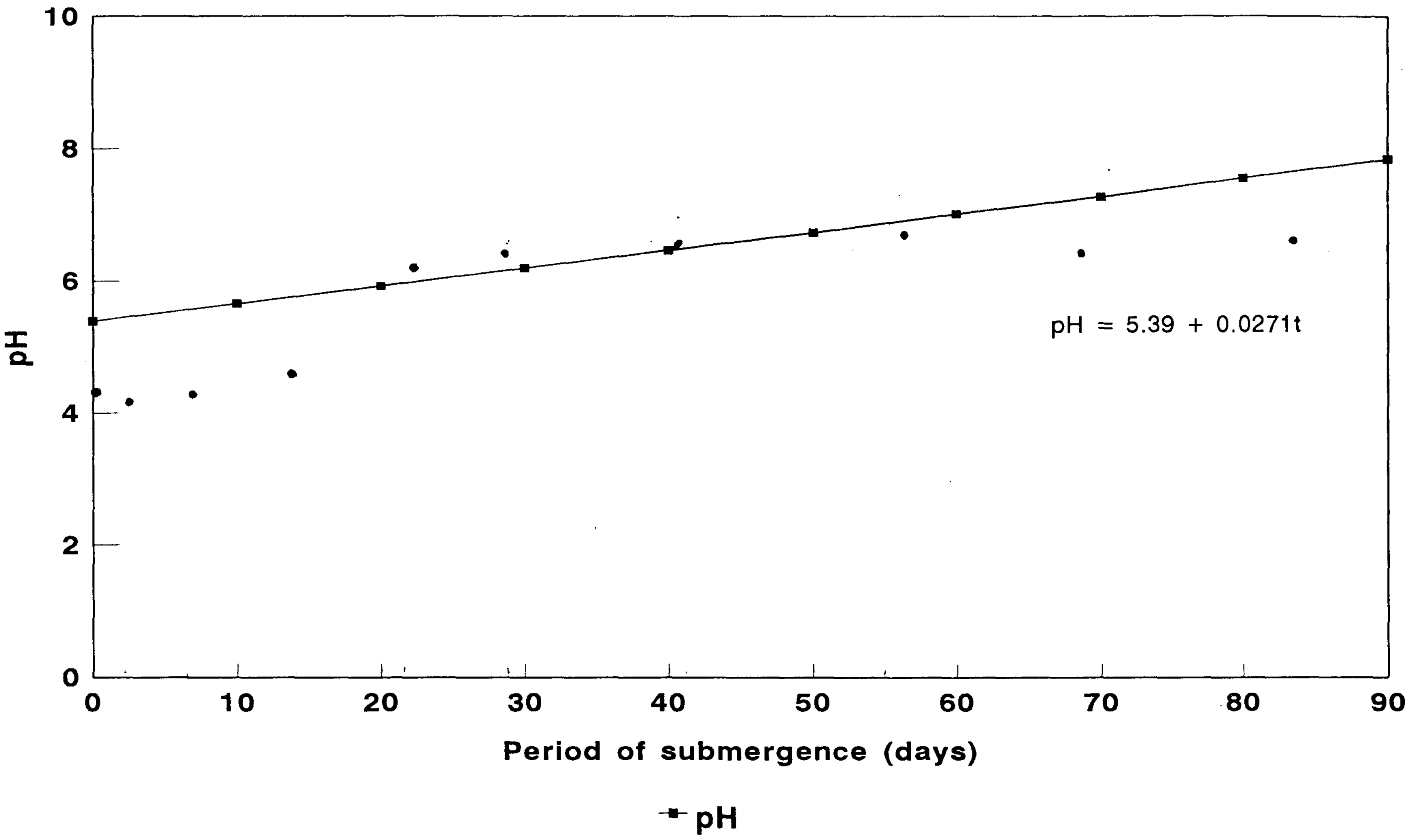

Fig. 23. Relationship between period of submergence and pH in Vellayani soils

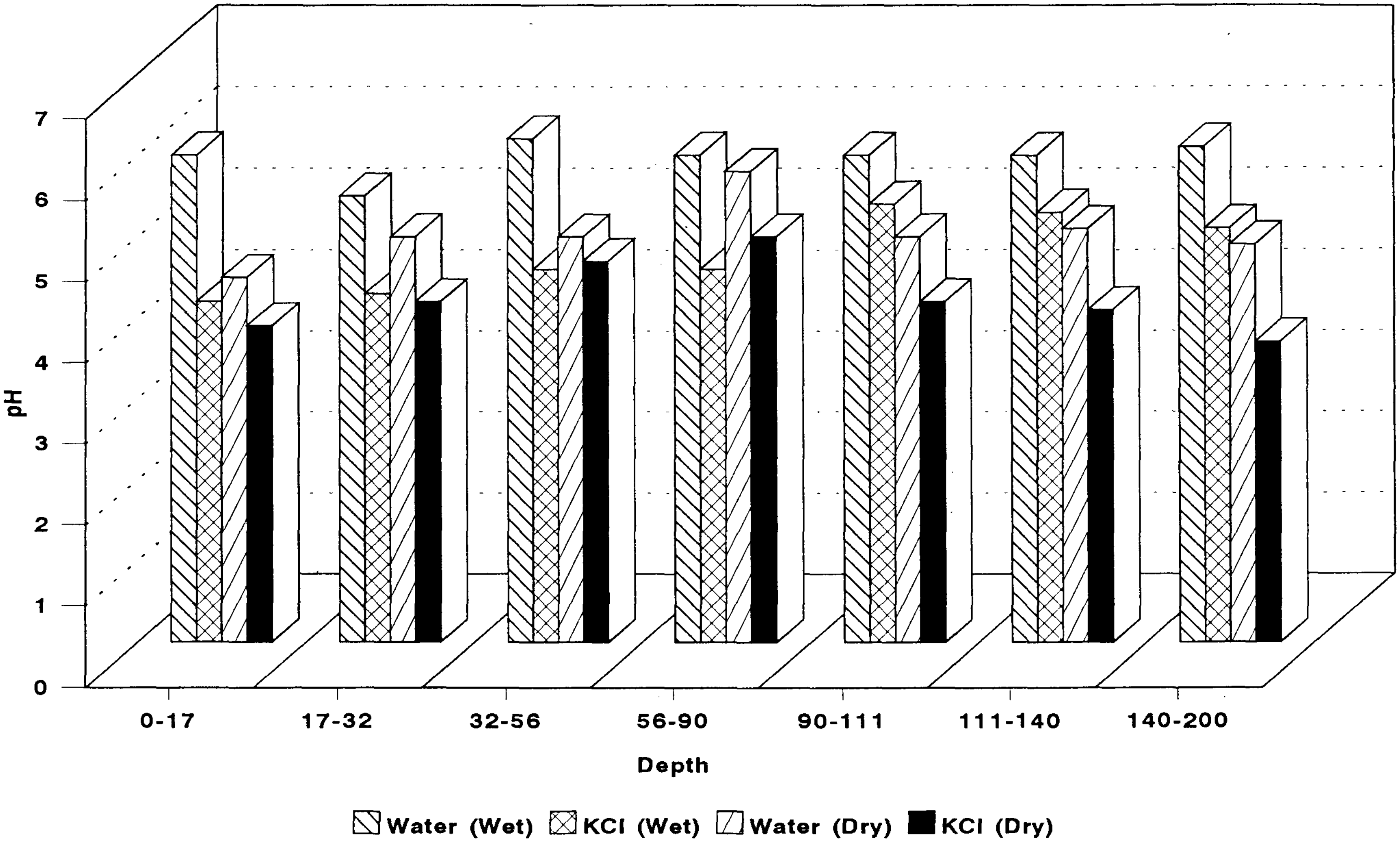

Fig. 24. Depth wise distribution of active acidity in terms of pH in Karamana profile

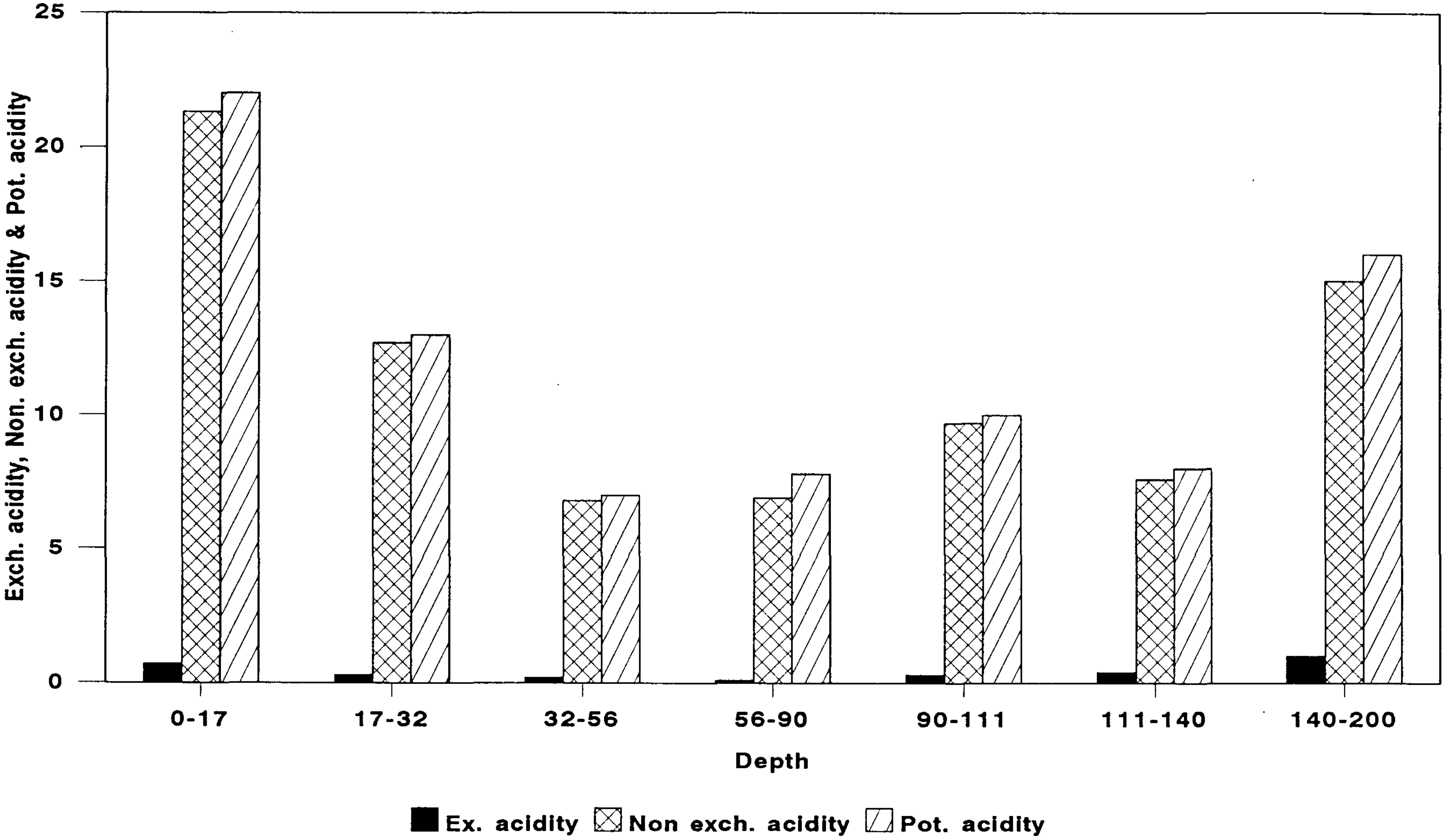

Fig. 25. Depth wise distribution of exchange acidity, non exchange acidity and potential acidity in Karamana Profile

Karamana profile representing the brown hydromorphic man made wet land registered the maximum active acidity in the first and lower most horizons. High exchangeable aluminium, exchangeable hydrogen and iron could be the reasons for this.

Exchange acidity was 0.7 cmol(+)/kg soil in the 0-17 cm horizon. Then it decreased upto 56-90 cm layer and then gradually increased and reached 1.0 cmol (+)/kg in the lower most horizon. The highest exchange acidity was at the lowest horizon. This was due to the presence of highest amount of exchangeable aluminium (0.45 cmol(+)/kg) on that layers. Non exchange acidity and potential acidity also followed the same trend. The highest non exchange and potential acidity were recorded by the top most layer. Then it decreased upto 56-90 cm layer and increased afterwards. In the top layer there is high exchangeable aluminium, high organic matter and low base saturation percentage. These factors were responsible for high acidity in the top layers. Exchangeable Al, hydrogen and organic matter decreased towards middle horizons and base saturation increased. This was due to the leaching away of bases from top layers to lower layers and accumulated in the middle portion due to the formation of a harder layer. This hard layer may be formed by the ploughing operations for rice cultivation year after year. But in the lowest layer there was high exchangeable aluminium, high exchangeable hydrogen, high iron and cation exchange capacity compared to middle part of the pedon leading to more acidity.

From the study of kinetics of pH due to submergence, it was found that Karamana surface soils (0-30cm) took only one week for attaining a pH of 6.2. From the lime requirements calculated based on three different methods, namely exchangeable Al method, base saturation elevation method and Shoemaker method it was found that exchangeable aluminium method was the best for

Karamana soils. Exchangeable aluminium method gave the highest negative correlation with pH in Karamana surface soils (r = -0.62). Based on this, Karamana soils required only 0.39 tonnes ha^{-1} of lime for ameliorating the acidity. Because Karamana soils attained a pH of 6.2 within a week of submergence this lime application could be done as a basal dressing during land preparation stage. By applying lime at this stage, the soil will be at the optimum pH range (reaction) even at the time of transplanting of seedling in the field. pH 5.5 to 6.5 was the best reaction range for maximum nutrient availability for rice and for soil microbial growth. If the Karamana soils can be kept under submergence (5 cm water above the surface) for 1 week before transplanting of seedlings there would be no need for application of lime for raising the pH. But lime application gave positive effects for increasing rice yields in Karamana soils because of the nutrient effect of calcium in rice plants.

In Karamana surface samples the average pH (average of 10 composite samples) under field wet condition 5.3. But the pH under dry condition (after air drying the soil samples) was 5.2. The decrease in reaction was only 0.1 units. Hydrolysis of Al^{3+} released H^+ ions and lowered the pH of soil solution. Similarly oxidation of Fe(11) and Mn(11) also released H^+ into the soil solution and decreased the pH. In Karamana surface samples, the exchangeable aluminium, iron and manganese were low compared to other soils. Hence the drop in pH was only very little.

With respect to the available nutrients, Karamana soils were medium in available nitrogen, phosphorus and potassium. Micro nutrients were not deficient in these soils. The percentage base saturation was 53.8. The cation exchange capacity was 7.12 cmol(+)/kg soil. The texture was sandy clay loam with an average clay content of 55.8 per cent. The dominant clay mineral was identified as kaolinite by XRD.

Karamana surface samples recorded 13.80 cmol(+)/kg soil potential acidity. Out of this 98 per cent (13.59 cmol(+)/kg) was non exchangeable acidity. The non exchangeable acidity in these soils was associated with aluminium hydroxy ions and with hydrogen and Al atoms that are bound in non exchangeable forms by organic matter and silicate clays.

The correlations between components of acidity and acidity contributing factors showed that organic matter and iron were the most important factor that controlled the pH in Karamana soils. Exchange acidity and exchangeable aluminium are highly correlated (0.91^{**}), since exchangeable Al is one of the main contributing factors towards exchange acidity. Alice (1984) also reported exchangeable aluminium as the main constituent of exchange acidity in the wet land rice soils of Kerala.

Exchangeable Al, organic matter, nitrogen, iron, manganese and exchangeable hydrogen gave positive significant correlations with exchange acidity.

5.2.3 *Kari* soils - Fine Loamy Mixed Isohyperthermic Typic Sulfaquent

The pattern of distribution of acidity in profile showed that even at field wet condition the pH of the surface horizon is 3.9. Then it increased towards lower depths. This was due to the reduction reactions in the soil. Reduction involved consumption of H^+ ions (Ponnamperuma, 1972). But on drying the samples, the pH had dropped to 3.0 in the surface layer. The pH decreased to very low levels in the lower three depths. The extreme acidity was noticed in the 18-30 cm layer. The highest exchangeable acidity and non exchange acidity were also noticed in this layer. The reasons for extreme acidity in this layer was due to highest exchange aluminium 23.58 (cmol(+)/kg soil), highest organic matter (8.79%), highest nitrogen compounds (283 ppm), highest CEC (33.5 cmol(+)/kg soil), lowest base saturation (38.98%) and highest exchangeable H^+ (64.32 cmol(+)/kg soil). Highest zinc concentration was also noticed in this layer because zinc may be get complexed with organic compounds in this layer and accumulated. High organic matter resulted in a significant build up of micro nutrient status especially zinc and manganese (Sam, 1982).

The surface samples of *Kari* registered a mean field wet pH of 5.02 but on drying the samples the pH has dropped to 3.20. KCl pH under dry condition was 2.82. Exchange acidity observed was very high 16.40 (c mol(+)/kg). The non exchange acidity was 113.65 cmol(+)/kg soil and potential acidity was 129.65 cmol(+)/kg. Eighty seven per cent of potential acidity was accounted by non exchangeable acidity. High exchangeable Al (5.72 cmol(+)/kg), high exchangeable H^+ (10.67 cmol(+)/kg) high organic matter content (10.50%), low % base saturation (36%), high nitrogen compounds (254.5 ppm) and high iron (2399 ppm) were the reasons for high acidity. These soils also accounted for a high available zinc status 89.28 ppm. High organic matter resulted in a singificant build up of micro nutrient status. High amounts of these acidity contributing factors was the reason for high acidity in *Kari* Soils.

Correlation studies revealed that water pH (1:1) had got negative significant correlations with exchangeable Al (-0.78^{**}), organic matter (-0.81^{**}), iron (-0.71^{**}), Mn (-0.79^{**}), cation exchange capacity (-0.88^{**}), exchangeable H^+ (-0.84^{**}) and effective CEC (-0.82^{**}). Of these factors 78 percentage of variation in exchange acidity was contributed by cation exchange capacity.

Seventy one per cent of variation could be accounted for by exchangeable H$^+$ and organic matter accounted for 68 per cent of variation. When base saturation increased,the pH also increased when exchangeable Al, organic matter, nitrogen, iron, manganese, cation exchange capacity, exchangeable H$^+$ and effective CEC increased,the pH had dropped to low levels. These factors registered high values in *Kari* Soils of Kuttanad. When exchangeable aluminium, organic matter, nitrogen, iron, manganese and cation exchange capacity increased the exchange acidity also increased in *Kari* soils. Eighty seven per cent of variation could be accounted for by exchangeable aluminium.

Potential acidity in *Kari* Soils increased when exchangeable aluminium, organic matter, nitrogen, iron, manganese, CEC, exchangeable H$^+$ and effective CEC increased. Of these CEC accounted for 95 percentage of variation in exchange acidity.

The surface soils of *Kari* recorded 15359 ppm of sulphur. But the available S was only 21% of the total. From profile studies we could observe that 18-30 cm layer had highest potential acidity. Sulphur accumulated in this layer as well as surface layers was due to inundation of sea water, and from accumulated organic materials. Sulphur on oxidation give rise to sulphuric acid. High cation exchange capacity of these soils was mainly due to high organic matter content and clay. Unnikrishnan (1993) also noted low pH (2,3) high organic matter (8.70 %), high total sulphur (7623 ppm), total Fe (11.7 %) and low base saturation (21.9 %) in this layer.

Submergence studies revealed that *Kari* soils took about 12 weeks to reach a pH value of 5.5 in the surface layers. Because of high organic matter content, high buffering action was there in the soil, Potential acidity was converted to active acidity even if we lime the soil. So liming should be based on both active and potential acidity. Liming and washing away of acidity is practiced in the *Kari* soils of Kuttanad. Subsurface tile drains are also used to leach away the acidity.

Based on exchangeable aluminium method, the lime requirement calculated for *Kari* soils was 8.59 tonnes ha^{-1}. Based on base saturation elevation method and titration method the lime requirement calculated were 23.22 tonnes ha^{-1} and 20.65 tonnes ha^{-1} respectively.

Based on correlation studies it was found that of the three methods tested base saturation elevation method was found to be best for *Kari* soils.

This method gave significant negative correlation with pH ($r = -0.85^{**}$). Seventy three per cent of variation in pH could be accounted by base saturation elevation method.

The pH gave positive significant correlations with exchangeable aluminium. Only 61 percentage of variation in pH could be accounted by exchangeable aluminium method of lime requirement. The lime requirement calculated based on exchangeable aluminium method could explain 87 percentage of positive variation in exchangeable acidity in *Kari* soils. The base saturation elevation method gave an r value $= 0.88^{**}$. Potential acidity in *Kari* Soils gave positive significant correlations with base saturation elevation method. (r = 0.98**, 96% of positive variation in potential acidity could be explained by this method of lime requirement. The exchangeable aluminium method of lime requirement could only explain 90 percentage of positive variation in potential acidity. From the comparison of these methods we can find that for *Kari* soil base saturation elevation method of lime requirement was the best. The titration method of calculating lime requirement also gave about the same value as that for base saturation elevation method.

Eventhough the analyses conducted unveil the severity of acidity the lime requirements calculated based on it could not be recommended to farmers considering the prohibitive cost of lime. Burned lime at the rate of 1000 kg/ha in two splits and washing away of acidity 2 or 3 times after maintaining 10cm water level can be recommended for economic returns from *Kari* lands. The experiments conducted at Karumadi Drainage research Station also obtained results on similar lines. Larger doses of lime cause faster rate of reacidification of the soil because of high potential acidity and apart from its negative economic aspect.

Iron toxicity is also a problem in the rice lands of *Kari*. Sheela (1993) found that concentrations of iron at 500 ppm given in the culture medium was toxic enough for the rice plant to produce physiological disorders which were manifested by visual symptoms on leaf during growth under unsatisfactory soil management situation. Iron toxicity to rice may develope at as low as even 100 ppm while in well managed situations even 400 or 500 ppm will be inadequate for the development of iron toxicity (Nhung and Ponnamperuma, 1966). Liming can reduce iron toxicity in *Kari* soils.

Under dry conditions aluminium toxicity may become a problem in highly acid soils like *Kari* and *Pokkali*. As these soils were also high in sulphates the shielding effect of SO_4^{-2} in the outer sphere of aluminium may render aluminium less accessible to plant roots. The role of SO_4^{-2} in reducing aluminium toxicity is of importance in sub soils where aluminium complexing organic ligands are present in extremely trace quantities. (Alva *et al*, 1991). In soils where sulphur is a limiting factor by the application of gypsum to the top soil the beneficial effect of SO_4^{-2} can be exploited. The reduction of aluminium toxicity by SO_4^{-2} can also be attributed for formation of Al SO_4^{+} ion pair species. Sulphate anion adsorbs on hydrous oxides of aluminium and iron in many soils by ligand exchange with surface hydroxyl groups (Turner and Kramer, 1991) and formation of Jarosite may be the reason for the accumulation of sulphur rich compounds in acid sulphate soils.

Since the highest active and potential acidity is found in the 18-30 cm horizon of *Kari* soil, rice is the only crop that can be grown here. Keeping the soil submerged as long as possible before transplanting, liming and use of varieties tolerant to acid sulphate conditions are the main solutions to maximise rice yields.

Low rates of lime application followed by maintaining 10 cm water on the surface and washing of the soil two or three times was found to be beneficial for *Kari* and *Pokkali* soils according to Marykutty, (1986). Higher rates of lime application introduces the problem of reacidification at a faster rate. Low liming rate and more frequent application along with washing can be better management practice that can be applied in these soils.

5.2.4 *Karapadom* soils - Fine Mixed Isohyperthermic Aeric Tropaquept

This comes under natural wetlands. These are double crop rice lands. *Karapadom* pedon showed an increase in pH in deeper horizons under field wet condition. This was due to the reduction of soil constituents under moisture saturation. From the analysis of dried samples, it was found that pH increased upto a depth of 52 cm from where it decreased to very low values. Exchange acidity and potential acidity were maximum in the lower most layer. Exchangeable aluminium, organic matter, manganese, exchangeable hydrogen and cation exchange capacity were high in the lower most horizon of *Karapadom* pedon.

Karapadom surface samples registered a mean pH value of 4.86 in wet condition. It dropped to 4.31 under dry condition. The DpH was 0.61. Exchange acidity and potential acidity were high in the surface sample. About 90 per cent of potential acidity was non exchangeable. These soils recorded high exchangeable aluminium, high organic matter, high nitrogen, high exchangeable H^+, low base saturation and high clay percentage. They were of high available nitrogen, medium phosphorus and high potassium.

Correlation studies revealed that under field wet condition, pH was determined mainly by the available magnesium. Menon (1975) also reported calcium and magnesium as the dominating cations in the exchange complex of *Karapadom* soils. KCl pH was governed by available iron in solution. When dried samples were analysed, the pH was mainly determined by exchangeable aluminium, exchangeable hydrogen and effective CEC. Exchange acidity in these samples were also determined by exchangeable aluminium exchangeable hydrogen, effective CEC, organic matter, nitrogen compounds, cation exchange capacity etc. Potential acidity was determined by organic matter, nitrogen and exchangeable hydrogen.

By submergence study we could observe that *Karapadom* soils attained 5.57 pH value within a week of submergence. Then it declined to 5.26. This may be due to the buffering action of organic matter. From 3rd week onwards it showed a steady increase and attained 6.26 pH by 12 weeks. This underlines the significance of good water management to nutralise acidity without liming in these soils.

Comparison of lime requirement methods concluded that exchangeable aluminium method was best for *Karapadom* soils. According to this *Karapadom* surface soils (0-30cm) require 3 tonnes ha^{-1} of lime for ameliorating acidity.

5.2.5 *Kayal* soils - Fine Mixed Isohyperthermic Typic Hydraquent

These are natural *Kayal* lands Here rice is cultivated as single crop. Natural vegetation is marsh land grasses and mangroves. In these lands the field pH was above 5.5 even in the surface layer. It increased towards lower depths and reached 7.4 at 103-151 cm layer. But under dry condition pH was 3.8 in the upper most horizon. Then it increased and reached 6.8 pH in the 22-33 cm layer. Again it decreased and reached 2.3 pH in the 41-97 cm layer. This horizon recorded the maximum exchange acidity (34.1 cmol(+)/kg soil) and potential acidity (87.2 cmol(+)/kg Soil). But under field wet condition the pH of this horizon was 6.9. The exchangeable aluminium, organic matter, nitrogen, iron etc. are very high in this horizon. These factors are the reason for low pH, high exchange acidity and high potential acidity in this layer of the pedon. Cation exchange capacity was also high in the lower layers. Even though the bases were high in the lower layers, the acidity produced by the acidity contributing factors were so high that it surpassed the limit. Menon (1975) also reported high percentage base saturation ranging between 73.5 to 97.7 in these soils. The total soluble salts were also very high in the lower layers of the kayal soils. The mean field wet pH of kayal surface samples was 5.07 and dry pH was 4.44. The presence of excess salt will displace adsorbed aluminium and cause an increase in the acidity of the soil solution. Divalent cations have a greater effect in lowering soil pH than monovalent cations. The aluminium, iron and manganese brought into solution undergo hydrolysis and resulted in a lowering of pH.

The exchange acidity and potential acidity were high in the surface layers because exchangeable aluminium, organic matter and clay content were high in the surface soils. CEC of the surface samples was also high (19.97 cmol(+)/kg). The total soluble salts present in *Kayal* soils were also high especially exchangeable calcium. This will displace adsorbed aluminium and iron into soil solution and this inturn on hydrolysis yield acidity. Iron and sulphur on oxidation yield H^+ ions. The soils also registered high active iron (3949 ppm) and total sulphur (1294 ppm). Correlation studies revealed that in *Kayal* soils, field wet pH was determined by available calcium in the Soil. The calcium content of these soils were high under dry condition. Exchangeable aluminium, exchangeable hydrogen and effective CEC determined the active acidity. Exchange acidity was determined by exchangeable aluminium and exchangeable hydrogen. Potential acidity in the *Kayal* lands were mainly contributed by exchangeable aluminium (R^2 = 0.77), cation exchange capacity (R^2 0.52), exchangeable hydrogen (R^2 = 0.77) and effective CEC (R^2 = 0.84). High clay (66 percentage) and high organic matter (5%) were the factors that resulted in high CEC in *Kayal* lands. High CEC soils, will hold more Al^{3+}, H^+, Fe^{2+} in their exchange complex. These cations are brought into soil solution phase.

Potential acidity is also called reserve acidity because when active acidity in the soil is neutralised by liming or any other means, the acidity in the Soil solution is maintained by converting potential acidity into active acidity by the buffering action.

By submergence study we could find that after drying *Kayal* surface soils (0-30 cm) required about 8 weeks to attain a pH of 5.00. This was a very long period. Because of high buffering action of the soil, sudden change in pH could not be obtained in these soils. Organic matter and clay are the main seat of potential acidity (exchangeable + non exchangeable). Once the *Kayal* lands are drained for rice cultivation the pH dropped to about 4.26 and it took about 8 weeks to attain a pH value of 5.0 so liming was essential for rice cultivation in these lands. By exchangeable aluminium method of lime requirement it was found that 4.41 tonnes ha^{-1} of lime should be added to avoid the deleterious effects of acidity in these soils. According to Shoemaker method it required 6.75 tonnes ha^{-1} of lime. Based on base saturation elevation method, the lime requirement was 2.85 tonnes ha^{-1}. The low lime requirement recorded in this method was due to the high base saturation of these soils. Titration method was also applied for these soils and found that it required 4.58 tonnes lime/ha. Exchangeable Al method and titration method recommended more or less the same quantity of lime. pH, exchange acidity and potential acidity gave positive significant correlation with the lime requirement obtained with exchangeable Al method.

5.2.6 *Pokkali* soils - Fine Mixed, Isohyperthermic, Sulfic Tropaquept

These are low lying saline acid soils. They are subjected to tidal waves and periodical inundation by saline water. It is in Ernakulam district. Profile studies conducted at Njarakkal showed that there was an increase in pH towards lower depths. Though the field pH ranged from 4.2 to 4.7, the dry pH was very low and it ranged between 2.69 and 2.91. The highest active acidity was noticed in the surface layers. The increase in pH towards lower depth was only 0.31 units. Exchangeable aluminium, organic matter, nitrogen compounds, iron and manganese, were high in the surface layers of *Pokkali* Soils. Cation exchange capacity was also high in the surface layers. These factors render the soil more acidic. The high total soluble salts in the surface layers (12.1 dSm^{-1}, 9.1 dSm^{-1} and 6.5 dSm^{-1}) also contributed to extreme acidity in these soils. Yu Rian Ren (1985) pointed out that the cations of the salts will displace adsorbed aluminium and cause an increase in the acidity of the soil solution. Divalent cations have a greater effect on lowering pH than monovalent metal cations. Brinkman (1970) also found that during submergence and soil reduction, the cations are displaced from exchange sites by Fe^{2+}, migrate out of the reduced zone and are lost when soil is drained and dried. The reduced iron is oxidised and precipitated leaving H^+ ions as the only major cation. The soil is acidified and the clay disintegrates. This phenomenon is called ferrolysis. The exchange acidity was maximum in the second layer (33.1 cmol(+)/kg). This could be attributed to the high exchangeable aluminium (13.5 cmol(+)/kg) and exchangeable hydrogen (19.6 cmol(+)/kg). This is in agreement with the findings of Coleman and Thomos (1967). Unnikrishnan (1993) also recorded high exchangeable aluminium and hydrogen in the surface layers of *Pokkali* soils. The non exchangeable acidity and potential acididty were also high in surface layers. The potential acidity of the surface (0-8 cm) horizon of *Pokkali* soils was 95 cmol(+)/kg. The active acidity, exchange acidity and potential acididty decreased towards deeper layers. The content of total soluble salts also decreased in lower layers. Upto 75-110 cm a decrease in these factors was observed but in the next lower horizon there occurred an increase. The acidity contributing factors like exchangeable aluminium were high in the surface layers especially in the second layer (8-20 cm). This layer recorded the highest exchange acidity. Exchange acidity had the highest positive correlations with exchangeable aluminium and exchangeable hydrogen. About 97 percentage of variation in exchange acidity could be accounted for by exchangeable aluminium ($R^2 = 0.97$).

The surface samples of *Pokkali* recorded mean field pH value of 5.58. But on drying it decreased to 3.18. A difference of 2.4 units occurred in *Pokkali* soils could be due to the hydrolysis of aluminium, iron and manganese compounds. The initial pH was attained by continuous submergence followed by reduction. Reduction is by consumption of H^+ ions. The mean total soluble salts of *Pokkali* soil was 6.91 dSm^{-1}. The soluble salts also contributed to the acidity of soil by displacing adsorbed aluminium and H^+ ions in exchange of cations of the salts from the exchange complex. Divalent cations like calcium and magnesium have a greater effect on lowering the pH than monovalent cations like sodium and potassium. This was in confirmity with the findings of Pons and Van Breemen (1973). The mean exchange acidity of surface samples was 8.03 cmol(+)/kg. Exchange acidity was positively and significantly correlated with exchangeable aluminium, exchangeable hydrogen and effective CEC. Ninety seven per cent of variation in exchange acidity could be accounted for by exchangeable aluminium in *Pokkali* soils. The coefficient of determination (R^2) for exchangeable hydrogen was 0.95. The mean potential acidity of this soil was 41.20 cmol(+)/kg soil. Out of this 80.5 per cent was non exchangeable. The H^+ in covalent bond with organic matter and mineral components of soil was high in *Pokkali* soils. This could be the reason for high non exchange acidity of these soils. The organic matter content of these soils was high (3.94

percentage). Cation exchange capacity was also high (23.38 cmol(+)/kg soil). The available nitrogen, phosphorus and potassium were medium.

The mean base saturation of *Pokkali* soils was 66 per cent. The available micronutrients like iron, manganese, zinc and copper were in sufficient quantities. The total soluble salts were high above the tolerance limit of rice. Active manganese was high (490 ppm) in *Pokkali* soils when compared to other wet land soils. Total sulphur was also found to be high (7759 ppm). The clay content of *Pokkali* soils was high (61 per cent). The predominant clay minerals in these soils were found to be kaolinite, smectite and illite. The other minerals were quartz, gibbsite and feldspars.

Correlation studies revealed that the field pH in *Pokkali* soils was determined mainly by the exchangeable aluminium. Under dry condition, the pH was mainly determined by exchangeable aluminium, exchangeable hydrogen and effective cation exchange capacity. When these factors were increasing in soils the pH decreased. This was clearly evident from the highly negative significant correlations between these factors and pH.

The exchange acidity was positively and significantly correlated with exchangeable aluminium, exchangeable H^+ and effective CEC. When these factors increased in soils there was a corresponding increase in exchange acidity.

Potential acidity which included both exchange and non exchange acidity was mainly controlled by effective CEC. Cation exchange capacity of the soils was determined by organic matter and clay content. Seventy five per cent of variation in potential acidity was determined by effective CEC.

From the kinetics of pH on submergence, it was found that *Pokkali* soils exhibited a very slow rise in pH. Even after 12 weeks of submergence it attained a pH of only 4.31. The reasons for slow increase in pH in *Pokkali* soils could be due to low organic matter content when compared to *Kari* Soils. Organic matter is the source of electrons for reduction. The proliferation of anaerobic bacteria was not sufficient to cause fast reduction in this soil. High total soluble salts especially sodium in *Pokkali* soils displace more Al^{3+} and H^+ into soil solution from exchange complex. The reduction of nitrogen compounds, iron and manganese was not sufficient to cause a drastic change in pH towards neutrality. The exchangeable aluminium in *Pokkali* soils was high (356 ppm). Exchangeable Al was not decreasing appreciably since the pH rise was very low. The final Al concentration was 91.95 ppm. The increase in pH by reduction was not sufficient to precipitate Al and render it insoluble by the formation of gibbsite ($Al(OH)_3$). The Eh decrease in this soil was also found to be low. The final Eh reached after twelve weeks of submergence was only +207 mV.

According to exchangeable aluminium method of lime requirement, *Pokkali* soils required 5.91 tonnes ha^{-1} of lime for neutralising acidity. The titration method of lime requirement gave a value of 5.53 tonnes ha^{-1}. But the Shoemaker method of lime requirement gave a value of 11.5 tonnes ha^{-1}. From the correlation studies it was found that exchangeable aluminium method gave negative significant correlation with dry pH ($R^2 = 0.71$) and positive significant correlation with exchange acidity ($R^2 = 0.97$).

Kotur and Srivastava (1983) showed that liming did not raise the pH to neutrality nor it completely overcome the extractable acidity but effectively reduced the exchangeable acidity. Lime just sufficient to suppress the excess of exchangeable aluminium may be used which will be more economical. Lime is used to overcome the toxicities/deficiencies rather than raising the soil pH to neutrality. This introduces the concept of underliming using exchangeable aluminium as a monitoring device. There are many reasons not to resort to high rates of liming even in highly acid soils. One of the important reason is the faster reacidification at higher levels of liming. Marykutty (1986) observed that the more reacidification rates observed in *Kole, Pokkali* and *Kari* soils with higher levels of lime application may be due to mineralisation of higher content of organic matter present in them and dissociation of organic acids in soil solution.

Since the highest acidity was noticed in the surface layers (0-35cm) in *Pokkali* soils, rice is the principal crop that can be grown here without allowing the field to dry up. In potential acid sulphate soils it is better to avoid oxidation of sulfidic materials by keeping soil under submergence in order to reduce creation of more acidity. Here acidity as well as salinity are problems to rice culture. Keeping the soil submerged as long as possible before transplanting and use of tolerant varieties may maximise rice yields in these area. Prawn culture can also be done during off seasons. In *Pokkali* soils, the traditional way of cultivation on mounds and spreading the rice seedlings through out the field after rains to avoid acidity and salinity problems has been found to have a scientific basis.

5.2.7 *Kole* Soils-Fine, Mixed Isohyperthermic, Typic Tropaquepts

It is a natural saline acid wetland soil. The natural vegetation is marsh land grasses and rice is cultivated in two seasons. The *Kole* areas lie contiguously along the coastal strips in the adjoining districts of Trichur and Palakkad with a total area of about 11,000 hectares. These are reclaimed back water areas. Acidity, salinity, poor drainage and presence of toxic salts are the characteristics of the soil.

From the profile studies we could observe that there was an increase in pH with increase in depth. This may be due to more reduction occurred with increase in depth. But the pH decreased after drying . The highest decrease was obtained in the lowest layers. The highest exchange acidity and potential acidity was also observed in the lower most layers. This could be due to high exchangeable aluminium, high organic matter content, high iron, high exchangeable H^+, low base saturation, high CEC and high total soluble salts in lower layers. The surface soils recorded a field pH value of 4.90. But on drying the soil samples, the pH came down to 4.63. The exchange acidity noticed in surface samples (0-30 cm depth) was 1.38 cmol(+)/kg and the non exchangeable acidity was 28.62. The mean exchangeable aluminium was only 0.82 cmol(+)/kg soil. The organic matter content was 2 per cent. Available manganese was high in this soil (46.3 ppm) when compared to other wetlands. The available nitrogen, phosphorus and potassium were medium. The micronutrients like iron, manganese, zinc and copper were found to be high in these soils. The per cent base saturation was 65.83. Cation exchange capacity was low (11.72 cmol(+)/kg). Calcium was the predominant base in this soil. In *Kole* soils the clay per cent is low (36 per cent) and the important clay mineral was Kaolinite. The active iron and manganese were also high in these soils.

Under dry condition the pH of *Kole* soils was mainly determined by available calcium. When available calcium in *Kole* soils increased there was an increase in pH. Exchange acidity was mainly determined by exchangeable aluminium and exchangeable H^+. Of these two factors, exchangeable aluminium accounted for 94 percentage of variation in exchange acidity. The potential acidity in this soil was mainly accounted by organic matter ($R^2 = 0.56$), nitrogen compounds ($R^2 = 0.64$) and cation exchange capacity ($R^2 = 0.57$). The content of organic matter and clay were low in *Kole* soils when compared to *Kari*, *Pokkali*, *Kayal* and *Karapadom* soils eventhough they accounted for a significant amount of potential acidity (30 cmol(+)/kg).

The Kinetics of soil pH on submergence showed that *Kole* Soils (surface samples 0-30 cm depth) took about 3 weeks to attain a pH value of 5.8. From this we can conclude that the *Kole* soils should be kept under submergence (5cm water above ground level) atleast for three weeks before transplanting of rice seedlings.

From the comparison of the three lime requirement methods, we could observe that to ameliorate the active and exchange acidity, 1.23 tonnes ha^{-1} of lime should be added to the surface soils. This was based on exchangeable aluminium method. If we adopt the base saturation elevation method the lime required was 1.84 tonnes ha^{-1}. In order to alleviate potential acidity (taking into consideration the non exchange acidity also) the Shoemaker method was found to be the best. According to this method *Kole* soils require 8.75 tonnes ha^{-1} of lime.

5.2.8 *Kaipad* Soils-Fine, Mixed, Isohyperthermic, Tropic Fluvaquent

These are natural low lying saline acid marshes of North Kerala found near the mouth of streams and rivers situated near the Arabian Sea. The lands are subjected to tidal effects and periodical inundation by saline water and the natural vegetation is mangrove and other halophytes. From the profile studies there observed a gradual increase in pH with depth. The field pH was 7.4 at the lowest horizon of *Kaipad* profile. But on drying, the surface horizon recorded a pH of 4.5, then it increased and recorded pH of 7.0 in the 59-84 cm layer. In the lower most layer (84-126 cm) the lowest pH of 3.3 was observed. The maximum exchange acididty was also noticed in this layer. The potential acidity was found to be highest (22 cmol(+)/kg soil) in the 59-84 cm layer. The maximum total soluble salts were observed in the surface horizon (7.2 dSm^{-1}). The maximum exchangeable aluminium (1.26 cmol(+)/kg) and exchangeable H^+ found in the lower most layer of *Kaipad* soil were the reasons for maximum exchange acidity in the lower most layer. The highest cation exchange capacity and lowest base saturation were also noticed in this layer. Calcium was found to be the prominent base.

The surface samples of *Kaipad* lands had a mean field pH value of 5.58. On drying pH had come down to 5.27. The Sandy nature of soil, low organic matter and clay resulting in very low CEC may be the reasons for the small variation in pH. The electrical conductivity of the surface layer was only 0.057 dSm^{-1}. This is below the toxic limit for rice. The exchange acidity was only 0.695 cmol(+)/kg soil. But the non exchange acidity was 15 cmol(+)/kg soil. Ninety five per cent of potential acidity was non exchangeable. The exchangeable aluminium in the surface samples of *Kaipad* lands was low (0.48 cmol(+)/kg). The organic matter was also low (0.28 per cent). Available nitrogen and potassium were low and the available phosphorus was medium. Iron, manganese, zinc and copper were found in sufficient quantities. The cation exchange capacity was found to be low due to the low organic matter and kaolinite clay minerals. Base saturation was sufficient (81 per cent) and calcium was the prominant basic cation. Active iron (1825 ppm), manganese (490 ppm) and total sulphur (6909 ppm) were high. Clay content of these soils was low 30.85%.

From the correlation studies, it was found that exchangeable aluminium, exchangeable hydrogen and effective CEC are the factors that mainly controlled pH under field wet condition. The negative significant correlations between pH, sodium and potassium can be attributed to the release of more exchangeable aluminium and H^+ into soil solution from the exchange complex by the mass action of salts. Thus the decrease in pH under dry condition was controlled by exchangeable aluminium, exchangeable hydrogen, effective CEC and CEC. When these parameters increased in *Kaipad* soils there was a decrease in pH.

Exchange acidity was mainly accounted by exchangeable aluminium and exchangeable hydrogen. Organic matter and effective CEC were the next two factors that controlled exchangeable acidity in *Kaipad* lands. Organic matter was the main factor that determined the CEC of the soil.

Kaipad soils reached a pH value of 6.0 within seven days submergence. Hence liming is not at all a must in these soils. According to exchangeable Al method of lime requirement, *Kaipad* surface soils require only 0.72 tonnes ha^{-1} of lime. But based on Shoemaker method these soils require 5 tonnes ha^{-1} of lime to alleviate acidity. Active acidity in terms of pH was negatively and significantly correlated with exchangeable aluminium method of lime requirement. The exchange acidity was found to be negatively and significantly correlated with exchangeable Al method and Shoemaker method. There is an equilibrium that exists between acidity in solution, exchangeable acidity and non exchangeable acidity. If we take into consideration only the acitive and exchange acidity, 0.72 tonnes ha^{-1} was necessary. If we consider both exchangeable and non exchangeable acidity we have to apply more lime in *Kaipad* soils.

5.2.9 Pattambi-Fine, Kaolinitic, Isohyperthermic, Aeric Kandiaqult

This is a manmade valley wetland comprising of lateritic alluvium. Rice is cultivated here in two seasons. Profile studies revealed that under field wet condition, in all the horizons the pH was above 5.0. On drying the samples the pH had dropped to 4.5 in the surface horizon and towards lower layers it increased to 5.2 because of high percentage base saturation. The exchange and non exchange acidities were high in the surface layer when compared to lower horizons. In the surface layer (0-20 cm), 95 per cent of potential acidity was in nonexchangeable form. In the second layer (20-30 cm) it was 97 per cent and in the third horizon (30-46 cm) it was 99 per cent.

The acidity recorded in the surface layers could be attributed to the presence of more exchangeable aluminium, organic matter, nitrogen, iron, manganese and low base saturation. The bases had leached from the surface and accumulated in the lower horizon.

The mean pH of surface samples was 5.64. It had come down to 4.93 on drying. Drying caused oxidation of iron, manganese, and aluminium. The exchange acidity noticed in surface layers was only 0.49 cmol(+)/kg. The non exchangeable acidity was 18.81 cmol(+)/kg. The mean exchangeable aluminium recorded was only 0.35 cmol(+)/kg. The organic matter content was 1.06 per cent and the available nitrogen and phosphorus were medium. Available potassium was low. Available iron, manganese, zinc and copper were comparatively high in these soils. The available copper content was 10ppm. Base saturation was found to be 60 per cent and the cation exchange capacity of the soils were low (6.36 cmol(+)/kg). Low contents of clay and organic matter and preponderance of kaolinite minerals may be cited as the reasons for low C.E.C. in these soils.

Under dry condition when the contents of exchangeable aluminium organic matter, nitrogen, iron and exchangeable H^+ increased in soil, the pH decreased.

Exchange acidity was positively and significantly influenced by exchangeable aluminium, exchangeable H^+, iron,organic matter and copper. Out of these, 98 per cent of variation could be accounted by exchangeable aluminium. Potential acidity was determined by ΔpH, exchangeable H^+, exchangeable aluminium and available iron.

Kinetics of pH on submergence revealed that Pattambi soils required only one week to attain a pH value of 5.82. Submerging the soil one week before transplanting rice seedlings could be adopted in these soils to get better performance of rice and eliminate the cost of liming in these soils. Experiments conducted at Pattambi also revealed no effect for lime application in increasing rice yield. According to exchangeable Al method of lime requirement, Pattambi soils require only 0.54 tonnes ha^{-1} of lime.

The dry pH gave negative significant correlations with exchangeable aluminium method of lime requirement. The exchange acidity gave positive significant correlation with exchangeable aluminium method and base saturation elevation method. Potential acidity gave no significant correlations with any of the three methods. Exchangeable aluminium method was found to be more suitable for Pattambi soils.

5.2.10 Kattampally - Loamy, Kaolinitic, Isohyperthermic, Tropic Fluvaquent

It is a natural swamp reclaimed area and rice is cultivated in two seasons. The analyses of profile samples indicated an increase in pH upto 100 cm, but in lower layer the pH attained very low values ie. 3.4. On drying, the lowest layer recorded a pH of 2.85. The total soluble salt content was also high in this horizon ($2.4dSm^{-1}$). The exchange acidity noticed in this layer was very high

(22 cmol(+)/kg). The non exchange acidity recorded was 10 cmol(+)/kg. The potential acidity was very high (32 cmol(+)/kg) and the exchangeable aluminium was 10.05 cmol(+)/kg. The organic matter content was 1.66 per cent and the available iron in this layer was 246.6 ppm. Compared to other layers it is very high. The high amounts of exchangeable aluminium, exchangeable H^+, organic matter, soluble salts and iron could be the reason for high exchangeable and potential acidity in the lowest layer of Kattampally soils. The Kattampally surface samples recorded a mean field wet pH of 5.7 which on drying came down to 5.46. The dry KCl pH was 4.61. The exchange acidity was only 0.165 cmol(+)/kg. The potential acidity recorded was 19.8 cmol(+)/kg and 99 per cent of potential acidity was accounted by non exchangeable acidity. These soils recorded very low exchangeable aluminium (0.132 cmol(+)/kg), low organic matter (0.63 per cent) and moderate iron content (143.2 ppm). Surface samples were medium in nitrogen, phosphorus and potassium and sufficient in micro nutrients like iron, manganese, zinc and copper. Cation exchange capacity was low due to low organic matter content. Under field wet condition, iron determined the pH. It could account for 68 per cent variation in pH under field wet condition. Under dry condition also iron determined the variations in active acidity. Magnesium and available zinc had got positive correlations with pH. Ninety nine per cent of variation in exchange acidity was accounted by exchangeable aluminium and H^+.

From the estimation of lime requirement we could find that Kattampally soils require only 0.20 tonnes ha^{-1} of lime according to the exchangeable Al method. But based on Shoemaker method the lime requirement was 2.58 tonnes ha^{-1}. Correlations between exchange acidity and exchangeable Al method of lime requirement gave high positive significant correlations.

Submergence studies revealed that Kattampally soils require only 2 days to reach a pH of 5.5. So lime was not at all essential to raise the pH of the soil for successful rice cultivation.

5.2.11 Wyanad -Loamy, Kaolinitic, Isohyperthermic, Typic Tropaquent

These are manmade valley wet lands and rice is cultivated twice an year. Profile studies revealed the surface horizons were more acidic than lower horizons. On drying the soils, the pH had dropped to 4.4 in the surface. The surface layers recorded more exchange acidity because of the presence of more exchangeable aluminium and organic matter. In the second horizon. the maximum potential acidity was noticed. This could be due to the presence of more exchangeable aluminium and low base saturation.

Surface samples had a field pH of 5.92 and on drying it reached 4.83. The exchange acidity noticed was 0.34 cmol(+)/kg and potential acidity was 13.2 cmol(+)/kg. The soils recorded 0.245 cmols(+)/kg aluminium, 1.83 per cent organic matter, iron 88.7 ppm and manganese 20.62 ppm. The soils were medium in available nitrogen and phosphorus but low in potassium. Cation exchange capacity was low but the base saturation was sufficient. The clay percentage was found to be very low when compared to other soils.

In Wyanad soils the field wet pH was mainly determined by available iron. Seventy nine per cent of variation in dry pH was accounted by ΔpH. Exchange acidity was determined by exchangeable H^+ ($R^2 = 0.94^{**}$). According to exchangeable aluminium method of lime requirement, Wyanad soils required only 0.37 tonnes ha^{-1} of lime. But based on Shoemaker method it was 2.94 tonnes ha^{-1} and based on base saturation elevation method it required 0.61 tonnes ha^{-1}. Correlation studies revealed that exchangeable aluminium method of calculating lime requirement was best for Wyanad soils.

Submergence studies revealed that eventhough the initial dry pH of Wyanad soils was 4.7, it reached 6.09 within one week of submergence. From this we may conclude that one week submergence can raise the pH of wynad soils to the desired soil reaction level necessary for rice cultivation thereby eliminating lime application.

5.2.12 Chittoor - Loamy, Mixed, Isohyperthermic, Petro-calcic Calciusterts

These are manmade non acid wetlands, where rice can be cultivated for two seasons. The soil was alkaline in reaction. The profile studies revealed that the exchangeable aluminium content was only traces. The organic matter content decreased with depth from 1.79 to 0.26 per cent. Available iron was low when compared to other profiles. Available manganese, zinc and copper were not much deficient. Available calcium was very high and in the lower most horizon it recorded 13144 ppm. The cation exchange capacity was also high which correlated with the major clay mineral found in these soils, the smectite.

The surface soils recorded an average organic matter content of 2.60 percentage. The available nitrogen and potassium were medium and the available phosphorus was high. Calcium was the major basic cation and the average available calcium was 4852 ppm. Cation exchange capacity and base saturation were high. Here pH was mainly determined by available calcium and percentage base saturation.

From the comparison of surface samples of wet lands we could observe that under field wet condition *Karapadom* soils recorded the lowest pH 4.86 and the maximum 7.43 was recorded by Chittoor soils (Fig 26). The *Karapadom* soils recorded lowest pH because at the time of collection the moisture percentage of the soil was not sufficient to bring a reduced condition. The samples were collected during the month of April after the harvest of first crop of rice.

After drying the lowest pH (3.2) was observed in the surface samples of *Pokkali* and *Kari* soils (Fig 26). The presence of sulfidic materials in *Pokkali* and *Kari* soils may be attributed for the drastic reduction in pH on drying due to the oxidation of sulfidic materials to sulfates and production of sulphuric acid. The maximum exchange acidity was noticed in the *Kari* Soil (16.4 cmol(+)/kg) followed by *Pokkali* soils (8.03 cmol(+)/kg). The maximum potential acidity was also noticed in *Kari* soils (129.95 cmol(+)/kg). The potential acidity of the wetlands was in the order *Kari* (129.95) > *Kayal* (41.6) > *Pokkali* (41.2) > *Karapadom* (36.3) > *Kole* (30.0) > *Kattampally* (19.3) > Chittoor (19.26) > Vellayani (19.0) > Karamana (13.8) Wyanad (13.2) (Fig 27). High CEC observed in Chittoor soils due to the preponderance of smectite clay mineral resulted in high basicity. Chittoor area is an extension of the basaltic Deccan plateau. Parent materials high in bases lead to the formation of soils rich in bases. High basicity and a neutral to alkaline reaction of the soil favour high plant nutrient availability and optimum microbial activities. Accumulation of calcium carbonate concretions is a characteristic features of these soils. Because of the dominance of expanding type clay minerals, the soils exhibit shrink-swell properties and deep open cracks are formed during summer months. The high concentration of calcium in these soils provides better

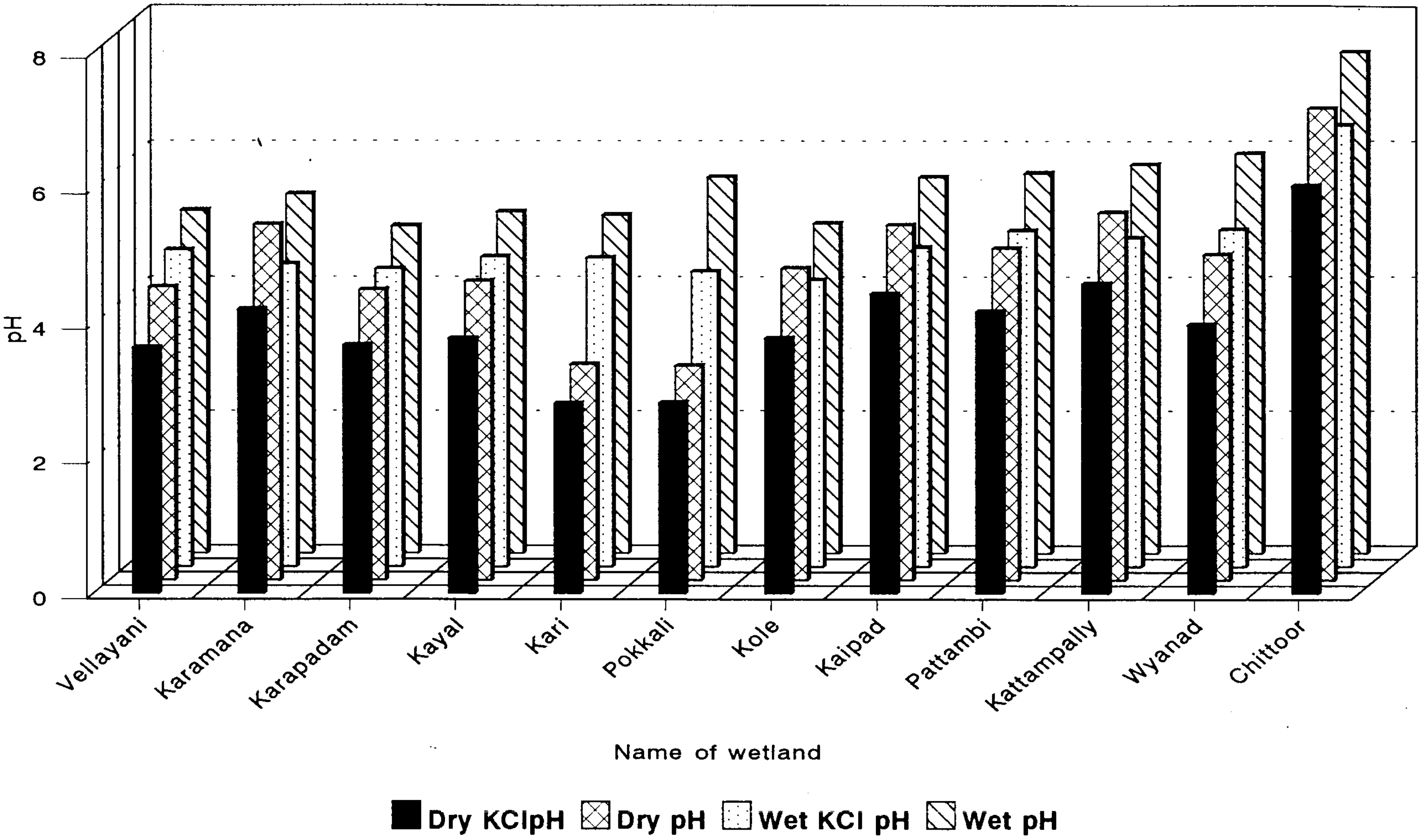

Fig. 26. Distribution of active acidity in surface samples of wet lands (Dry pH, Wet pH, Dry KCl pH and Wet KCl pH)

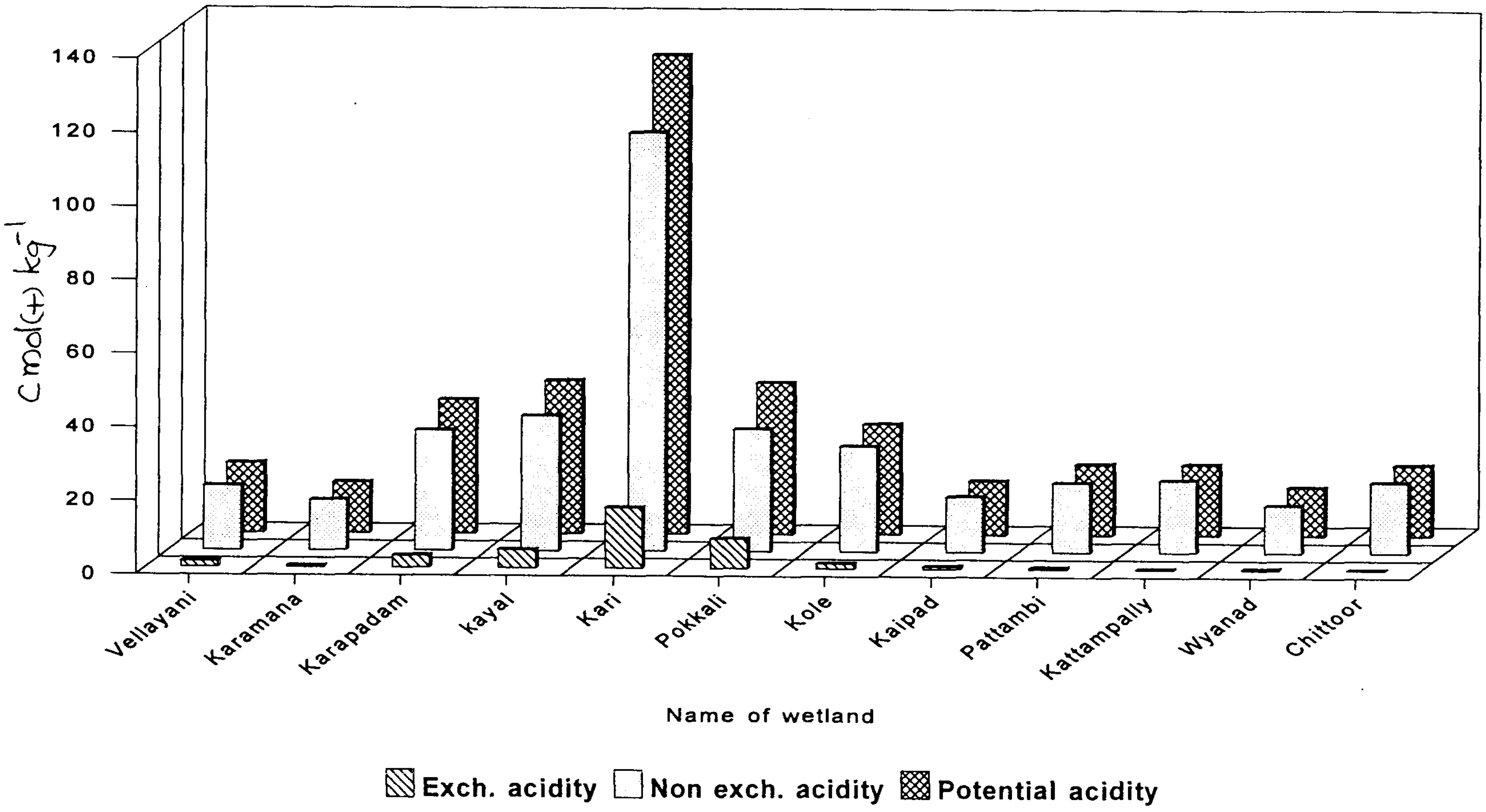

Fig. 27. Distribution of exchange acidity, non exchange acidity and potential acidity in surface samples of wetlands

aggregation and leaching loss of nutrients are very much reduced. Because of neutral to alkaline pH and presence of carbonates and toxicity of Fe, Al, Mn etc. are never concentrated in these soils. The physical as well as chemical properties of the soil are so optimum that it provides better fertilizer use efficiency and conditions for the better performance of rice crop.

Parent material is the most important factor that decides a soil to be a acidic or basis. By adopting efficient management practices like liming, reducing the continous use of acid forming fertilizers, water management, proper manurial practice and use of acid tolerant varieties can boost the yield of rice in our fields.

Even though Chittoor soils are neutral to alkaline in reaction, it recorded 19.13 cmols of non exchange acidity and 0.125 cmols exchange acidity. H^+ in covalent bonds with organic and mineral fractions of the soil is responsible for this non exchangeable acidity. The percentage base saturation of this soil is about 74.0. The rest of exchangeable sites may be occupied by H^+, Fe and Mn ion etc. The H^+ from the organic reactive groups like carboxylic, phenolic also contribute to potential acidity.

Free oxides and hydroxides of Fe and Al may also account for this potential acidity. But the acid characteristics are masked by the high basicity of the soil. In Chittoor soil we can see large number of calcium carbonate concretions embeded in the soil.

In Chittoor soils 99.33 per cent of potential acidity was non exchangeable. In *Kari* soils 87.46 per cent of potential acidity was non exchangeable. In *Pokkali* only 80.51 per cent was nonexchangeable.

The acidity contributing factors like exchangeable aluminium (5.72 cmol(+)/kg), organic matter (10.55 per cent), iron (2399.66 ppm), cation exchange capacity (40.99 cmol(+)/kg), total sulphur (12914.64 ppm) and clay content (66.43 per cent) were maximum in *Kari* Soils. The lowest mean per cent base saturation (36.42) was also noticed in *Kari* soils.

5.3 Relationship between components of acidity, acidity contributing factors and other soil characteristics

The 120 surface samples of twelve wetlands were taken together and correlations and regressions worked out. When the exchangeable aluminium, organic matter, nitrogen and exchangeable H^+ increased in soil the pH under field wet condition decreased. It is well known that the exchangeable Al^{3+} on hydrolysis will yield H^+ ions. Further organic acids and CO_2 produced in the decomposition process of organic matter will also lead to a reduction in pH. The reactive carboxylic and phenolic groups will dissociate releasing H^+ ions, resulting in a pH decrease.

It has been evident that the pH in wet lands increased when the calcium and percentage base saturation of soils increased.

The electrical conductivity of the soil under field condition increased with increase in cation exchange capacity, exchangeable aluminium, available potassium, magnesium and sodium.

The studies also indicated that pH under dry condition decreased with increase in cation exchange capacity, ECEC, exchangeable aluminium, organic matter, nitrogen compounds, iron and exchangeable H^+.

It could be concluded that eighty six per cent of variation in exchange acidity was accounted by exchangeable aluminium. Exchange acidity in wetlands of Kerala increased with increase in exchangeable aluminium, exchangeable hydrogen, organic matter, nitrogen, iron, manganese, cation exchange capacity and effective CEC. But it decreased when base saturation percentage increasd. Earlier studies by Hoyt (1977) and Mary kutty (1986) also obtained similar results.

The non exchangeable acidity was mainly contributed by H^+ in covalent bonds with organic and mineral soil fractions. Here non exchange acidity had highly significant positive correlations with exchangeable H^+ ($R^2 = 0.86$), cation exchange capacity ($R^2 = 0.77$) and organic matter ($R^2 = 0.73$).

Potential acidity was mainly controlled by exchangeable hydrogen, cation exchange capacity, organic matter and iron compounds. Eh had negative correlation with pH under field wet condition ($r = 0.4329^{**}$) and dry condition ($r = -0.8280^{**}$). When the total as well as available sulphur increased in soil the pH registered a decrease in wet land soils of Kerala. High content of clay in soils was found to have a positive relationship with active acidity where as high sand content show a negative relationship.

From the correlations worked out in selected 36 samples it could also be concluded that exchange acidity increased in soils having high total sulphur, available sulphur, redox potential, clay content etc. Non exchangeable acidity also increased when these factors were high in soils. Potential acidity had also got this relationship.

5.4 Interrelation ship between acidity components and available nutrients in wetland soils of Kerala

Available nitrogen recorded a negative significant correlation with pH. When available nitrogen in soils increased there was a decrease in pH. Nitrification of organic or ammoniacal forms of nitrogen release H^+ ions and results in the acidification of the soil. It recorded positive significant correlation with exchange acidity, non exchange acidity and potential acidity. Organic matter which is the potential source of H^+ ions in soil through its functional groups and its complexation with iron and aluminium compounds in turn influenced the available nitrogen in soil. In soils, 90-92 per cent of available nitrogen is from organic matter.

Available phosphorus showed a positive correlation with pH under field condition (reduced condition) but a negative correlation under dry condition because most of P will be fixed as Fe and Al phosphates. Cation exchange capacity of the soil and organic matter content were the two main capacity factors that ultimately decided the acidity of the soils studied. When CEC and organic matter of a soil increase there is an increase in active as well as potential acidity. Available phosphorus showed positive correlations with exchange, non exchange and potential acidity.

Available potassium also showed negative significant correlation with pH and positive correlation with exchange, non exchange and potential acidity. DTPA extractable iron also showed negative significant correlation with pH and positive significant correlation with exchange, non exchange and potential acidity. manganese and zinc also followed the same trend. But copper showed positive significant correlation with pH and negative significant correlation with exchange, non exchange and potential acidity. This may be due to the complexation of copper with organic matter making it unavailable. Available calcium showed positive significant correlation with pH. Manganese and sodium had negative significant correlations with pH but positive significant correlations with exchange acidity, non exchange acidity and potential acidity. In Kerala, most of the natural wetlands namely *Kari, Karapadom, Kayal, Pokkali, Kole* and *Kaipad* are characterised by their nearness to sea and periodical inundation with salt water due to their geographic position below sea level. These salt affected soils are also highly acidic. Hence this kind of relationship was obtained. The availability of soil nutrients is mainly controlled by the cation exchange capacity of soil which in turn depend on the organic matter and clay content. There exists a highly positive significant correlation between organic matter and CEC ($r = 0.8673^{**}$) CEC and clay per cent also correlated positively and significantly ($r = 0.51^{**}$) CEC determine the exchangeable H^+ in soil ($r = 0.83^{**}$). CEC is positively and significantly correlated with available nitrogen, available phosphorus, iron, manganese, zinc, calcium, magnesium and sodium but a negative significant correlation with copper. Copper complexation with organic ligands increases at pH 5.0 and above pH 7.0 almost all Cu^{2+} is chelated on the soil solution (Driessen, 1978). The stronger complexation of Cu and higher stability of these complexes in the soil may be the reason for the deficiency of copper in peat soil like *Kari*. CEC had negative significant correlation with pH and positive significant correlation with exchange, non exchange and potential acidity.

Exchangeable aluminium had positive significant correlation with available nitrogen, iron, manganese, zinc and magnesium but negatively correlated with copper. Alexander and Durairaj (1968) and Marykutty (1986) also found similar relationships in soils of Kerala because most of the wet lands are acidic as well as salt affected. Percentage base saturation had negative significant correlation with available nitrogen, available phosphorus, iron and zinc but positive significant correlation with calcium. It is natural because when bases are increasing in the exchange complex other cations are excluded from the exchange complex.

5.5 Multiple regressions between components of acidity and acidity contributing factors

Under field wet condition, exchangeable aluminium, organic matter, available nitrogen, available phosphorus, available potassium, available iron, manganese, calcium, magnesium, sodium, cation exchange capacity and percentage base saturation could explain only 57 per cent of variation in pH under field wet condition. But these factors could account for 86 per cent of variation in pH under dry condition. These factors could explain 99 per cent of variation in exchange acidity and 96 per cent variation in potential acidity.

Multiple relationship between components of acidity and acidity related factors in 36 selected surface samples were worked out and we could observe that active manganese, active iron, total sulphur, available sulphur, Eh and clay per cent could explain 38 per cent of variation in pH under field wet condition, 74 per cent of variation in pH under dry condition, 75 per cent of variation in exchange acidity and 66 per cent of variation in potential acidity.

5.6 Direct and indirect effect of acidity contribnting factors towards pH, exchange acidity and potential acidity

Exchangeable aluminium had maximum direct effect towards pH (-2.52). Maximum positive indirect effect was also found to be far exchangeable aluminium followed by organic matter and exchangeable hydrogen. Maximum negative indirect effect was for exchangeable hydrogen followed by total soluble salts, total sulphur and cation exchange capacity.

Exchange acidity was directly influenced by exchangeable Al^{3+}. Maximum positive indirect effect was for exchangeable hydrogen followed by total soluble salts and total sulphur. Non exchange acidity was directly influenced by exchangeable hydrogen through the indirect effects of cation exchange capacity, organic matter, iron, sulphur and clay content.

Potential acidity was directly influenced by exchangeable hydrogen, cation exchange capacity and organic matter. Maximum positive indirect effect was recorded by iron followed by exchangeable aluminium and cation exchange capacity. Effective CEC, percentage base saturation, CEC and ΔpH negatively and indirectly affected potential acidity. Exchangeable hydrogen, CEC, effective CEC and organic matter positively and indirectly affected potential acidity. The total negative indirect effect was maximum for percentage base saturation.

5.7 Kinetics of pH, Eh and available nutrients due to submergence in wetland rice soils of Kerala

The wetlands under this study showed at first a decrease in pH due to submergence and then increased to a fairly stable value (Fig. 28). The initial low pH values were recorded by *Kari* and *Pokkali* soils but even after 12 weeks the *Pokkali* soils did not show much rise in pH. All the wetlands reached above pH 5.5 within two weeks of submergence except *Pokkali*, *Kari*, *Kayal* and *Kole* lands. The fall in pH in few days after submergence may be due to the accumulation of CO_2 produced by respiration of aerobic bacteria because CO_2 depresses the pH of acid soils. The subsequent increase in pH of acid soils is due to soil reduction (Ponnamperuma, 1972). Since most soils contain more Fe (iii) oxide hydrates than any other oxidant the increase in pH of acid soils is largely due to the reduction of iron. The pH values of submerged soils whether

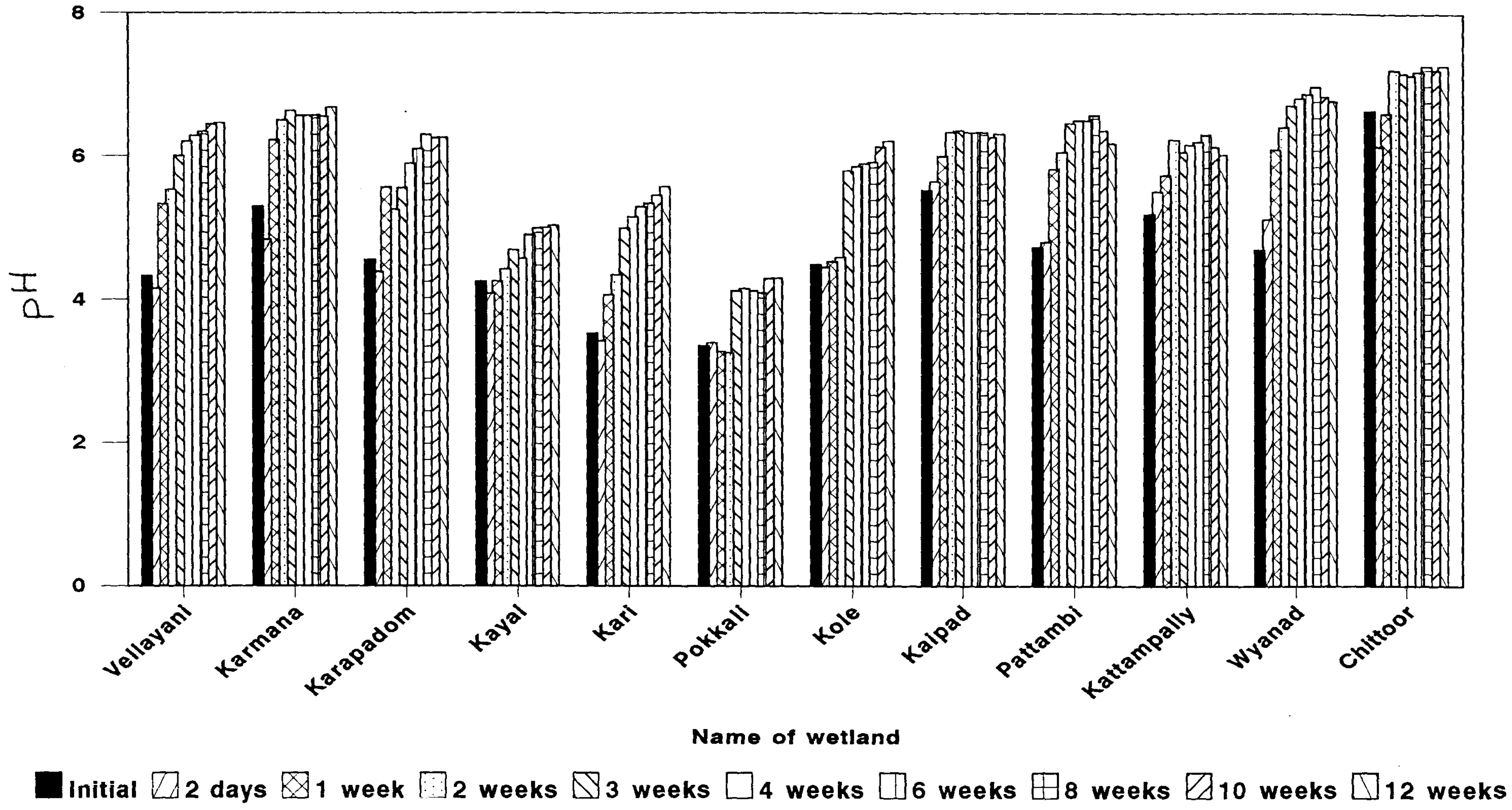

Fig. 28. Kinetics of pH due to submergence in wetlands

acid or alkaline are highly sensitive to loss of CO_2. In waterlogged paddy soils, redox and carbonate systems control pH. The pH value profoundly influence hydroxide, carbonate, sulphide, phosphate and silicate equilibria in submerged soils. The pH of a submerged soil markedly influence the concentration of nutrients and toxic substances through its effects on chemical equilibria, sorption and desorption, NH_3 volatilization and microbial process that release or destroy plant nutrients or that generate toxic substance. *Kari* and *Pokkali* soils are identified as potential acid sulphate soils by (Iyer 1989) and Unnikrishnan (1993). Reduction of Fe compounds is the most important process that causes increase in soil pH following submergence in acid sulphate soils. Since these soils contain considerable amounts of sulphur, the reduction of SO_4^{2-} can also significantly increase soil pH at low redox potential (Van Breeman, 1975). Several researchers have found that the pH of most flooded acid sulphate soils increase slowly as compared to normal soils and the pH merely exceeds six, even after six months of submergence (Nhung and Ponnamperuma, 1966, Tanaka and Navasero, 1966, Van Breeman and Pons, 1978). The slow increase in pH has been attributed to adverse conditions for microbial reduction, low contents of metabolizable organic matter and low contents of easily reducible ferric oxide. (Ponnamperuma *et al* 1982, Van Breeman, 1976). The higher buffer capacity due to dissolved and exchangeable aluminium, adsorbed SO_4^{2-} and basic sulphate mineral components would also require large amounts of Fe reduction to produce a significant increase in pH (Van Breeman and Moormann, 1975). The slow increase in pH of *Kayal, Kari* and *Pokkali* soils could be attributed to the above seasons.

With respect to Eh all the soils recorded high positive potentials in the initial stage (Fig. 29). *Pokkali* soils registered high positive potential even after 12 weeks of submergence because of slow reduction due to adverse

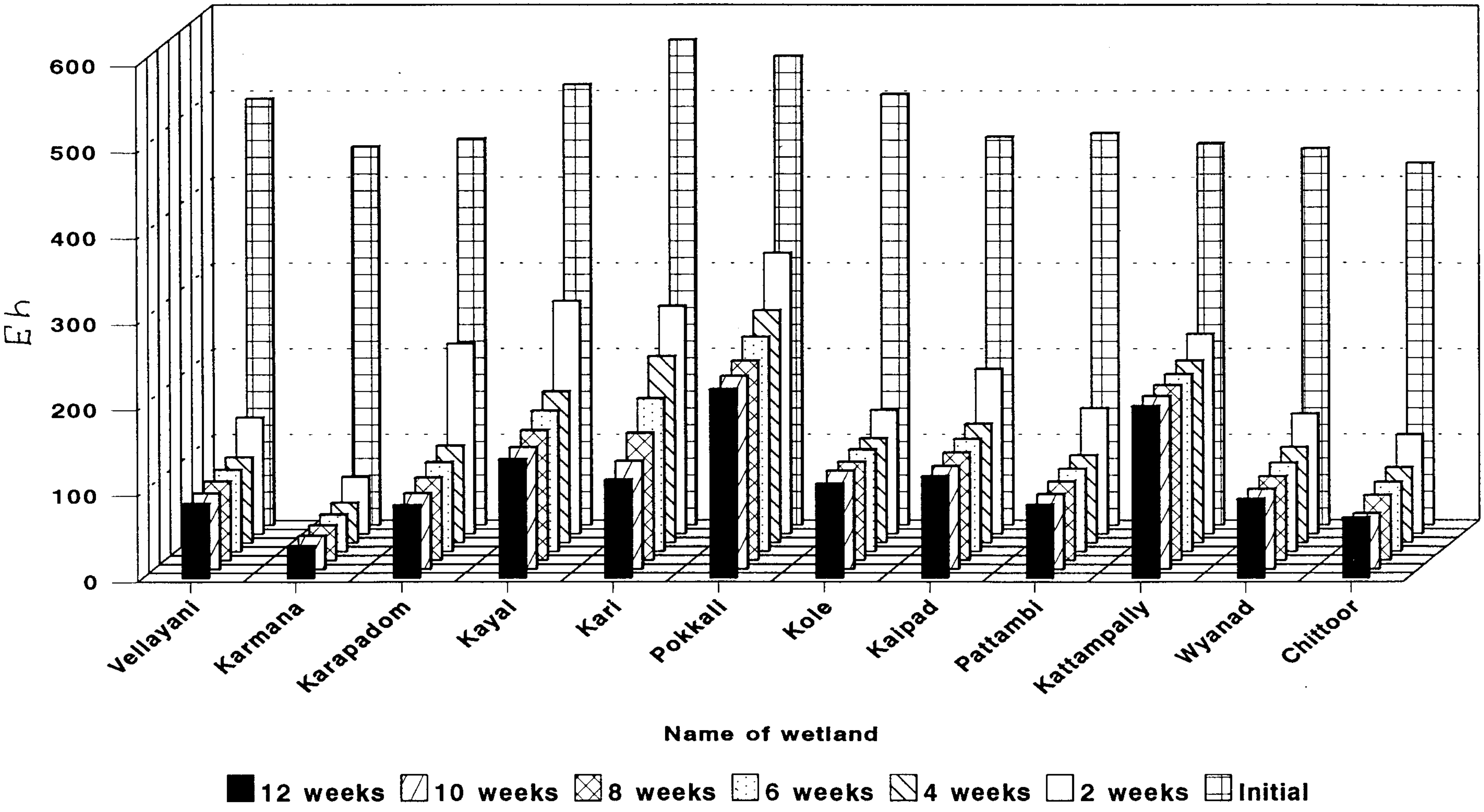

Fig. 29. Kinetics of Eh due to submergence in wetlands

conditions like very low pH, low microbial activity, low contents of metabolizable organic matter and low contents of easily reducible ferric oxide. The pH of *Pokkali* soils were also not increasing significantly due to submergence. None of the soils reached negative values of Eh. The rapid initial decrease of Eh is due to the release of reducing substance accompanying oxygen depletion before manganese and iron oxides can mobilise their buffer capacity. Soils high in nitrate (more than 275 ppm NO_3^-) have positive potentials for several weeks after submergence.

In potential acid sulphate soils of *Kari* and *Pokkali*, the initial Eh value was found to be high and positive submergence . Even under submergence the soils did not show significant increase in pH or a decrease in Eh. This is due to the slow reduction taking place in these soils. Cogger et al (1992) observed that reduction of iron occurs at $\leq$ 200 mv and pH 5-7. In Pokkali soils the conditions are not suitable for iron reduction to take place, so a low pH and a high redox potential are maintained by these soils even after twelve weeks of submergence.

All the soils showed an increase in available nitrogen due to flooding. The peak increase was noticed during the first two weeks and then a slow build up was noticed. Mohanty and Patnaik (1975) also reported the same pattern of increase of ammonium - N due to submergence. The increase in availability of nitrogen may be attributed to velocity of NH_4^+ release from the mineralisation of organic nitrogen. Here the highest availability was noticed in *Kari* soils (Fig. 30) which contained the highest organic matter and initial nitrogen status. The kinetics of ammonification varied with the soil, temperature and pretreatment of the soil. The soils having high nitrogen in the initial stage produced more NH_4^+ faster than others and the high leap in availability was in the first two weeks. In this study air dried soils were used for the anaerobic

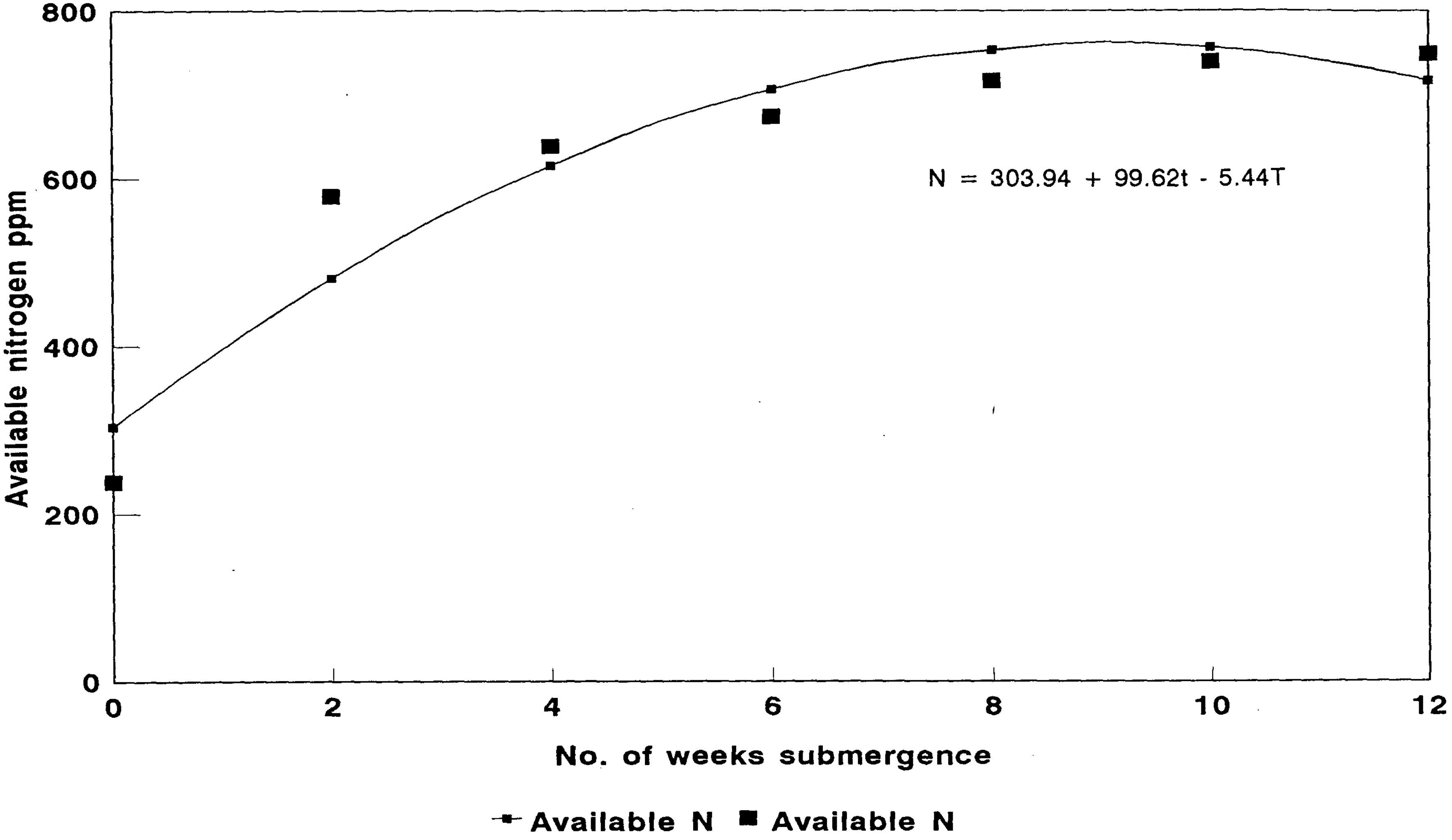

Fig. 30. Relationship between period of submergence and available nitrogen in Kari soils

incubation. Air drying before anaerobic incubation is also a reason for the increased availability of nitrogen. Sahrawat (1983) also proved that air drying peat soils before anaerobic incubation caused a release of 200-500 ppm NH_4^+ in 8 weeks compared with almost zero for the non dried wet peat soils. In this study *Kari* soils having high organic matter also showed an increase of 510 ppm nitrogen within 12 weeks of submergence. Usha (1986) also reported similar results in rice soils of Kerala.

Phosphorus availability increased in all the soils studied and the high increase was noticed during first two weeks, a slow increase there after (Fig. 31). Vellayani and *Karapadom* soils gave the highest available phosphorus after twelve weeks. The increase in solubility of phosphorus by flooding was caused by reduction of $Fe\ PO_4 . 2H_2O$ to $Fe\ (PO_4)_2\ 8H_2O$, desorption following reduction of Fe (111) hydrous oxides to Fe (11), hydrolysis of $FePO_4$ and $Al\ PO_4$, release of occluded P and anion exchange. Vellayani, *Karapadom* and *Pokkali* soils are having high iron and aluminium phosphates like strengite and variscite. The release of P from these fixed forms is the reason for the highest increase in these soils.

Available potassium showed a decrease at first except kattampally soil, then increased, reached a peak and again decreased. The initial decrease can be attributed to the moving of K^+ to lower layers by flooding the soils. Subsequent increase in availability could be accounted by the desorption from clay complex, displacement by the action of water through hydration and hydrolysis, release from non exchangeable form etc. potassium availability is primarily governed by silt + clay content of the soil. The final decrease might be due to lattice fixation or precipitation as carbonates.

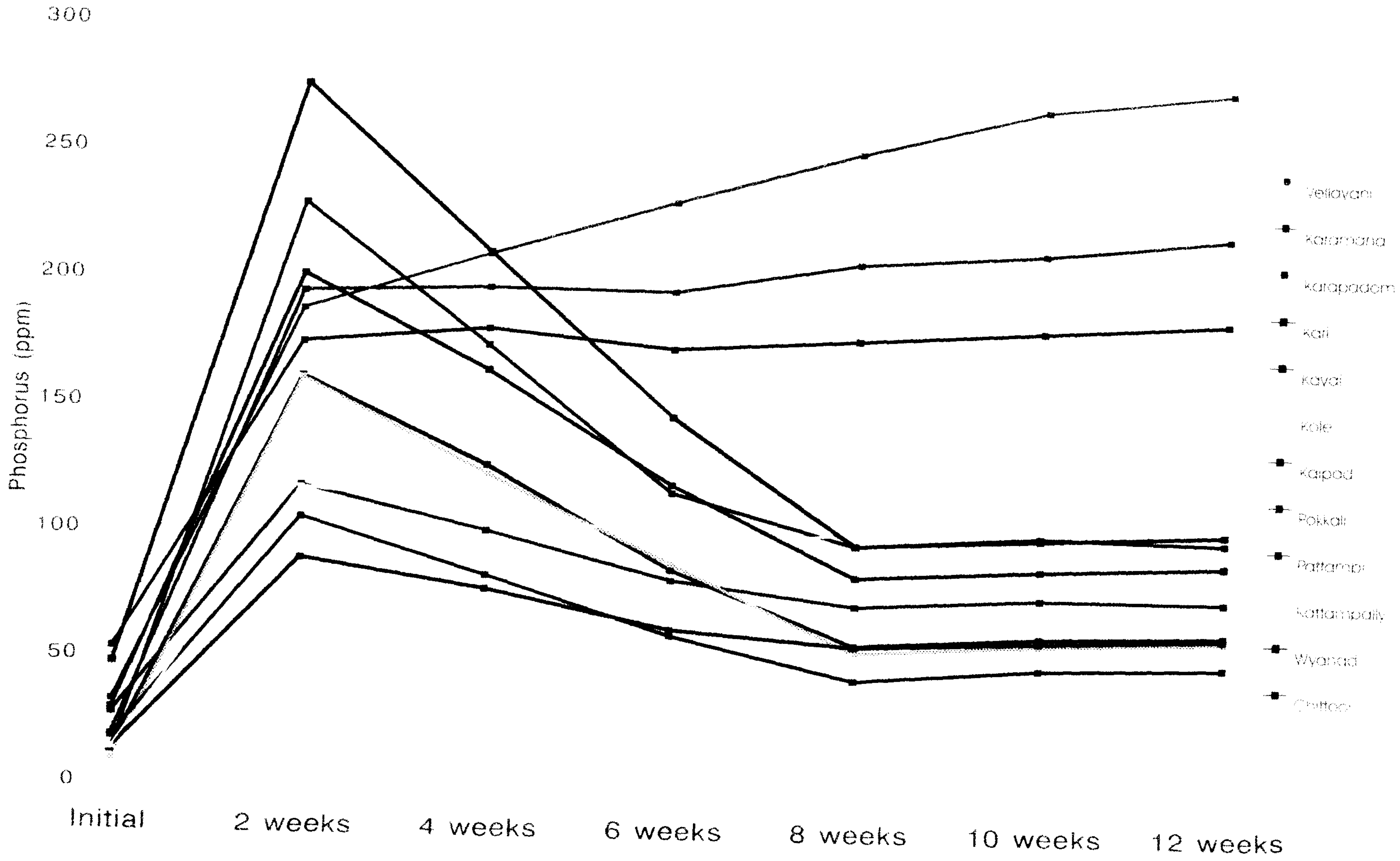

Fig. 31. Kinetics of available phosphorus due to submergence

Calcium, magnesium and sodium are found to increase due to flooding in the soils studied. The availability of these three cations increased on account of their displacement by the action of water through hydration and hydrolysis.

The availability of iron increased due to flooding (Fig. 32). This change caused by flooding dry soil is by the reduction of Fe (III) to Fe (II) and the accompanying increase in the solubility of iron. The reduction followed a quadratic pattern, the velocity of reduction and the maximum amount reduced varied with the active iron, organic matter, temperature and reactivity of the Fe (III) oxides.

On flooding Mn (IV) and Mn (III) hydrous oxides are reduced to Mn^{2+}. The reduction was complete within two weeks of submergence. After reduction the concentration of water soluble Mn^{2+} increases, but it moves down the profile of wetlands rice soils. This eluviation of Mn^{2+} may be the reason for the slight low values of available mangenese in some of the soils studied. Manganese toxicity is not a problem in wetland rice soils. The decline in concentration after the peak availability is due to the precipitation of $Mn\ Co_3$.

Submergence caused a decrease in the concentrations of available zinc and copper. The precipitation of zinc as hydroxide, carbonate and sulphide and its adsorption into the surface of hydrated oxides of iron are partly responsible for the decrease in zinc on submergence. Water soluble plus exchangeable, organically complexed and amorphous sesquioxide forms are found to be major importance in determining zinc concentration. In acid soils, the decrease in zinc concentration may be partly due to increase in pH following soil reduction because solubility of zinc in water decrease 100 times when pH increases by

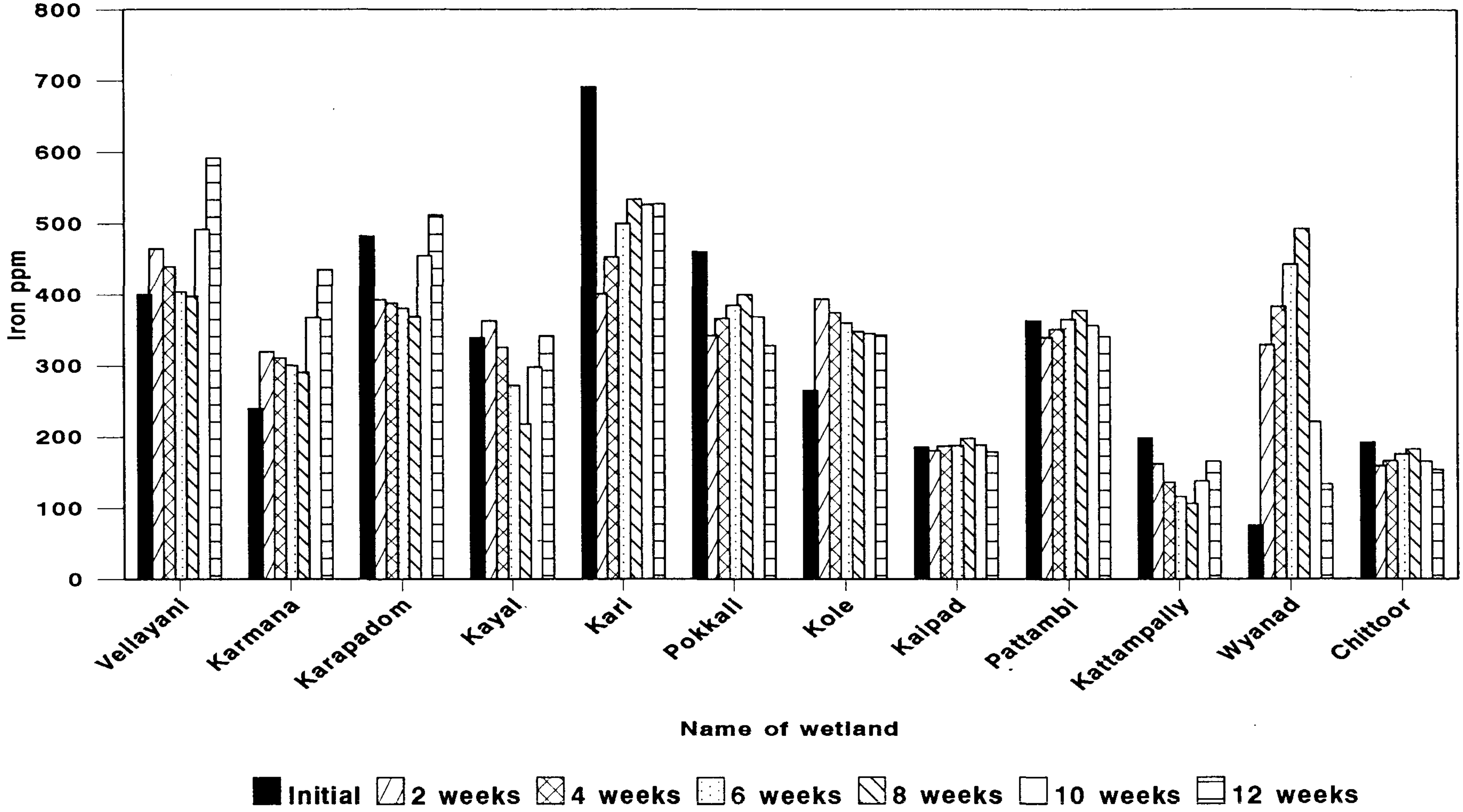

Fig. 32. Kinetics of available iron due to submergence

one unit. Zinc deficiency occurs in continuously flooded soils. A simple remedy is to drain the soil and aerate it temporarily (Rajendran 1981).

Water soluble and exchangeable copper had highly significant negative correlation with pH. At high pH copper availability decreased due to precipitation of copper as hydroxide or sulphide. Copper can also present as insoluble complexes with organic matter. The soluble copper decreases on flooding despite desorption from Fe (III) and Mn (IV) oxide hydrates because the solubility of copper decreases 100 fold for each unit increases in pH (Ponnamperuma 1972).

A decrease in available sulphur was noticed in all soils (Fig. 33). The concentration decreased drastically during the first 6 weeks and then a slow decrease was observed. The main change related to sulphur is the reduction of SO_4^{2-} to S^- by obligate anaerobic bacteria (Desulfovibrio). Because Fe reduction precedes SO_4^{2-} reduction, Fe^{2+} will always be present in the solution by the time H_2S is produced so that insoluble sulfides will be formed. Aside from Fe^{2+}, other ions Mn^{2+}, Cu^{2+} and Zn^{2+} may be transferred to sulphides. Only in soils low in active iron such as bleached sandy soils, peat soils and some acid sulphate soils H_2S toxicity may occur (Tanaka *et al.*, 1968).

All the soils registered an increase in available silica on flooding and the maximum value was recorded by *Pokkali* soils. The higher availability of silica after flooding may be due to the release of silica following reduction of hydrous oxides of Fe (III) sorbing silica and action of CO_2 on alumino silicates. The subsequent decrease may be the result of recombination with alumino-silicates following the decrease in PCO_2. *Pokkali* soils which are identified as acid sulphate soils registered high silica availability because buffering under

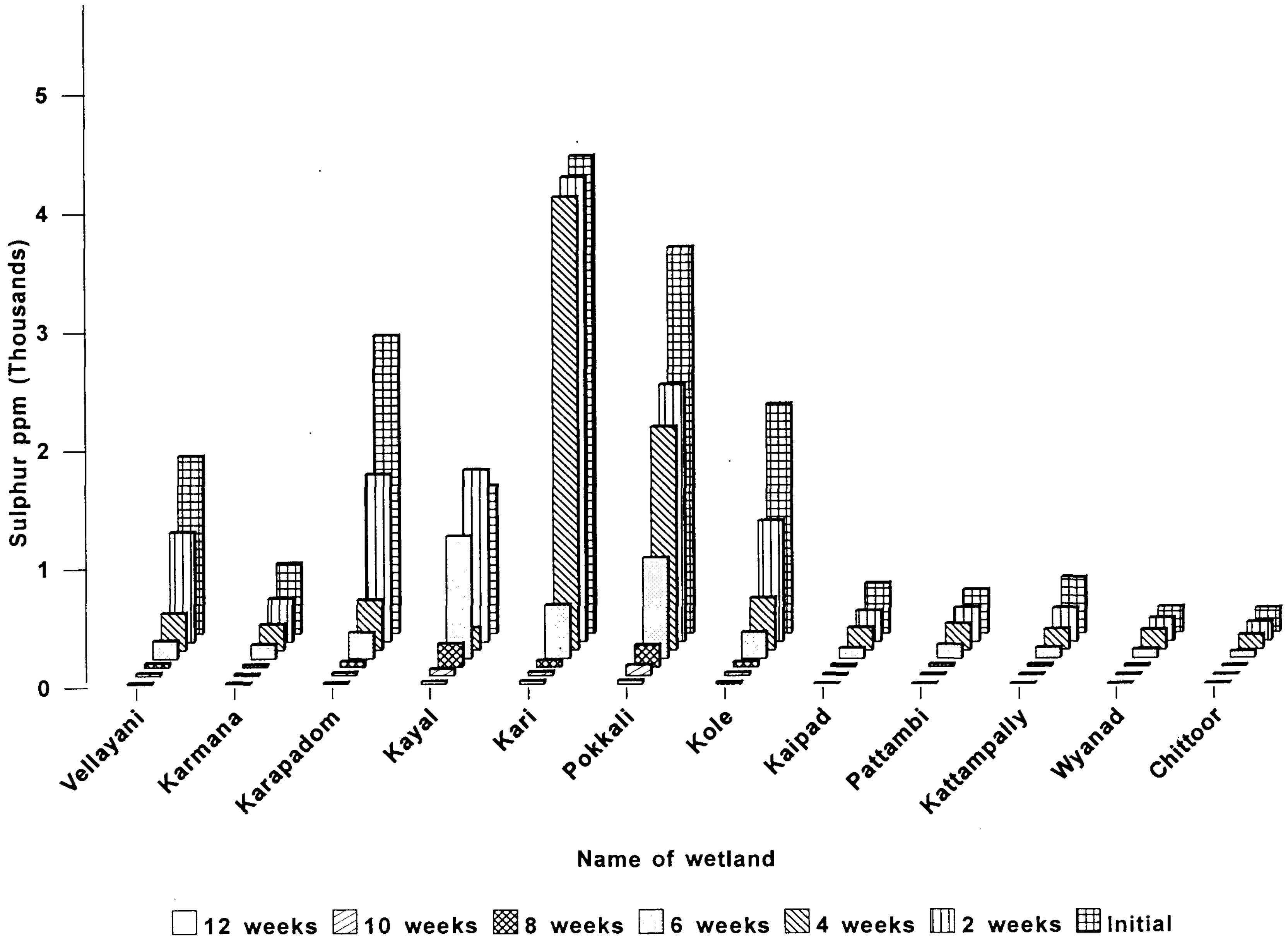

Fig. 33. Kinetics of available sulphur in wetlands

severely acid conditions is attributed to the acid hydrolysis of alumino silicate clays (Dent,1990).

Available aluminium decreased to very low values in all soils except *Kayal, Kari* and *Pokkali* soils due to flooding (Fig. 34). Al^{3+} activity is directly related to pH, as pH rises due to flooding, aluminium is precipitated as hydroxide or sulphates. Aluminium concentration starts to decrease when the pH increases above pH 4.0. In most acid wetland soils the pH rises well above 5 shortly after flooding so that aluminium toxicity is not a problem. Tanaka and Nava Sero (1967) in solution cultures of low pH found that aluminium is toxic to young rice seedlings at 0.05 - 2 ppm while 3 to 4 week old plants show toxicity only at 25 ppm. In acid sulphate soils, where aluminium toxicity frequently occurs, aluminium reaches 1 ppm at a pH of 4.8 and increase by a factor of 10 fold for unit decrease in pH (Van Breemen 1973). In *Pokkali* soils the pH rises to only 4.3 even after 12 weeks of submergence and the aluminium concentration is 91 ppm. The toxicity can be minimised by liming followed by keeping the soil under flooded condition and leaching away of salts.

Flooding a soil sets in motion chemical and electro chemical processes that affect the supply of nutrients and their uptake by rice. After 2 to 4 weeks period of rapid changes, the processes tend to stabilise. The stable milieu favours rice because the nutrient supply is adequate and the level of toxins is low. An yield increase of about one tonne /ha can be obtained by merely delaying transplanting for 2 weeks after flooding. (IRRI 1963). Wet land soils have many advantages for food production but they have some disadvantages also. In Kerala all the wetland rice soils are acidic except Chittoor soils. *Kari* and *Pokkali* are classified as acid sulphate soils. Here the sulphidic materials are mainly concentrated in the surface layers i.e. < 50 cm depth. Hence rice is the

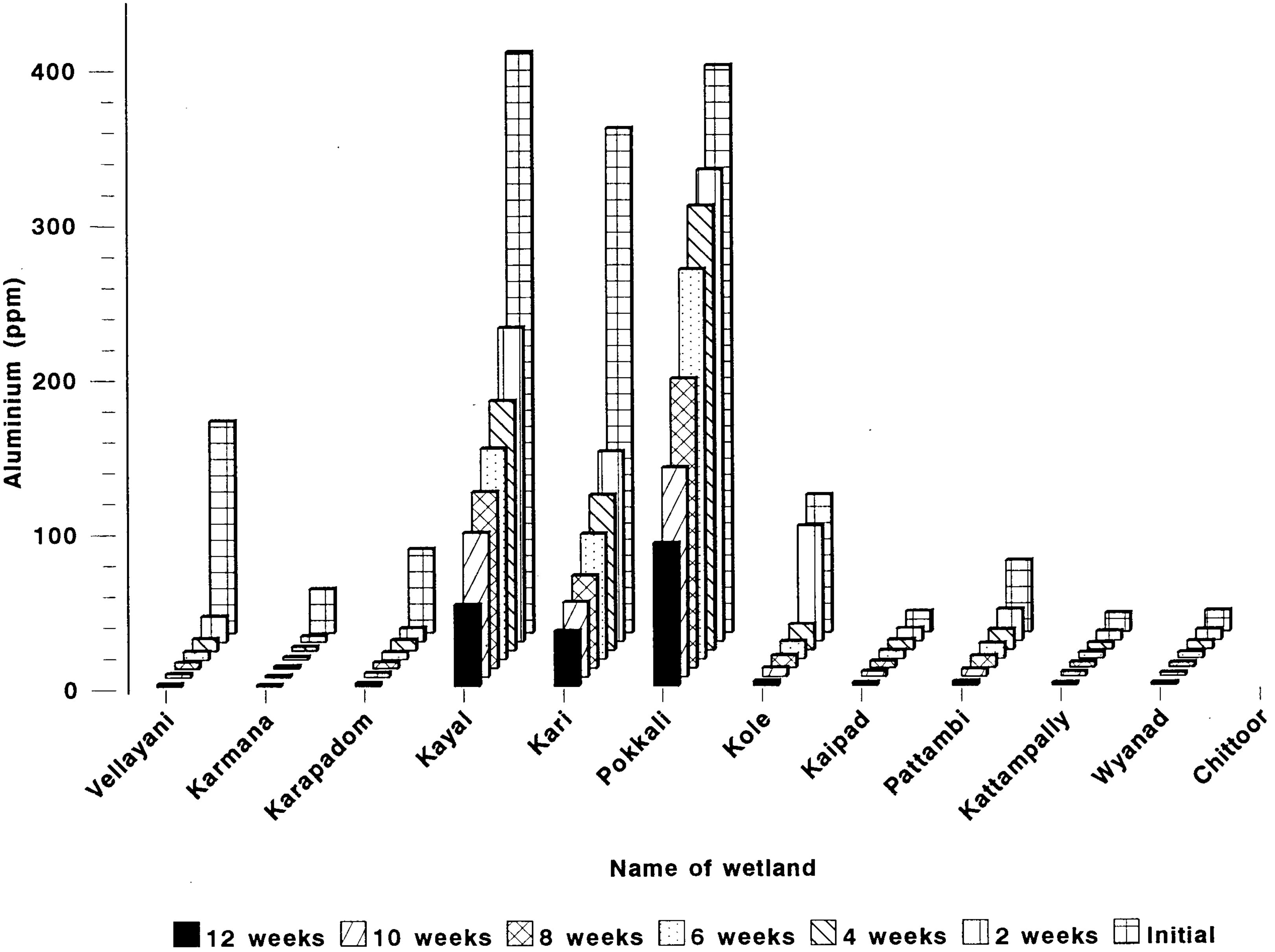

Fig. 34. Kinetics of available aluminium in wetlands

principal crop that can be grown here without much acidity development. In order to avoid oxidation of sulphidic materials these areas should be kept under flooding for major part of the year. Liming, flooding and leaching away of acidity and salts is the practice in such areas. Use of tolerant varieties and proper manuring can increase rice yields in these areas. Subsurface drainage can also be adopted for leaching away of acidity and salts. Even though we have estimated lime requirement for each soil based on laboratory studies it should be tested in the field. The invitro study conducted to draw conclusions on the availability of nutrients and minimising toxicities will have to be confirmed by field trials in respective soil types to suggest suitable management techniques to rice farmers of Kerala State.

SUMMARY

SUMMARY

Detailed investigations have been carried out to evaluate the acidity parameters in the wetland rice soils of Kerala in relation to nutrient availability and suggest suitable ameliorative measures to alleviate the acidity in such soils. Twelve soil profiles and 120 surface soil samples representing the major rice growing tracts of Kerala were used for this study. The important conclusions from this study are summarised below.

Out of the twelve representative soil profiles studied Vellayani, Karamana, Thakazhi, D-Block, Pazhayangadi, Wyanad and Kattampally were Entisols, Nedumudi, Njarakkal and Anthikkad came under Inceptisols; Pattambi belonged to Ultisol and Chittoor came under Vertisol.

All the soils studied were acidic except black soils of Chittoor which were neutral to alkaline in reaction. The *Kari* soil profile of Thakazhi and *Pokkali* soil profile of Njarakkal recorded the highest active acidity. The third layer (18-30cm) of *Kari* and the sixth layer (41-97cm) of *Kayal* recorded the lowest dry pH (1:1 H_2O) of 2.3 followed by the two upper horizons (0-8 and 8-20cm) of *Pokkali* and lowest horizon of *Karapadom* registering a pH of 2.6.

In the case of surface soil samples, maximum mean dry pH (1:1 H_2O) was recorded by Chittoor soils (7.0) whereas minimum was registered by *Kari* and *Pokkali* soils (3.2).

Based on the severity of active acidity in the surface samples the wetland rice soils of Kerala can be arranged as *Kari* ≥ *Pokkali* > *Karapadom*

> Vellayani > *Kayal* > *Kole* > Wyanad > Pattambi > *Kaipad* > Karamana > Kattampally. But based on the mean value of pH of profile samples, the soils can be rated as *Kari* > *Pokkali* > *Kole* > *Kayal* > *Karapadom* > Vellayani > Wyanad > Pattambi > Karamana > Kattampally > *Kaipad.*

All the soils having the low pH recorded high exchange, non exchange and potential acidity, the relationship being r = -0.60, -0.48 and -0.50 respectively.

Maximum exchange acidity was noticed in the 18-30cm layer of *Kari* soil profile. In *Kari* and *Pokkali* soils, throughout the profile high exchange acidity was noticed. Comparing the surface samples maximum mean exchange acidity was noticed in *Kari* soils (16.4 cmols) followed by *Pokkali* soils (8.03 cmols) and the minimum in Chittoor soils (0.125 cmols).

Mean exchange acidity was < 1.0 cmol in the profiles of Vellayani, Karamana, Pattambi, Wyanad, *Kaipad* and Chittoor. Mean value of surface samples revealed that Karamana, Pattambi, *Kaipad*, Kattampally, Wyanad and Chittoor soils had only < 1.0 cmols of exchange acidity. Exchange, non exchange and potential acidities are highly correlated and the relationship between them are r = 0.90 and 0.93 respectively.

Major part of potential acidity was constituted by non exchange acidity (pH dependent acidity) because pH dependent charges are more in Kerala soils having Kaolinite as the predominant clay mineral and high content of sesquioxides. Maximum non exchange acidity was recorded in the 0-8cm layer of *Pokkali* soil profile followed by 18-30 cm layer of *Kari* soil profile. With regard to surface samples *Kari* soils registered highest mean value for this component. The non exchange acidity and potential acidity are highly correlated (r = 0.99).

Highest value for potential acidity was also recorded by the 18-30cm layer of *Kari* soil profile and upper layers of *Pokkali* profile. The surface samples of *Kari* also registered highest potential acidity. In the highly acid soils of *Kari* (Typic Sulfaquent) and *Pokkali* (Sulfic Tropaquept), the maximum acidity layers are located within 50cm depth.

Based on mean potential acidity of surface samples, the soils can be rated as *Kari* > *Pokkali* > *Kayal* > *Karapadom* > *Kole* > Pattambi > Kattampally > Vellayani > *Kaipad* > Karamana > Wyanad. But based on mean values of profile samples, the sequence was *Kari* > *Pokkali* > *Kayal* > *Karapadom* > *Kole* > Wyanad > Vellayani > Kattampally > Pattambi > Kaipad > Karamana.

From the correlations worked out it may be recommended that pH (1:1 H_2O) under dry condition is a more reliable parameter for evaluating acidity than pH under wet condition or in salt solutions because this parameter gave more significant correlation with acidity generating factors and available nutrients in the wetland rice soils of Kerala.

The important acidity contributing factors identified in the wetland rice soils of Kerala were organic matter, clay minerals, cation exchange capacity, exchangeable hydrogen, exchangeable aluminium, iron, manganese, sulphur and total soluble salts. Path coefficients analysis revealed that these nine proton sources could account for 95.19 per cent of pH (dry) and 84 per cent of exchange acidity. Organic matter, clay, cation exchange capacity, exchangeable hydrogen, exchangeable aluminium, iron and sulphur compounds could account for about 65 per cent of non exchange acidity. Organic matter, cation exchange capacity, ECEC, exchangeable hydrogen, exchangeable aluminium, ΔpH and percentage base saturation were found to contribute 82 per cent of potential acidity.

Available sulphur mainly contributed soil acidity, both active and potential, rather than the total sulphur in sulphur rich soils.

Path coefficient analysis of important acidity contributing factors and the correlation and regression analysis of soil characteristics indicated that exchangeable aluminium was the best parameter for measurement of soil acidity. From the regression analysis it may be inferred that exchangeable aluminium accounted for 48 per cent of variation in dry pH, 87 per cent of variation in exchange acidity, 57 per cent of variation in non exchange acidity and 63 per cent of variation in potential acidity.

Exchangeable aluminium method for calculating lime requirement was found to be the best for all soils. Low rates of lime (1000 kg) in split doses and washing 2 or 3 times after maintaining 10cm water level can be recommended for economic returns from *Kari* and *Pokkali* lands. High dose of lime application causes reacidification of soil at a faster rate especially in soils having high potential acidity. Lower lime requirements were noted by Kattampally (0.20 t/ha), Wyanad (0.37 t/ha), Karamana (0.39 t/ha), Pattambi (0.54 t/ha) and *Kaipad* (0.72 t/ha). Eventhough others required high quantities of lime it is not advisable to use such doses because of reacidification problem and high cost of lime.

Studies on submergence showed that wetland rice soils of Vellayani, Karamana, *Karapadom, Kole, Kaipad,* Pattambi, Kattampally and Wyanad do not require lime to raise the pH for rice cultivation because all these soils attain a pH value of 5.5 within 2 weeks of submergence.

Available nitrogen, phosphorus, calcium, magnesium, sodium, iron, manganese and silica were found to increase due to submergence. Peak increase was found within 2 weeks of submergence. After 2 weeks of rapid change, a slow increase was found, the stable milieu favours rice because the nutrient supply is adequate and the level of toxins is low. Aluminium and sulphur are reduced to very low values by submergence. Zinc and copper were found to decrease by prolonged submergence. By simply draining the field and aerating it, zinc availability can be increased. Copper deficiency occur in peat soils like *Kari* because solubility of copper decreases 100 fold for each unit increase in pH and stronger complexation of copper with organic ligands and higher stability of these complexes.

The detailed investigations conducted in this study on the evaluation of acidity parameters of wetland rice soils of Kerala in relation to nutrient availability have unveiled many intricate phenomena of soil acidity which are of great theoretical and practical significance. Contrary to the conventional concept that liming is a must in all acid soils, the present study underlines the cheap and easy method of alleviating acidity of certain wetland rice soils by optimum submergence and scientific water management. Further the study has revealed the feasibility of liming in soils with severe acidity based on specific methods of estimating the lime requirement of soils. However it is necessary to confirm the results of these *in-vitro* studies by adequate field studies in specific wetland rice tracts of Kerala State.

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* Originals not seen

APPENDICES

Appendix - 1

Places of collection of surface soil samples of wetlands

Vellayani - Natural kayal land

VLY-1	Kakkamoola
2	Panangode
3	Vellayani Temple road
4	Pandarakkari South
5	Pandarakkari North
6	Punchakkari South
7	Punchakkari North
8	Palappoor
9	Vellayani Farm (Double cropped area)
10	Vellayani Farm - Northern Boundary

Karamana - Man made valley

KRM - 1	Pravachambalam
2	Peyad
3	Paravamkunnu
4	Pavumkode
5	Nemom
6	Chavadinada
7	Andoorkonam
8	Konchira
9	Karakulam
10	Aruvikkara

Karapadom lands

KPD - 1	Moncompu
2	Veliyanadu
3	Ramankari
4	Edathua
5	Viapuram
6	Niranam
7	Muttar
8	Kavalam
9	Kidangara
10	Chambakkulam

Kayal lands

KYL - 1	T-Block
2	S-Block
3	Q-Block
4	Q-Block
5	E-Block
6	E-Block
7	H-Block
8	K-Block
9	J-Block
10	F-Block

Kari lands

KR - 1	Purakkadu
2	Thottappalli
3	Karumadi
4	Ambalapuzha
5	Mupathupadasekharam - Pazhukari
6	Kallara - I - Vadakkupadinjare Padasekharam
7	Kallara - II
8	Kallara
9	Kallara
10	Kallara

Pokkali lands

PKL - 1	Vipin
2	Puthuvaippu
3	Varappuzha
4	North Paravur
5	Vyttila
6	Thrippunithura
7	Palluruthi
8	Pallippuram
9	Edavanakkadu
10	Ezhikkara

Kole lands

KOL - 1	Kanjanippadavu
2	Pazhamkole
3	Chettupuzha kole
4	Anthikkadu
5	Enammakkal
6	Vendarapadom
7	Jayanthi kole
8	Jubileepadom
9	Chemban padom
10	Karimpadom

Kaipad lands

KAPD - 1	Pappinisseri
2	Kallasseri
3	Kannapuram
4	Cherukunnu
5	Pazhayangadi
6	Cheruthazham
7	Ezhhimala
8	Kunjimangalam
9	Ramanthali
10	Payyannur

Pattambi wet lands

PTB - 1	Pattambi
2	Koppam
3	Muthuthala
4	Perumundiyoor
5	Kodumunda
6	Njangattiri
7	Maruthur
8	Oangattoor
9	Vadanakkurussy
10	Karakkadu

Kattampalli wet lands

KTPLY - 1	Vendode
2	Kannadiparambu
3	Aalinkizhil
4	Narath (W)
5	Kakkaturuthi
6	Narath East
7	Chakkarakkal
8	Pachappuram
9	Ottamavu
10	Pulloopy

Wynad man made valley

WYD - 1	Anappara
2	Chulliyode
3	Koliyadi
4	Sulthanbattery
5	Kappammudy
6	Amboothi
7	Karapuzha
8	Andoor
9	Cheerapputtu
10	Nellarchal

Chittur man made valley

CHR - 1	Erattakkulam
2	Kalayam kolumbu
3	Kambilichunkam
4	Manchira
5	Vaccode
6	Karinjalippalam
7	Kanakkampara
8	Goundan kolam
9	Parakkal
10	Manamkutty

Appendix - 2

Exchangeable bases in profile samples of major wetlands (cmol (+)/kg soil)

Location & depth (cm)	Exch. Ca	Exch. Mg	Exch. Na	Exch. K.
Vellayani				
0-11	5.24	1.33	1.01	0.13
11-16	4.58	2.88	1.37	0.09
16-28	2.34	1.05	1.15	0.07
28-40	3.18	0.78	0.90	0.07
40-56	2.26	0.94	1.25	0.13
56-82	2.90	1.06	1.29	0.24
82-150	2.46	1.24	1.39	0.28
150-172	3.57	2.39	1.46	0.20
172-200	4.33	3.96	1.97	0.37
Karamana				
0-17	2.99	1.11	1.09	0.21
17-32	3.84	1.06	1.11	9.17
32-56	3.99	1.33	1.13	0.12
56-90	2.34	1.46	1.11	0.15
90-111	2.68	1.31	1.01	0.16
111-140	0.47	0.31	0.94	0.16
140-200	2.94	3.81	1.36	0.29
Kari - (Thakazhi)				
0-12	15.02	11.21	1.37	0.15
12-18	4.50	6.43	1.69	0.50
18-30	7.89	3.91	1.01	0.26
30-54	5.12	1.69	0.45	0.11
54-134	3.86	1.37	0.24	0.06
Karapadam - (Nedumudi)				
0-16	5.16	3.93	1.50	0.19
16-24	5.36	4.83	1.81	0.51
24-34	6.08	8.19	2.10	0.59
34-52	6.68	6.47	2.14	0.57
52-69	8.08	8.05	2.19	0.69
69-164	16.92	10.43	0.40	0.08

Contd...

Appendix - 2 (Contd...)

Location & depth (cm)	Exch. Ca	Exch. Mg	Exch. Na	Exch. K.
Kayal - (D - Block)				
0-10	7.68	0.67	1.32	0.53
10-18	10.75	0.55	0.85	0.41
18-22	10.90	0.17	1.65	0.68
22-23	9.09	0.68	1.04	0.43
33-41	10.63	1.67	0.78	0.23
41-97	4.07	7.88	0.67	0.16
97-103	20.15	10.00	0.09	0.08
103-151	23.67	6.38	4.87	0.15
Pokkali - (Njarakkal)				
0-8	8.77	4.85	9.56	0.06
8-20	7.69	5.29	7.52	0.01
20-35	8.05	4.27	5.72	0.63
35-75	5.14	1.64	1.09	0.01
75-110	5.32	1.33	1.35	0.03
110 & below	4.55	1.68	1.25	0.13
Kole - (Anthikkad)				
0-10	7.0	4.58	1.09	0.37
10-20	6.07	0.85	1.16	0.23
20-30	4.55	0.68	0.88	0.17
30-40	3.28	1.39	0.61	0.13
40-50	3.54	1.20	0.73	0.16
50-60	2.42	1.01	0.61	0.15
60-70	2.96	1.38	0.77	0.25
70-100	3.95	1.22	0.50	0.20
Pattambi				
0-20	1.88	0.80	0.35	0.31
20-34	2.33	0.86	0.63	0.67
34-46	2.97	1.25	0.42	0.18
46-56	3.35	0.56	0.57	0.35
56-89	2.71	1.20	0.52	0.13
89 & below	1.74	1.09	1.00	0.07

Contd...

Appendix - 2 (Contd...)

Location & depth (cm)	Exch. Ca	Exch. Mg	Exch. Na	Exch. K.
Chittur				
0-25	17.36	2.32	1.15	0.12
25-49	13.08	5.36	0.78	0.11
49-65	13.86	5.87	0.96	0.02
65-88	18.96	3.39	0.99	0.11
88-150	20.72	7.07	0.50	0.07
Wynad				
0-36	1.59	0.72	0.66	0.46
36-72	1.16	0.68	0.95	0.06
72-112	2.00	0.73	0.73	0.07
112-150	1.88	0.51	0.22	0.02
Kaipad - (Pazhayangadi)				
0-9	3.94	1.21	2.38	1.51
9-17	2.86	1.69	4.38	1.34
17-26	5.00	4.04	7.91	1.98
26-45	5.01	2.85	6.18	1.43
45-59	4.26	2.40	3.86	1.00
59-84	5.35	2.49	5.93	1.43
84-126	6.52	2.89	4.47	0.11
Kattampally				
0-26	4.49	0.64	0.64	0.08
26-47	2.99	1.56	0.64	0.05
47-76	3.86	1.76	0.94	0.05
76-100	3.73	1.04	0.83	0.07
100-150	5.32	1.49	1.30	0.11
150 & below	6.00	1.50	0.61	0.01

Appendix - 3

Exchangeable bases in surface samples of major wetlands (Cmol (+)/kg soil)

Name of wetland		Exch. Ca	Exch. Mg	Exch. Na	Exch. K
L1	Vellayani	2.10	0.98	0.74	0.14
L2	Karamana	1.84	0.85	0.85	0.20
L3	Karapadam	1.58	1.39	1.28	0.51
L4	Kayal	4.59	2.47	1.80	0.90
L5	Kari	5.63	2.71	1.86	0.31
L6	Pokkali	4.72	3.72	6.59	0.46
L7	Kole	5.36	1.11	0.96	0.21
L8	Kaipad	1.91	0.64	0.68	0.07
L9	Pattambi	2.23	1.11	0.46	0.13
L10	Kattampally	3.07	1.45	0.80	0.21
L11	Wynad	2.66	0.99	0.43	0.11
L12	Chittoor	14.46	1.02	0.56	0.17
	CD	1.98	0.55	0.41	0.20
	SE	0.70	0.19	0.14	0.07

Appendix - 4. Correlation between components of acidity and other soil parameters in surface samples of major wetlands (n = 120)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Field Water pH	1.0000																															
KCl pH	0.8189	1.0000																														
CaCl$_2$	0.8884	0.8638	1.0000																													
E.C.	-0.0285	-0.1822	0.1141	1.0000																												
Dry Water pH	0.8642	0.8237	0.5303	-0.4449	1.0000																											
Kcl pH	0.6894	0.8659	0.5862	0.3986	0.9647	1.0000																										
CaCl$_2$ pH	0.8820	0.8423	0.5795	-0.3742	0.9637	0.9807	1.0000																									
E.C.	-0.0953	-0.2209	0.0866	0.8047	-0.8284	-0.5269	-0.5462	1.0000																								
Exch. acidity	-0.2476	-0.2114	-0.1098	0.2044	-0.8062	-0.5031	-0.5456	0.8630	1.0000																							
Non exch. acidity	-0.1846	-0.1205	-0.0677	0.0362	-0.4822	-0.3746	-0.4294	0.4949	0.9009	1.0000																						
Potential acidity	-0.1947	-0.1349	-0.0728	0.0637	-0.5073	-0.4074	-0.4520	0.5287	0.9275	0.9875	1.0000																					
Exch. Al	-0.3200	-0.2729	-0.1509	0.2884	-0.8930	-0.8038	-0.6206	0.6752	0.9319	0.7574	0.7929	1.0000																				
O.M.	-0.2068	-0.0551	-0.0416	0.0651	-0.5023	-0.4121	-0.4201	0.4319	0.7708	0.8539	0.8538	0.7250	1.0000																			
Av. N	-0.2579	-0.1215	-0.1211	0.0535	-0.4428	-0.3828	-0.3928	0.3343	0.5790	0.8323	0.6317	0.5810	0.8040	1.0000																		
Av. P	0.0043	0.0611	0.0743	0.0438	-0.0689	-0.0512	-0.0484	0.1413	0.1540	0.1540	0.1528	0.2062	0.2519	0.2579	1.0000																	
Av K	-0.1853	-0.1088	-0.275	0.2326	-0.2268	-0.1925	-0.1412	0.2012	0.0468	0.0458	0.0473	0.1529	0.2134	0.1747	0.1985	1.0000																
Fe	-0.1618	0.0923	-0.068	-0.0014	-0.3560	-0.2737	-0.3325	0.4232	0.8457	0.8291	0.8431	0.8276	0.6164	0.4552	0.0473	-0.0465	1.0000															
Mn	-0.0503	-0.0135	-0.0403	-0.152	-0.0124	0.0258	0.0031	0.0458	0.2444	0.3402	0.3315	0.0827	0.1719	0.1901	-0.0123	-0.0354	0.4197	1.0000														
Zn	-0.0951	-0.0738	-0.0382	0.0655	-0.2719	-0.1724	-0.2542	0.4180	0.5911	0.6427	0.6437	0.3449	0.4517	0.3098	0.0864	-0.085	0.7834	0.4236	1.0000													
Cu	0.1165	0.1921	0.0808	-0.218	0.3383	0.2742	0.2817	-0.3915	-0.3690	-0.2412	-0.2694	-0.4202	-0.2858	-0.0374	0.1368	-0.085	-0.1387	0.2406	-0.1402	1.0000												
Av. Ca	0.5860	0.5899	0.6675	0.1150	0.4329	0.5273	0.5284	0.1430	0.0605	0.0687	0.0674	0.0217	0.1388	0.0903	0.1768	0.0279	0.0359	0.0135	0.0372	0.1029	1.0000											
Av. Mg	-0.0888	-0.1642	0.0924	0.6773	-0.5277	-0.4283	-0.4189	0.7747	0.4767	0.3647	0.3877	0.2685	0.4001	0.2656	0.0839	0.4054	0.1358	-0.0322	0.1343	-0.3367	0.1778	1.0000										
Av. Na	-0.0394	-0.2197	0.0947	0.9229	-0.4890	-0.4249	-0.4162	0.8770	0.2922	0.1089	0.1395	0.3829	0.1159	0.1171	0.0841	0.2486	0.0250	-0.1303	0.0817	-0.2958	-0.1303	0.7558	1.0000									
CEC	-0.0123	0.0432	0.1661	0.2381	-0.3929	-0.2637	-0.2894	0.6119	0.8285	0.8815	0.8862	0.7357	0.8673	0.6280	0.2696	0.1683	0.6871	0.2201	0.5723	-0.2604	0.4044	0.5264	0.3072	1.0000								
Exch. Ca	0.5385	0.5662	0.6425	0.0896	0.3736	0.4538	0.4630	0.1198	0.1349	0.1901	0.1847	0.0898	0.2511	0.1824	0.1903	0.013	0.1252	0.0540	0.0994	0.1186	0.93880	0.1545	0.0590	0.5067	1.0000							
Exch. Mg	-0.0862	-0.1469	0.1027	0.6576	-0.5654	-0.4579	-0.4523	0.7856	0.5231	0.4478	0.4661	0.5946	0.4762	0.3189	0.1010	0.4896	0.2006	-0.0034	0.1881	-0.3519	0.1804	0.9479	0.7353	0.6127	0.1732	1.0000						
Exch. Na	-00.0179	-0.2113	0.0783	0.9035	-0.5294	-0.4536	-0.4460	0.8803	0.3372	0.1695	0.1985	0.4357	0.1954	0.1518	0.1268	0.3285	0.0589	-0.1180	0.1011	-0.3207	0.1169	0.7852	0.9612	0.3691	0.0685	0.7889	1.0000					
Exch. K	-0.1808	-0.1189	-0.0285	0.2404	-0.2044	-0.1780	-0.1257	0.1847	0.0267	0.0376	0.0370	0.1151	0.1845	0.1301	0.2175	0.6300	-0.0411	-0.0202	-0.0832	-0.0559	0.0331	0.3667	0.2462	0.1700	0.0307	0.4263	0.3425	1.0000				
ΔpH	0.3000	0.2273	0.1364	-0.4075	0.6054	0.3980	0.4138	-0.5394	-0.4803	-0.3575	-0.3810	-0.5891	-0.4176	-0.3160	-0.1103	-0.2240	-0.2204	0.0340	-0.1083	0.3392	-0.0523	-0.5461	-0.4531	-0.4302	-0.0253	-0.5139	-0.5043	-0.2151	1.0000			
Exch. H	-0.1943	-0.1659	-0.0811	0.1414	-0.5253	-0.4205	-0.4746	0.6191	0.9806	0.9277	0.9481	0.8427	0.7518	0.5451	0.1167	-0.0134	0.9160	0.3180	0.6909	-0.3205	0.0631	0.4004	0.2266	0.8320	0.1515	0.4550	0.2648	-0.0228	-0.4033	1.0000		
ECEC	0.0336	0.0406	0.2291	0.4095	-0.4091	-0.2784	-0.3024	0.7510	0.8601	0.7592	0.7850	0.8230	0.7014	0.5225	0.2180	0.1801	0.6784	0.1756	0.4988	-0.2983	0.4683	0.6364	0.4868	0.8975	0.5390	0.6808	0.5352	0.1719	0.0809	0.8316	1.0000	
Base saturation	0.4463	0.2981	0.3586	0.0531	0.4770	0.4725	0.4758	-0.1591	-0.4598	-0.4983	-0.5017	-0.4722	-0.6262	-0.5446	-0.2011	-0.1739	-0.3723	-0.0989	-0.2490	0.0790	0.2225	-0.1012	0.0298	-0.4398	0.1926	-0.1218	-0.0033	-0.1553	0.1784	-0.4212	-0.2447	1.0000

1. - Field pH (H_2O) 2. - Field pH (KCl) 3. - Field pH ($CaCl_2$) 4. - Field E.C. 5. - Dry pH (H_2O) 6. - Dry pH (KCl) 7. - Dry pH ($CaCl_2$) 8. - Dry EC 9. - Exch. acidity 10. - Non exch. acidity 11. - Pot acidity 12. - Exch. Al. 13. - Org. matter 14. - Av. N 15. - Av. P 16. Av. K
17. - Fe 18. - Mn 19. - Zn 20. - Cu 21. - Av. Ca 22. - Av. Mg 23. - Av. Na 24. -CEC 25. - Exch. Ca 26. - Exch. Mg 27. - Exch. Na 28. - Exch. K 29. - DpH 30. - Exch. H 31. - ECEC 32. - Base saturation

Appendix - 5. Correlation between components of acidity and other soil parameters in selected (36) surface samples of major wetlands

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
Exch. Al	1.000																																							
Exch. H	0.94	1.000																																						
CEC	0.62	0.78	1.000																																				
Exch. Ca	0.18	0.25	0.62	1.000																																		
Ex.Mg	0.80	0.78	0.68	0.28	1.000																																
Exch. Na	0.67	0.65	0.37	0.11	0.69	1.000																														
Exch. K	0.39	0.32	0.25	0.01	0.54	0.49	1.000																												
Org. matter	0.46	0.62	0.83	0.29	0.47	0.13	0.13	1.000																											
Av. N	0.24	0.31	0.44	0.20	0.20	-0.02	-8.07	0.70	1.000																										
Av. P	0.27	0.48	0.60	0.18	0.13	-0.02	-0.08	0.61	0.31	1.000																									
Av. K	0.39	0.32	0.25	0.01	0.54	0.43	1.00	0.13	0.07	0.08	1.000																								
DTPA Fe	0.52	0.62	0.52	-0.05	0.46	0.36	0.27	0.59	0.27	0.44	0.28	1.000																							
Av. Mn	-0.16	0.19	-0.10	0.03	-0.13	-0.10	0.00	-0.13	-0.01	0.19	0.00	0.18	1.000																						
Av. Zn	0.04	0.11	0.17	0.18	0.23	0.53	-0.15	0.02	0.04	-0.09	-0.14	0.13	-0.03	1.000																					
Av. Cu	-0.50	-0.50	-0.36	-0.09	-0.39	-0.33	-0.04	-0.31	-0.01	-0.18	-0.04	-0.16	0.09	-0.14	1.000																				
Av. Ca	0.17	0.23	0.55	0.94	0.27	0.19	0.01	0.18	0.11	0.15	0.01	-0.12	0.02	0.22	-0.07	1.000																			
Av. Mg	0.69	0.67	0.55	0.23	0.92	0.80	0.40	0.31	0.10	0.04	0.24	0.37	-0.08	0.44	-0.34	0.27	1.000																		
Av. Na	0.60	0.58	0.30	0.10	0.60	0.98	0.28	0.06	0.00	-0.09	0.29	0.28	-0.10	0.63	-0.31	0.20	0.77	1.000																	
Active Mn	-0.20	-0.27	-0.20	0.18	-0.10	0.21	0.10	-0.28	-0.03	-0.18	-0.10	0.36	0.28	-0.02	-0.09	0.15	-0.09	-0.19	1.000																
Active Fe	0.16	0.13	0.15	0.02	0.04	0.03	0.08	0.25	0.15	0.14	0.08	0.11	0.15	-0.12	-0.19	0.05	-0.02	0.01	-0.11	1.000															
Total S	0.65	0.72	0.69	0.56	0.58	0.60	0.05	0.38	0.06	0.29	0.06	0.43	-0.22	0.35	-0.40	0.52	0.63	0.69	-0.13	0.06	1.000														
Av. S	0.58	0.67	0.68	0.13	0.55	0.56	0.19	0.64	0.36	0.39	0.20	0.60	0.02	0.25	-0.22	0.07	0.54	0.50	-0.44	0.18	0.57	1.000													
Av. Si	0.18	0.17	0.09	0.14	0.09	0.29	0.17	-0.10	-0.11	0.04	0.17	-0.08	0.02	-0.13	-0.14	0.21	0.19	0.28	-0.06	-0.10	0.25	0.14	1.000												
Eh	0.83	0.82	0.64	0.13	0.70	0.58	0.25	0.58	0.31	0.28	0.25	0.66	-0.10	0.24	-0.51	0.05	0.60	0.52	-0.25	0.08	0.63	0.70	-0.10	1.000											
Sand %	-0.45	-0.45	-0.45	-0.10	-0.40	-0.24	-0.24	-0.43	-0.31	-0.22	-0.24	-0.53	0.04	-0.11	0.10	0.06	-0.28	-0.17	0.36	0.04	-0.38	-0.55	0.13	-0.68	1.000										
Silt %	-0.03	-0.09	-0.04	-0.03	-0.04	-0.17	0.04	0.004	-0.06	-0.22	0.04	-0.03	-0.20	-0.22	-0.21	-0.15	-0.13	-0.22	0.003	-0.01	0.08	0.00	-0.18	0.14	0.42	1.000									
Clay %	0.51	0.54	0.51	0.12	0.45	0.35	0.24	0.48	0.37	0.35	0.24	0.60	0.05	0.23	0.01	0.01	0.37	0.30	-0.40	-0.03	0.37	0.61	-0.06	0.68	-0.89	-0.04	1.000								
Field pH 1:1	-0.30	-0.25	-0.04	-0.32	-0.23	-0.17	-0.11	-0.21	-0.24	-0.03	-0.11	-0.31	-0.15	0.02	0.02	0.43	-0.21	-0.14	0.06	-0.11	-0.02	-0.35	0.05	-0.43	0.24	-0.22	-0.27	1.000							
Field pH 1:2.5	-0.28	-0.25	-0.04	0.29	-0.23	-0.17	0.002	-0.22	-0.26	-0.001	0.004	-0.29	-0.14	0.01	0.04	0.38	-0.23	-0.15	0.04	0.12	-0.04	-0.38	0.11	-0.42	0.20	-0.008	-0.23	0.95	1.000						
Field KCl pH	-0.34	-0.29	0.02	0.34	-0.27	-0.36	-0.06	-0.05	-0.11	0.11	-0.07	-0.21	-0.08	-0.07	0.09	0.38	-0.33	-0.35	0.05	0.20	-0.12	-0.36	0.02	-0.39	0.17	0.01	-0.20	0.91	0.89	1.000					
Field CaCl$_2$pH	-0.10	-0.04	0.20	0.50	0.01	0.03	-0.03	-0.06	-0.23	0.09	-0.03	-0.15	-0.20	0.17	-0.08	0.61	0.04	0.07	0.13	0.17	0.27	-0.17	0.23	-0.24	0.25	-0.18	-0.19	0.83	0.77	0.76	1.000				
EC	0.36	0.36	0.20	0.05	0.54	0.82	0.17	0.01	-0.09	-0.20	0.18	0.28	-0.16	0.70	-0.17	0.15	0.77	0.86	-0.17	-0.09	0.47	0.39	0.25	0.36	-0.13	0.21	0.25	-0.10	-0.15	-0.30	0.09	1.000			
Dry pH 1:1	-0.72	-0.68	-0.42	0.14	0.64	-0.53	-0.25	-0.48	-0.31	-0.11	-0.25	-0.64	0.13	-0.18	0.33	0.24	-0.57	-0.47	0.19	-0.03	-0.35	-0.58	0.11	-0.82	0.46	0.06	-0.54	0.65	0.63	0.60	0.50	-0.38	1.000								
Dry pH 1:2.5	-0.72	-0.68	-0.42	0.14	0.64	-0.53	-0.24	-0.48	-0.30	-0.11	-0.25	-0.65	0.14	-0.21	0.32	0.24	-0.58	-0.49	0.23	-0.03	-0.37	-0.62	0.12	-0.83	0.48	0.07	-0.56	0.64	0.62	0.60	0.49	-0.40	0.99	1.000							
Dry KCl pH	-0.64	-0.58	-0.31	0.16	-0.54	-0.46	-0.19	-0.39	-0.26	-0.06	-0.19	0.60	0.4	-0.20	0.28	0.29	-0.46	-0.42	0.20	-0.004	-0.31	-0.53	0.21	-0.79	0.48	0.01	-0.53	0.64	0.62	0.59	0.55	0.34	0.97	0.97	1.000						
Dry CaCl$_2$ pH	-0.63	-0.58	-0.31	0.18	-0.49	0.42	-0.13	-0.40	-0.29	-0.11	-0.14	-0.62	0.16	-0.16	0.29	0.30	0.42	0.38	0.16	0.02	-0.28	-0.49	0.20	-0.77	0.43	0.02	-0.48	0.62	0.60	0.56	0.55	-0.29	0.96	0.95	0.98	1.000					
EC	0.77	0.75	0.44	0.14	0.68	0.93	0.26	0.21	0.08	0.06	0.26	0.38	-0.14	0.44	-0.39	0.22	0.81	0.94	-0.23	0.11	0.69	0.59	0.32	0.62	-0.25	-0.17	0.35	-0.17	-0.19	-0.36	0.06	0.77	-0.56	-0.57	-0.48	-0.46	1.000				
Δ pH	-0.73	-0.75	-0.55	0.02	-0.76	0.54	-0.37	-0.55	-0.35	-0.22	-0.37	-0.53	0.03	-0.08	0.36	0.02	-0.71	-0.48	0.10	-0.10	-0.38	-0.55	-0.23	-0.66	0.26	0.21	-0.40	0.46	0.45	0.42	0.18	-0.40	0.74	0.72	0.57	0.58	0.60	1.000			
Exch. acidity	0.91	0.90	0.71	0.22	0.72	0.48	0.14	0.59	0.28	0.43	0.14	0.55	-0.13	0.06	-0.53	0.18	0.64	0.44	-0.21	0.16	0.71	0.61	0.10	0.81	-0.46	-0.01	0.54	-0.34	-0.32	-0.34	-0.11	0.29	-0.70	-0.69-	0.61	-0.62	0.66	-0.72	1.000		
Non exch. acidity	0.60	0.77	0.88	0.31	0.57	0.23	0.15	0.84	0.46	0.67	0.15	0.63	-0.08	0.02	-0.36	0.21	0.42	0.13	-0.19	0.13	0.58	0.77	-0.03	0.69	-0.53	0.03	0.56	-0.20	-0.18	-0.11	-0.03	0.021	0.49	-0.51	-0.41	-0.42	0.31	-0.58	0.74	1.000	
Potential acidity	0.66	0.81	0.89	0.30	0.56	0.21	0.16	0.83	0.44	0.16	0.64	-0.09	0.02	-0.32	0.20	0.46	0.18	-0.21	0.14	0.62	0.72	-0.00	0.73	-0.54	-0.03	0.58	-0.23	-0.21	-0.14	-0.04	0.06	-0.54	-0.55	-0.45	-0.45	-0.46	0.37	-0.62	-0.80	-0.99	1.000

1 - Exch. Al 2 - Exch. H 3 - CEC 4 - Exch. Ca 5 - Ex.Mg 6 - Exch. Na 7 - Exch. K 8 - Org. matter 9 - Av. N 10 - Av. P 11 - Av. K 12 - DTPA Fe 13 - Av. Mn 14 - Av. Zn 15 - Av. Cu 16 - Av. Ca 17 - Av. Mg 18 - Av. Na 19 - Active Mn 20 - Active Fe
21 - Total S 22 - Av. S 23 - Av. Si 24 - Eh 25 - Sand % 26 - Silt % 27 - Clay % 28 - Field pH 1:1 29 - Field pH 1:2.5 30 - Field KCl pH 31 - Field CaCl$_2$pH 32 - EC 33 - Dry pH 1:1 34 - Dry pH 1:2.5 35 - Dry KCl pH 36 - Dry CaCl$_2$ pH 37 - EC 38 - Δ pH
39 - Exch. acidity 40 - Non exch. acidity 41 - Potential acidity

EVALUATION OF ACIDITY PARAMETERS IN WETLAND SOILS OF KERALA IN RELATION TO NUTRIENT AVAILABILITY

By

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ABSTRACT OF THE THESIS
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ABSTRACT

Soil acidity is a major constraint in the wetland rice soils of the tropics, which has got aggravated in recent times with the introduction of high yielding varieties of rice and intensive use of fertilizers. Kerala State, with its unique geomorphology, climate, hydrology and other environmental factors has led to the formation of wetland soils with specific physico-chemical and mineralogical properties. These soils sustain a major part of the rice tracts in the State. Attempts to bring these lands under rice cultivation brought to light the intensity and severity of soil acidity in the natural as well as manmade wetlands of this region. Though studies have started way back in 1920 to tackle the problem of acidity and associated nutritional factors, a detailed study to unveil the intricate physico chemical phenomena contributing to acidity and an economic and efficient methodology to alleviate the severity of acidity has not been attempted so far. Hence a study has been conducted to evaluate the acidity parameters in relation to nutrient availability in wetland rice soils of Kerala.

Twelve major wetland rice soils have been identified and classified according to Soil Taxonomy. They belong to natural as well as manmade wetlands, some of them having been indigenously classified and known by vernacular names like *Kari* land (acid peat), *Karapadom* (riverine alluvium), *Kayal* land (lake bed sediments), *Pokkali* lands (saline acid), *Kole* lands (flood plain), *Kaipad* lands (saline marsh).

Twelve profile samples representing the major wetland rice soils comprising an area of 6 lakh ha have been subjected to detailed investigations for morphological, physical, chemical, mineralogical and electro chemical parameters.

Surface samples, each at a radial distance of 5 km from the twelve locations were collected and subjected to detailed studies to evaluate the acidity parameters and acidity generating factors. Studies were also taken up to observe the kinetics of pH and nutrient availability under submergence for different intervals of time. A comparative study on the efficacy of different methods of estimating the lime requirement was also taken up.

From the detailed investigations on the evaluation of acidity parameters of wetland rice soils of Kerala, it has been observed that there exists a great extent of variation with respect to the severity of active acidity in the profile and surface samples. Barring Chittoor soils which were slightly alkaline, all the soils under study were acidic in reaction. The profile and surface samples of *Kari* soil of Thakazhi and *Pokkali* soil of Njarakkal recorded the highest active acidity with a dry soil pH around 3.2. The rating of these surface soils on the basis of active acidity was *Kari* ≥ *Pokkali* > *Karapadom* > Vellayani > *Kayal* > *Kole* > Wyanad > Pattambi > *Kaipad* > Karamana > Kattampally. However, with respect to the mean values of pH of profile samples the rating was *Kari* > *Pokkali* > *Kole* > *Kayal* > *Karapadom* > Vellayani > Wyanad > Pattambi > Karamana > Kattampally > *Kaipad*. All the soils having high active acidity recorded high exchange, non-exchange and potential acidity with significant correlation between them. It was observed that major part of potential acidity of wetland soils of Kerala was constituted by non-exchange acidity due to the preponderance of Kaolinite clay minerals and high content of sesquioxides. Highest values for potential acidity were recorded by 18-30 cm. of *Kari* and surface layers of *Pokkali* profiles. Based on mean potential acidity of surface samples the soils could be rated as *Kari* > *Pokkali* > *Kayal* > *Karapadom* > *Kole* > Pattambi > Kattampally > Vellayani > *Kaipad* ≥ Karamana > Wyanad. However, with respect to profile samples the sequence was *Kari* > *Pokkali* > *Kayal* > *Karapadom* > *Kole* > Wyanad > Vellayani > Kattampally > Pattambi > *Kaipad* > Karamana.

From the correlations worked out, it was found that aqueous pH (1:1) under dry condition was a more reliable parameter for evaluating acidity in the wetland rice soils of Kerala than pH under wet condition or in salt solution, because this parameter gave more significant correlations with acidity generating factors and available nutrients. It was also observed that available sulphur determined both active and potential acidity rather than total sulphur in sulphur rich soils. Path coefficient analysis of acidity contributing factors indicated that exchangeable aluminium was the best parameter for measurement of acidity which accounted for 48 per cent of variation in active acidity, 87 per cent of variation in exchange acidity, 57 per cent of variation in non-exchange acidity and 63 per cent of variation in potential acidity.

Comparison of different methods for calculating lime requirement proved the superiority of exchangeable aluminium method for the wetland rice soils of Kerala. Lower rates of lime requirement were observed by this method for Kattampally, Wyanad, Karamana, Pattambi and *Kaipad* soils.

Studies on submergence showed that wetland rice soils of Vellayani, Karamana, *Karapadom*, *Kole*, *Kaipad*, Pattambi, Kattampally and Wyanad do not require lime to raise the pH for rice cultivation because all these soils attain a pH value of 5.5 within two weeks of submergence. Consequently there was increased availability of nitrogen, phosphorus, potassium, calcium, magnesium, iron, manganese and silica. However, zinc, copper and sulphur were found to decrease by prolonged submergence.

The detailed investigations conducted under this study on the evaluation of acidity paramcters of wetland rice soils of Kerala in relation to nutrient availability have unveiled many intricate phenomena of soil acidity which are of great theoretical and practical significance. Contrary to the conventional concept that liming is a must in all acid soils, the present study underlines the cheap and easy method of alleviating acidity of certain wetland rice soils by optimum submergence and scientific water management. Further the study has revealed the feasibility of liming in soils with severe acidity based on specific methods of estimating the lime requirement of soils. However it is necessary to confirm the results of these *in-vitro* studies by adequate field studies in specific wetland rice tracts of Kerala State.