# MORPHOLOGICAL, PHYSICAL AND CHEMICAL CHARACTERISATION OF THE SOILS OF NORTH KUTTANAD

By

**K. C. MANORAMA THAMPATTI**

**THESIS**

Submitted in partial fulfilment of the requirement for the degree

***Doctor of Philosophy in Agriculture***

Faculty of Agriculture
Kerala Agricultural University

**Department of Soil Science and Agricultural Chemistry**
**COLLEGE OF HORTICULTURE**
**VELLANIKKARA, THRISSUR 680 654**

**1997**

# DECLARATION

I hereby declare that the thesis entitled ***"Morphological, physical and chemical characterisation of the soils of North Kuttanad"*** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship, associateship or other similar title of any other University or Society.

K. C. Manorama

Vellanikkara
Date: 10 June 1997

K. C. Manorama Thampatti

Phone: 0487-370822 (office), 370790 (direct), 370005 (resi); Gram: Agrivarsity
Telex: 887-268-KAU-IN; Fax: 91-0487-370019; E-mail: kauhqr @ ren. nic. in

KERALA AGRICULTURAL UNIVERSITY
COLLEGE OF HORTICULTURE

Dr. A. I. Jose
Associate Dean

Vellanikkara 680 654
Thrissur, Kerala, India
Dated : 10 June 1997

# CERTIFICATE

Certified that the thesis entitled *"Morphological, physical and chemical characterisation of the soils of North Kuttanad"* is a record of research work done independently by Smt. K.C. Manorama Thampatti 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.

A. I. Jose
Chairman
Advisory Committee

# CERTIFICATE

We, the undersigned members of the Advisory Committee of Smt. K.C. Manorama Thampatti, a candidate for the degree of **Doctor of Philosophy in Agriculture**, with major in **Soil Science and Agricultural Chemistry**, agree that the thesis entitled ***"Morphological, physical and chemical characterisation of the soils of North Kuttanad"*** may be submitted by Smt. K.C. Manorama Thampatti, in partial fulfilment of the requirement for the degree.

A. I. Jose
Associate Dean
College of Horticulture
Vellanikkara

R. R. Nair
Associate Director of Research (Rtd.)
Kerala Agricultural University
Vellanikkara

P. A. Wahid
Associate Dean
College of Agriculture
Nileswar

P. V. Prabhakaran
Professor & Head
Dept. of Agricultural Statistics
College of Horticulture
Vellanikkara

V.K. Venugopal
Associate Professor
Dept. of SS & AC
College of Agriculture
Vellayani

*Approved by*

External Examiner

## ACKNOWLEDGEMENT

I wish to place on record my heartfelt gratitude and obligation to *Dr. A. I. Jose*, Associate Dean, College of Horticulture, Vellanikkara, and Chairman of my Advisory Committee for his expert guidance, keen interest, constant encouragement and patience that he has bestowed on me during the course of investigation and preparation of this manuscript.

I am extremely greatful to *Dr. R. R. Nair*, Associate Director (Rtd) Regional Agricultural Research Station, Kumarakom, and *Dr. P. A. Wahid*, Associate Dean, College of Agriculture, Nileswar, for their timely suggestions as members of the Advisory committee.

My sincere thanks are also due to *Shri. P. V. Prabhakaran*, Professor and Head, Department of Agricultural Statistics, College of Horticulture, Vellanikkara for his valuable advise in statistical analysis.

I am deeply obliged to *Dr. V. K. Venugopal*, Associate Professor, Department of Soil Science and Agricultural Chemistry, Colllege of Agriculture, Vellayani, for the valuable suggestions and generous help he has always accorded to me during the course of study.

I express my sincere thanks to Shri. C. S. Gopi, Dr. K. C. Marykutty and Shri. Rajendraprasad for the help extended to me during the work. Profound thanks are also due to each and every staff member of the Department of Soil Science and Agricultural Chemistry for their kind co-operation and sincere help.

With all regards, I acknowledge the generous help rendered to me by Dr. Lalitha Bai, Dr. Mercy George, Dr. Jim Thomas. Dr. M. Nandakumar and Smt. Joicy C. John.

The help and support received from the staff members of Regional Agricultural Research station, Kumarakom and Punja Special office, Kottayam, are greatfully acknowledged.

My sincere thanks are due to Smt. K. M. Mary for her neat typing and prompt service.

It is with pleasure that I express my sincere and heartfelt thanks to my brother shri. Manohara Varma and to all my friends for their innumerable help and support provided during the course of study.

At this moment I may recall with love and gratitude the constant encouragement and inspiration given to me by my husband and other family members.

Vellanikkara *K. C. Manorama Thampatti*

CONTENTS Page No.

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF PLATES

# *Introduction*

# INTRODUCTION

Kuttanad region of Kerala is a unique agricultural area, lying 0.6 to 2.2 m below mean sea level. Nowhere else in the world such a low lying tract below mean sea level has been observed except in the Netherlands. Kuttanad is a deltaic formation of four major rivers viz., Meenachil, Manimala, Pamba and Achankoil draining into Vembanad lake. The area extends from 9° 17′ to 9° 40′N latitude and 76° 19′ to 76° 33′E longitude on the west coast of Kerala. The geographical area of the region is 874 $km^2$ distributed within Alappuzha, Kottayam and Pathanamthitta districts. Out of this, wetlands comprise 584 $km^2$.

In the geological past, the region was a part of the shallow coastal area of Arabian Sea. As a result of the geological uplift, a shallow bay was formed into which several rivers discharged. The silt carried out by these rivers got deposited at river mouths giving rise to the present coast and converting the shallow bay into a lake-lagoon-backwater system extending from Alappuzha to Kochi and connecting the sea by Kochi estuary. According to another theory, the entire area was a dense forest which caught fire and engulfed by the sea during the succeeding geological ages. Years later sea receded exposing the land which forms a part of midland and coastal region of Kerala. Soils in these areas have vast organic deposits as also fossils of timber and shell fish in varying depths, reminiscent of submersion under sea for long periods.

Kuttanad is considered as the rice bowl of Kerala. Rice is cultivated in an area of 55000 ha, identified as punja lands of Kuttanad constituting several "padasekharams" or contiguous fields separated by channels and bunds. The area is divided into karappadam, kayal and kari lands with reference to elevation, geological formation and soil characteristics. Based on flood incidence, salinity intrusion and soil acidity , Kuttanad has been divided in to seven agro-ecological zones viz.,. Upper Kuttanad, Lower Kuttanad, kayal lands, North Kuttanad, Coastal Kuttanad, Purakkad kari and Vaikom kari. The area is periodically inundated by saline water of tidal inflow from the sea. During the periods of south-west monsoon and north-east monsoon, the rivers pour fresh water into the area and as north-east monsoon recedes, sea water again enters the Vembanad lake and the whole area becomes saline. Kuttanad therefore, is faced with serious problems of hydrology, floods and salinity. The extent of salinity and flood incidence varies among the agro-ecological zones. Maximum flood impact is found in areas of Upper Kuttanad and minium in kayal lands, while salinity intrusion follows a reverse trend. North Kuttanad, the deltaic formation of Meenachil river is subjected to both flood submergence and salinity intrusion.

A substantial part of the area was reclaimed from the Vembanad lake and this has considerably reduced the lake area. The reclamation processes virtually came to a halt four decades ago. Since then emphasis has been on making the land more productive. The major hindrances for intensive agriculture were the regular flood submergence during monsoons and saline water intrusion during summer season. To check the floods during monsoons, a spillway was constructed at Thottappally for the speedy drainage of water from the lake to the Arabian Sea which was commissioned during 1955. To prevent salt water intrusion and to promote double crop of rice in about 55000 ha of lowlying fields in the area, it was decided to construct a 1462 m long barrage, rising 92 cm above the level of high tide at Thanneermukkom in the

Vembanad lake. Designed as a bridge cum regulator with facilities for allowing navigation, the work of the barrage was started in 1958. When it become temporarily functional in March 1975 with an earthen bund in the middle portion, it became the second biggest salt water barrage in the country, next to Farraka barrage in the Ganga river. The barrage /regulator started regular functioning from the summer of 1976 and since then the regulator remains closed from December to May every year. Consequent to the construction of regulator rice is cultivated during two seasons in Kuttanad viz., additional crop (April to September) and punja crop (October to January).

The Thanneermukkom regulator has been relatively successful in preventing the intrusion of saline water into Vembanad lake and from there to Kuttanad. The most benefitted areas due to the closure of the regulator are 8100 ha of kayal lands and 10120 ha of North Kuttanad. North Kuttanad being adjacent to Vembanad lake, used to be severely affected by incursion of saline water during summer in the pre-barrage period.

During summer, when the regulator is closed, there is virtually no flow of water beyond the regulator on the southern side which results in water stagnation. Due to this situation, an almost fresh water condition prevails during major part of the year in the southern side of the regulator while there exists varying grades of salinity in the northern side. This phenomenal change in the hydrodynamics of the system has triggered off several unexpected changes on farming and ecology of the region. The ecological backlash began to manifest in the form of reduction in rice yield, proliferation of weeds, deterioration of water quality, increased morbidity and destruction of fishes and other aquatic organisms. The entire Kuttanad becomes a static pool after the closure of the Thanneermukkom regulator. The periodic tidal inflow which used to flush the waterbody is completely prevented with the result that the drained water from the rice fields with heavy load of pesticides and fertiliser residues remain stagnant in the waterbody. Added to these pollutants, the human, animal and agricultural wastes and industrial effluent that are emptied into the Kuttanad water system virtually turn Kuttanad, the rice bowl of Kerala into a poison bowl.

The continuous cultivation in rice fields with soil exhausting high yielding rice varities along with indiscriminate use of fertilisers and pesticides is causing serious soil health problems in Kuttanad. The developmental activities and intensive cultivation in Kuttanad have resulted in the depletion of soil organic matter and increase in soil acidity making the soil sick and less productive. Under these circumstances, the present study was taken up to assess the impact of closure of Thanneermukkom regulator during summer season on the following soil properties of North Kuttanad, the most benefitted area due to the construction of Thanneermukkom regulator.

1) Morphological, physical and chemical properties of soils of Notrh Kuttanad

2) The extent of variation in fertility characteristics of the area

3) The extent of variation in native toxic soil characteristics in the area due to the restricted movement of water

4) The development and accumulation of introduced toxic factors in the area and its impact on soil environment.

# *Review of literature*

# REVIEW OF LITERATURE

## 1. General description of the area under study

Kuttanad is a low-lying area of costal Kerala formed by the confluence of four major river systems viz., Meenachil, Manimala, Pamba and Achankoil draining into the Vembanad lake. It measures approximately 25 km east-west and 60 km north-south on the west coast of Kerala. The area encompasses 79 revenue villages lying in Karthigappally, Mavelikkara, Chengannur, Kuttanad, Thiruvalla, Kottayam, Ambalapuzha, Cherthala and Vaikom taluks.

From the very early days, Kuttanad has been acknowledged as the rice bowl of Kerala. Millions of years ago this land was a dense forest. In succeeding geological ages, the sea advanced and engulfed many places including this area. Several thousand years later, the sea receded exposing part of midlands and coastal region. During these geological upheavals, the entire forest area was submerged far below the ground and thereafter silted up to varying levels (Pillai, 1940). This area was further converted into garden lands and wet lands by the process of reclamation which now characterises Kuttanad.

Geologically, Kuttanad is an alluvial belt formed of Tertiary and Quaternary sediments. The region appears as a saucer shaped basin flanked by sand dunes in the west and low lateritic hills in the east. This deltaic alluvium is alternating layers of sand and clay of varying sizes and variable percentages of organic matter (Mathai and Rajendran, 1983).

The deltaic formations of the river systems in the basin gradually slopes down to the Vembanad lake and merge with it which is connected to the Arabian sea by the Cochin estuary. Therefore, the flood incidence and the salinity intrusion affect variously the different parts of the delta formation. The maximum flood impact is found in areas of Upper Kuttanad and the least in kayal lands, while salinity intrusion follows a reverse trend. The deltaic formation of Meenachil river identified as North Kuttanad is subjected to both flood submergence and saline water intrusion (Aravindakshan and Joseph, 1985).

The geographical area of Kuttanad is 874 km$^2$ in which 290 km$^2$ are garden lands rising 1 to 2 m above msl. The remaining area is 0.6-2.2 m below msl. Based on flood incidence, salinity intrusion and soil acidity, Kuttanad has been divided in to following seven agroecological zones. (1) Upper Kuttanad (2) Lower Kuttanad, (3) Kayal lands, (4) North Kuttanad, (5) Coastal Kuttanad, (6) Purakkad kari and (7) Vaikom kari.

During south-west monsoon, the entire area will be submerged under flood water. The flood water gradually drains through the water courses and Vembanad lake into the sea through the Cochin gut. As the monsoon recedes, the sea water enters the Vembanad lake by tidal action and from there it spreads to other parts of Kuttanad, through interconnected waterways and canals. Thus, the area is subjected to continued flood submergence during monsoons and saline water ingression during summer months.

The soil characteristics in a waterlogged region like Kuttanad are entirely different from those of a normal well drained region. Accumulation of toxic products of anaerobic decomposition of organic matter, production of ammonia, reduction of nitrates and sulphates, mobilisation of iron and manganese, increase in available phosphorus, variation in redox potential, soil reaction and electrical conductivity are the resultant effects of waterlogging which in turn cause drastic changes in soil environment and influence crop growth (Money and Sukumaran, 1973). Seasonal fluctuations of salinity due to high monsoonal discharge along with fluviatile and estuarine silts have further modified the chemical and biological characters of the soil. Another point to be reckoned with is the environment related leaching process. In some parts of the year leaching takes place under the influence of rain water in a saline water environment and in other times it is a fresh water environment. The construction of a 12 m wide road between Alleppey and Changanachery aggravated the flood problems of the region.

Soils of Kuttanad are known as acid saline or acid sulphate soils. They are further sub-divided and named according to the morphological conditions viz., karappadam, kayal and kari. These three types fall in great soil groups of Tropaquents (karappadam and kari) and Tropopsamments (kayal) (Chattopadhyay and Sidharthan, 1985).

Karappadam soils occur along the inland waterways and rivers, and are spread over a large part in the Upper Kuttanad covering an area of 40000 ha. They are river-borne alluvial soils. The fields lie about 1-2 m below msl. Soils are very deep, poorly drained, dark grey in colour with clay loam surface texture followed by silty clay sub soil. The subsoils also show the presence of abundant prominent red and yellow mottles, gley horizons, streaks and concretions. The presence of sand pockets in the subsurface horizon is another feature (KAU, 1994). The soils are characterised by high acidity, salt content and a fair amount of decomposing organic matter (Chattopadhyay and Sidharthan, 1985; KAU, 1994).

Kayal soils are found in reclaimed beds of Vembanad and Kayamkulam lakes in Kottayam and Alleppey districts and they occupy an area of 8000 ha, constituting about 14.3 per cent of total area of Kuttanad. These soils are most severely affected by salinity. Crop failure is a common feature in these soils (Chattopadhyay and Sidharthan, 1985; KAU, 1994). Sea water intrusion is prevented to a certain extent by the construction of a permanent regulator between Vechoor and Thanneermukkom in Cherthala taluk. Two crops of rice are now being raised in many places.

The kari lands are confined to a few pockets in a non-contiguous manner along the coastal plains adjoining the backwaters in Alleppey and Kottayam districts covering an area of 20000 ha. They exhibit characteristics of the submerged forest area.. The soils are deep black in colour, heavy in texture, poorly aerated and ill drained. Top soil is admixed with well decomposed organic matter in the range of 10-30 per cent. But very often this layer is underlain by partially decomposed fibrous plant residues and contains less than 50 per cent mineral matter. In some places, big logs of wood locally known as "Kandamaram" occur embedded in the subsoil which are used as firewood or timber (Koshy *et al.*, 1977; Chattopadhyay and Sidharthan, 1985; KAU, 1994).

The kari soils are affected by severe acidity and periodic saline water inundation with consequent accumulation of soluble salts. In these soils, free sulphuric acid is formed by oxidation of sulphur compounds of organic residues or that accumulated in the soil from sea water by repeated inundation. The soils are of low fertility status. Besides they contain toxic concentrations of iron, aluminium and many unidentified toxic organic compounds. The presence of large quantities of organic matter that resisted decomposition for a long time and high acidity inspite of large accumulation of lime shells are some of the peculiar characteristics of the kari soils (Nair and Iyer, 1948; Subramoney, 1958; 1959; Money, 1961a; Pillai and Subramoney, 1967; Money and Sukumaran, 1973; Chattopadhyay and Sidharthan, 1985; KAU, 1994).

## 2. General properties of Kuttanad soils

### 2.1 *Soil reaction (pH)*

The Kuttanad soils in general are acidic in reaction.The pH values depend on location of the soils from which they are collected. Among karappadam, kayal and kari soils, the kari soils are the most acidic.The pH values for karappadam and kayal soils range from 2.6 to 5.8 and 3.0 to 7.3, respectively (Koshy and Brito-Mutunayagam, 1961; Nair and Aiyer, 1968; Nair, 1973; Sreedevi and Aiyer, 1974; Kabeerathumma, 1975; Kabeerathumma and Bidappa, 1975; Venugopal and Koshy, 1978; Aiyer and Nair, 1979; Amma *et al.*, 1979; Nair and Padmaja, 1983; Bhargava and Abrol, 1984; Amma, 1988; Mathew, 1989; Kuruvila and Patnaik, 1994).

Kari soils register lower pH values than karappadam and kayal soils. The pH values reported by different workers for different locations ranged from 2.6 to 5.9 (Koshy and Brito-Mutunayagam, 1961; Subramoney, 1961; Nair and Aiyer, 1968; Koshy, 1971; Sreedevi and Aiyer, 1974, Aiyer *et al.*, 1975; Praseedom and Koshy, 1975; Ghosh, *et al.*, 1976; Venugopal and Koshy, 1976a; Aiyer and Nair, 1979; Kabeerathumma and Patnaik, 1980; Mathews and Jose, 1984; Marykutty and Aiyer, 1987; Amma, 1988; Raju, 1988; Mathew, 1989; KAU, 1994). The lowest value of 2.6 was recorded by the kari soils from Kallara (Marykutty and Aiyer, 1987).

Variations in pH with depth do not show any definite pattern in profile samples. Depending upon the locations, pH remains unaltered, increases (Kurup, 1967; Pillai and Subramoney, 1967; Santhakumari, 1975) or decreases with depth (Money, 1961a; Varghese and Aiyer, 1973).

The pH value of an acid soil increases on submergence due to soil reduction and may attain a value near 6.5. In fact, acid sulphate soils low in iron may not attain a value greater than 5.0 (Ponnamperuma, 1972). The Kuttanad soils on submergence shows only a small increase in pH and on no occasion it exceeds 5.0 even though the soil is rich in iron (Kabeerathumma, 1975).

### 2.2 *Electrical conductivity (EC)*

The Kuttanad soils are saline in nature. Among the three types of acid saline soils, i.e., karappadam, kayal and kari, the kayal soils are more saline. The EC values depend on the location of the soil and season in which they are collected.The maximum values are observed during summer (March to April) and minimum during October to November (Kurup and Aiyer, 1973). The EC values recorded by different workers range from 0.1 to 43.6 dS $m^{-1}$ (Ghosh *et al.*, 1976; Kabeerathumma and Patnaik, 1978; Aiyer and Nair, 1979; Kabeerathumma and Patnaik, 1980; Bhargava and Abrol, 1984; Marykutty and Aiyer, 1987; Amma, 1988; Raju, 1988; Mathew, 1989; Kuruvila and Patnaik, 1994). The electrical conductivity of the Kuttanad soils increases with depth in profile samples (Kurup, 1967; Varghese and Aiyer, 1973; Santhakumari, 1975).

Sodium, calcium, magnesium, chloride and sulphate ions are dominant in saline soils with sodium chloride being the most frequent cause of salinity. Due to the high mobility of water soluble salts, rains remove salts vertically or laterally or dilute them to non-toxic concentration. Salts may concentrate in lower layers of soil through seepage or run off (Van Mensvoort *et al.*, 1984). In monsoon areas rainfall may be high enough to provide for sufficient dilution and drainage downwards. In karappadam, kayal and kari lands, the heavy monsoonic showers and the consequent flood incidence completely wash away the soluble salts and make the entire area a fresh water zone by October-November. As the summer advances, the sea water again enters this region through canals and the area becomes saline by January-February (Money, 1961b; Kurup, 1967; Kurup and Aiyer, 1973). The construction of Thanneermukkom regulator prevents the entry of salt water into Kuttanad during summer and maintains the salinity of soils within safer limits (DEEM, 1987; Raju, 1988; KAU, 1994).

In areas with marine salinity the most logical solution is protection by dikes.This practice may however, be very hazardous where acid sulphate soils or potential acid sulphate soils are present. Blocking the entry of salt water lowers the water table during dry season and causes severe acidification(Brinkman and Singh, 1982).

The EC is positively correlated with combined percentage of silt and clay indicating that soils containing more finer fractions the salts are not freely washed away as in the case of sandy soils (Nair and Money, 1972).

### *2.3 Soil acidity*

The acid sulphate soils occurring along the sea coast of Kerala are extremely acidic because of the presence of excess amount of S and lack of $CaCO_3$ (Segeren and Smits, 1974).The Kuttanad soils are no exception to this phenomenon. In certain areas (kari) free sulphuric acid is formed by oxidation of S compounds of organic residues or that accumulated from the sea water during repeated inundation by the action of sulphur oxidising bacteria (Nair and Iyer, 1948; Subramoney, 1958; Money, 1961a). Besides sulphuric acid, exchangeable $H^+$, $Al^{3+}$, $Fe^{3+}$, $Mn^{2+}$ and other hydrolytic ions on the soil exchange complex (Panda, 1987; Misra *et al.*, 1989; Adhikari and Si, 1991; Prabhuraj and Murthy, 1994) and organic acids (Brito-Mutunayagam, 1948; Van Mensvoort *et al.*, 1984) also contribute towards soil acidity in an acid sulphate soil.

The exchangeable acidity of kari soils varies from 22.9 to 39.6 cmol(+) $kg^{-1}$ (Kabeerathumma and Nair, 1973; Kabeerathumma and Bidappa, 1975; Kabeerathumma and Patnaik, 1978; Marykutty and Aiyer, 1987). In karappadam soils it ranges from 5.8 to 14.6 cmol(+) $kg^{-1}$ (Kabeerathumma and Nair, 1973; Kabeerathumma and Bidappa, 1975; Kabeerathumma and Patnaik, 1978). In kayal soils it is about 6.1 to 8.0 cmol(+) $kg^{-1}$ (Kabeerathumma and Patnaik, 1978). Compared to total acidity, exchangeable acidity is rather low, and the nature of soil acidity is mostly pH dependent (Sharma *et al.*, 1990; Adhikari and Si, 1991; Ananthanarayana and Hanumantharaju, 1994). The pH dependent acidity is about 70 to 90 per cent of total acidity (Panda, 1987; Anathanarayana and Hanumantharaju, 1994). The contribution of pH dependent acidity to total acidity decreases with lowering of pH (Pal *et al* ., 1991).

The percentage contribution of exchangeable $H^+$ to exchangeable acidity varies from 16 to 46 and the rest is contributed by exchangeable $Al^{3+}$ (Kabeerathumma and Nair, 1973; Marykutty, 1986; Marykutty and Aiyer, 1987).

The Kuttanad soils are very high in exchangeable Al (0.22-6.45 cmol[+] $kg^{-1}$) and $BaCl_2$-TEA extractable acidity which varies from 8.0 to 39.6 cmol(+) $kg^{-1}$ (Kabeerathumma and Patnaik, 1978). The exchangeable Al content of karappadam soils is about 4.10 to 5.84 cmol(+) $kg^{-1}$ (Marykutty and Aiyer, 1990).

The acidity of rice soil is characterised by a periodical change induced by alternate irrigation and drainage and the rate and extent of such changes are far greater than those occurring in upland soils. The increase in acidity, on the exposure of soils to air is a character exhibited by most of the soils of Kuttanad though it varies in degree from place to place. The presence of toxic subsoil layer is a source of permanent danger to crops as the acid salts can enter the permiable layer with the rise of ground water (Money, 1961a).

Kari soils have a much higher content of exchangeable $Al^{3+}$, exchangeable $H^+$ and exchangeable acidity than karappadam and kayal soils (Kabeerathumma and Nair, 1973; Marykutty, 1986; Marykutty and Aiyer, 1990). The acidity in Kuttanad soils is due to dissolved substances such as sulphuric acid, and ferric and aluminium sulphates, whereas the acidic species of naturally occurring clays ($H^+$ and $Al^{3+}$) remains bound to clay (Panda and Koshy, 1982).

A definite relationship exists between pH, exchangeable $H^+$ and exchangeable $Al^{3+}$ (Kabeerathumma and Nair, 1973). Organic carbon and exchangeable $Al^{3+}$ were significantly correlated with pH dependent acidity whereas exchangeable acidity is significantly correlated with exchangeable $Al^{3+}$ alone (Pal *et al.*, 1991; Singh *et al.*, 1993). In highly acidic soils potential acidity contribute to a major portion of cation exchange capacity, and such soils are mostly associated with low base saturation (Anathanarayana and Hanumantharaju, 1994).

## 2.4 *Organic carbon*

Acid saline soils are reported to contain a fairly high amount of organic carbon. In karappadam, kayal and kari soils the organic carbon content ranges from 1.3 to 13.9, 0.4 to 5.5 and 1.8 to 25.0 per cent, respectively (Subramoney, 1961; Zachariah and Sankarasubramoney, 1961; Nair and Aiyer, 1968; Alexander and Durairaj, 1968; Koshy, 1971; Nair and Money, 1972; Money and Sukumaran, 1973; Sreedevi and Aiyer, 1974; Aiyer *et al.*, 1975; Praseedom and Koshy, 1975; Sreedevi *et al.*, 1975; Ghosh *et al.*, 1976; Venugopal and Koshy, 1976b; Kabeerathumma and Patnaik, 1978; Aiyer and Nair, 1979; Amma, *et al.*, 1979; Bhargava and Abrol, 1984; Mathews and Jose, 1984; Marykutty and Aiyer, 1987; Amma, 1988; Raju, 1988; Mathew, 1989; KAU, 1994).

The organic matter of kari soils is largely a lignoprotein complex consisting of mainly lignin, ether and alcohol soluble substances (Nair and Iyer, 1948). In this organic matter there is a preponderance of alcohol and ether extractable fractions, and cellulose and hemicellulose are entirely absent (Koshy, 1970).

In profile samples of kari soils, organic matter content decreases with depth. Undecomposed plant residues are seen in profiles at different depth. The C:N ratios of the soils of different horizons are wider than normal soils indicating the presence of undecomposed plant residues of higher carbohydrates like lignin of wood fossils. The C:N ratio of karappadam soil is also above 10.0 indicating the presence of undecomposed organic matter. Compared to karappadam and kari soils, the C:N ratio is low in kayal soils (KAU, 1994).

## 2.5 *Phosphorus*

In karappadam and kayal soils, available P (Bray No.1) ranges from traces to 45 ppm and 6 to 51 ppm, respectively (Money and Sukumaran, 1973; Kabeerathumma and Patnaik, 1978; Aiyer and Nair, 1979; Amma, 1988;

Raju, 1988; Mathew, 1989). In kari soils, it ranges from traces to 63 ppm (Alexander and Durairaj, 1968; Ghosh *et al.*, 1973; Money and Sukumaran, 1973; Kabeerathumma and Patnaik, 1978; Aiyer and Nair, 1979; Mathews and Jose, 1984; Nair,1986; Amma, 1988; Raju, 1988; Mathew, 1989).

One of the major nutritional problems of Kuttanad soils is P deficiency and more than 50 per cent of the area is P deficient (Kuruvila and Patnaik, 1994; KAU, 1994). The total $P_2O_5$ content of karappadam, kayal and kari soils ranges from 0.094 to 0.156, 0.094 to 0.108 and 0.018 to 0.025 per cent, respectively (Sreedevi and Aiyer, 1974).

### 2.6 *Potassium*

The available K content in karappadam, kayal and kari soils ranges from 35 to 72, 37 to 72 and 37 to 78 ppm, respectively showing that these soils are relatively deficient in available K (Alexander and Durairaj, 1968; Nair and Money, 1972; Money and Sukumaran, 1973; Sreedevi and Aiyer, 1974). Though the Kuttanad soils are deficient in available K, they are well supplied with total K (Brito-Mutunayagam, 1961; Sreedevi and Aiyer, 1974) and non-exchangeable K (Gopalaswami, 1961; Nair and Money, 1972; Sreedevi and Aiyer, 1974).

Liming decreases the exchangeable K due to its fixation in Kuttanad soils (Kabeerathumma and Bidappa, 1975). However, the overall effect of submergence is increased availability of K (Kabeerathumma and Patnaik, 1978).

### 2.7 *Cation exchange capacity (CEC) and exchangeable cations*

The CEC of Kuttanad soils is comparatively higher as compared to the other acid soils of Kerala due to large amount of organic mattert in these soils. It ranges from 8.0 to 35.0, 10.4 to 31.6 and 16.6 to 50.0 cmol(+) $kg^{-1}$ for karappadam, kayal and kari soils, respectively (Pisharody and Brito-Mutunayagam, 1966; Pillai and Subramoney, 1967; Alexander and Durairaj, 1968; Sreedevi and Aiyer, 1974; Praseedom and Koshy, 1975; Venugopal and Koshy, 1976b; Venugopal and Koshy, 1978; Amma *et al.*, 1979; Kabeerathumma and Patnaik, 1980; Bhargava and Abrol, 1984; Amma, 1988; Raju, 1988; Mathew, 1989).

Though the soils of Kuttanad possess high CEC, they have low base saturation. It varies from 15 to 80 per cent of CEC (Kurup, 1967). Among the exchangeable cations, hydrogen dominates and occupies 75 to 80 per cent of exchange complex (KAU, 1994). In saline patches Na dominates the exchange complex.

The ranges of exchangeable Ca, Mg and Na in karappadam soils are 0.9 to 4.7; 1.3 to 3.5 and 3.3 to 15.2 cmol(+) $kg^{-1}$, respectively (Sreedevi and Aiyer, 1974; Aiyer *et al.*, 1975; Kabeerathumma and Bidappa 1975; Kabeerathumma and Patnaik, 1980; Amma, 1988). The exchangeable Ca, Mg and Na in kari soils are in the range of 1.0 to 7.4, 2.5 to 4.9 and 2.2 to 19.6 cmol(+) $kg^{-1}$, respectively (Sreedevi and Aiyer, 1974; Aiyer *et al.*, 1975; Venugopal and Koshy, 1976a; Kbeerathumma, 1975; Kabeerathumma and Patnaik, 1978; Marykutty, 1986; Marykutty and Aiyer, 1987; Amma, 1988).

The exchangeable + water soluble Ca, Mg and Na of kayal soils varied from 2.0 to 9.1, 1.2 to 8.6 and 0.2 to 32.6 cmol(+) $kg^{-1}$ (Mathew, 1989).

Saline water intrusion and seepage render these soils poor in exchangeable Ca but rich in Na. In karappadam and kari soils increasing the period of flooding results in gradual increase in exchangeable Ca content during the entire period of incubation, whereas in kayal soils an initial increase followed by a decrease occurs (Kabeerathumma, 1975).

### 2.8 *Sulphur*

The Kuttanad soils are generally rich in S content. These soils contain large amounts of S compounds, principally mineral sulphates of iron and aluminium which on hydrolysis produce free sulphuric acid. This is one of the major reason for the high acidity of these soils (Money, 1961a; Subramoney, 1965; Nair and Subramoney, 1969; KAU, 1984; Chattopadhyay and Sidharthan, 1985).

Among the karappadam, kayal and kari soils, kari soils contains more total S than the other two types. The karappadam and kayal soils contain 491 to 6398 ppm and 1505 to 4873 ppm total S, respectively (Jacob, 1966; Hegde *et al.*, 1980; Mathew, 1989). In kari soils it varies from 4950 to 30000 ppm (Jacob, 1966; Leela, 1967; Varghese, 1973; Ghosh *et al.*, 1976; Hegde *et al.*, 1980; Mathew, 1989).

Organic S generally constitutes the major portion of total S in most of the soils. In karappadam soils the contribution of organic S to total S is about 64 per cent while in kayal and kari it accounts to 95 per cent.The organic S content of karappadam, kayal and kari soils are in the range of 225 to 4061, 420 to 4585 and 507 to 24000 ppm, respectively (Jacob, 1966; Leela, 1967; Varghese, 1973; Ghosh *et al.*, 1976; Mathew, 1989).

Sulphate S of karappadam, kayal and kari soils varies from traces to 422, 80 to 1175 and 112 to 3677 ppm, respectively (Money, 1961a; Ghosh *et al.*, 1976; Bhargava and Abrol, 1984; Mathew, 1989). Kari soils are reported to contain fairly good amount of non-sulphate sulphur which may be sulphide, sulphite, polysulphide, thiosulphate and elemental sulphur.

The available S content of karappadam, kayal and kari soils are in the range of 20 to 208, 233 to 481 and 571 to 1500 ppm, respectively (Hegde *et al.*, 1980; Mathew, 1989).

The sulphate content of Kuttanad soils are high and there is no marked reduction due to flooding. Eventhen these soils do not exhibit S toxicity (Kuruvila and Patnaik, 1994).

### 2.9 *Chloride*

The surface soils of Kuttanad contain 3.0 to 4.0 per cent water soluble salts nearly all chlorides and sulphates. The chloride content of these soils varies between 0.41 and 3.10 per cent (Money, 1961a). .The content of chlorides and sulphates are dependent on the electrical conductivity (Varghese et al., 1970).

## 3. Major nutrient transformations due to submergence

On submergence, the $O_2$ supply in a soil is curtailed and facultative and anaerobic microorganisms start the reduction of soil components with high oxidation state. The soil reduction takes place roughly in a sequence. During this process organic matter is oxidised, acid is consumed and pH rises (Ponnamperuma, 1972; Van Mensvoort *et al.*, 1984).

### 3.1 *Nitrogen transformations*

Transformations of N in wet land rice soil include changes in both aerobic and anaerobic microsystems. Accumulation of $NH4^+$, instability of $NO_3$, a lowered N requirement for organic matter decomposition and inefficient utilisation of applied N are some of the important aspects of N transformations in a waterlogged soil. Ammonia volatilization, nitrification, leaching and run-off are the pathways through which N is lost from the rice soil

(Patrick and Mahapathra, 1968; Broadbent, 1978; Savant and De Datta, 1982).

In a submerged rice soil, a reductive plough layer in which most of the rice roots proliferate and derive N, is usually sandwitched between a thin oxidised surface layer and a partly oxidised subsurface layer. The rice rhizosphere is also oxidised (Mandal, 1961).

As in dry land a major portion of N in wet lands occurs in organic pool. Mineralisation of organic N to $NH_4^+$ ions presumably takes place in the reduced layer. Because of the lack of adequate oxygen, mineralisation stops at this stage resulting accumulation of $NH_4^+$ ions (Abichandani and Patnaik, 1958; Ponnamperuma, 1972; Rose, 1976; John and Thomas, 1990). Mineralisation and immobilisation are opposed to each other and are influenced by C:N .ratio, temperature, easily decomposable organic carbon, presence of amorphous Fe and Mn oxides (Savant and De Datta, 1982).

The conversion of urea to $NH_4^+$ is usually completed within 3-4 days either surface or subsurface applied, both in flood water and the root zone soil solution of flooded rice fields (Panda *et al.*, 1988). The volatilization losses of $NH_3$ does not exceed 10 per cent of the applied urea in flooded rice fields (Rekhi *et al.*, 1982; Panda *et al.*, 1989).

Nitrification takes place in aerobic environments of flood water viz., the thin oxidised surface layer and rice rhizosphere. The nitrates thus formed leach down or diffuses to the reduced layer and get denitrified to $N_2O$ or $N_2$ gas (Patrick and Reddy, 1976; 1978; Savant and De Datta, 1982). Nitrification occurs at Eh values greater than $^+$200mv and denitrification occurs at Eh values less than $^+$200mv. The rate of denitrification increases with restricted supply of $O_2$ and the loss extends up to 20 to 30 per cent.

In soils having appreciable contents of Fe and Al oxides and pH lower than 6.0, there can be weak adsorption of $NO_3$, presumably in the thin oxidised layer of flooded soil. $NH_4$ fixation is also less under waterlogged conditions. A positive correlation exists between $NH_4$ fixing capacity and active iron content (Sahrawat, 1979).

The total N content of kari soils varies from 0.095 to 0.996 per cent (Varghese, 1973; Sreedevi and Aiyer, 1974; Kabeerathumma and Patnaik, 1978; Marykutty and Aiyer, 1987). For karappadam and kayal soils the ranges are in between 0.11 and 0.3, and 0.14 and 0.17 per cent, respectively (Sreedevi and Aiyer, 1974). Total N content of Kuttanad soils decreases with depth (KAU, 1994). The available N content of Kuttanad soils varies from 112 to 500 ppm (Pillai, 1964; Kabeerathumma, 1969).

Nitrogen mineralisation and nitrification in acid sulphate soils are supposed to be affected by high soil acidity (pH around 4.0) although the level of soil organic matter is very high (Sahrawat, 1980). Under aerobic and anaerobic conditions of incubation N gets mineralised and accumulated as $NH_4$-N since the nitrifying organisms fail to function at very low pH (Sahrawat, 1980; Laskar *et al.*, 1991). In acid sulphate soils rich in organic matter, the $NH_4$-N plays and important role in plant nutrition. Nitrogen losses in potential acid sulphate soils by leaching and denitrification are prevented because of the lack of nitrate formation (Mandal, 1961).

The accumulation of $NH_4^+$ is relatively low in kari soils even with higher content of organic matter, possibly because of the fibrous nature of the organic matter (Kuruvila and Patnaik, 1994).

### *3.2 Transformation of Fe*

Most of the anaerobic organic matter decomposition taking place in soil are supported by oxidised bioreducible ferric compounds. The oxidised iron compounds provide a large reservoir for accepting electrons during the microbial decomposition of organic matter by facultative anaerobes that function after oxygen has been depleted from the soil. Although occupying a negative position on the redox potential scale, the high capacity for accepting electrons of the oxidised Fe compounds make Fe the key redox element in flooded soil (Patrick, 1981). Insoluble $Fe^{3+}$ compounds are reduced to soluble $Fe^{2+}$ compounds within a redox potential range of Eh values $^-50$ to $^-200$ mv due to submergence (Ponnamperuma, 1972; Van Mensvoort *et al.*, 1984; Johnkutty and Anilakumar, 1990).

The reduction of Fe is more dominant than that of Mn. The reason being the presence of much higher content of active Fe in rice soils (Mitra and Mandal, 1983). The concentration of iron usually exceeds the total amount of other redox elements by a factor of 10 or more. Five to fifty per cent of free iron oxide present in soil may be reduced within a few weeks of flooding (Subramoney and Kurup, 1961; Ponnamperuma, 1972; Kabeerathumma and Nair, 1973; Kabeerathumma and Patnaik, 1978; Van Mensvoort *et al.*, 1984; Amma, 1988; Raju, 1988; KAU, 1994).

Iron exists in water soluble, exchangeable, organically complexed and precipitated forms in a waterlogged soil. The amount of water soluble $Fe^{2+}$ in the flooded soils is determined chiefly by the organic matter content and pH of the soil. The water soluble $Fe^{2+}$ compounds may be distinguished into ionic and chelated forms and ionic form accounts for more than 70-90 per cent while chelated forms accounts for 10-30 per cent. In some soils rich in organic matter the chelated form may account for 40 per cent of total water soluble iron (Jakobsen *et al.*, 1981; Mandal, 1991).

The amount of exchangeable $Fe^{2+}$ in rice soils increases with the decrease in the redox potential and it accounts for less than 20 per cent of total $Fe^{2+}$. Sulphide ions can compete for $Fe^{2+}$ with the cation exchange sites of the soils to form FeS precipitate, thus causing a decrease in the quantity of exchangeable $Fe^{2+}$ (Mandal, 1961; Ponnamperuma, 1972).

In flooded rice soils the organically complexed $Fe^{2+}$ usually accounts for 15-30 per cent of total $Fe^{2+}$ and the amount is closely related to soil organic matter content (Mandal, 1984).

The precipitated form of iron occupies the most important portion of $Fe^{2+}$, accounting for 60-80 per cent of the total $Fe^{2+}$ iron. In rice soils with large amount of sulphide, this proportion decreases after the addition of easily decomposable organic matter, although the absolute amount of precipitated iron increases (Mandal, 1991).

The problems of iron toxicity are often encountered in Kuttanad soils and this is more serious in kari and karappadam soils rather than kayal soils (Subramoney and Kurup, 1961; Aiyer *et al.*, 1975). The exchangeable Fe concentration of karappadam and kayal soils increases during the first few weeks of flooding and then decreases. The kari soils however, maintained the initial increase in exchangeable Fe throughout the period of flooding. The peak values of exchangeable Fe in karappadam and kayal soils are in the range of 30-270 ppm and in kari soil it is about 1508 to 3411 ppm (Kabeerathumma and Patnaik, 1978). The decrease in concentration of $Fe^{2+}$ after attainment of peak value is due to its precipitation as hydroxides resulting from increase in pH (Ponnamperuma, 1972; Kabeerathumma and Patnaik, 1978; Amma, 1988; Raju, 1988).

The different forms of Fe such as DTPA, $NH_4OAc$ and KCl extractable Fe of karappadam soils are in the range of 82-148, 6-53 and 23-1346 ppm, respectively. In kayal soils the values are in between 100-137, 16-24 and 15-427 ppm, respectively. In kari soils their concentrations are about 111-122, 5-35 and 19-385 ppm, respectively (Raju, 1988).

The free iron contents of karappadam and kari soils varie from 7031 to 17187 and 7031 to 31250, ppm respectively. The ratio of amorphous to crystalline form of Fe varies from 0.69 to 13.49 in karappadam and 0.69 to 8.2 in kari soils (Amma, 1988).

Iron toxicity has been reported at Fe levels varying between 20 ppm (Van Breeman and Moorman, 1978) and 400 ppm (IRRI, 1964). At very low levels of other nutrients or in strongly imbalanced nutrient solutions and in presence of respiration inhibitors such as $H_2S$, toxicity may appear at 30 ppm Fe. Deficiencies of P and K stimulate the uptake of excess iron (Trolldenier, 1977). Low levels of P, K, Ca and Mg rather than high levels of active Fe induce Fe toxicity (Ottow *et al.*, 1982).

Critical levels of iron toxicity are difficult to establish in plant and soil, and the wide range of critical concentrations reported in the literature make it questionable whether Fe itself is toxic to rice or is an indicator for other processes that inhibit rice growth. However, the critical limit fixed for Fe deficiency is 2 ppm in Kuttanad soils (Aiyer *et al.*, 1975). In acid condition Fe concentration of 50 ppm in solution has been found to harm rice if the concentrations of other nutrients are very low. At high nutrient concentrations, Fe concentrations up to a few hundred ppm are still tolerated. At very low concentrations of soluble Fe or at moderate concentrations in presence of adequate concentration of nutrients, particularly K, Ca and P, the rice plant takes not more than required amount of Fe.

The available Fe is significantly and positively correlated with organic carbon and CEC and negatively correlated with pH and exchangeable Ca + Mg (Subramoney and Kurup, 1961; Aiyer *et al.*, 1975; Adhikari and Si, 1991). High negative correlation exists between pH and ferrous iron (Kabeerathumma and Nair, 1973). Fe content is rather low in ploughed horizon and high in illuvial horizon and lowest in gleyed horizon (Tong, 1983).

### *3.3 Transformations of Mn*

On flooding a soil Mn(iv) and Mn(iii) hydrous oxides are reduced to $Mn^{2+}$.The reduction occurs at a higher Eh ($^{+}$200mv) than Fe(iii) oxides and precedes that of Fe(iii). Mn reduction follows an asymptotic course and in most soils it is completed within 2 weeks of submergence (Ponnamperuma, 1972; Gupta, 1974).

The reduction of Mn is both chemical and biochemical. Acid soils high in Mn and organic matter, build up water soluble Mn concentration of more than 100 ppm immediately after submergence. The level declines thereafter to a stable concentration of around 10 ppm (Mandal, 1961; Neue and Mamaril, 1984). The water soluble Mn moves down the profile in wet land rice soils. The solubility of Mn is highly dependent on pH and Eh. At pH values below 5.0 the solubility is controlled by pH alone (Patrick and Reddy, 1978).

Manganese in soils is categorised as (1) water soluble (2) exchangeable (3) easily reducible (active) and (4) difficultly soluble Mn. The easily reducible form constitutes the major part of Mn in rice soils. The reduction of Mn in flooded soil is influenced by temperature, amount of easily decomposable soil organic matter, content of active oxides of Mn and their degree of crystallinity. Application of organic matter enhances the reduction process of Fe and

Mn resulting in higher peak values and prolonged period of maintenance of increased values of $Mn^{2+}$ in solution. Fluctuating moisture regimes markedly influence the Mn transformations in soils (Mandal, 1961; Mandal and Mitra, 1982; Mandal, 1991).

The total Mn content of rice soils of Kerala is about 355 to 625 ppm in surface soils and 367 to 764 ppm in subsoils of waterlogged profiles. The water soluble Mn of these soils ranges from 1.8 to 14.8 ppm (Pisharody, 1965). The available Mn content of kayal and kari soils ranges from 4 to 33 ppm and 7 to 100 ppm, respectively. A value of 3 ppm (DTPA extractable Mn) has been fixed as the critical limit for Mn in Kuttanad soils (Aiyer *et al.*, 1975). In karappadam soils, available Mn content varied from 2 to 25 ppm (Aiyer *et al.*, 1975; Rajendran and Aiyer, 1981, KAU, 1994). The Kuttanad soils are fairly rich in Mn (Rajendran and Aiyer, 1981).

In karappadam, kayal and kari soils, exchangeable Mn content increases for about 30 to 40 days of submergence after which there is a rapid decrease. The magnitude of increase in exchangeable Mn in kari and karappadam is 10 to 20 ppm while in kayal soils it is very high. After attaining the peak value, the exchangeable Mn content decreases. The decrease is due to the formation of Mn carbonates or by removal of Mn by occlusion or sorption by hydrated Fe oxides which get precipitated at Eh-pH values that were necessary for precipitation of Mn (Kabeerathumma and Patnaik, 1978).

## 4. Distribution of Cu and Zn in Kuttanad soils

Karappadam, kayal and kari soils are deficient in available Cu (Praseedom, 1970; Aiyer *et al.*, 1975; Rajagopal *et al.*, 1977; KAU, 1994). Among the three soils Cu deficiency is much prominent in kari soils. These soils contain 0.16 to 0.22, 0.04 to 0.62 and 0.20 to 0.56 ppm of available Cu, respectively (Aiyer *et al.*, 1975). The profile samples of kayal soils showed 0.16 to 0.40 ppm of available Cu. The available Cu content increases with depth (Menon, 1975).

The total Cu content ranges from 18.8 to 23.0 ppm with an average of 19 ppm in kari soils. The total Cu is negatively correlated with pH, organic carbon and sesquioxides, while available Cu is negatively correlated with organic carbon only (Gopinath, 1973).

The Zn content of Kuttanad soils is highly variable. More than 50 per cent of the area is deficient in Zn (Aiyer *et al.*, 1975; Menon, 1975; Rajendran and Aiyer, 1981; KAU, 1994). Certain parts of Kuttanad contain substantial amount of Zn, which sometimes attains toxic levels (Ghosh *et al.*, 1973; Kuruvila and Patnaik, 1994). Karappadam, kayal and kari soils contain 0.3 to 10.5, 0.0 to 5.5 and 0.2 to 4.0 ppm available Zn, respectively (Aiyer *et al.*, 1975). The available Zn content of profile samples collected from Rani kayal, R Block kayal and Chithira kayal varies from traces to 9.0 ppm. The available Zn content increases with depth (Menon, 1975).

The total Zn content varies from 12.5 to 41.6 ppm with an average of 27 ppm in surface samples collected from Vadayar, Thuravoor and Thottapally area (Varghese, 1971).

The critical level of Zn for wetland rice has been fixed as 0.55 ppm DTPA extractable or 1 ppm of 0.05 *N* HCl+0.025 *N* $H_2SO4$ extractable Zn (Sharma *et al.*, 1986). In rice, Zn deficiency is observed when available Zn concentration is below 0.2 ppm (Aiyer, 1946). Zn deficiency is observed in many parts of Kuttanad due to antagonistic effects of dominant cations and organic complex formation (Aiyer *et al.*, 1975; Rajendran and Aiyer, 1981; KAU, 1994).

### 5. Aluminium toxicity in Kuttanad soils

Aluminium is normally the major exchangeable cation in acid soils. In wetland rice soils Al toxicity occur only in very acidic conditions. Al concentration is directly related to soil pH and toxic concentrations occurs only at pH values below 5. In acid sulphate soils the pH rise may be slower and Al toxicity may occur even after a prolonged period of flooding. The young acid sulphate soils that contain appreciable quantities of K, Mg, Fe and Al, Al toxicity is caused mainly by free Al in soil solution, but in old acid sulphate soils most of K, Mg and Fe have been leached down or transported by flood water leaving the clay with high Al saturation (Van Mensvoort *et al.*, 1984). Al toxicity in rice is likely to occur at pH 4.5-5.0 for seedlings and 3.4-4.0 for older plants (Van Breeman, 1973).

The exchangeable Al is very high in rice soils of Kerala whose pH is less than 6.0. The Al saturation of total and effective CEC in these soils is also very high and they are above the critical limits for rice (Abraham, 1984). The exchangeable Al content of karappadam, kayal and kari soils ranges from 0.22 to 22.20, 2.40 to 22.3, 4.42 to 41.20 cmol(+) $kg^{-1}$, respectively (Kabeerathumma and 'Nair, 1973; Kabeerathumma and Patnaik, 1978; Amma *et al.*, 1979; Abraham 1984; Marykutty and Aiyer, 1987; Raju, 1988, Marykutty and Aiyer, 1990). The water soluble Al contents of these soils are in the range of 2-8, 1-5 and 5-16 ppm, respectively.

Flooding decreases the exchangeable Al content of soil. Exchangeable Al decreases during the first 20-30 days after flooding and then increases in kari soils. In karappadam it remains more or less unchanged after initial decrease. The decrease was due to increase in pH resulting in hydrolysation (Kabeerathumma and Patnaik, 1978; Abraham, 1984). The polymerised forms were not replaced by 1 *N* KCl and are likely to get precipitated as $Al(OH)_3$ in the pH ranges occurring in flooded soil system (Kuruvila, 1974). Water soluble Al also decreases along with exchangeable Al due to flooding (Abraham, 1984). Exchangeable Al content of Kuttanad soil is very high and is also responsible for the hazards encountered in growing rice in these soils (Money and Sukumaran, 1973; Kabeerathumma and Patnaik, 1978; Marykutty and Aiyer, 1987; Kuruvila and Patnaik, 1994).

In karappadam and kayal soils the Al saturation varies from 47 to 62 and 37 to 41 per cent of ECEC. In kari soil it is greater than 75 per cent (Marykutty and Aiyer, 1990).

Exchangeable Al saturation is negatively correlated with pH of soils in water and in 1 *N* KCl. But a significant negative correlation exists between pH and exchangeable Al only in near neutral soils of pH 5.5-6.0 (Abraham, 1984). Different forms of Al are positively correlated with organic matter and clay fractions (Amma, *et al.*, 1979; Adhikari and Si, 1991).

The exchangeable Al content of Kuttanad soils has been effectively controlled by addition of liming materials followed by submergence. On treating these soils with liming materials @ twice the lime requirement shows zero values for exchangeable Al and the soils maintain this up to 60th day of liming (Kurup, 1967). At full lime requirement in kari soil and half lime requirement in karappadam soil the exchangeable Al decreases to zero values. The concentration of exchangeable Al decreases with time and minimum value is observed on 45th day (Kabeerathumma and Nair,1973).

In Kuttanad, flooding of soils after treatment with lime and steatite controls the rate of release of Fe and Al, but the mean value for exchangeable Al is above critical limit. However, flooding has been found to be effective in controlling the Al toxicity in these soils (Abraham, 1984).

## 6. Pesticide contamination of the environment

The wide spread use of pesticides for combating the pest and disease problems in agriculture has resulted in the contamination of the environment leading to pollution of harvested produce, soil, water, air and ultimately the human beings. In India the use of pesticides steadily increased from a meagre 4000 tonnes of technical grade material in 1960 to more than 82000 tonnes in 1991 out of which 68000 tonnes are insecticides. Among the insecticides hexachlorocyclohexane (HCH) and 1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)-ethane (DDT) alone constitute 70 per cent (SPPL, 1992). The organochlorines have a tendency to persist in the environment, and due to their high fat solubility they accumulate and magnify in various organisms. This can lead to the transfer of these toxic compounds to human beings (Siddique *et al.*, 1981; Kaphalia and Seth, 1983; Ahmad *et al.*, 1988; Bhatnagar *et al.*, 1992). On the contrary, organophosphorus and carbamate group of pesticides, being biodegradable, do not accumulate in the environment. However, most of these are highly toxic and can cause acute toxicity on consumption of the contaminated food containing these pesticides.

In Kerala, Kuttanad one of the major rice growing tract of the state is facing the serious threat of environmental pollution due to the increased and indiscriminate use of pesticides (KSSP, 1978). The pesticide consumption in Kuttanad during 1987-88 was 485 tonnes. Presently it increases to about 1000 tonnes (KSSP, 1992).

### *6.1 Degradation of pesticides*

Soil is the major sink for the bulk of pesticides applied directly to soil as granules or eventually reaching the soil after foliar application. A pesticide reaching the soil is degraded by various physical, chemical and biological forces. The processes involved are volatilization, photodecomposition and microbial degradation. Under hot and humid conditions of tropics and subtropics pesticides reaching the soil dissipate much faster than in temperate soils.

Volatilization is a major means of pesticide loss from site of its application in hot climate of tropics. Within 28 days of soil incorporation or surface application of lindane and DDT @ 10 kg ai $ha^{-1}$, the volatilization losses account for 1.33-9.3 and 0.23-2.51 kg $ha^{-1}$, respectively (Gajbhiye, 1989; Gajbhiye and Agnihotri, 1991; 1992). Maximum volatilization occurs during rainy season followed by summer season. The air around the flooded rice fields of Tamil Nadu contains 15 ng $m^{-3}$ residue of HCH and 0.28 ng $m^{-3}$ of DDT due to volatilization (Ramesh *et al.*, 1989). Soil applied carbofuran is readily absorbed by rice plants, translocated to foliage and eventually lost through evapotranspiration (Vijayalakshmi 1988).

Among the physical factors influencing residual fate of pesticides in nature, sunlight is the most significant factor. Many pesticides undergo photodecomposition in air, water and surface of soil and plant (Matsumura, 1988). In contrast to other degradation processes it is more exhaustive and non-specific leading to several additional degradation products (Dureja *et al.*, 1990).

Chemical transformation of pesticides in soil is common and widespread (Kearney and Helling, 1969). For instance carbamate (Rajagopal *et al.*, 1984) and organophosphorus (Sethunathan *et al.*, 1977) insecticides undergo rapid hydrolysis under alkaline conditions and products formed depend on the physicochemical properties of soil.

Biological degradation plays the most important role in more complete transformation of pesticides to inorganic products in soil environment (Sethunathan *et al.*, 1991). Aerobic-anaerobic interface in flooded rice soil helps in better mineralisation of complex organic pollutants than in exclusively aerobic or anaerobic systems. Anaerobic condition generated after flooding hastens the decomposition of HCH isomers in flooded soils (Drego *et al.*, 1990).

### 6.2 *Accumulation of pesticide residues in soil*

The degradation flux of different isomers of HCH in flooded rice soil increases for 60 days and then decreases (Singh *et al.*, 1989). From an agricultural soil about 99.4 per cent lindane, 96.3 per cent aldrin, 94.4 per cent dieldrin and 80.4 per cent heptachlor are lost within 180 days after application (Agnihotri *et al.*, 1977). In a sandy loam soil during monsoon both $^{14}$C-*pp*-DDT and $^{14}$C-HCH dissipate most rapidly during initial 60 days (Samuel *et al.*, 1988).

The studies on pesticide residues have been initiated in Kerala during 1974. In certain parts of Kuttanad the concentration of HCH is as high as 6000 ng kg$^{-1}$ of soil during summer season. The level of DDT is as high as 12000 ng kg$^{-1}$ of soil. In water samples the concentration of HCH and DDT are 0-400 and 0-4000 ng l$^{-1}$, respectively during the same season. Closure of Thanneermukkom barrage before the onset of summer results in water stagnation in Kuttanad, with heavy load of pesticide residues and other organic wastes (KSSP, 1992). Sunilkumar *et al.* (1994) reported the presence of detectable levels of $\alpha$-HCH (0.036-0.240 ppt) and $\gamma$-HCH (traces-0.138 ppt) in water and traces in sediments of Kuttanad. In the coastal sediments of Kerala from Cochin to Neendakara,concentrations of $\alpha$-HCH and $\gamma$-HCH ranged from 0.70 to 2.97 and 1.46 to 6.93 ng g$^{1}$, respectively during 1993-94. The highest value was obtained from Alleppey (2.97 ng g$^{-1}$ of $\alpha$-HCH and 6.93 ng g$^{-1}$ of $\gamma$-HCH). There appears to be no seasonal variation, though slightly higher values were recorded during monsoon and post-monsoon periods compared to pre-monsoon period. The concentration of $\alpha$-HCH and $\gamma$-HCH in Alleppey during monsoon, post-monsoon and pre-monsoon periods are 2.89 and 6.54; 2.97 and 6.93 and 2.13 and 6.01 ng g$^{-1}$, respectively (Balakrishnan and Ouseph, 1995). Rosalind (1995) reported the presence of HCH in water (4.43-6.66 ppb), sediments (0.97-5.43 ppb) and fish (0.080-0.430 ppb) in Kuttanad ecosystem.

The dissipation of biodegradable pesticides belonging to organophosphorus and carbamate groups are also faster in tropical conditions, though the soils are low in organic matter (Agnihotri, *et al.*, 1981; Meher *et al.*, 1985; 1989). Residues of some of the organophosphorus insecticides like chlorpyriphos and fensulfothion persist in soil for 4-6 months when applied at normal rate (@ 1.5 kg ai ha$^{-1}$). Residues of synthetic pyrithroids persist in soil for a long time particularly when incorporated into the soil (Kumar and Agnihotri, 1991).

About 20 to 80 per cent of soil applied pesticides could end up as bound residues in soil but only a very small fraction (<1% of activity) of it is translocated to the plants (Kumar, 1989; Verma and Pillai, 1990; 1991). The persistent organochlorine insecticides form comparatively less bound residues in soil than the non persistent organophosphorus and other class of pesticides (Khan, 1982).

# *Materials and methods*

# MATERIALS AND METHODS

Kuttanad is a deltaic region extending from 9° 17′ to 9° 40′N latitude and 76° 19′ to 76° 33′E longitude, situated in and around the Vembanad lake (Fig 1). The area lies 0.6 to 2.0 m below msl and presents extensive flat rice fields separated by a network of tiny drainage outlets merging with Vembanad lake. The area is prone to twin natural hazards of floods during monsoons and salinity intrusion during summer. A spillway was constructed at Thottappally to drain off excess flood water during monsoons. The discharge through the spillway is less than the designed quantity and hence it is able to control the flood incidence to a certain extent only. The salinity intrusion into Kuttanad is prevented by constructing a regulator at Thanneermukkom, and kepping closed during summer, from December to May. As a result of the above measures, major part of the area has been switched over to double cropping. The extent of flood incidence and salinity intrusion varies widely within the area. North Kuttanad is one of the most benefitted areas on account of the commissioning of Thannermukkom regulator. However, the closure of regulator and the consequent restricted water flow during summer has brought in a series of environmental problems. With these in view, the present study was envisaged to evaluate the morphological and physicochemical characteristics of soils of North Kuttanad during rainy and summer (before and after the closure of Thanneermukkom regulator) seasons.It consisted of following three parts:

1. **Morphological and physicochemical characteristics**

2. **Fertility characteristics and**

3. **Toxic characteristics** *(3.1. Native toxic characteristics and 3.2. Introduced toxic characteristics)*

## 1. Collection and preparation of soil samples

### *1.1 Morphological and physicochemical characteristics*

Profile pits were dug in the typical areas identified and the morphological features were observed and recorded as per Soil Survey Staff (1992). The salient features of the areas in respect of location, physiography, drainage, vegetation and land use were also recorded. After morphological examination of profiles, soil samples representing different layers were drawn for laboratory examination.

A part of the soil samples collected was air dried, gently powdered, passed through 2 mm sieve and stored in properly labelled polythene bags for the estimation of physical properties and total nutrient content. Other chemical parameters were estimated from the wet soil samples which were kept in plastic containers. The results were expressed on oven dry basis. Moisture content of the samples were determined simultaneously at the time of each estimation.

### *1.2 Fertility characteristics*

From the twenty seven randomly selected padasekharams of North Kuttanad comprising the villages Arpookkara, Aymanam, Kumarakom, Thiruvarpu and Kaipuzha (Fig 2), ninety seven surface soil samples from 0 to 15 cm depth were collected during rainy and summer seasons of 1993-94 (before and after the closure of Thanneermukkom regulator) and their mean values are presented. In the rainy season the samples were collected during May-June which coincides with the initial cultivation operations for additional crop. In summer, the samples were collected during January-February (after the closure of Thanneermukkom regulator) at

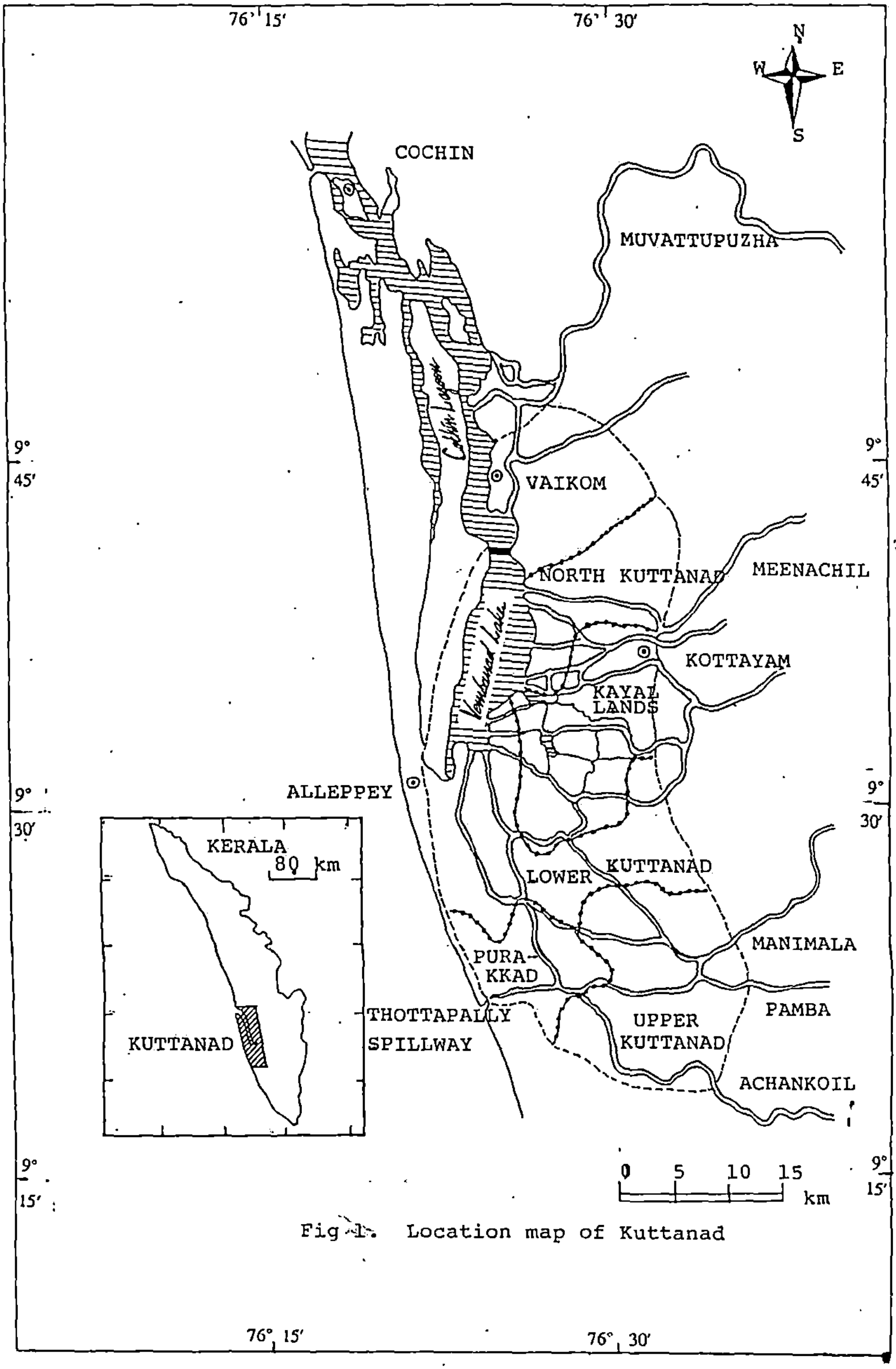


Fig 1. Location map of Kuttanad

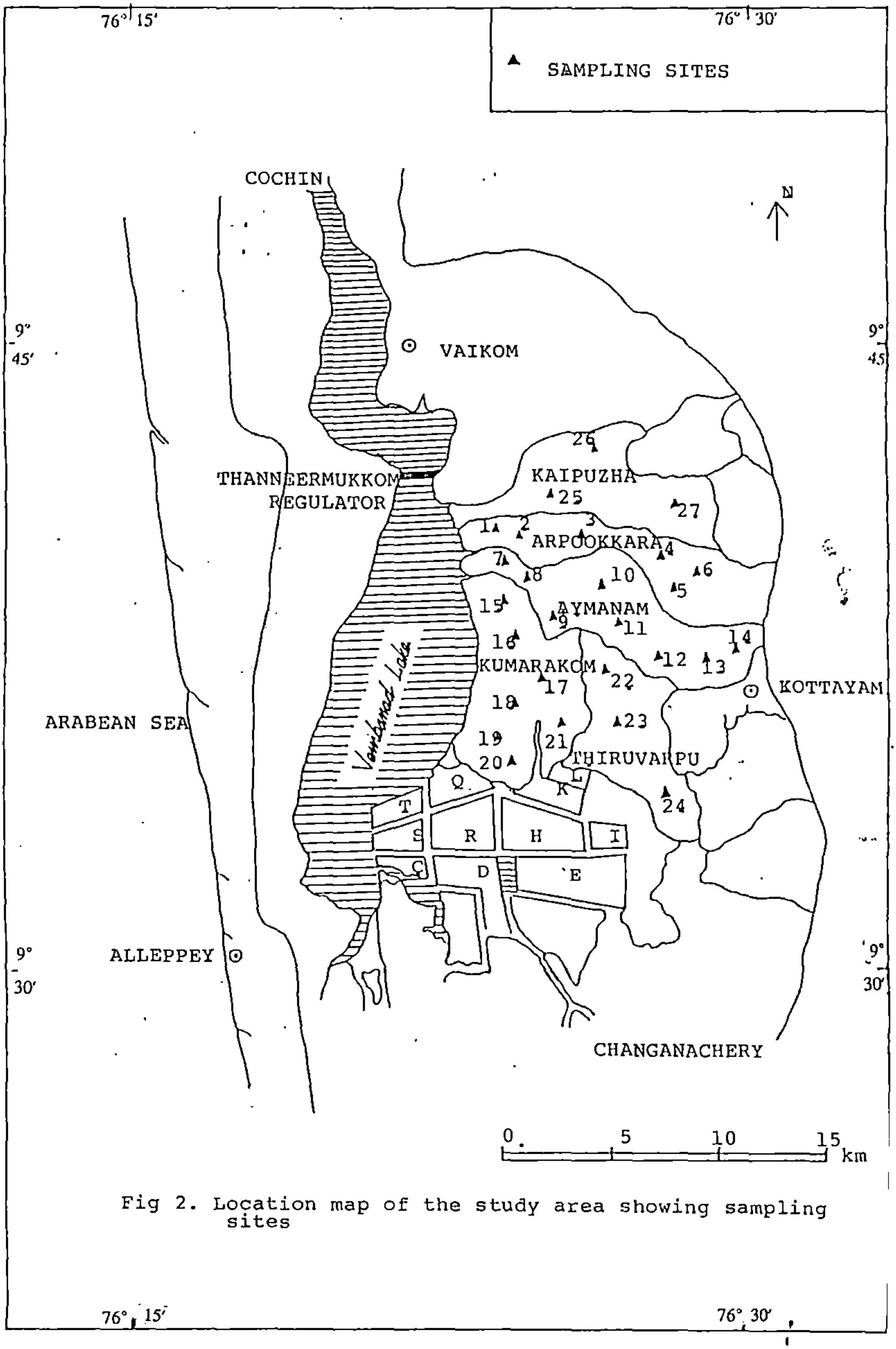


Fig 2. Location map of the study area showing sampling sites

the time of initial cultivation operations for punja crop. The soil samples were properly labelled and kept in plastic containers under wet condition for chemical analysis. The results were expressed on oven dry basis. The details of soil sampling sites are presented below:

| Site No. | Name of Padasekharam | Land Type |
|---|---|---|
| 1 | Akatheakari | Kari |
| 2 | Kelakarivattakayal | Kayal |
| 3 | Chalakari | Kari |
| 4 | Choorathranaduvilekkara | Karappadam |
| 5 | Mangalasserithollayiram | Karappadam |
| 6 | Aryattuzham | Karappadam |
| 7 | Arunoorupadasekharam | Kayal |
| 8 | Maleekayal | Kayal |
| 9 | Vattakayalthattepadam | Kayal |
| 10 | Ooloorankayal | Kayal |
| 11 | Mangattukuzhi Puthenkari | Kari |
| 12 | Thollayiramvarampinakam | Karappadam |
| 13 | Nooruparapadam | Karappadam |
| 14 | Naluthodinakam | Karappadam |
| 15 | Thekkepallipadam | Karappadam |
| 16 | Vadakkepallipadam | Karappadam |
| 17 | Keezhumuttathusseri | Karappadam |
| 18 | Kannadichal | Karappadam |
| 19 | Pothiyodupunkassery | Karappadam |
| 20 | Kadayakolmidavali | Karappadam |
| 21 | Mupaikari | Kari |
| 22 | Puthiyarapadam | Karappadam |
| 23 | Vettikad | Karappadam |
| 24 | J Block | Karappadam |
| 25 | Kakkadichalnedumchal | Karappadam |
| 26 | Nooruparamakothra | Karappadam |
| 27 | Kaipuzhakari | Kari |

### *1.3 Toxic characteristics*

*Native toxic characteristics:* Bulk soil samples to a depth of 0-25 cm were collected from the above mentioned 27 padasekharams during rainy and summer seasons of the year 1993-94 (before and after closure of Thanneermukkom regulator) and wet soil samples were properly labelled and kept in plastic containers. Along with soil samples, surface water samples from field and ground water samples from nearby wells were collected during the above two seasons, properly labelled and kept in polypropylene containers.

*Introduced toxic characteristics:* For carrying out the analysis of soil for fertiliser residues, surface soil samples (0-15 cm) and field water samples from the above mentioned twenty seven padasekharams were drawn just before draining away the water from the field at the time of fertiliser application and 4 to 7 days after it. The samples were collected at the time of basal application and topdressing with fertilisers during additional and punja crop seasons for two years (1993-94 and 1994-95). The farmers in general followed a fertiliser recommendation of 45 kg N and $P_2O_5$ as factomphos (20:20) and 30 kg $K_2O$ as muriate of potash for basal dressing and 45 kg N as urea and 30 kg $K_2O$ as muriate of potash for top dressing per hectare of rice. For the estimation of pesticide residues, soil and water samples were collected from the above sites during rainy and summer seasons (before and after the closure of Thanneermukkom regulator).

## 2. Analytical procedures

### *2.1 Soil*

*Physical properties:* Apparent and absolute specific gravity, pore space, maximum water holding capacity and volume expansion were determined by Keen-Razcowski brass cup method as described by Piper (1942). Particle size distribution of soil was determined by International pipette method as outlined by Piper (1942).Hydraulic conductivity of saturated soil was determined by constant head method as described by Black *et al.* (1965).

*Chemical properties:* The pH of soil water suspension (1:2.5) was determined using a pH meter. Electrical conductivity of the supernatant liquid of soil water suspension was read with the help of a conductivity bridge (Jackson, 1958). Organic carbon content was estimated by the method of Walkley and Black (1934) as described by Jackson (1958).

*Available nutrients:* Available N was estimated by alkaline permanganate method (Subbiah and Asija, 1956). Available P was extracted by Bray No.1 extractant (0.025 *N* HCl + 0.03 *N* $NH_4F$; soil solution ratio 1:10; period of extraction 5 min) and the P content was determined colorimetrically by the ascorbic acid reduced molybdophosphoric blue colour method in hydrochloric acid systems (Watanabe and Olsen, 1965).

Available K, Na, Ca and Mg were determined from the neutral normal ammonium acetate extract of the soil. A known weight of soil was extracted with neutral normal ammonium acetate (1:5) for 10 min and centrifuged. Three more additional extractions were done in same manner to maintain a final dilution ratio of 1:20 as described by Page (1982). The K and Na content of the samples were determined using a flame photometer (Jackson, 1958). Ca and Mg were determined by versenate titration method (Hesse, 1971).

Available S was extracted with Morgan's reagent (pH 4.5) and estimated turbidimetrically (Chesnin and Yien, 1951). Soil and Morgan's reagent (100 g sodium acetate and 30 ml 99.5 per cent acetic acid dissolved in 500 ml of water and made up to one litre) in the ratio 1:10 were shaken for half an hour and the suspension was filtered and S content in the aliquot of the extract was determined turbidimetrically.

The available Fe, Mn, Cu, Zn, Cd and Pb were estimated from the DTPA extract (soil solution ratio 1:2; period of extraction 2 h) by using an atomic absorption spectrophotometer (Lindsay and Norvell, 1978). The available Fe, Mn, Cu and Zn were determined from the diacid extract (0.05 *N* HCl + 0.025 *N* $H_2SO_4$; soil solution ratio 1:4 and period of extraction 30 min) of soil also, by atomic absorption spectrophotometry (Perkins, 1970).

Available chloride of soil was estimated from the water extract (soil solution ratio 1:5, period of extraction 1 h) of soil by titration with standard silver nitrate solution using potassium chromate as indicator (Jackson, 1958).

*Water soluble cations:* A known weight of soil was extracted with water in 1:5 ratio for 1 hour and the filtrate obtained was used for analysis (Hesse, 1971). K, Na, Ca, Mg, Fe and Mn of the extract were determined by the analytical techniques described under available nutrients. The soluble Al was determined colorimetrically by aluminon method (Hsu, 1963; Jayman and Sivasubramaniam, 1974).

*Exchangeable cations:* Exchangeable K, Na, Ca, and Mg were determined by subtracting their water soluble fractions from the neutral normal ammonium acetate extractable K, Na, Ca and Mg, respectively (Jackson, 1958). The exchangeable Fe and Mn were estimated from neutral normal ammonium acetate extract by atomic absorption spectrophotometry after subtracting the water soluble fractions (Hesse, 1971).

Cation exchange capacity was determined by neutral normal ammonium acetate method (Jackson, 1958). Base saturation was calculated by dividing the sum of exchangeable K, Na, Ca and Mg by CEC and expressed as percentage (Jackson, 1958). Effective cation exchange capacity was obtained by adding exchangeable acidity (Yuan, 1959) to the sum of exchangeable K, Na, Ca and Mg (Coleman *et al.*, 1959). Aluminium saturation was calculated by dividing exchangeable aluminium by effective cation exchange capacity and expressed as percentage of ECEC.

*Dithionite citrate extractable iron, manganese and aluminium:* A known weight of soil was extracted with a solution containing 17% sodium citrate and 1.7% sodium dithionite in a ratio of 1:120 for about 24 h (Holmgren, 1967). The Fe and Mn were determined by atomic absorption spectrophotometry. Al was estimated colorimetrically by aluminon method (Hsu, 1963; Jayman and Sivasubramaniam, 1974).

*Total nutrients:* Total N was estimated by Kjeldahl digestion and distillation (Jackson, 1958). Total content of other nutrients were determined from the nitric-perchloric acid digest. The soil was digested with nitric-perchloric acids (2:1) and made up to a constant volume (Hesse, 1971). From the extract P was determined by vanadomolybdate yellow colour method in $HNO_3$ system (Jackson, 1958). Total K, Na, Ca, Mg, S, Fe, Mn, Cu and Zn from the extract were determined by methods described under available nutrients.

*Different forms of nitrogen:* Ammoniacal, nitrite and nitrate N were determined from 2 *M* KCl extract (soil solution ratio 1:10; period of extraction 60 min) of soil by macro-Kjeldahl distillation (Bremner and Keeney, 1965). Ammoniacal N was first estimated from the 2 *M* KCl extract by distilling in presence of MgO and liberated ammonia was absorbed in boric acid and titrated against standard $H_2SO4$ using bormocresol green-methyl red mixed indicator. After the removal of ammoniacal N the distillation was continued in presence of Devarda alloy to estimate nitrite and nitrate N. The distillate was collected in boric acid and titrated against standard acid as in the case of $NH_4$ -N.

*Different forms of acidity:* Potential acidity of the soil was estimated by extracting the soil with 0.5 *M* $BaCl_2$ + 0.2 *M* Triethanolamine extractant at pH 8.2 (soil solution ratio 1:10; period of extraction 60 min) and titrating with standard HCl to a repeatable end point from green to purple using bromocresol green and methyl red-methylene blue mixed indicator (Mehlich, 1939; 1953).

Exchangeable acidity of the soil was estimated by titrating 1 *M* KCl extract of soil (soil solution ratio 1:5; period of extraction 30 min) with standard NaOH using phenolphthalein as indicator (Yuan, 1959).

The exchangeable Al was determined from the same extract after the estimation of exchangeable acidity, by adding 10 ml of 1 *N* KF and titrating against standard HCl until the pink colour disappears. Exchangeable H was estimated by subtracting exchangeable Al from exchangeable acidity (Yuan, 1959).

Hydrolytic or pH dependent acidity was calculated from the difference between potential acidity and exchangeable acidity.

### *2.2 Water*

The collected water samples were centrifuged to remove the suspended particles and the clear liquid was used for analysis. The pH, EC and water soluble P, K, Na, Ca, Mg, Fe, Mn, Cu, Zn, chloride and sulphate were determined by the analytical techniques described under available nutrients. Al in water was estimated colorimetrically by aluminon method (Hsu, 1963; Jayman and Sivasubramaniam, 1974).

The ammoniacal, nitrite and nitrate nitrogen were determined by macro-Kjeldahl distillation (Bremner and Keeney, 1965).

## 3. Residue analysis of chlorinated hydro carbon pesticides

### *3.1 Soil*

Five undisturbed soil samples were collected randomly from the surface layer of each padasekharam. The samples were mixed and 30 g of moist soil was placed in a vessel, to which 100 ml acetone and 30 ml distilled water were added and homogenised with a blender at 18000 rpm for 3min.The supernatant solution of homogenised soil was collected and 4 ml aliquot was transferred to a funnel flask, to which 10 ml of n-hexane and 150 ml of 17% NaCl solution were added and vigorously shaken by hand for 200 strokes (Goto and Kato, 1980). Sample clean up was accomplished by fractionation on a chromatographic column packed with florisil as per the specifications of APHA (1985).The column used was a packed glass column containing 3% OV-17 on chromosorb WHP and 80/100 mesh.The aliquots were analysed by gas chromatograph (Shimadzu, GC-15A) coupled with $^{63}$Ni electron capture detector.The identification and quantification of pesticide residues were performed by comparing the relative retention time and peak area with respect to that of pure organochlorine sample. The operating conditions were as follows, Column temp-230° C; injection temp-240 °C; detector temp-250° C; carrier gas- $N_2$; flow rate - 60 ml min$^{1}$

### *3.2 Water*

Half litre of water was taken in a separating funnel and 10 to 15 g NaCl was added to it. After dissolving NaCl, 50 ml of 15 per cent methylene chloride in hexane was added and thoroughly mixed and allowed to stand for 5 min. The hexane portion along with the lower water portion was again extracted with 15 per cent methylene chloride in hexane and this was continued for 3 more times, each time with 50 ml of methylene chloride in hexane. The extracted hexane was passed through an adsorbent column containing anhydrous sodium sulphate to remove water molecules in the extract. The pooled extract was evaporated to 1 ml and the remaining methylene chloride was destroyed by further addition of hexane. Rest of the analysis was followed as in the case of soil extract (Goto and Kato, 1980).

## 4. Statistical analysis

The data were subjected to statistical analysis using the analysis of variance technique for Randomised Block Design (Cochran and Cox, 1965; Panse and Sukhatme, 1985). Coefficients of simple linear correlation were worked out as described by Snedecor and Cochran (1967).

# *Results and discussion*

# RESULTS AND DISCUSSION

The present study was taken up to investigate the morphological, physical and chemical characteristics of North Kuttanad as influenced by the closure of Thanneermukkom regulator during summer and to assess the extent of toxic factors that persist in the soil due to restricted movement of water under the influence of the regulator. The salient results of this investigation are summarised below. The study consisted of three parts.

## PART 1. MORPHOLOGY AND PHYSICOCHEMICAL CHARACTERISTICS

This part of the study was carried out with the objective of evaluating the morphological and physicochemical characteristics of the North Kuttanad by examining 15 soil profiles from the area. The profile samples were collected 1 to 2 weeks prior to the opening of Thanneermukkom regulator during April, 1994.

Fifteen soil profiles were drawn from North Kuttanad at the rate of three profiles from each of the villages Arpookkara, Aymanam, Thiruvarpu, Kaipuzha and Kumarakom (Fig 2). The depth of profile samples was limited by the presence of high water table even though the profile pits were taken at a period when soil was dried upto the maximum extent possible. In general, the depth of soil profiles ranged from 69 to 110 cm.

The study area, in general, represented ill drained flat lands lying 0.6 to 2.0 m below msl, developed over marine, lucustrine and fluvial deposits. Some of the special features observed were the presence of layers of fibrous organic matter, lime shell deposits and partially decomposed wooden fragments in subsoil layers.

### 1. Morphological characteristics

The morphological features of the soils are presented in Table 1. A great deal of heterogeneity was revealed by the morphological characteristics. Hue of the soil matrix varied from 7.5 YR to 10 YR with a colour change of dark brown or dark greyish brown to black in surface soils and to dark greyish black in subsoils. The greyish colour of submerged soil is attributed to the presence of ferrous sulphide in combination with other soil constituents (Ponnamperuma, 1972). In the present study also, large quantities of Fe and S were observed in soil (Table 6).A light textured horizon was noticed in profiles I and II, which was light grey in profile I and slightly dark coloured in profile II (Plates IX and X). The colour variation was due to the difference in pigmenting and cementing substances like organic matter and clay. The light textured horizon of profile II contained 2.47 per cent organic carbon and 6.9 per cent clay while in profile I their contents were 1.30 and 1.0 per cent (Fig 3), respectively. Random deposits of lime shells were observed in profiles II and IV, apparently due to the marine nature of the parent material. Except profile IX all other soil profiles have only AC horizons reflecting their immaturity. The Kuttanad soils are young soils with immature profiles (Chattopadhyay and Sidharthan, 1985). Deposition of sand and silt by the estuarine and fluvial agencies and sedimentary nature of the parent materials resulted in the development of this type of immature profiles in Kuttanad region. Soil texture varied from sandy to clayey reflecting the strong textural variation between surface and subsoil horizons due to sedimentary

Table 1. Morphological characteristics of profiles

| Horizon | Depth cm | Colour (moist) |  | Boundary | Texture | Structure | Consistence | Remarks |
|---|---|---|---|---|---|---|---|---|
|  |  | Matrix | Mottles |  |  |  |  |  |
| **I. Akathekaripadam** |  |  |  |  |  |  |  |  |
| Ap | 0-15 | 10YR 3/2 | - | cs | scl | c 2 sbk | dh, mfi, ws, wp | Abundance of roots |
| C1 | 15-25 | 10YR 7/1 | - | cs | s | sg | dh, mvfr, wso, wpo | - |
| C2 | 25-37 | 10YR 5/1 | - | as | ls | m 2 sbk | ds, mfr, wss, wps | Humus accumulation |
| C3 | 37-77 | 10YR 2.5/1 | - | cs | c | vc 1 sbk | dsh, mfi, wss, wps | „ „ |
| C4 | 77-110+ | 10YR 3/1 | - | - | c | m 3 sbk | dvh, mefi, wvs, wvp | - |
| **II. Kelakarivattakayal** |  |  |  |  |  |  |  |  |
| Ap | 0-16 | 10YR 2.5/1 | - | cs | c | c 3 sbk | dh, mfi. ws. wp | Abundance of roots |
| C1 | 16-32 | 10YR 3/2 | - | cs | scl | c 3 sbk | dh, mfi. ws. wp |  |
| C2 | 32-42 | 10YR 3/2 | - | gw | sl | f 1 sbk | dsh, mfr, wss, wps | Presence of lime shells |
| C3 | 42-68 | 10YR 3/2 | - | gw | scl | m 3 sbk | dh, mfr, ws, wp | „ |
| C4 | 68-110 | 10YR 4/2 | - | - | sl | sg | dh, mfi, wvs, wvp | „ |
| **III. Chalakari** |  |  |  |  |  |  |  |  |
| Ap | 0-19 | 10YR 3/2 | 7.5YR 5/4, m 2 p | gw | l | c 2 sbk | dh, mfi, ws, wp | Abundance of roots |
| C1 | 19-39 | 7.5YR 3/2 | - | cs | l | vc 3 sbk | dh, mefi, ws, wp | Root canals present |
| C2 | 39-90 | 10YR 4/1 | 10YR 8/3, f 1 f | - | c | c 3 sbk | dvh, mefi, wvs, wvp | - |
| **IV. Arunoorupadasekharam** |  |  |  |  |  |  |  |  |
| Ap | 0-16 | 7.5YR 3/2 | - | dw | l | c 3 sbk | dsh, mfr. ws. wp | Abundance of roots |
| C1 | 16-30 | 7.5YR 4/2 | 7.5YR 5/4, f 1 f | dw | sl | m 3 sbk | dsh, mfr, ws, wp | Presence of root canals |
| C2 | 30-45 | 7.5YR 4/2 | 7.5YR 5/4, c 2 f | dw | sl | m 3 sbk | dsh, mfr, ws, wp | - |
| C3 | 45-70 | 7.5YR 3/0 | - | dw | sl | c 3 sbk | dl, mfr, wso, wpo | - |
| C4 | 70-100 | 7.5YR 3/2 | - | - | ls | c 3 sbk | dsh, mfr, wss, wps | Presence of lime shells |
| **V. Maleekayal** |  |  |  |  |  |  |  |  |
| Ap | 0-15 | 10YR 3/3 | - | gw | ls | m 3 sbk | dsh, mfi, ws, wp | Abundance of roots |
| C1 | 15-35 | 10YR 3/2 | 7.5YR 5/4, f 2 d | - | ls | m 2 sbk | dsh, mfr, wss, wps | - |
| C2 | 35-90 | 10YR 3/2 |  | - | ls | c 2 sbk | dsh, mfi, ws, wp | - |
| **VI. Ooloorankayal** |  |  |  |  |  |  |  |  |
| Ap | 0-17 | 10YR 3/2 | 7.5YR 5/6, c 2 d | gs | scl | c 3 sbk | dh, mfi, ws, wp | Abundance of roots and root canals |
| C1 | 17-65 | 10YR 2.5/1 | - | gs | sc | m 3 sbk | dh, mfi, ws, wp | - |
| C2 | 65-90 | 10YR 3/2 | - | - | sc | c 3 sbk | dh, mfi, ws, wp | - |
| **VII. Thekkepallipadam** |  |  |  |  |  |  |  |  |
| Ap | 0-15 | 10YR 4/2 | 7.5YR 5/4, m 1 d | cs | scl | m 2 sbk | dsh, mfi, ws, wp | Abundance of roots and root canals |
| C1 | 15-36 | 10YR 4/2 | - | gw | s | m 2 sbk | dl, mfr, wss, wps | - |
| C2 | 36-90 | 10YR 3/1 | 7.5YR 6/4, f 1 d | - | sl | m 2 sbk | dsh, mfr, wss, wps | - |

Table 1 (continued)

| Horizon | Depth cm | Colour (moist) | | Boundary | Texture | Structure | Consistence | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | Matrix | Mottles | | | | | |
| **VIII. Keezhimuttathusseri** | | | | | | | | |
| Ap | 0-15 | 10YR 4/2 | 7.5YR 6/8, c 2 p | dw | sl | c 3 sbk | ds, mfr, wso, wpo | Abundance of roots and root canals |
| C1 | 15-35 | 10YR 3/1 | 7.5YR 6/6, f 2 d | dw | sl | c 2 sbk | dsh, mfi, wss, wps | Presence of fine root canals |
| C2 | 35-78+ | 10YR 4/1 | - | - | sl | c 3 sbk | dsh, mfi, ws, wp | - |
| **IX. Kadayakolmidavali** | | | | | | | | |
| Ap | 0-20 | 10YR 4/4 | 7.5YR 5/6, m 2 d | gw | scl | vc 3 sbk | dh, mfi, ws, wp | Abundance of roots and root canals |
| Bw1 | 20-64 | 10YR 5/3 | - | gw | scl | c 2 sbk | dh, mfi, ws, wp | - |
| Bw2 | 64-95 | 10YR 5/2 | 10YR 8/3, c 2 f | - | sicl | m 2 sbk | dh, mfi, ws, wp | - |
| **X. Puthiyaripadam** | | | | | | | | |
| Ap | 0-24 | 10YR 3/2 | - | cs | sc | vc 3 sbk | dh, mfi, ws, wp | Abundance of roots |
| C1 | 24-50 | 7.5YR 2.5/0 | 10YR 8/3, f 1 d | dw | sl | c 2 sbk | ds, mfi, ws, wp | Presence of fine root canals |
| C2 | 50-85+ | 10YR 3/1 | 10YR 8/3, f 1 d | - | c | m | dvh, mefi, wvs, wvp | - |
| **XI. Vettikad** | | | | | | | | |
| Ap | 0-17 | 10YR 4/2 | 7.5YR 6/4, f 2 d | ds | sil | m 2 abk | dsh, mfi, ws, wp | Abundance of roots |
| C1 | 17-32 | 10YR 3/2 | - | gw | sil | c 3 sbk | dsh, mfi, ws, wp | - |
| C2 | 32-85 | 10YR 3/1 | - | - | sicl | c 2 sbk | dh, mfi, ws, wp | - |
| **XII. J Block** | | | | | | | | |
| Ap | 0-26 | 7.5YR 2.5/0 | - | gw | sil | m 3 sbk | dh, mfi, ws, wp | Abundance of roots and root canals |
| C1 | 26-72 | 10YR 3/2 | - | gw | sil | c 3 sbk | dh, mfi, ws, wp | - |
| C2 | 72-105 | 10YR 3/1 | 10YR 8/3, f 1 f | - | sicl | c 3 sbk | dh, mefi, ws, wp | - |
| **XIII. Kakadichalnedumchal** | | | | | | | | |
| Ap | 0-26 | 7.5YR 3/0 | 7.5YR 5/6, c 2 f | cs | c | c 3 sbk | dvh, mfi, ws, wp | Abundance of roots and root canals |
| C1 | 26-49 | 7.5YR 2.5/0 | - | gw | sic | c 2 sbk | dvh, mefi, wvs, wvp | - |
| C2 | 49-85+ | 10YR 4/1 | 10YR 8/3, f 2 d | - | cl | m | dvh, mefi, wvs, wvp | Presence of fine mica |

Table 1 (continued)

| Horizon | Depth cm | Colour (moist) | | Boundary | Texture | Structure | Consistence | Remarks |
|---|---|---|---|---|---|---|---|---|
| | | Matrix | Mottles | | | | | |
| **XIV. Nooruparamakothra** | | | | | | | | |
| Ap | 0-21 | 10YR 3/2 | 7.5YR 5/8, m 2 d | cs | sic | vc 3 sbk | dh, mfi, ws, wp | Abundance of roots |
| C1 | 21-37 | 7.5YR 2.5/0 | - | gw | c | m 3 sbk | dvh, mfi, ws, wp | - |
| C2 | 37-69+ | 10YR 4/1 | 10YR 8/3, f 2 d | - | sic | c 2 sbk | dvh, mfi, ws, wp | - |
| **XV. Kaipuzhakari** | | | | | | | | |
| Ap | 0-30 | 10YR 4/2 | 7.5YR 6/8, c 2 d | cs | sl | m 3 abk | dsh, mfi, wss, wps | Abundance of roots and root canals |
| C1 | 30-61 | 10YR 6/3 | 7.5YR 6/6, c 2 d | dws | ls | m 2 sbk | dsh, mfr, wss, wps | Presence of fine root canals |
| C2 | 61-95 | 10YR 5/2 | 7.5YR 6/6, c 2 d | - | scl | m 3 sbk | dh, mfi, ws, wp | - |

Mottles — f = few, c = common, m = many; 1 = fine, 2 = medium; f = faint, d = distinct, p = prominent

Boundary — a = abrupt, c = clear, g = gradual, d = diffused; s = smooth, w = wavy, i = irregular

Texture — s = sandy, si = silty, l = loam, c = clay

Structure — c = coarse, vc = very coarse, m = medium, f = fine; 1 = weak, 2 = moderate, 3 = strong, abk = angular blocky, sbk = subangular blocky, sg = single grain, m = massive

Consistence — d = dry, l = loose, s = soft, sh = slightly hard, h = hard, vh = very hard; m = moist, vfr = very friable, fi = firm, efi = extremely firm; w = wet, so = non-sticky, ss = slightly sticky, s = sticky, vs = very sticky, po = non-plastic, ps = slightly plastic, p = plastic, vp = very plastic

discontinuities and differential transport of eroded materials.

Faint to prominent reddish yellow or brown mottles of hue 7.5 YR to 10 YR were noticed in most of the soil profiles, right from the surface downwards due to mobilisation and immobilisation of Fe as a result of alternating oxidising and reducing conditions. In profiles I and II the mottle were not observed.

Soil structure in general was subangular blocky with occasional exceptions to massive or single grain structure. Soils were sticky and plastic. Soil clays of Kuttanad constitute a mixture of hydrous mica, montmorillonite and illite (Gopalaswamy, 1961). Large number of rice roots were observed in the Ap horizon. Reddish yellow or brown root canals were noticed in the first two layers of soil as remnants of ferric oxide deposition on root surface.

## 2. Physical characteristics (Table 2)

A definite pattern of distribution of sand, silt or clay was not observed within the profile.

Table 2. Physical characteristics of profiles

| Profile No. | Horizon | Sand | Silt | Clay | Specific gravity | | WHC | Pore space | Vol. expansion | HC cm h$^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Per cent | | | Apparent | Absolute | Per cent | | | |
| I | Ap | 64.7 | 9.0 | 24.8 | 1.05 | 2.04 | 50.7 | 56.8 | 10.18 | 3.23 |
| | C1 | 93.1 | 5.1 | 1.0 | 1.24 | 2.51 | 43.2 | 49.6 | 0.59 | 28.86 |
| | C2 | 79.3 | 5.6 | 13.3 | 0.94 | 1.75 | 55.3 | 49.1 | 5.60 | 28.86 |
| | C3 | 20.5 | 17.3 | 60.6 | 0.67 | 1.60 | 90.3 | 66.3 | 6.59 | 59.71 |
| | C4 | 22.9 | 17.2 | 59.9 | 1.13 | 1.96 | 57.4 | 58.2 | 28.52 | 4.48 |
| II | Ap | 24.2 | 23.4 | 50.9 | 0.91 | 1.82 | 63.2 | 60.8 | 13.5 | 6.97 |
| | C1 | 44.8 | 20.1 | 33.7 | 0.98 | 1.97 | 55.1 | 57.2 | 7.92 | 2.99 |
| | C2 | 80.9 | 11.5 | 6.9 | 1.19 | 2.09 | 51.1 | 55.8 | 1.87 | 29.86 |
| | C3 | 49.4 | 15.8 | 34.3 | 0.91 | 1.84 | 55.8 | 52.2 | 7.80 | 8.96 |
| | C4 | 65.1 | 18.6 | 16.3 | 1.21 | 1.80 | 47.7 | 47.3 | 26.50 | 2.50 |
| III | Ap | 25.5 | 48.2 | 25.1 | 1.15 | 2.20 | 46.6 | 54.7 | 9.62 | 3.48 |
| | C1 | 17.0 | 49.5 | 32.6 | 0.95 | 1.60 | 54.3 | 53.8 | 15.04 | 2.49 |
| | C2 | 9.1 | 38.8 | 51.1 | 1.03 | 2.27 | 61.6 | 57.9 | 12.24 | 1.00 |
| IV | Ap | 45.6 | 13.9 | 37.4 | 1.10 | 2.14 | 48.1 | 52.4 | 5.60 | 7.96 |
| | C1 | 70.4 | 12.2 | 15.3 | 1.21 | 2.69 | 42.3 | 58.2 | 1.19 | 6.47 |
| | C2 | 72.4 | 10.3 | 16.3 | 1.25 | 2.09 | 37.5 | 45.2 | 7.92 | 4.98 |
| | C3 | 84.1 | 6.6 | 8.8 | 1.34 | 2.44 | 37.0 | 48.2 | 5.15 | 9.95 |
| | C4 | 83.8 | 11.2 | 4.0 | 1.29 | 2.31 | 35.7 | 46.3 | 2.66 | 22.89 |
| V | Ap | 81.6 | 10.1 | 6.3 | 1.21 | 2.21 | 40.6 | 48.5 | 5.27 | 38.8 |
| | C1 | 84.1 | 11.6 | 4.1 | 1.29 | 2.20 | 37.0 | 45.7 | 7.59 | 20.9 |
| | C2 | 84.9 | 3.0 | 10.2 | 1.25 | 2.29 | 38.8 | 48.2 | 3.90 | 6.97 |
| VI | Ap | 44.6 | 12.8 | 41.3 | 0.96 | 2.01 | 61.2 | 60.9 | 10.70 | 3.98 |
| | C1 | 45.5 | 20.5 | 33.1 | 1.00 | 1.64 | 47.1 | 49.7 | 11.17 | 0.37 |
| | C2 | 46.5 | 18.3 | 35.0 | 0.99 | 1.82 | 50.0 | 54.6 | 10.22 | 0.54 |
| VII | Ap | 74.8 | 2.4 | 21.1 | 1.09 | 2.05 | 43.3 | 48.6 | 1.11 | 17.91 |
| | C1 | 90.8 | 3.7 | 5.2 | 1.30 | 2.18 | 30.6 | 40.9 | 0.26 | 25.88 |
| | C2 | 73.5 | 15.4 | 9.7 | 1.17 | 2.09 | 40.8 | 47.1 | 5.18 | 5.97 |

Table 2 Continued

| Profile No. | Horizon | Sand | Silt | Clay | Specific gravity | | WHC | Pore space | Vol. expansion | HC cm $h^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Per cent | | | Apparent | Absolute | Per cent | | | |
| VIII | Ap | 54.2 | 37.2 | 8.0 | 1.35 | 2.47 | 35.7 | 47.9 | 3.85 | 0.42 |
| | C1 | 57.7 | 21.0 | 19.8 | 1.20 | 2.12 | 39.5 | 47.8 | 5.07 | 1.24 |
| | C2 | 58.7 | 19.0 | 20.0 | 1.21 | 2.22 | 40.1 | 48.5 | 5.10 | 1.37 |
| IX | Ap | 52.0 | 14.9 | 31.1 | 1.21 | 2.20 | 42.2 | 50.4 | 7.78 | 5.08 |
| | Bw1 | 47.1 | 26.4 | 24.0 | 1.27 | 2.17 | 39.1 | 49.1 | 11.00 | 1.12 |
| | Bw2 | 13.7 | 54.2 | 30.5 | 1.33 | 2.14 | 44.9 | 55.8 | 28.71 | 1.37 |
| X | Ap | 44.6 | 15.5 | 38.7 | 1.03 | 1.94 | 58.3 | 57.0 | 16.72 | 0.75 |
| | C1 | 61.1 | 11.8 | 26.2 | 1.10 | 1.94 | 49.8 | 51.1 | 13.30 | 2.49 |
| | C2 | 1.8 | 25.6 | 70.4 | 1.03 | 1.92 | 53.4 | 61.5 | 16.91 | 1.49 |
| XI | Ap | 15.0 | 55.2 | 29.7 | 1.02 | 2.04 | 59.1 | 59.6 | 15.06 | 3.73 |
| | C1 | 20.0 | 56.3 | 23.2 | 1.13 | 2.15 | 46.7 | 54.3 | 10.67 | 2.99 |
| | C2 | 20.1 | 56.6 | 21.9 | 1.12 | 2.15 | 47.5 | 53.8 | 9.38 | 2.90 |
| XII | Ap | 7.0 | 65.0 | 26.5 | 1.11 | 1.92 | 53.8 | 57.5 | 17.56 | 0.87 |
| | C1 | 14.3 | 40.5 | 45.0 | 1.04 | 2.07 | 60.8 | 61.6 | 17.34 | 1.49 |
| | C2 | 13.5 | 51.1 | 33.1 | 1.05 | 2.09 | 57.7 | 62.2 | 20.80 | 3.73 |
| XIII | Ap | 5.8 | 32.0 | 61.3 | 0.96 | 1.72 | 56.0 | 55.7 | 10.76 | 1.00 |
| | C1 | 2.4 | 39.4 | 55.6 | 0.79 | 1.38 | 60.8 | 52.0 | 4.74 | 1.00 |
| | C2 | 28.0 | 32.4 | 38.6 | 1.19 | 1.97 | 47.3 | 55.3 | 22.80 | 4.98 |
| XIV | Ap | 15.0 | 42.5 | 41.4 | 0.99 | 1.89 | 55.3 | 56.4 | 11.40 | 1.22 |
| | C1 | 7.3 | 21.2 | 69.5 | 0.95 | 1.72 | 58.8 | 59.9 | 9.09 | 1.08 |
| | C2 | 5.8 | 49.6 | 42.5 | 1.04 | 2.09 | 57.8 | 59.0 | 8.53 | 1.49 |
| XV | Ap | 62.7 | 15.5 | 21.3 | 1.17 | 2.00 | 39.4 | 50.2 | 8.94 | 0.50 |
| | C1 | 72.0 | 23.1 | 4.0 | 1.36 | 2.28 | 34.3 | 49.7 | 12.05 | 11.94 |
| | C2 | 56.8 | 20.0 | 23.1 | 1.6 | 1.79 | 42.1 | 51.2 | 19.29 | 3.23 |

HC = Hydraulic conductivity

WHC = Water holding capacity

The estuarine and fluvial deposition during each year results in the development of strata with varying quantities of sand, silt and clay. The sand content of soil profiles varied from 1.8 to 93.1 per cent, clearly indicating the extent of textural variation in the study area. The range observed for silt was 2.4 to 65.0 per cent and for clay it was 1.0 to 70.4 per cent. Generally sand predominates in the Ap horizon. None of the soil profiles showed uniform sand/silt ratio indicating a lesser intensity of weathering. The Kerala soils in general, are highly weathered due to the typical topographic and climatic conditions of the state. But the peculiar physiographic position of Kuttanad retarded the profile development in this tract.

The apparent specific gravity of the profiles varied from 0.67 to 1.36 and absolute specific gravity from 1.38 to 2.69. The difference in the amount of organic matter, sand, silt and clay fractions of soil profiles accounted this variation. This has already influenced other physical properties like water holding capacity, pore space and volume expansion. Water holding capacity in general was high due to the presence of organic matter and clay in large quantities. The range observed was 30.6 to 90.3 per cent. Pore space of the profiles varied from 40.9 to 66.3 per cent. The volume expansion varied from 0.59 to 28.71 per cent which was very low for sandy layers, while the presence of clay and organic matter increased it. The hydraulic conductivity ranged from 0.37 to 59.71 cm $h^{-1}$. Even though the range observed for hydraulic conductivity was wide, most of the layers showed lower values due to the dominance of clay in soil fractions. The presence of saline water also decreases hydraulic conductivity (Antony and Koshy, 1988). The soil layers that recorded higher values were sandy, except C3 horizon of profile I that contained large quantities of fibrous organic matter which allowed easy percolation of water. The above horizon recorded the maximum hydraulic conductivity. Kerala soils in general, showed very high values for saturated hydraulic conductivity (36-50 cm $h^{-1}$) with exceptions to soils of brown hydromorphic group (Antony and Koshy, 1985). The extent of variation in texture was reflected in all the above physical parameters.

As expected, sand recorded a highly significant negative correlation with water holding capacity (-0.657$^{**}$), pore space (-0.735$^{**}$) and volume expansion (-0.537$^{**}$), while silt, clay and organic carbon showed a significant positive relationship with the above properties

Table 3. Correlation matrix showing inter-relationships among various soil properties

| Characteristics | App. sp. gravity | Ab. sp. gravity | MH WC | Pore space | Vol. expn. | HC | Sand | Silt | Clay | OC |
|---|---|---|---|---|---|---|---|---|---|---|
| App. sp. gravity | 1.000 | | | | | | | | | |
| Ab. sp. gravity | 0.762$^{**}$ | 1.000 | | | | | | | | |
| MHWC | -0.885$^{**}$ | -0.596$^{**}$ | 1.000 | | | | | | | |
| Pore space | -0.635$^{**}$ | -0.284$^{*}$ | 0.830$^{**}$ | 1.000 | | | | | | |
| Vol. expn. | -0.072 | -0.330$^{*}$ | 0.282$^{*}$ | 0.409$^{**}$ | 1.000 | | | | | |
| HC | -0.060 | 0.059 | 0.137 | -0.095 | -0.415$^{**}$ | 1.000 | | | | |
| Sand | 0.573$^{**}$ | 0.473$^{**}$ | -0.657$^{**}$ | -0.735$^{**}$ | -0.537$^{**}$ | 0.427$^{**}$ | 1.000 | | | |
| Silt | -0.174 | -0.151 | 0.288$^{*}$ | 0.441$^{**}$ | 0.457$^{**}$ | -0.427$^{**}$ | 0.790$^{**}$ | 1.000 | | |
| Clay | -0.731$^{**}$ | 0.602$^{**}$ | 0.759$^{**}$ | 0.736$^{**}$ | 0.415$^{**}$ | -0.270 | -0.825$^{**}$ | 0.306$^{*}$ | 1.000 | |
| OC | -0.680$^{**}$ | -0.667$^{**}$ | 0.709$^{**}$ | 0.465$^{**}$ | 0.334$^{*}$ | 0.090 | -0.417$^{**}$ | 0.080 | 0.583$^{**}$ | 1.000 |

MHWC - Maximum water holding capacity HC - Hydraulic conductivity $^{*}$ Significant at 5% level $^{**}$ Significant at 1% level

(Table 3) and they were significantly and negatively correlated with sand. Sand was positively and significantly correlated with hydraulic conductivity, apparent and absolute specific gravity, while clay and silt were negatively correlated with them.

## 3. Chemical characteristics

### *3.1 General soil properties (Table 4)*

Kerala soils in general are acidic in nature due to the removal of bases by intense weathering action and leaching due to heavy rainfall during monsoon seasons. The Kuttanad soils, especially the kari soils showed very high acidity. The production of free sulphuric acid on oxidation of S compounds, organic acids released from partially decomposed wooden fragments and production of $H^+$ ions by hydrolysis of Fe and Al hydroxides are responsible for the extreme acidity. The study area represented mainly karappadam type land and hence the severity of acidity was not as intense as in kari land.

The soils of the study area were invariably acidic with a pH range of 3.0 to 5.3 in surface soil and 2.0 to 6.1 in subsoil layers. Ap horizon recorded lesser acidity compared to lower layers. Liming and washing and surface drainage have washed down a part of acidity from the Ap horizon. The results of the experiments carried out at AICRP on Agricultural Drainage, Karumadi (KAU, 1988) revealed that soil acidity increases with depth. Liming and washing induce downward movement of $H^+$ ions and they get settled at deeper layers, which subsequently move to the surface layers gradually during next season (summer) in response to the water movement due to the typical hydrophysiography of the area. Providing subsurface drainage removes a major part of subsoil acidity and salinity (Mathew, *et al.*, 1993) from the soils of kari lands and promotes rice growth.

Kuttanad soils are grouped under acid saline soils showing very high acidity and salinity. The extent of salinity as indicated by EC values ranged from 0.33 to 2.63 dS $m^{-1}$ in surface soil. The subsoil layers showed still higher values for EC due to the accumulation of salts. The contribution of Na to salinity is much greater in this tract. The soil analysis data (Table 7) also revealed this, even though the quantity of Na present in soil has been reduced considerably due to the closure of Thanneermukkom regulator. The total Na content of profiles ranged from 280 to 8640 ppm (Table 6) and it accumulated mainly in lower layers. Of the total Na, a major portion was in available form (Table 7) mostly contributed by water soluble Na (Table 8). The $H^+$ ions present due to high acidity also contributed towards the increase in EC values.

The Kuttanad soils contained large quantities of organic matter either well decomposed, partially decomposed or undecomposed. The surface soil recorded 0.12 to 5.62 per cent of organic carbon and subsoil layers 0.07 to 16.22 per cent (Fig 3). An accumulation of organic carbon in lower layers was observed. The presence of sand layers, differential accumulation of organic matter and sedimentary nature of parent materials are attributed to be the reason for the heterogeneity in organic carbon distribution. Increase in organic carbon content with depth in the Kuttanad soils have been earlier reported by Menon (1975).

Average CEC of Kerala soils is 3.0 to 5.0 cmol(+) $kg^{-1}$. The soils of the study area recorded higher values for CEC due to the presence of large quantities of clay and organic matter. It ranged from 7.6 to 28.9 cmol(+) $kg^{-1}$ in surface soil. Most of the subsurface layers recorded still higher values and C3 horizon of profile I showed the highest. Clay and organic carbon contents were significantly and

Plate I. Karappadams of Kuttanad (Puthiyaripadam of Thiruvarpu village)

Plate II. Kayal lands of Kuttanad (R Block kayal)

Plate III. Rice fields of kari lands at Karumadi

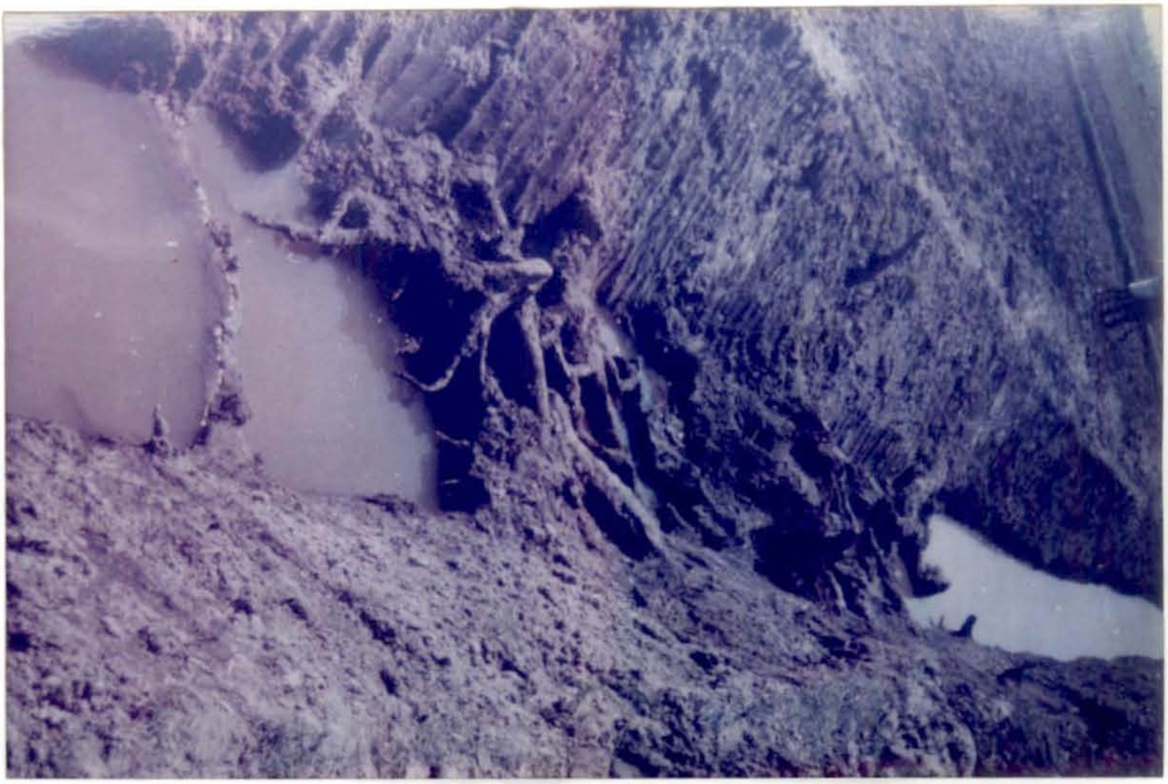


Plate IV. Wooden logs embeded in kari soils of Karumadi

Plate V. Thottapally spillway

Plate VI. Thanneermukkom regulator - a distant view

Plate VII. Thanneermukkom regulator - a closer view

Plate VIII. Road traffic through the Thanneermukkom regulator positively correlated with CEC ($0.413^{*}$ and $0.567^{**}$). The influence of organic carbon on CEC was more pronounced than that of clay content in acid soils of Kuttanad as evidenced by the higher value of correlation coefficient (Table 5). CEC estimated by neutral 1 *N* $NH_4OAc$ method gave higher values in acid soils, since the soil pH was brought towards neutrality by which additional negative charges are induced and this pH dependent charges contribute towards higher CEC. Hence effective CEC was worked out as the sum of exchangeable bases (K, Na, Ca and Mg) and exchangeable acidity.

Table 4. General properties of soils

| Profile No | Horizon | OC | pH | EC | ECEC | CEC | PBS |
|---|---|---|---|---|---|---|---|
| | | % | | dS $m^{-1}$ | cmol(+) $kg^{-1}$ | | |
| I | Ap | 3.00 | 4.5 | 1.39 | 6.56 | 19.0 | 22.9 |
| | C1 | 1.30 | 3.3 | 3.76 | 5.48 | 15.9 | 23.8 |
| | C2 | 2.82 | 2.0 | 8.93 | 28.59 | 33.0 | 34.6 |
| | C3 | 16.22 | 2.6 | 6.18 | 23.12 | 62.4 | 32.2 |
| | C4 | 8.58 | 3.3 | 5.78 | 19.97 | 29.5 | 55.6 |
| II | Ap | 5.62 | 3.8 | 2.32 | 12.32 | 16.4 | 48.7 |
| | C1 | 8.40 | 2.8 | 4.52 | 7.60 | 10.7 | 15.5 |
| | C2 | 2.47 | 2.4 | 1.57 | 6.66 | 12.7 | 26.9 |
| | C3 | 5.80 | 2.5 | 5.49 | 8.54 | 10.3 | 9.1 |
| | C4 | 12.98 | 3.3 | 4.72 | 28.03 | 34.7 | 76.7 |
| III | Ap | 2.62 | 4.2 | 0.71 | 5.16 | 14.9 | 7.5 |
| | C1 | 2.86 | 4.1 | 0.60 | 6.19 | 16.8 | 14.5 |
| | C2 | 2.68 | 2.8 | 4.87 | 12.79 | 18.8 | 18.5 |
| IV | Ap | 1.99 | 3.9 | 0.62 | 8.52 | 12.7 | 42.1 |
| | C1 | 1.24 | 4.4 | 0.45 | 4.05 | 10.9 | 17.6 |
| | C2 | 1.12 | 4.6 | 0.49 | 5.47 | 7.8 | 50.7 |
| | C3 | 0.69 | 4.4 | 0.64 | 8.74 | 9.9 | 77.5 |
| | C4 | 0.36 | 4.6 | 0.49 | 5.47 | 7.6 | 56.1 |
| V | Ap | 0.64 | 4.6 | 1.14 | 7.69 | 7.6 | 74.6 |
| | C1 | 0.28 | 6.1 | 2.34 | 4.02 | 8.7 | 40.2 |
| | C2 | 1.03 | 5.5 | 1.52 | 7.10 | 11.0 | 48.1 |
| VI | Ap | 5.23 | 4.1 | 0.55 | 18.00 | 23.7 | 34.7 |
| | C1 | 9.68 | 4.3 | 2.44 | 16.90 | 24.6 | 49.0 |
| | C2 | 6.80 | 4.2 | 1.88 | 14.46 | 22.4 | 44.9 |
| VII | Ap | 0.36 | 5.0 | 0.62 | 9.44 | 19.1 | 26.8 |
| | C1 | 0.79 | 3.4 | 1.21 | 3.70 | 17.0 | 10.2 |
| | C2 | 1.31 | 4.8 | 1.00 | 7.44 | 19.0 | 24.5 |

|  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
|  | C1 | 0.77 | 4.2 | 0.47 | 8.09 | 22.1 | 26.0 |
|  | C2 | 1.49 | 4.2 | 0.40 | 7.82 | 20.2 | 28.9 |
| IX | Ap | 0.12 | 4.8 | 0.33 | 5.75 | 15.1 | 33.7 |
|  | Bw1 | 0.07 | 5.5 | 0.39 | 9.69 | 15.1 | 61.0 |
|  | Bw2 | 2.75 | 3.3 | 3.06 | 13.61 | 32.6 | 38.0 |
| X | Ap | 2.80 | 3.7 | 2.03 | 12.49 | 28.9 | 25.7 |
|  | C1 | 5.42 | 2.9 | 4.77 | 14.50 | 32.2 | 26.8 |
|  | C2 | 5.21 | 3.3 | 4.31 | 26.00 | 35.5 | 51.6 |
| XI | Ap | 2.92 | 5.3 | 0.57 | 9.17 | 17.8 | 26.5 |
|  | C1 | 2.89 | 4.5 | 0.56 | 9.32 | 21.9 | 26.6 |
|  | C2 | 2.81 | 4.2 | 0.71 | 7.85 | 14.9 | 33.4 |
| XII | Ap | 1.11 | 3.9 | 1.03 | 20.85 | 27.6 | 48.2 |
|  | C1 | 3.87 | 3.0 | 3.09 | 22.61 | 30.0 | 34.7 |
|  | C2 | 6.10 | 3.2 | 2.68 | 22.08 | 28.9 | 47.8 |
| XIII | Ap | 3.31 | 3.3 | 1.59 | 16.02 | 22.9 | 16.7 |
|  | C1 | 10.97 | 3.1 | 4.06 | 17.54 | 23.7 | 33.0 |
|  | C2 | 3.96 | 3.2 | 2.76 | 22.33 | 25.5 | 37.4 |
| XIV | Ap | 4.77 | 3.5 | 1.46 | 17.32 | 21.7 | 44.0 |
|  | C1 | 6.69 | 3.8 | 1.34 | 15.16 | 17.1 | 42.0 |
|  | C2 | 3.37 | 2.8 | 5.14 | 24.02 | 21.9 | 67.5 |
| XV | Ap | 1.89 | 3.0 | 2,63 | 15.07 | 27.8 | 10.9 |
|  | C1 | 0.22 | 2.5 | 7.13 | 5.52 | 29.5 | 4.0 |
|  | C2 | 1.71 | 4.5 | 4.80 | 10.31 | 35.3 | 3.2 |

PBS = Percentage base saturation

ECEC values were lower than that of CEC, and it ranged from 5.16 to 20.85 cmol(+) kg$^{-1}$ in surface soils. ECEC also showed positive and significant correlation with clay and organic carbon (0.559$^{**}$, 0.599$^{**}$).

The base saturation showed a very wide range which extended from 3.2 to 77.5 per cent. This was evidently due to the strong textural variation of the soil from sandy to clayey and difference in organic matter content. The influence of clay on percentage base saturation is also very clear from its highly significant positive correlation with it (0.940$^{**}$). However, in the present study the correlation between organic carbon and percentage base saturation was not significant.

The percentage base saturation was negatively correlated with all the acidity contributing characteristics but the inter-relationships were not significant.

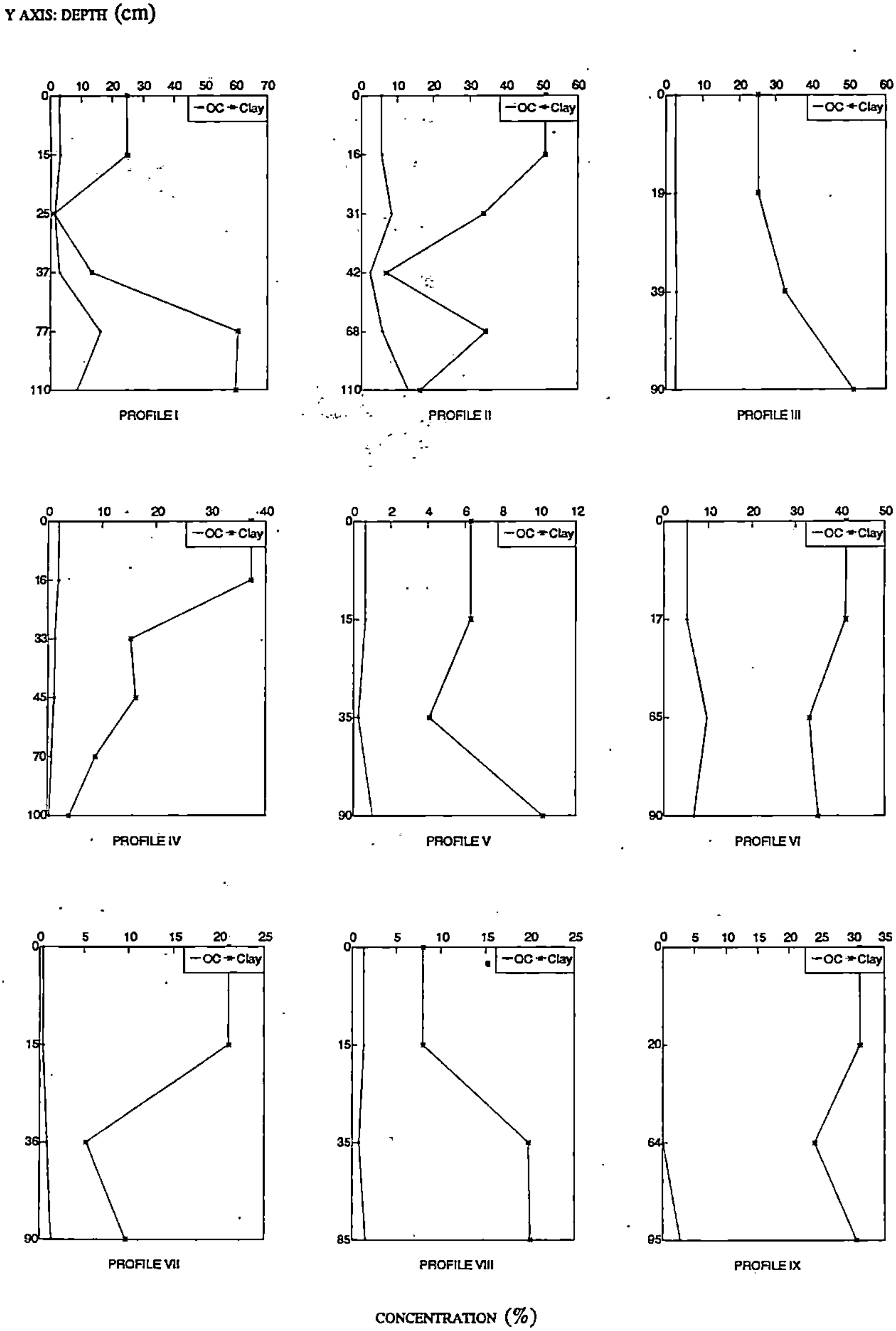


Fig 3. Distribution of clay and organic carbon in soil profiles of North Kuttanad

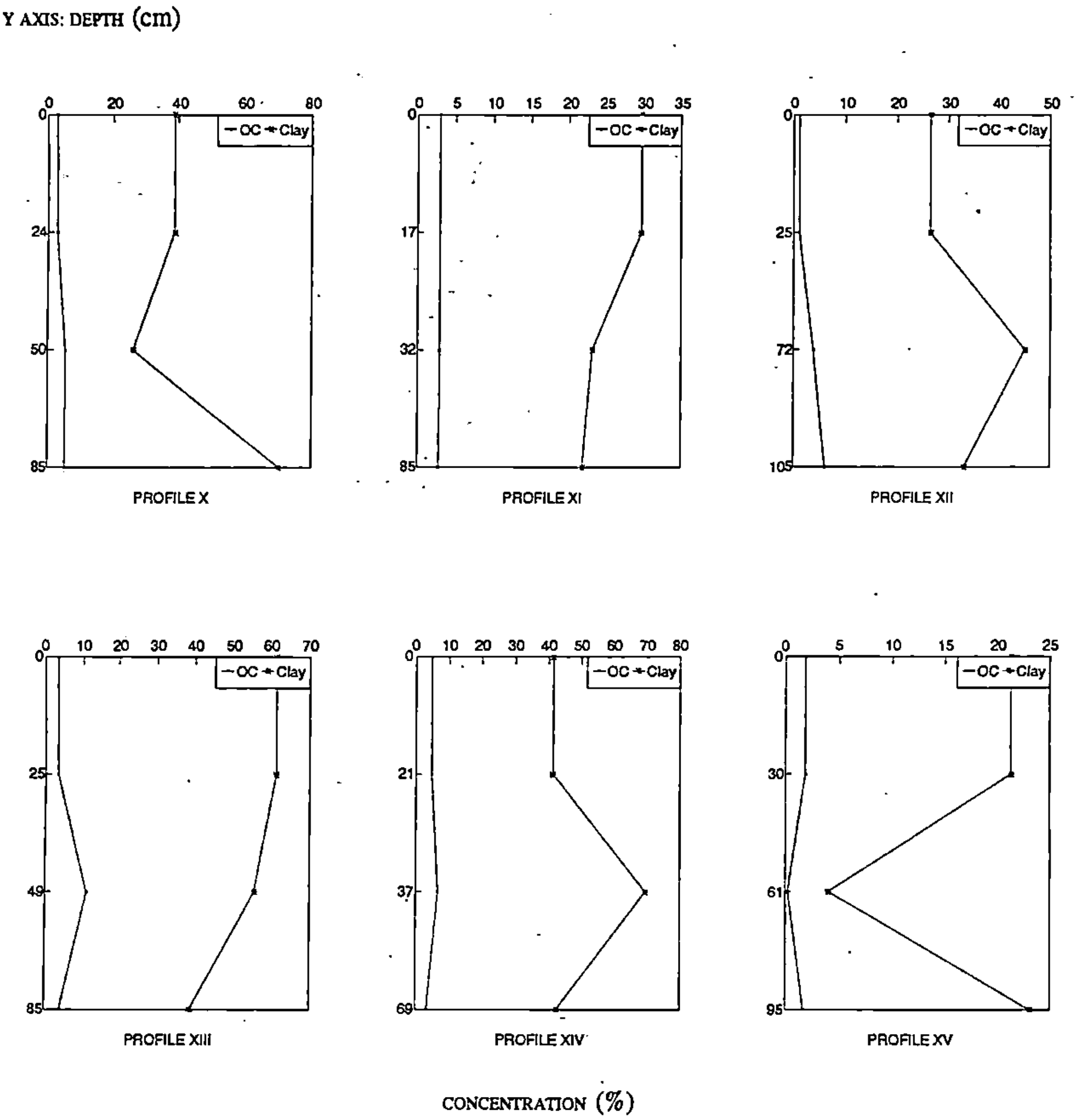


Fig 3. (continued) Distribution of clay and organic carbon in soil profiles of North Kuttanad

### *3.2 Total nutrients (Table 6)*

The Kerala soils are medium in total N content. But the Kuttanad soils are an exception to this. The total N content of the study area varied from 0.02 to 0.54 per cent in surface layers. and 0.02 to 1.10 per cent in subsoil layers. The soil layers that showed very low values for total N were sandy with low organic carbon content. Major part of the study area recorded medium to high N content.

About 63 per cent of Kerala soils are medium to high in total P. Nair (1986) classified the soils having a total P content of 451 to 900 ppm in the medium range.The total P content of surface soils ranged from 69 to 982 ppm.Out of these soils 67 per cent was rated as low, 26 per cent as medium and 7 per cent as high. Surface layers showed higher total P status compared to subsoil layers, presumably due to application of P fertilisers,low mobility and greater retention and fixation of P by clays and sesquioxides.

Table 5. Correlation matrix showing inter-relationships among various soil characteristics

| Characteristics | Clay | OC | pH | EC | CEC | PBS | Poten. acidity | Hydr. acidity | Exch. acidity | Exch. $H^+$ | Exch. $Al^{3+}$ | ECEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Clay | 1.000 | | | | | | | | | | | |
| OC | 0.583** | 1.000 | | | | | | | | | | |
| pH | -0.324* | -0.434** | 1.000 | | | | | | | | | |
| EC | 0.226 | 0.460** | -0.703** | 1.000 | | | | | | | | |
| CEC | 0.413** | 0.567** | -0.472** | 0.562** | 1.000 | | | | | | | |
| PBS | 0.940** | 0.156 | 0.204 | 0.100 | -0.069 | 1.000 | | | | | | |
| Poten. acidity | 0.578** | 0.598** | -0.608** | 0.530** | 0.699** | -0.163 | 1.000 | | | | | |
| Hydr. acidity | 0.548** | 0.605** | -0.567** | 0.497** | 0.692** | -0.143 | 0.993** | 1.000 | | | | |
| Exch. acidity | 0.464** | 0.204 | -0.561** | 0.472** | 0.360** | -0.214 | 0.489** | 0.379** | 1.000 | | | |
| Exch. $H^+$ | 0.452** | 0.170 | -0.481** | 0.438** | 0.313* | -0.191 | 0.434** | 0.326* | 0.962** | 1.000 | | |
| Exch. $Al^{3+}$ | 0.386** | 0.222 | -0.589** | 0.430** | 0.372** | -0.210 | 0.488** | 0.398** | 0.854** | 0.680** | 1.000 | |
| ECEC | 0.559** | 0.599** | -0.518** | 0.517** | 0.685** | 0.389** | 0.585** | 0.533** | 0.626** | 0.588** | 0.565** | 1.000 |

* Significant at 5% level ** Significant at 1% level PBS - Percentage base saturation

The major rice soils of Kerala contained fairly high amounts of total and exchangeable K and the highest amount of total K was found in the fine sand fraction in all the soil types (Godwin, 1986). The Kuttanad soils are well supplied with total K (Brito-Mutunayagam, 1961). The range observed for total K in the present study was 440 to 3600 ppm in surface soils. The lower layers recorded comparatively higher content of total K due to accumulation of salt in the subsoil.

Generally, the different soil groups of Kerala are deficient in Ca and Mg reserves, except black soils due to the removal of bases by the action of rain water. The Kuttanad soils were reported to contain large quantities of Ca and Mg due to their marine origin. The surface soils recorded 0.20 to 1.60 per cent of total Ca. The subsurface layers contained larger quantities of Ca than the surface layers, but a definite pattern of variation with depth was not observed. Mg also showed a similar pattern of distribution. It ranged from 0.06 to 1.68 per cent in the surface soil. None of these soils was deficient in Mg since they contained more than 250 ppm of total Mg, the critical level suggested by Prema (1992) for Mg deficiency. The subsurface layers having high Mg content showed lower Ca content.

The Kuttanad soils are rich in S due to the presence of large quantities of iron and aluminium sulphides (Money, 1961a). In the present study the total S content of profile samples varied from 0.15 to 7.12 per cent. The profiles collected from Kaipuzha village recorded very high values for S in all the layers indicating the presence of large quantities of Fe and Al sulphides (Table 6).

The micronutrient status of Kuttanad soils was reported to be high except for Cu (KAU, 1994). Compared to Zn and Cu, Mn is present in larger quantities. The total Mn content of the profile samples ranged from 34 to 354 ppm. Its distribution did not follow any definite pattern. Total Cu contents of the study area ranged from 2 to 84 ppm. Among the micronutrients, Cu was present in the smallest quantity. According to Tandon (1995), more than 90 per cent of the area in Kerala state is deficient in Cu. The total Zn content of the area ranged from 8 to 122 ppm.

Table 6. Total nutrient content of soils

| Pro-file No. | Hori-zon | N % | P | K | Na | Ca | Mg | S | Fe | Mn | Cu | Zn | Al % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (ppm) | | | % | | | | (ppm) | | | |
| I | Ap | 0.54 | 220 | 1420 | 960 | 0.60 | 0.60 | 1.07 | 4.43 | 34 | 12 | 86 | 3.39 |
| | C1 | 0.18 | 18 | 360 | 1240 | 0.60 | 0.30 | 0.51 | 3.52 | 90 | 18 | 40 | 0.82 |
| | C2 | 0.35 | 115 | 1080 | 1680 | 1.60 | 0.06 | 1.52 | 3.29 | 78 | 24 | 32 | 1.45 |
| | C3 | 1.57 | 124 | 1320 | 8640 | 0.40 | 0.30 | 4.42 | 4.72 | 128 | 26 | 54 | 2.11 |
| | C4 | 0.91 | 418 | 4080 | 5600 | 0.60 | 0.12 | 4.59 | 7.51 | 354 | 32 | 56 | 4.77 |
| II | Ap | 0.49 | 330 | 3200 | 1840 | 0.80 | 1.68 | 1.07 | 4.30 | 88 | 50 | 52 | 8.28 |
| | C1 | 0.82 | 161 | 2240 | 2320 | 1.40 | 0.24 | 2.70 | 4.13 | 76 | 36 | 32 | 4.88 |
| | C2 | 0.21 | 133 | 1120 | 1080 | 0.80 | 0.18 | 2.87 | 4.74 | 36 | 12 | 44 | 1.91 |
| | C3 | 0.51 | 27 | 2000 | 1800 | 0.60 | 0.24 | 4.37 | 5.62 | 130 | 34 | 68 | 3.48 |
| | C4 | 1.10 | 220 | 1520 | 5840 | 1.80 | 0.24 | 1.26 | 3.48 | 108 | 24 | 8 | 3.87 |
| III | Ap | 0.21 | 665 | 1200 | 720 | 0.50 | 0.54 | 0.64 | 8.67 | 34 | 44 | 62 | 9.41 |
| | C1 | 0.24 | 239 | 3360 | 1040 | 1.00 | 0.30 | 0.77 | 4.04 | 36 | 50 | 48 | 10.16 |
| | C2 | 0.20 | 248 | 3560 | 1720 | 0.60 | 0.78 | 3.99 | 6.96 | 40 | 24 | 68 | 3.26 |
| IV | Ap | 0.16 | 69 | 800 | 400 | 1.40 | 0.72 | 0.15 | 2.93 | 60 | 20 | 22 | 2.62 |
| | C1 | 0.11 | 220 | 1160 | 360 | 1.30 | 0.72 | 0.43 | 3.27 | 46 | 22 | 58 | 3.53 |
| | C2 | 0.09 | 399 | 1120 | 640 | 2.60 | 0.18 | 1.09 | 11.01 | 350 | 44 | 60 | 3.20 |
| | C3 | 0.07 | 270 | 760 | 520 | 1.31 | 0.07 | 1.01 | 11.36 | 336 | 34 | 64 | 2.07 |
| | C4 | 0.05 | 229 | 880 | 520 | 1.59 | 0.31 | 1.11 | 5.40 | 190 | 26 | 76 | 2.05 |
| V | Ap | 0.05 | 234 | 760 | 560 | 1.60 | 0.18 | 1.14 | 5.45 | 218 | 28 | 56 | 2.07 |
| | C1 | 0.02 | 248 | 840 | 520 | 1.00 | 0.18 | 0.36 | 2.75 | 98 | 50 | 62 | 1.97 |
| | C2 | 0.11 | 106 | 1160 | 840 | 0.80 | 0.60 | 3.69 | 3.49 | 100 | 14 | 46 | 2.52 |
| VI | Ap | 0.43 | 729 | 1920 | 800 | 0.30 | 0.96 | 1.05 | 5.59 | 74 | 36 | 64 | 7.38 |
| | C1 | 0.87 | 349 | 2720 | 2640 | 0.80 | 0.78 | 1.29 | 5.22 | 66 | 82 | 54 | 5.27 |
| | C2 | 0.62 | 303 | 2020 | 2520 | 0.80 | 0.72 | 1.14 | 4.88 | 88 | 64 | 56 | 4.81 |
| VII | Ap | 0.03 | 243 | 960 | 440 | 0.90 | 0.36 | 0.51 | 2.75 | 44 | 14 | 38 | 2.44 |
| | C1 | 0.06 | 73 | 600 | 400 | 0.90 | 0.48 | 0.51 | 10.72 | 36 | 2 | 14 | 1.61 |
| | C2 | 0.14 | 349 | 1200 | 560 | 0.90 | 0.48 | 0.54 | 3.01 | 90 | 14 | 44 | 5.27 |

Table 6 Continued

| Profile No. | Horizon | N % | P | K | Na | Ca | Mg | S | Fe | Mn | Cu | Zn | Al % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (ppm) | | | % | | | | (ppm) | | | |
| VIII | Ap | 0.14 | 229 | 440 | 280 | 1.10 | 0.06 | 0.28 | 1.62 | 52 | 6 | 32 | 1.76 |
| | C1 | 0.08 | 390 | 1800 | 440 | 0.60 | 0.66 | 0.39 | 4.59 | 70 | 20 | 38 | 5.31 |
| | C2 | 0.13 | 320 | 1420 | 420 | 0.55 | 0.66 | 0.37 | 4.87 | 94 | 18 | 40 | 4.23 |
| IX | Ap | 0.02 | 321 | 1360 | 520 | 0.30 | 0.90 | 0.41 | 7.10 | 64 | 36 | 88 | 6.52 |
| | Bw1 | 0.01 | 248 | 1320 | 640 | 0.40 | 1.32 | 0.41 | 5.19 | 94 | 34 | 64 | 5.08 |
| | Bw2 | 0.30 | 303 | 3200 | 1840 | 0.20 | 1.32 | 2.08 | 5.33 | 156 | 32 | 122 | 4.96 |
| X | Ap | 0.26 | 271 | 880 | 1260 | 0.40 | 0.72 | 0.47 | 3.77 | 50 | 16 | 30 | 4.18 |
| | C1 | 0.51 | 220 | 3760 | 3520 | 0.40 | 0.72 | 4.80 | 6.96 | 122 | 30 | 62 | 6.52 |
| | C2 | 0.47 | 413 | 4200 | 4040 | 1.30 | 0.72 | 5.14 | 8.06 | 236 | 30 | 70 | 7.62 |
| XI | Ap | 0.26 | 982 | 2880 | 880 | 0.20 | 0.84 | 1.24 | 8.00 | 42 | 42 | 54 | 8.13 |
| | C1 | 0.29 | 596 | 3080 | 800 | 0.30 | 0.66 | 0.64 | 7.94 | 50 | 48 | 70 | 5.39 |
| | C2 | 0.25 | 665 | 2960 | 860 | 0.30 | 0.62 | 0.77 | 7.82 | 74 | 46 | 76 | 5.14 |
| XII | Ap | 0.10 | 500 | 3600 | 960 | 0.70 | 1.02 | 1.33 | 7.10 | 60 | 42 | 58 | 8.12 |
| | C1 | 0.39 | 509 | 3720 | 2280 | 0.50 | 1.08 | 1.67 | 9.39 | 64 | 32 | 56 | 5.39 |
| | C2 | 0.49 | 253 | 2840 | 5000 | 0.40 | 1.14 | 5.02 | 5.54 | 60 | 16 | 42 | 3.14 |
| XIII | Ap | 0.29 | 390 | 2160 | 1280 | 0.30 | 0.66 | 1.22 | 6.62 | 88 | 46 | 54 | 8.98 |
| | C1 | 1.06 | 83 | 1360 | 3640 | 0.30 | 0.72 | 1.67 | 2.95 | 144 | 84 | 48 | 2.38 |
| | C2 | 0.35 | 202 | 5000 | 1960 | 0.70 | 1.20 | 4.46 | 8.26 | 304 | 34 | 46 | 7.26 |
| XIV | Ap | 0.40 | 284 | 2560 | 1440 | 0.40 | 0.40 | 1.22 | 10.20 | 88 | 46 | 46 | 7.42 |
| | C1 | 0.53 | 202 | 2640 | 1600 | 0.90 | 0.40 | 1.67 | 5.09 | 90 | 42 | 74 | 7.77 |
| | C2 | 0.32 | 551 | 5000 | 4320 | 0.80 | 0.90 | 4.46 | 9.48 | 322 | 28 | 58 | 6.50 |
| XV | Ap | 0.21 | 881 | 1760 | 720 | 0.30 | 0.66 | 3.47 | 5.39 | 52 | 20 | 58 | 8.98 |
| | C1 | 0.12 | 1330 | 1680 | 280 | 0.40 | 1.92 | 4.37 | 10.96 | 52 | 38 | 78 | 9.10 |
| | C2 | 0.16 | 569 | 2040 | 600 | 0.80 | 0.42 | 7.12 | 15.80 | 76 | 36 | 56 | 7.77 |

### *3.3 Fe and Al toxicity*

The contents of Fe and Al are high in Kerala soils. The intense weathering and leaching due to heavy rainfall remove the exchangeable bases from soil and result in the accumulation of Fe and Al. The incidence of Fe and Al toxicity has been reported from many places in Kerala. It is a frequent phenomenon in Kuttanad due to the large quantities of Fe and Al present in soluble form. The high acidity and reduced soil conditions will keep iron in soluble $Fe^{2+}$ form, affecting the concentration of other cations. The cations displaced from the exchange complex may be lost by leaching and on oxidation the soil gets acidified.

The total Fe content of surface soils ranged from 1.62 to 10.20 per cent (Table 6). The total Fe of subsurface layers was still higher due to the downward movement and accumulation in response to the water movement as a result of peculiar hydro-physiography of the area. The available Fe also showed a similar trend as that of total Fe and ranged from 121 to 538 ppm (Table 7) in surface soil. An irregular increase in available Fe concentration with depth was observed. Iron toxicity has been reported at Fe levels varying between 20 ppm (Van Breeman and Moorman, 1978) to 400 ppm (IRRI, 1964) in soil solution. Generally the Fe toxicity symptoms will appear only at 300 to 500 ppm of available Fe. But at low levels of P, K, Ca and Mg, it may appear even at very low concentration of Fe in soil (Ottow *et al.*, 1982).The study area is highly susceptible to Fe toxicity (Plates XVIII and XIX) since majority of samples recorded values above 300 ppm for available Fe and the Fe:P ratio is very high. Even after proper management practices the available Fe of the area varied between 358 and 421 ppm (Table 15) under submerged condition. Available Fe content of soil depends on total Fe content, crystallinity of Fe oxides, soil texture, organic matter content, soil reaction, redox potential and position of capillary fringe. The closure of Thanneermukkom regulator during summer had resulted in an accumulation of leachates brought down by the rivers from the upper fringes of eastern hills which also finally results in an enhancement of Fe and Al concentration in the area.

The total Al content of soils ranged from 0.82 to 10.16 per cent (Table 6). Al also did not follow any definite pattern of distribution within the profile. However, greater concentration was observed in surface layer in contrast to the distribution of Fe. The acidity of the soils highly influenced the Al content. If the soil pH is less than 3.5 it will damage the alumino-silicate structure of clay minerals which will result in the release of Al from the disrupted structure.The pH of soil regulates the hydrolysis and release of Al from clay minerals. The exchangeable $Al^{3+}$ content ranged from 0.33 to 5.99 cmol(+) $kg^{-1}$ in surface soils (Table 9). Al toxicity in rice usually occurs at a pH of 4.5 to 5.0 for seedlings and 3.4 to 4.0 for older plants (Van Mensvoort *et al.*, 1984). In the study area about 46 per cent of the samples recorded a pH below 4.0 under maximum dried condition of soil. The lower layers were more acidic than surface layers and hence there is every chance for Al toxicity in the study area on soil drying. Compared to Fe toxicity, Al toxicity is less severe since the solubility of Al decreases rapidly above a soil pH of 4.0, which can be much easily attained by flooding and other soil management practices. This was further confirmed from the Al content of field water (Table 32) which was very negligible indicating that the management practises could alleviate the Al toxicity to a considerable extent in the study area.

### *3.4 Available nutrients (Table 7)*

In general, Kerala soils are medium in their available N content. Available N content of surface soils under this study ranged from 81 to 319 ppm. The soils are rated under medium to high category. The available N also followed the same trend as that of total N.

The surface horizons showed a range of 0.92 to 7.55 ppm of available P. The soils in the study area were generally deficient in available P. The high P fixation capacity of the soil results in P deficiency (Kuruvila and Patnaik, 1994). Available P was comparatively greater in lower layers since the crop removed P mainly from the surface layers.

The available K of surface soil ranged from 14 to 408 ppm. About 8.0 per cent of the area was rated under high, 78.7 per cent under medium and 13.3 per cent under low as per soil test criteria followed in Kerala. The lower layers recorded higher available K content similar to that of total K due to salt accumulation.

Table 7. Available nutrient content of soils (ppm)

| Profile No. | Horizon | N | P | K | Na | Ca | Mg | S | Fe | Mn | Cu | Zn | $Cl^-$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I | Ap | 202 | 2.70 | 213 | 895 | 621 | 172 | 829 | 329 | 0.50 | 0.64 | 5.10 | 753 |
| | C1 | 56 | 4.27 | 121 | 1212 | 824 | 436 | 1895 | 334 | 0.65 | - | 2.57 | 956 |
| | C2 | 87 | 5.15 | 98 | 1628 | 1289 | 774 | 3943 | 462 | 80.10 | 1.76 | 11.13 | 58 |
| | C3 | 235 | 8.35 | 435 | 8477 | 2817 | 1408 | 10528 | 487 | 66.25 | - | 24.52 | 6636 |
| | C4 | 140 | 41.05 | 963 | 5279 | 2347 | 2549 | 7957 | 488 | 235.00 | - | 7.07 | 5622 |
| II | Ap | 319 | 2.40 | 408 | 1684 | 1404 | 268 | 2632 | 395 | 1.06 | 0.64 | 1.74 | 1070 |
| | C1 | 176 | 3.53 | 198 | 2294 | 1201 | 450 | 3356 | 469 | 15.51 | 1.50 | 7.55 | 1850 |
| | C2 | 77 | 5.34 | 45 | 1052 | 1245 | 455 | 3452 | 305 | 13.35 | 2.00 | 3.07 | 54 |
| | C3 | 157 | 3.72 | 73 | 1574 | 1055 | 198 | 4494 | 669 | 25.28 | 2.64 | 29.90 | 65 |
| | C4 | 338 | 8.80 | 615 | 5732 | 2951 | 2213 | 7043 | 512 | 145.88 | 8.85 | 16.31 | 5092 |
| III | Ap | 241 | 1.59 | 150 | 702 | 664 | 512 | 1749 | 293 | 5.48 | 5.48 | 1.26 | 312 |
| | C1 | 118 | 22.19 | 144 | 1069 | 690 | 414 | 1170 | 327 | 15.59 | 7.86 | 1.72 | 567 |
| | C2 | 101 | 19.45 | 294 | 1607 | 1487 | 1239 | 4482 | 572 | 119.80 | 3.86 | 17.35 | 81 |
| IV | Ap | 167 | 5.24 | 46 | 387 | 557 | 401 | 652 | 345 | 6.68 | - | 5.45 | 384 |
| | C1 | 154 | 3.81 | 63 | 313 | 360 | 28 | 391 | 224 | 5.40 | 3.30 | 4.65 | 222 |
| | C2 | 143 | 4.95 | 116 | 365 | 394 | 236 | 380 | 227 | 1.52 | 2.63 | 2.92 | 259 |
| | C3 | 129 | 2.18 | 103 | 449 | 739 | 432 | 381 | 160 | 1.60 | 1.54 | 1.23 | 364 |
| | C4 | 98 | 0.91 | 94 | 403 | 484 | 203 | 515 | 177 | 3.87 | 1.77 | 1.29 | 382 |
| V | Ap | 179 | 1.44 | 156 | 533 | 869 | 276 | 777 | 260 | 5.96 | 1.53 | 1.87 | 655 |
| | C1 | 129 | 1.43 | 151 | 442 | 999 | 218 | 1184 | 218 | 53.61 | 0.76 | 4.14 | 493 |
| | C2 | 129 | 1.52 | 161 | 570 | 966 | 319 | 912 | 276 | 10.30 | 2.25 | 3.06 | 809 |
| VI | Ap | 230 | 1.27 | 225 | 677 | 811 | 535 | 3678 | 538 | 5.95 | 3.24 | 0.19 | 720 |
| | C1 | 244 | 1.36 | 457 | 2283 | 1298 | 1453 | 3099 | 529 | 5.05 | 2.88 | 0.03 | 1962 |
| | C2 | 215 | 1.30 | 468 | 2220 | 1382 | 1037 | 2919 | 484 | 5.48 | 2.14 | 0.29 | 1745 |
| VII | Ap | 188 | 0.92 | 164 | 409 | 648 | 247 | 435 | 335 | 4.12 | 2.55 | 2.13 | 453 |
| | C1 | 84 | 2.23 | 70 | 290 | 334 | 201 | 666 | 235 | 2.65 | 0.98 | 0.91 | 516 |
| | C2 | 148 | 0.75 | 152 | 469 | 476 | 457 | 775 | 319 | 4.12 | 2.54 | 2.28 | 246 |

Table 7 Continued

| Profile No. | Horizon | N | P | K | Na | Ca | Mg | S | Fe | Mn | Cu | Zn | $Cl^-$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VIII | Ap | 174 | 1.57 | 83 | 277 | 997 | 449 | 779 | 281 | 7.31 | 2.99 | 3.66 | 246 |
|  | C1 | 171 | 0.74 | 98 | 196 | 517 | 395 | 714 | 240 | 6.11 | 2.66 | 1.73 | 185 |
|  | C2 | 174 | 1.12 | 136 | 228 | 611 | 395 | 702 | 228 | 7.20 | 2.40 | 1.68 | 218 |
| IX | Ap | 174 | 2.07 | 118 | 328 | 377 | 377 | 686 | 121 | 2.62 | 2.83 | 1.57 | 279 |
|  | Bw1 | 132 | 3.17 | 168 | 491 | 606 | 606 | 449 | 29 | 8.41 | 1.35 | 1.85 | 348 |
|  | Bw2 | 123 | 5.94 | 323 | 1768 | 1163 | 1746 | 2636 | 259 | 2.67 | 3.80 | 39.9 | 430 |
| X | Ap | 120 | 2.75 | 295 | 1129 | 875 | 788 | 2035 | 396 | 8.13 | 4.17 | 3.54 | 678 |
|  | C1 | 140 | 9.16 | 447 | 3142 | 2514 | 1146 | 5046 | 464 | 170.26 | 2.35 | 5.70 | 1586 |
|  | C2 | 146 | 44.24 | 663 | 3916 | 2169 | 3188 | 4853 | 368 | 380.23 | 1.08 | 27.11 | 2245 |
| XI | Ap | 288 | 6.39 | 219 | 821 | 657 | 591 | 392 | 516 | 6.96 | 6.36 | 5.03 | 324 |
|  | C1 | 235 | 6.30 | 174 | 798 | 753 | 483 | 936 | 295 | 7.08 | 3.48 | 1.88 | 309 |
|  | C2 | 241 | 6.41 | 209 | 741 | 812 | 508 | 848 | 288 | 8.26 | 3.52 | 12.46 | 274 |
| XII | Ap | 199 | 6.09 | 377 | 1885 | 905 | 659 | 1490 | 405 | 9.26 | 6.25 | 4.09 | 828 |
|  | C1 | 319 | 8.45 | 448 | 2242 | 1166 | 1184 | 3770 | 170 | 46.03 | 3.62 | 0.90 | 1592 |
|  | C2 | 218 | 31.43 | 739 | 4049 | 2282 | 2966 | 6361 | 143 | 240.84 | 1.26 | 29.08 | 2875 |
| XIII | Ap | 221 | 4.43 | 224 | 1212 | 537 | 483 | 1439 | 450 | 1.12 | 2.46 | 2.46 | 1721 |
|  | C1 | 188 | 7.76 | 575 | 3432 | 2348 | 2446 | 4357 | 111 | 3.43 | 3.30 | 18.05 | 1584 |
|  | C2 | 112 | 40.29 | 248 | 1923 | 1518 | 2036 | 4409 | 933 | 285.00 | 8.34 | 31.26 | - |
| XIV | Ap | 159 | 3.42 | 343 | 1411 | 1089 | 784 | 1969 | 478 | 11.37 | 5.32 | 4.56 | 1288 |
|  | C1 | 171 | 5.20 | 293 | 1464 | 1280 | 452 | 1234 | 462 | 3.01 | 1.76 | 3.51 | 1560 |
|  | C2 | 154 | 19.32 | 399 | 4131 | 2667 | 1723 | 4229 | 635 | 4.28 | 2.51 | 28.37 | 3135 |
| XV | Ap | 81 | 7.55 | 14 | 452 | 476 | 301 | 2107 | 295 | 12.86 | 2.51 | 2.52 | 692 |
|  | C1 | 42 | 28.88 | 26 | 192 | 506 | 474 | 3120 | 362 | 26.68 | 1.99 | 9.60 | 91 |
|  | C2 | 53 | 40.09 | 44 | 471 | 1252 | 876 | 2688 | 561 | 63.47 | 1.04 | 13.44 | 103 |

The Ca and Mg contents of Kuttanad soils were fairly high compared to other acid soils of Kerala. The frequent additions of liming materials, intrusion of sea water and the marine origin of soils have increased the Ca and Mg contents. The available Ca content varied from 377 to 1404 ppm in surface soils. The available Mg content ranged from 172 to 788 ppm in the surface layers. Kerala soils containing greater than 100 ppm of available Mg is rated as "sufficient" and above 500 ppm as "high" (Prema, 1992). As per this criterion 40 per cent of the soils were rated as high and rest as sufficient in Mg status. Lower layers showed higher concentration of above nutrients. The unique hydrophysiography of the area contributed towards it by favouring easy water movement and leaching of constituents.

The Kuttanad soils are immensely rich in available S because of their acid sulphate nature. The S ore pyrite is present in these rice fields. The available S content of surface layers varied from 392 to 3678 ppm and found to increase irregularly with depth.

Total S content was also very high and the same was reflected on available S content of the soil. However, the large quantities of Fe present in the soil protect the crop from $H_2S$ injury by forming ferrous sulphide which is insoluble and harmless to rice under reduced condition. Since the redox potential of Fe is greater than that of S, the presence of Fe prevents the reduction of S and formation of $H_2S$.

Available Mn content of the surface soils of the study area varied from 0.50 to 12.86 ppm. The study area was not deficient in Mn as per the criteria suggested by Aiyer *et al*. (1975) or Tandon (1995). However, no Mn toxicity was reported from the area.

Kuttanad soils are reported to be deficient in available Cu (Nair, 1970; KAU, 1994). However, in the study area only 6.6 per cent of surface soil was deficient in available Cu as per the critical level suggested by Tandon (1995).

The available Zn content ranged from 0.19 to 5.45 ppm in surface soils. Here also the deficiency rate was only 6.6 per cent according to the above criterion. The micronutrient content of the area appeared to be a function of clay and organic carbon content.

Chloride content of these soils were very high compared to other soils of Kerala. The values ranged from 246 to 1721 ppm in Ap horizon and the lower layers recorded still higher values. C3 horizon of profile I registered the highest value of 6636 ppm. It was present as NaCl in C3 horizon since the available Na content of the horizon was very high (8477 ppm). Nearness to the sea and saline water intrusion resulted the very high concentration of chloride.

### *3.5 Water soluble and exchangeable cations*

The data on water soluble and exchangeable cations of profile samples are presented in Table 8.

The water soluble and exchangeable cations followed the same trend as that of total cations. Here also the lower layers showed higher values compared to surface layers, evidently due to salt accumulation in response to leaching and downward water movement. Major portions of available K and Mg were retained in water soluble form, while for Ca it was mainly held in exchangeable form. The Ca recorded very low values for its water soluble fraction compared to its available fraction. Among the exchangeable cations, Ca was the dominant one followed by Mg. This was in contrary to the opinion that Na is the dominant cation of the exchange complex in karappadam soils (Aiyer *et al.*, 1975; Kabeerathumma, 1975; Kabeerathumma and Bidappa, 1975). However, presently the southern region of Vembanad lake experienced a reduction in salinity of about 92.4 per cent during March, compared to that of pre-barrage period (Nair and Pillai, 1990). The prevention of saline water entry into Kuttanad during summer had considerably reduced the Na content of the study area.

The total exchangeable base content of the study area varied from 0.94 to 26.6 cmol (+) $kg^{-1}$. The lower layers showed higher base status compared to the surface layers in all most all the profiles.

Table 8. Water soluble and exchangeable cations of soils

| Profile No. | Horizon | Water soluble cations (ppm) | | | | Exchangeable cations, cmol(+) $kg^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | K | Na | Ca | Mg | K | Na | Ca | Mg | Total |
| I | Ap | 117 | 663 | 143 | 86 | 0.244 | 1.008 | 2.39 | 0.72 | 4.36 |
| | C1 | 70 | 876 | 412 | 422 | 0.131 | 1.464 | 2.06 | 0.12 | 3.78 |
| | C2 | 20 | 1547 | 234 | 106 | 0.199 | 0.353 | 5.27 | 5.57 | 11.39 |
| | C3 | 330 | 4999 | 2347 | 1127 | 0.267 | 15.120 | 2.35 | 2.35 | 20.08 |
| | C4 | 168 | 4037 | 2127 | 1610 | 2.032 | 5.400 | 1.11 | 7.82 | 16.37 |
| II | Ap | 195 | 1507 | 351 | 101 | 0.544 | 0.770 | 5.27 | 1.40 | 7.98 |
| | C1 | 113 | 2085 | 1126 | 405 | 0.218 | 0.907 | 0.38 | 0.38 | 1.66 |
| | C2 | 18 | 902 | 920 | 325 | 0.069 | 0.653 | 1.62 | 1.08 | 3.43 |
| | C3 | 18 | 1466 | 989 | 198 | 0.140 | 0.471 | 0.33 | - | 0.94 |
| | C4 | 336 | 3680 | 1918 | 797 | 0.712 | 8.922 | 5.16 | 11.80 | 26.6 |
| III | Ap | 123 | 571 | 664 | 455 | 0.069 | 0.572 | - | 0.47 | 1.12 |
| | C1 | 141 | 1038 | 230 | 155 | 0.008 | 0.133 | 2.30 | 2.16 | 2.44 |
| | C2 | 223 | 1607 | 1239 | 991 | 0.182 | - | 1.24 | 2.07 | 3.49 |
| IV | Ap | 37 | 155 | 111 | 150 | 0.023 | 1.008 | 2.23 | 2.09 | 5.35 |
| | C1 | 38 | 250 | 68 | 14 | 0.063 | 0.271 | 1.46 | 0.12 | 1.92 |
| | C2 | 37 | 182 | 66 | 79 | 0.202 | 0.793 | 1.64 | 1.31 | 3.95 |
| | C3 | 41 | 192 | 92 | 55 | 0.158 | 1.116 | 3.23 | 3.14 | 7.65 |
| | C4 | 48 | 202 | 121 | 29 | 0.117 | 0.877 | 1.81 | 1.45 | 4.26 |
| V | Ap | 77 | 355 | 230 | 92 | 0.203 | 0.771 | 3.20 | 1.53 | 5.70 |
| | C1 | 98 | 442 | 432 | 209 | 0.136 | - | 2.84 | 0.08 | 3.51 |
| | C2 | 83 | 536 | 266 | 145 | 0.199 | 0.146 | 3.50 | 1.45 | 5.29 |
| VI | Ap | 77 | 507 | 243 | 24 | 0.380 | 0.734 | 2.84 | 4.26 | 8.21 |
| | C1 | 240 | 2040 | 562 | 571 | 0.553 | 1.055 | 3.68 | 7.35 | 12.09 |
| | C2 | 242 | 1980 | 562 | 518 | 0.576 | 1.043 | 4.10 | 4.32 | 10.04 |
| VII | Ap | 68 | 245 | 118 | 53 | 0.242 | 0.592 | 2.65 | 1.62 | 5.10 |
| | C1 | 46 | 290 | 146 | 113 | 0.059 | - | 0.94 | 0.73 | 1.73 |
| | C2 | 15 | 463 | 143 | 143 | 0.348 | 0.026 | 1.67 | 2.62 | 4.66 |

Table 8 continued

| Profile No. | Horizon | Water soluble cations, ppm | | | | Exchangeable cations, cmol(+) kg$^{-1}$ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | K | Na | Ca | Mg | K | Na | Ca | Mg | Total |
| VIII | Ap | 27 | 69 | 224 | 15 | 0.142 | 0.903 | 3.86 | 3.61 | 8.52 |
| | C1 | 39 | 98 | 71 | 42 | 0.150 | 0.425 | 2.23 | 2.94 | 5.74 |
| | C2 | 40 | 131 | 141 | 56 | 0.244 | 0.425 | 2.35 | 2.82 | 5.84 |
| IX | Ap | 21 | 191 | 71 | 14 | 0.247 | 0.596 | 1.53 | 2.71 | 5.09 |
| | Bw1 | 28 | 315 | 76 | - | 0.358 | 0.762 | 3.03 | 5.04 | 9.20 |
| | Bw2 | 222 | 1717 | 327 | 851 | 0.258 | 0.220 | 4.47 | 7.45 | 12.40 |
| X | Ap | 173 | 1116 | 281 | 356 | 0.311 | 0.571 | 2.97 | 3.60 | 7.45 |
| | C1 | 363 | 3091 | 1106 | 1007 | 0.214 | 0.221 | 7.04 | 1.16 | 8.63 |
| | C2 | 518 | 3464 | 1193 | 1854 | 0.369 | 1.964 | 4.88 | 11.11 | 18.32 |
| XI | Ap | 142 | 730 | 493 | 197 | 0.196 | 0.397 | 0.83 | 3.28 | 4.70 |
| | C1 | 132 | 697 | 502 | - | 0.107 | 0.440 | 1.26 | 4.03 | 5.83 |
| | C2 | 134 | 725 | 562 | 94 | 0.192 | 0.070 | 1.25 | 3.45 | 4.96 |
| XII | Ap | 136 | 898 | 129 | 116 | 0.615 | 4.292 | 3.88 | 4.52 | 13.31 |
| | C1 | 309 | 1993 | 583 | 457 | 0.357 | 1.083 | 2.91 | 6.05 | 10.40 |
| | C2 | 704 | 4029 | 1204 | 1977 | 0.090 | 0.085 | 5.39 | 8.24 | 13.81 |
| XIII | Ap | 116 | 1166 | 235 | 262 | 0.277 | 0.202 | 1.51 | 1.85 | 3.84 |
| | C1 | 343 | 3432 | 1853 | 1853 | 0.439 | - | 2.47 | 4.95 | 7.86 |
| | C2 | 156 | 1489 | 983 | 1474 | 0.235 | 1.887 | 2.70 | 4.69 | 10.29 |
| XIV | Ap | 141 | 1210 | 218 | 327 | 0.515 | 0.877 | 4.36 | 3.81 | 9.56 |
| | C1 | 126 | 1465 | 377 | 181 | 0.428 | - | 4.52 | 2.26 | 7.21 |
| | C2 | 157 | 3704 | 1231 | 1108 | 0.619 | 1.858 | 7.18 | 5.13 | 14.79 |
| XV | Ap | 8 | 418 | 251 | 90 | 0.014 | 0.151 | 1.13 | 1.75 | 3.03 |
| | C1 | 18 | 192 | 276 | - | 0.019 | - | 1.15 | - | 1.17 |
| | C2 | 26 | 435 | 1226 | 783 | 0.044 | 0.157 | 0.13 | 0.78 | 1.11 |

## *3.6 Soil acidity*

The Kuttanad soils are extremely acidic in nature due to the presence of large quantities of sulphides which on oxidation produce free sulphuric acid. The organic acids released from the decomposing organic debris aggravate the situation. The common methods for controlling soil acidity are flooding, liming and washing and providing drainage. By submergence, the pH of the Kuttanad soils increases to about 4.5 to 5.7 depending upon the buffering capacity of the soil (Kabeerathumma and Patnaik, 1978). Due to the high buffering capacity of these soils, liming and washing, and other management practices could only temporarily control the acidity. The large portion of the reserve acidity remains there itself and cannot be neutralised by these methods.

The acidity contributing characteristics are presented in Table 9. The potential acidity is comprised of hydrolytic or pH dependent acidity and exchangeable acidity. Potential acidity of the surface horizons ranged from 2.8 to 92.7 cmol(+) $kg^{-1}$ (Fig 4). The lower layers recorded comparatively higher values and the highest value of 147.8 cmol(+) $kg^{-1}$ was observed in C3 horizon of Profile I, evidently due to high organic carbon content. The clay and organic carbon contents of the soil decide the extent of soil acidity, as evidenced by their high correlation (Table 5) with potential acidity ($0.578^{**}$ and $0.598^{**}$).

Table 9. Acidity contributing characteristics of soils

| Profile No. | Horizon | Potential acidity | Hydrolitic acidity | Exch. acidty | Exch. $H^+$ | Exch. $Al^{3+}$ | Contribution to potential acidity, % | | Contribution to exch. acidity, % | | Al saturation % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | cmol(+) $kg^{-1}$ | | | | | Hydr. acidity | Exch. acidity | Exch. $H^+$ | Exch. $Al^{3+}$ | |
| I | Ap | 13.3 | 11.1 | 2.20 | 1.26 | 0.94 | 83.5 | 16.5 | 57.3 | 42.7 | 14.3 |
| | C1 | 16.2 | 14.5 | 1.70 | 0.47 | 1.21 | 89.5 | 10.5 | 27.6 | 72.4 | 22.1 |
| | C2 | 61.9 | 44.7 | 17.20 | 11.15 | 6.02 | 72.4 | 27.6 | 66.9 | 33.1 | 21.1 |
| | C3 | 147.8 | 144.8 | 3.04 | 0.44 | 2.60 | 98.0 | 2.0 | 14.5 | 85.5 | 11.2 |
| | C4 | 31.1 | 27.4 | 3.60 | 2.02 | 1.57 | 55.9 | 44.1 | 56.1 | 43.9 | 7.9 |
| II | Ap | 28.4 | 24.0 | 4.34 | 2.57 | 1.77 | 84.5 | 15.5 | 59.2 | 40.8 | 14.4 |
| | C1 | 62.6 | 56.6 | 5.94 | 3.44 | 2.50 | 90.4 | 9.6 | 57.9 | 42.1 | 32.9 |
| | C2 | 42.1 | 38.9 | 3.23 | 1.73 | 1.50 | 92.4 | 7.6 | 53.6 | 46.4 | 22.5 |
| | C3 | 33.0 | 25.4 | 7.60 | 5.41 | 2.19 | 77.0 | 23.0 | 71.2 | 28.8 | 25.6 |
| | C4 | 41.0 | 39.6 | 1.43 | 0.21 | 1.22 | 96.6 | 3.4 | 14.7 | 85.3 | 4.35 |
| III | Ap | 42.1 | 38.1 | 4.04 | 1.23 | 2.81 | 90.5 | 9.5 | 30.4 | 69.6 | 54.5 |
| | C1 | 44.7 | 41.0 | 3.75 | 1.68 | 2.07 | 91.7 | 8.3 | 44.8 | 55.2 | 33.4 |
| | C2 | 64.3 | 55.0 | 9.30 | 7.23 | 2.07 | 85.5 | 14.5 | 77.7 | 22.3 | 16.2 |
| IV | Ap | 6.2 | 3.0 | 3.17 | 1.16 | 2.01 | 48.4 | 51.6 | 36.6 | 63.4 | 23.6 |
| | C1 | 5.0 | 2.9 | 2.13 | 0.56 | 1.56 | 58.0 | 42.0 | 26.3 | 73.7 | 38.5 |
| | C2 | 4.9 | 3.4 | 1.52 | 1.43 | 0.12 | 69.4 | 30.6 | 92.1 | 7.9 | 2.2 |
| | C3 | 5.1 | 4.0 | 1.09 | 0.32 | 0.77 | 78.4 | 21.6 | 29.4 | 70.6 | 8.8 |
| | C4 | 5.4 | 4.2 | 1.21 | 0.67 | 0.54 | 77.7 | 22.3 | 55.4 | 44.6 | 9.9 |
| V | Ap | 2.8 | 0.8 | 1.99 | 1.42 | 0.57 | 28.6 | 71.4 | 71.4 | 28.6 | 7.4 |
| | C1 | 10.1 | 9.6 | 0.51 | 0.13 | 0.38 | 95.0 | 5.0 | 25.5 | 74.5 | 9.5 |
| | C2 | 2.7 | 0.9 | 1.81 | 1.14 | 0.67 | 33.3 | 66.7 | 63.0 | 37.0 | 9.4 |
| VI | Ap | 31.5 | 21.8 | 9.79 | 7.54 | 2.25 | 69.2 | 30.8 | 77.0 | 23.0 | 12.5 |
| | C1 | 19.2 | 14.4 | 4.81 | 3.37 | 1.44 | 75.0 | 25.0 | 70.1 | 29.9 | 8.5 |
| | C2 | 18.1 | 13.7 | 4.42 | 3.01 | 1.40 | 75.7 | 24.3 | 68.1 | 31.9 | 9.7 |
| VII | Ap | 16.4 | 12.0 | 4.34 | 4.01 | 0.33 | 36.2 | 63.8 | 92.4 | 7.6 | 3.5 |
| | C1 | 4.6 | 2.7 | 1.97 | 0.93 | 1.04 | 73.0 | 27.0 | 47.2 | 52.8 | 28.1 |
| | C2 | 15.9 | 13.1 | 2.78 | 1.72 | 1.06 | 82.4 | 17.6 | 61.9 | 38.1 | 14.3 |

Table 9. Continued

| Profile No | Horizon | Potential acidity | Hydrolytic acidity | Exch. acidity | Exch. $H^+$ | Exch. $Al^{3+}$ | Contribution to potential acidity, % |  | Contribution to exch. acidity, % |  | Al saturation % |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | cmol(+) $kg^{-1}$ |  |  |  |  | Hydr. acidity | Exch. acidity | Exch. $H^+$ | Exch. $Al^{3+}$ |  |
| VIII | Ap | 14.6 | 12.8 | 1.73 | 0.35 | 1.38 | 88.1 | 11.9 | 20.2 | 79.8 | 13.5 |
|  | C1 | 23.5 | 21.1 | 2.35 | 1.04 | 1.31 | 90.0 | 10.0 | 44.3 | 55.7 | 16.2 |
|  | C2 | 17.4 | 15.4 | 1.98 | 0.97 | 1.01 | 88.6 | 11.4 | 49.0 | 51.0 | 12.9 |
| IX | Ap | 10.5 | 9.8 | 0.66 | 0.07 | 0.59 | 93.6 | 6.4 | 10.6 | 89.4 | 10.3 |
|  | Bw1 | 5.6 | 5.1 | 0.49 | 0.47 | 0.02 | 91.4 | 8.6 | 100.0 | - | - |
|  | Bw2 | 32.3 | 31.1 | 1.21 | 0.20 | 1.01 | 96.3 | 3.7 | 16.5 | 13.5 | 7.4 |
| X | Ap | 34.7 | 29.7 | 5.04 | 3.65 | 1.39 | 85.6 | 14.4 | 72.4 | 27.6 | 11.1 |
|  | C1 | 50.3 | 44.4 | 5.87 | 3.91 | 1.96 | 88.3 | 11.7 | 66.7 | 33.3 | 13.5 |
|  | C2 | 100.0 | 92.3 | 7.68 | 5.57 | 2.11 | 92.3 | 7.7 | 72.6 | 27.4 | 8.1 |
| XI | Ap | 14.6 | 10.1 | 4.47 | 2.83 | 1.64 | 69.3 | 30.7 | 63.3 | 36.7 | 17.9 |
|  | C1 | 38.3 | 34.9 | 3.49 | 1.92 | 1.57 | 91.0 | 9.0 | 55.0 | 45.0 | 16.9 |
|  | C2 | 30.3 | 27.4 | 2.89 | 1.57 | 1.32 | 90.6 | 9.4 | 54.3 | 45.7 | 16.7 |
| XII | Ap | 46.7 | 39.1 | 7.54 | 4.67 | 2.87 | 83.8 | 16.2 | 61.9 | 38.1 | 13.8 |
|  | C1 | 79.7 | 67.5 | 12.21 | 9.96 | 2.25 | 84.7 | 15.3 | 81.6 | 18.4 | 10.0 |
|  | C2 | 56.3 | 48.1 | 8.27 | 5.81 | 2.46 | 85.4 | 14.6 | 70.3 | 29.7 | 11.1 |
| XIII | Ap | 37.3 | 25.1 | 12.18 | 7.72 | 4.46 | 67.3 | 32.7 | 63.4 | 36.6 | 27.9 |
|  | C1 | 61.8 | 52.1 | 9.68 | 6.95 | 2.73 | 84.3 | 15.9 | 71.8 | 28.2 | 15.5 |
|  | C2 | 64.5 | 52.5 | 12.04 | 6.06 | 5.99 | 81.3 | 18.7 | 50.3 | 49.7 | 27.8 |
| XIV | Ap | 92.7 | 85.0 | 7.76 | 3.93 | 3.93 | 91.7 | 8.3 | 50.6 | 49.4 | 22.1 |
|  | C1 | 66.9 | 59.0 | 7.95 | 4.18 | 3.77 | 88.2 | 11.8 | 52.6 | 47.4 | 24.9 |
|  | C2 | 11.4 | 2.16 | 9.23 | 4.67 | 4.56 | 18.9 | 81.1 | 50.6 | 49.4 | 19.0 |
| XV | Ap | 30.6 | 18.5 | 12.04 | 6.06 | 5.99 | 60.7 | 39.3 | 50.3 | 49.7 | 39.8 |
|  | C1 | 63.9 | 59.6 | 4.35 | 2.17 | 2.18 | 93.2 | 6.8 | 49.9 | 50.1 | 39.3 |
|  | C2 | 36.1 | 26.9 | 9.20 | 6.45 | 2.75 | 74.5 | 25.5 | 70.1 | 29.9 | 36.4 |

The soil acidity is mainly pH dependant, and exchangeable acidity is present in very small amounts (Adhikari and Si, 1991). In the present study also , this was evidensed by the significant positive correlation between hydrolytic and potential acidity ($0.993^{**}$). The correlation between potential and hydrolytic acidity was comparatively lower ($0.489^{*}$). The hydrolytic acidity of surface layers varied from 0.8 to 85.0 cmol(+) $kg^{-1}$. It followed the same trend as that of potential acidity. The percentage contribution of hydrolytic acidity

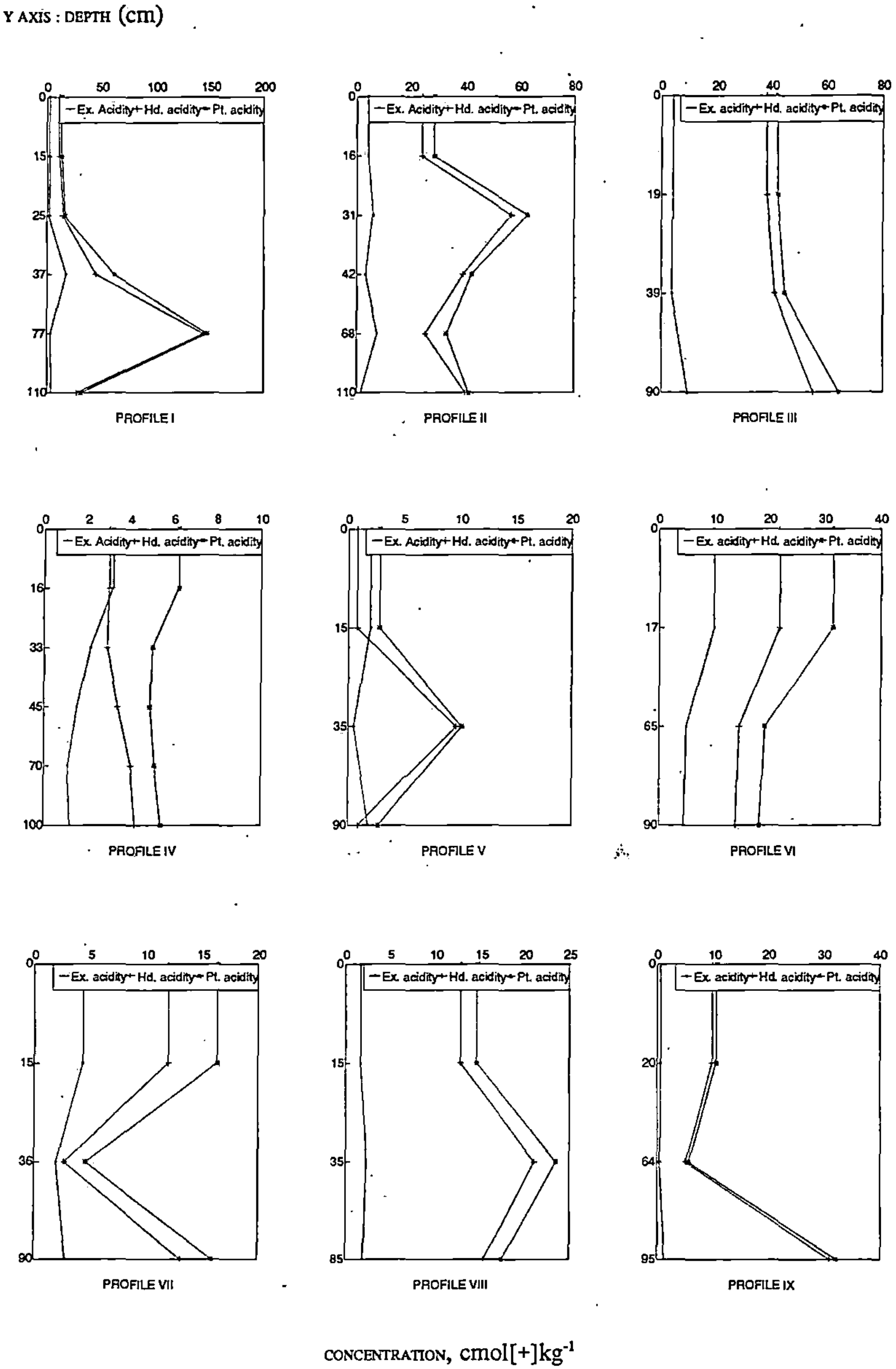
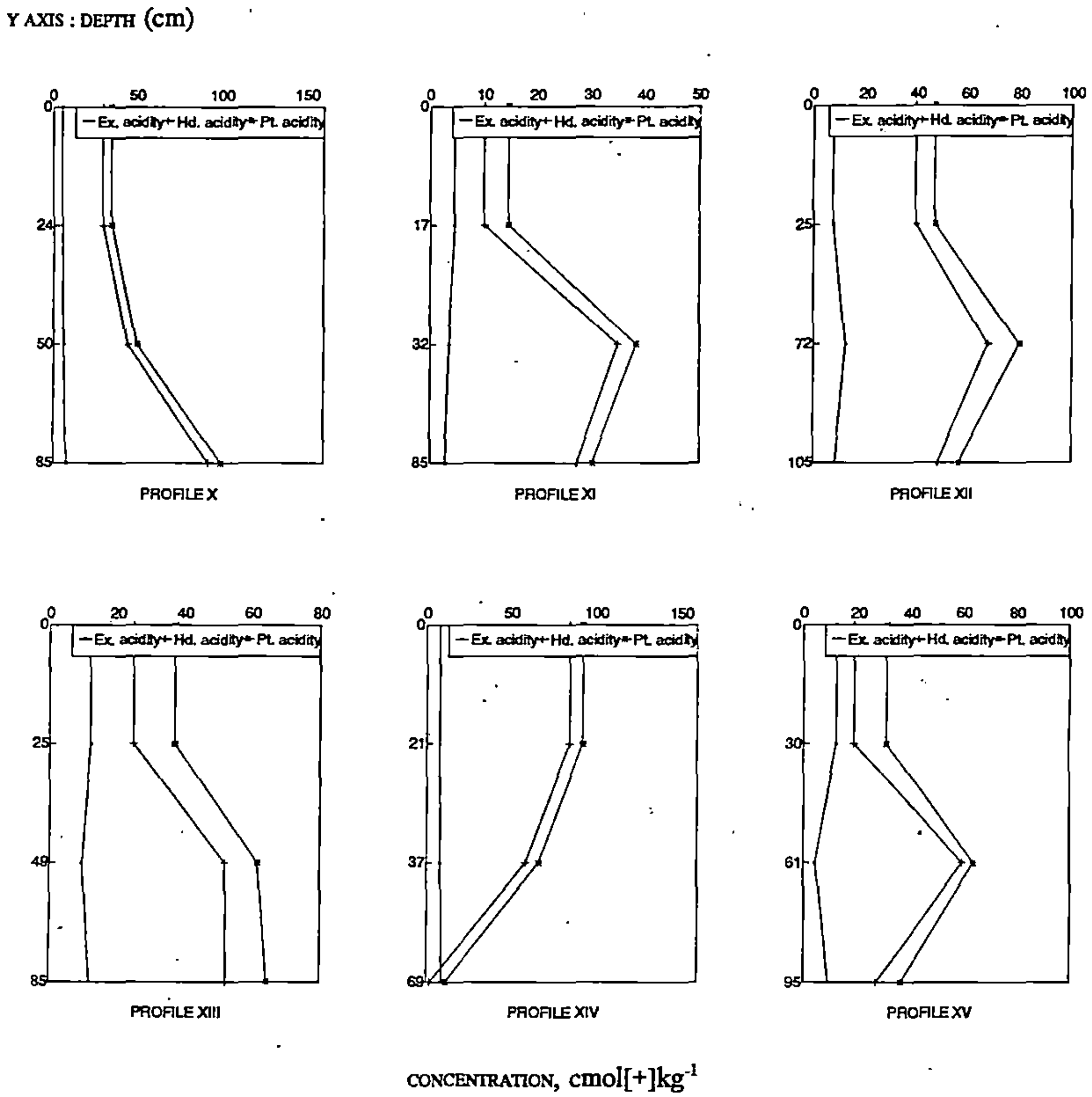


Fig 4. Different forms of acidity in soil profiles of North Kuttanad



PROFILE X PROFILE XI PROFILE XII

PROFILE XIII PROFILE XIV PROFILE XV

Fig 4. (continued) Different forms of acidity in soil profiles of North Kuttanad

to potential acidity was 28.6 to 93.6 per cent in surface soils and 18.9 to 98.0 per cent in subsurface layers. The variation was definitely due to the difference in soil pH.

The exchangeable acidity is cotributed by exchangeable H$^+$ and exchangeable Al$^{3+}$. The exchangeable acidity of surface layers ranged from 0.66 to 12.18 cmol(+) kg$^{-1}$. A greater portion of exchangeable acidity was contributed by exchangeable H$^+$ in these samples since the soil pH was very low (Table 4) due to soil drying. Exchangeable H+ is present in measurable quantities only at pH values less than 4.0 (Panda, 1987). This was confirmed by the higher correlation between exchangeable acidity and exchangeable H$^+$ (0.962$^{**}$) than with exchangeable Al$^{3+}$ (0.854$^{**}$). This also followed the same trend as that of potential acidity.

The potential acidity was positively and significantaly correlated with EC (0.530$^{**}$), CEC (0.699$^{**}$) and ECEC (0.585$^{**}$).

### 4. Taxonomic classification

Taxonomic classification of the pedons have been attempted up to subgroup level based on the available data (Table 10) as per Soil Survey Staff (1987). Profile IX was classified under order Entisol and all other soil profiles were included under order Inceptisol since they are having only AC horizons.

Profile IX gets keyed out under order Inceptisol, suborder Tropept because of an isohyperthemic temperature regime, great group Dystropept because it has less than 50 per cent base saturation in some sub horizons and Fluventic subgroup because of irregular organic carbon content (Plate XIII).

Profiles I, II, III, IV, VI, X, XI, XII, XIII, XIV, and XV have sulphidic materials with 0.75 per cent S in some sub-horizon within 50 cm and have aquic properties, leading to keying out under suborder Aquents, great group Sulfaquents and subgroup Typic Sulfaquents.

Profile V is a Psamment because of loamy sand textures and presumed Udic moisture, keys out under great group Tropopsamment and subgroup Typic Tropopsamment (Plate XI). Profile VII gets keyed out under suborder Fluvent, great group Tropofluvents because of Isohyperthermic temperature regime and under subgroup Typic Tropofluvent (Plate XII). Profile VIII keys out under suborder Aquents, great group Fluvaquents and subgroup Typic Fluvaquents.

Table 10. Taxonomic classification of soil profiles of North Kuttanad

| Profiles | Order | Suborder | Great group | Subgroup |
|---|---|---|---|---|
| I | Entisol | Aquent | Sulfaquent | Typic Sulfaquent |
| II | Entisol | Aquent | Sulfaquent | Typic Sulfaquent |
| III | Entisol | Aquent | Sulfaquent | Typic Sulfaquent |
| IV | Entisol | Aquent | Sulfaquent | Typic Sulfaquent |
| V | Entisol | Psamment | Tropopsamment | Typic Tropopsamment |
| VI | Entisol | Aquent | Sulfaquent | Typic Sulfaquent |
| VII | Entisol | Fluvent | Tropofluvent | Typic Tropofluvent |
| VIII | Entisol | Aquent | Fluvaquent | Typic Fluvaquent |
| IX | Inceptisol | Tropept | Dystropept | Fluventic Dystropept |
| X | Entisol | Aquent | Sulfaquent | Typic Sulfaquent |
| XI | Entisol | Aquent | Sulfaquent | Typic Sulfaquent |
| XII | Entisol | Aquent | Sulfaquent | Typic Sulfaquent |
| XIII | Entisol | Aquent | Sulfaquent | Typic Sulfaquent |
| XIV | Entisol | Aquent | Sulfaquent | Typic Sulfaquent |
| XV | Entisol | Aquent | Sulfaquent | Typic Sulfaquent |

Plate IX. Profile I - Akatheakaripadam of Arpookkara village

Order : Entisol, Subgroup : Typic Sulfaquent

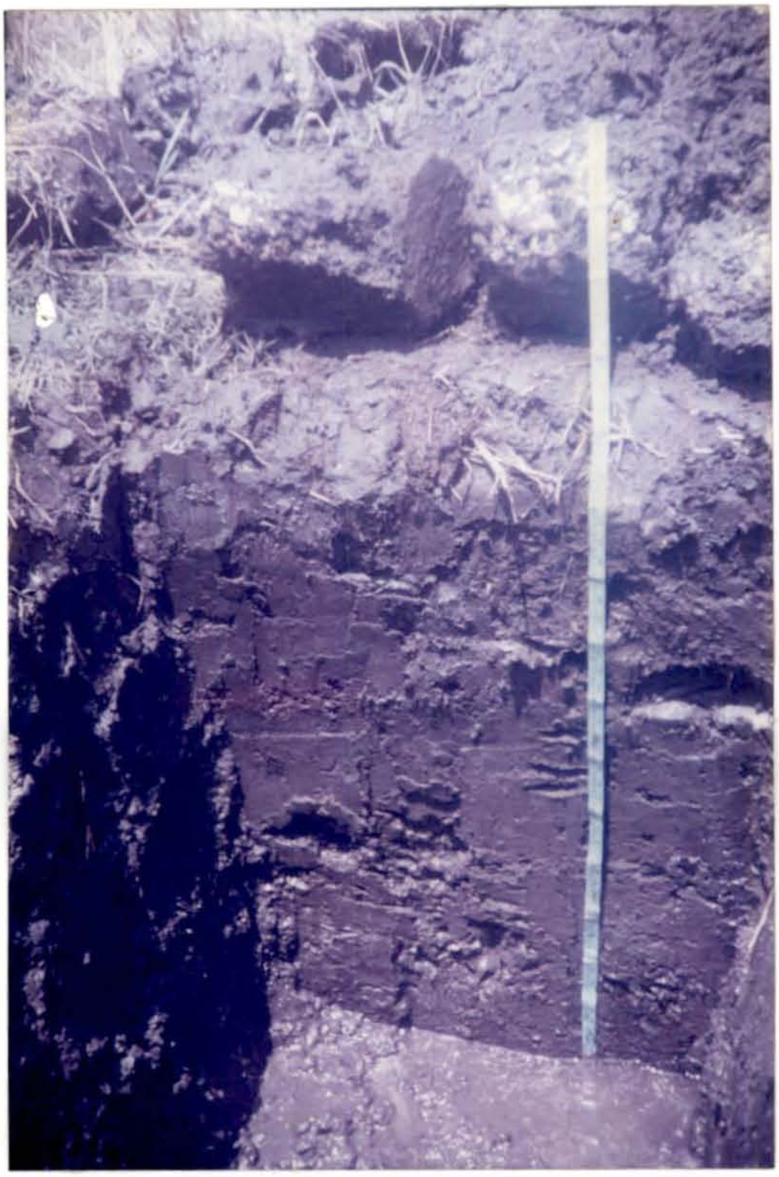


Plate X. Profile II - Kelakarivattakayal of Arpookkara village showing lime shell deposits
Order : Entisol, Subgroup : Typic Sulfaquent

Plate XI. Profile V - Maleekayal of Kumarakom village

Order : Entisol, Subgroup : Typic Tropopsamment

Plate XII. Profile - VII - Thekkepallipadam of Kumarakom village

Order : Entisol, Subgroup : Typic Tropofluvent

Plate XIII. Profile IX - Kadayakolmidavali padasekharam of Kumarakom village

Order : Inceptisol, Subgroup : Fluventic Dystropept

Plate XIV. A locally fabricated bridge across the Kaipuzha river

## PART 2. FERTILITY CHARACTERISTICS

The impact of the closure of Thanneermukkom regulator during summer, from December to April on the fertility characteristics of the soils of North Kuttanad is evaluated under this part of the study.

### 1. General properties of soil (Table 11)

### *1.1 Soil reaction (pH)*

The Kuttanad soils are extremely acidic, often recording pH values less than 5.5 even after prolonged submergence. The seasonal influence/closure of the regulator had significantly influenced the pH of the area. The mean value of pH during rainy season was 4.4 and it decreased to 4.0 during summer. The partial removal of active acidity by the action of rain water or its downward movement along with water have reduced the acidity of surface layers during rainy season. As the summer advances the upward movement of $H^+$ ions along with water molecules will be initiated resulting an increase in soil acidity. The soil pH was negatively correlated with all acidity contributing characteristics (Table 12). The role of exchangeable acidity in deciding the pH is clearly evident from its highest significant negative correlation with pH (-0.418*).

### *1.2 Electrical conductivity (EC)*

The soils of Kuttanad are termed as acid saline soils. Sea water intrusion during summer made the entire area saline. The magnitude of salinity intrusion has been considerably reduced after the construction of the regulator at Thanneermukkom (Nair and Pillai, 1990). Presently the area is only mildly saline during summer. The present study also supports this, since the EC values observed were not sufficient to categorise the study area as saline. The mean value of EC during rainy season was 1.35 dS $m^{-1}$ which reduced to 0.67 dS $m^{-1}$ during summer. The EC values were very low compared to those of pre-barrage period. The area cannot be rated as saline since the mean values were less than 2 dS $m^{-1}$, the level fixed by the soil testing laboratories of the state for 1:2.5 soil water extract to be considered as saline. However, 19 per cent of the study area recorded values above this level during rainy season, while in summer, the entire area recorded values below this. The higher value for EC during rainy season was due to the influence of sea water intruded into the study area during summer after the opening of regulator. It is probable that the salts were not completely washed off from the fields at the time of soil collection which coincided with early monsoon. Na salts are mainly responsible for the salinity in the area which is clearly evident from Fig 5.

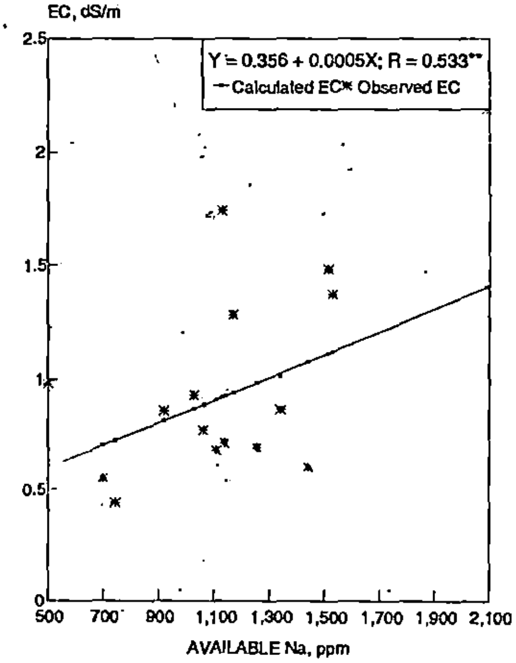


Fig 5. Relationship between available Na and soil EC. (R = Regression coefficient)

Table 11. General properties of soils during different seasons

| Padasekharam No. | Organic carbon, % | | pH | | EC dS m$^{-1}$ | | ECEC | | CEC | | Base saturation, % | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | cmol(+) kg$^{-1}$ | | | | | |
| | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII |
| 1 | 4.08 | 4.16 | 4.0 | 3.4 | 2.39 | 0.35 | 23.5 | 16.6 | 32.7 | 20.0 | 67.1 | 52.7 |
| 2 | 3.91 | 4.74 | 3.9 | 3.0 | 1.83 | 1.14 | 22.5 | 17.0 | 31.7 | 23.7 | 63.1 | 42.1 |
| 3 | 3.90 | 3.58 | 5.1 | 4.6 | 1.03 | 0.36 | 17.5 | 12.1 | 30.6 | 19.4 | 39.3 | 39.3 |
| 4 | 5.29 | 2.28 | 3.7 | 3.5 | 2.96 | 1.71 | 16.9 | 22.3 | 26.1 | 30.7 | 30.9 | 32.9 |
| 5 | 4.39 | 4.18 | 4.6 | 4.5 | 0.95 | 0.78 | 15.5 | 16.3 | 27.0 | 23.0 | 39.8 | 42.0 |
| 6 | 4.04 | 4.68 | 5.2 | 4.8 | 0.60 | 0.28 | 14.6 | 16.0 | 26.3 | 23.4 | 42.2 | 38.2 |
| 7 | 2.46 | 2.34 | 3.7 | 3.6 | 4.00 | 0.38 | 15.4 | 9.0 | 20.1 | 11.5 | 63.5 | 40.2 |
| 8 | 1.98 | 1.55 | 5.1 | 4.6 | 1.00 | 0.72 | 11.7 | 7.1 | 16.6 | 11.2 | 68.6 | 48.9 |
| 9 | 2.09 | 2.81 | 3.2 | 3.0 | 2.96 | 0.52 | 18.3 | 8.2 | 29.0 | 9.7 | 38.9 | 34.9 |
| 10 | 5.28 | 6.78 | 3.3 | 3.8 | 3.02 | 0.81 | 23.5 | 25.2 | 38.8 | 33.5 | 40.8 | 41.3 |
| 11 | 3.00 | 3.09 | 4.0 | 5.0 | 0.87 | 0.23 | 13.4 | 11.7 | 16.7 | 18.3 | 45.5 | 44.8 |
| 12 | 3.85 | 4.20 | 3.6 | 3.8 | 1.02 | 0.53 | 20.7 | 16.5 | 27.8 | 21.8 | 43.7 | 35.1 |
| 13 | 3.79 | 3.02 | 5.2 | 4.5 | 0.98 | 0.46 | 15.3 | 9.4 | 29.0 | 16.9 | 49.8 | 39.0 |
| 14 | 3.35 | 2.92 | 4.6 | 4.2 | 0.43 | 0.77 | 12.7 | 14.9 | 27.4 | 22.5 | 38.3 | 44.5 |
| 15 | 3.10 | 2.12 | 4.8 | 3.8 | 0.91 | 0.45 | 9.3 | 8.1 | 16.9 | 14.8 | 45.4 | 34.0 |
| 16 | 2.67 | 2.12 | 4.6 | 3.7 | 1.22 | 1.34 | 13.1 | 8.5 | 21.7 | 15.7 | 52.1 | 33.4 |
| 17 | 3.68 | 4.26 | 4.9 | 3.8 | 1.02 | 0.84 | 15.3 | 15.7 | 22.4 | 19.4 | 38.5 | 52.1 |
| 18 | 3.65 | 3.99 | 4.1 | 3.8 | 0.84 | 0.65 | 18.9 | 17.2 | 25.3 | 20.1 | 51.0 | 40.8 |
| 19 | 3.73 | 4.05 | 4.5 | 4.6 | 1.07 | 0.84 | 16.6 | 17.3 | 33.2 | 21.8 | 31.3 | 42.0 |
| 20 | 2.53 | 2.08 | 4.6 | 4.4 | 0.52 | 0.26 | 9.8 | 7.5 | 16.7 | 15.6 | 43.2 | 31.9 |
| 21 | 2.72 | 2.78 | 4.5 | 4.6 | 0.53 | 0.25 | 8.9 | 10.7 | 17.0 | 15.0 | 37.4 | 49.9 |
| 22 | 3.53 | 3.92 | 4.5 | 4.3 | 1.07 | 0.53 | 12.4 | 14.6 | 24.1 | 22.2 | 42.1 | 40.9 |
| 23 | 4.49 | 3.60 | 4.8 | 4.5 | 1.44 | 0.25 | 17.1 | 14.7 | 28.9 | 20.2 | 46.9 | 47.7 |
| 24 | 3.37 | 4.95 | 4.0 | 3.5 | 0.89 | 1.52 | 15.6 | 23.7 | 31.2 | 28.5 | 32.0 | 46.7 |
| 25 | 4.76 | 2.74 | 4.8 | 3.7 | 1.24 | 0.98 | 20.0 | 11.3 | 29.5 | 16.3 | 50.9 | 34.5 |
| 26 | 4.32 | 3.50 | 5.4 | 3.7 | 0.67 | 0.58 | 16.8 | 12.9 | 25.2 | 16.6 | 39.1 | 41.3 |
| 27 | 5.03 | 2.64 | 4.7 | 3.7 | 1.08 | 0.79 | 19.0 | 11.1 | 25.4 | 16.5 | 46.3 | 39.6 |
| **Mean** | **3.66** | **3.45** | **4.4** | **4.0** | **1.35** | **0.67** | **16.1** | **13.9** | **25.8** | **19.6** | **45.5** | **41.1** |
| Range | 1.98 - 5.29 | 1.55 - 6.78 | 3.2 - 5.4 | 3.0 - 5.0 | 0.43 - 4.00 | 0.23 - 1.71 | 8.9 - 23.5 | 7.1 - 25.2 | 16.6 - 38.8 | 9.7 - 33.5 | 30.9 - 68.6 | 31.9 - 52.7 |
| CD (0.05) | NS | | 0.291 | | 0.366 | | 1.74 | | 2.02 | | 4.27 | |
| SEm± | 0.143 | | 0.101 | | 0.126 | | 0.598 | | 0.694 | | 1.47 | |

SI - Rainy season (before the closure of Thanneermukkom regulator)
SII - Summer season (after the closure of Thanneermukkom regulator)

Table 12. Correlation matrix showing inter-relationships among various chemical properties of soils

| Characters | pH | EC | Exch. acidity | Exch. H$^{+}$ | Exch. Al$^{3+}$ | Hydr. acidity | Poten. acidity | ECEC | Al saturation | CEC |
|---|---|---|---|---|---|---|---|---|---|---|
| pH | 1.000 | | | | | | | | | |
| EC | -0.484$^{*}$ | 1.000 | | | | | | | | |
| Exch. acidity | -0.418$^{*}$ | 0.052 | 1.000 | | | | | | | |
| Exch. H$^{+}$ | -0.402$^{*}$ | -0.145 | 0.832$^{**}$ | 1.000 | | | | | | |
| Exch. Al$^{3+}$ | -0.311 | 0.213 | 0.862$^{**}$ | 0.437 | 1.000 | | | | | |
| Hydr. acidity | -0.044 | 0.245 | 0.085 | -0.102 | 0.237 | 1.000 | | | | |
| Poten. acidity | -0.185 | 0.280 | 0.393$^{*}$ | 0.164 | 0.492$^{**}$ | 0.947$^{**}$ | 1.000 | | | |
| ECEC | -0.333 | 0.474$^{*}$ | 0.619$^{**}$ | 0.392$^{*}$ | 0.643$^{**}$ | 0.376 | 0.552$^{**}$ | 1.000 | | |
| Al saturation | -0.215 | -0.034 | 0.684$^{**}$ | 0.286 | 0.851$^{**}$ | 0.033 | 0.242 | 0.211 | 1.000 | |
| CEC | -0.197 | 0.471$^{*}$ | 0.407$^{*}$ | 0.125 | 0.546$^{**}$ | 0.735$^{**}$ | 0.813$^{**}$ | 0.855$^{**}$ | 0.162 | 1.000 |

$^{*}$ Significant at 5% level; $^{**}$ Significant at 1% level

The different forms of Na are presented in Fig. 6.

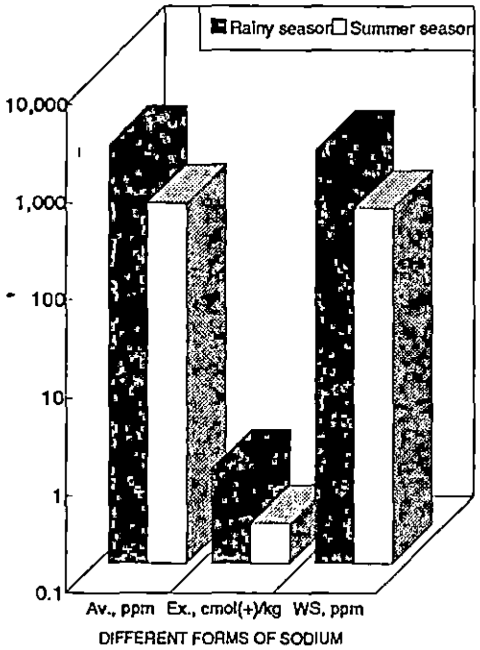


Fig 6. Available, water soluble and exchangeable forms of Na in soil during rainy and summer seasons. (Av - Available, Ex - Exchangeable, WS - Water slouble)

The available Na during rainy season was 1983 ppm (range 608-5158 ppm) and it decreased to 501 ppm (range 194-1496 ppm) during summer (Table 14) due to the prevention of saline water entry). The decrease was of 75 per cent. The available and water soluble Na were significantly correlated with soil EC (0.730$^{**}$, 0.718$^{**}$).

The water soluble Na followed the same trend as that of available Na (Table 16) since more than 87 per cent of the latter was in water soluble form. The exchangeable Na, though present in very small quantity, also followed a similar trend.

The exchangeable Na constituted 8.10 per cent of the total exchangeable bases during rainy season and it decreased to 3.60 per cent during summer (Fig 13). Electrical conductivity was significantly and positively correlated with CEC and ECEC (Table 12). The electrical conductivity also recorded highly positive and significant correlation with available and water soluble fractions of K, Na, Ca and Mg (Tables 13).

Table 13. Correlation coefficients (r) between various chemical properties of surface soils

| Variables | | | r |
|---|---|---|---|
| Org. carbon | vs | Available N | 0.583** |
| Org. carbon | vs | Available K | 0.474* |
| Org. carbon | vs | Available Ca | 0.402* |
| Org. carbon | vs | Available Fe | 0.448* |
| Org. carbon | vs | Total exch. bases | 0.523** |
| Org. carbon | vs | CEC | 0.631** |
| Org. carbon | vs | ECEC | 0.715** |
| Org. carbon | vs | Exch. acidity | 0.530** |
| Org. carbon | vs | Exch. $H^+$ | 0.385* |
| Org. carbon | vs | Exch. $Al^{3+}$ | 0.508** |
| Org. carbon | vs | Hydr. acidity | 0.387* |
| Org. carbon | vs | Poten. acidity | 0.521** |
| EC | vs | Av. K | 0.579** |
| EC | vs | Av. Na | 0.730** |
| EC | vs | Av. Ca | 0.500** |
| EC | vs | Av. Mg | 0.513** |
| EC | vs | Wat. solu. K | 0.651** |
| EC | vs | Wat. solu. Na | 0.718** |
| EC | vs | Wat. solu. Ca | 0.540** |
| EC | vs | Wat. solu. Mg | 0.560** |
| Exch. K | vs | Exch. Na | 0.529** |
| Exch. K | vs | Exch. Ca | 0.411* |
| Exch. Na | vs | Exch. Ca | 0.546** |
| CEC | vs | Total exch. bases | 0.825** |
| PBS | vs | Al saturation | 0.584** |

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

### 1.3 Organic carbon

The organic carbon content of the Kuttanad tract is fairly high, in contrast to the other soil types of Kerala. Certain parts of kari lands recorded organic carbon content as high as 17.5 per cent (KAU, 1994). A considerable reduction in organic matter content of the area during the post-barrage period has been reported (Kabeerathumma and Patnaik, 1978; Amma *et al.*, 1979; Marykutty, 1986; Marykutty and Aiyer, 1987; Amma, 1988; Raju, 1988; Mathew, 1989). In the present study also a similar observation was noted.

Like pH and EC, organic carbon content of the area was also greater during rainy season (before the closure of Thanneermukkom regulator) which is shown in Fig 7. The mean value of organic carbon content was 3.66 per cent during rainy season and decreased to 3.45 per cent during summer. The lowest value of 1.55 per cent was registered by the Maleekayal due to the sandy nature of that field. The increased rate of organic matter decomposition during summer under the influence of high temperature and continuous cultivation activities during the punja season which provide better aeration in the soil might have caused the reduction in organic carbon content.

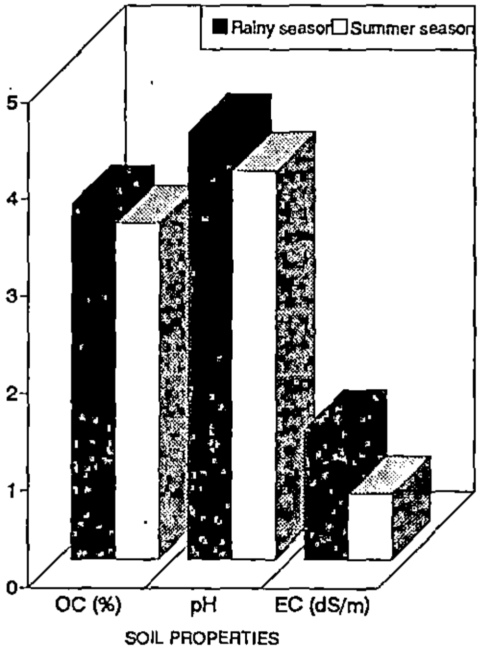


Fig 7. Organic carbon, pH and EC of soils during rainy and summer seasons

The organic carbon showed significant and positive correlation with acidity contributing characteristics like the exchangeable acidity (0.530**), exchangeable $H^+$ (0.385*), exchangeable $Al^{3+}$ (0.508**), hydrolytic acidity (0.387*) and potential acidity (0.521**), revealing the major role of organic matter in increasing the soil acidity in Kuttanad.

*1.4 CEC, ECEC and base saturation*

In general, soils of Kerala are poor in CEC due to the predominance of the 1:1 type clay mineral, kaolinite and sesquioxides as a result of high weathering intensity. However, the relatively high CEC of Kuttanad soils projects the role of soil organic matter in considerably increasing the CEC of soil (Marykutty and Aiyer, 1987).

CEC of the study area varied from 16.6 to 38.8 cmol(+) $kg^{-1}$ with a mean value of 25.8 cmol(+) $kg^{-1}$ during rainy season. The seasonal influence was significant on the CEC of soils and the mean value decreased to 19.6 cmol(+) $kg^{-1}$ during summer (Fig 8). The decrease was due to reduction in organic carbon content and soil pH. Lowering the pH of soils containing large quantities of adsorbed hydroxy Al-polymers decreases the soil CEC by increasing the positive charge on the polymers.

The neutral normal ammonium acetate method usually overestimates CEC of acid soils by bringing it to a point of neutrality by which additional negative charges are induced and this pH dependent charges increase the CEC. Hence ECEC which measures only the permanent charge component was also estimated for different seasons. The mean value of ECEC during rainy season was 16.1 cmol(+) $kg^{-1}$ and it decreased to 13.9 cmol(+) $kg^{-1}$ during summer. The reduction observed for ECEC was 39.0 and 29.0 per cent, during rainy and summer seasons, respectively from the corresponding CEC values, indicating the presence of excess pH dependent charges during rainy season. About 19-20 per cent of ECEC was contributed by exchangeable Al during both the seasons.

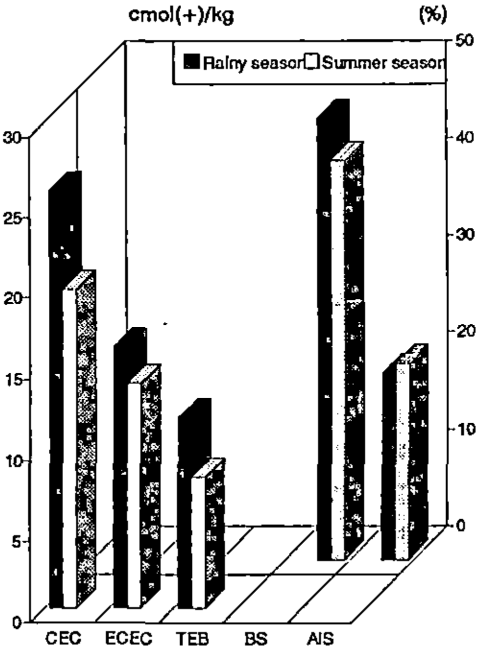


Fig 8. Exchange properties of soil during different seasons (TEB - Total exchangeable bases; BS - Base saturation; AlS - Al saturation)

The influence of soil organic matter and potential acidity on CEC and ECEC was clearly evident from their significant positive inter-relationship with organic carbon (0.631**, 0.715**) and potential acidity (0.813**, 0.522**).

Even though the CEC was high, the base saturation was below 50 per cent indicating a greater degree of base unsaturation. The dominance of $H^+$ ions in the exchange complex due to the highly acidic condition reduced the extent of base saturation in these soils. The CEC was highly correlated with sum of exchangeable bases (0.825**).

*1.5 Available nutrients (Tables 14, 15 and Fig 9)*

*Available nitrogen:* The Kuttanad soils are reported to be high in available N compared to the other soils of Kerala (KAU, 1994). The available N content of the study area was significantly influenced by the season/closure of the Thanneermukkom regulator. The mean value was 286 ppm (range 185-431 ppm) during the rainy season and it increased to 324 ppm (range 175-489 ppm) during summer.The enhanced decomposition of organic matter resulting the release of easily decomposable compounds and greater mineralisation duing summer increased the N availability. The available N content of the area was also high as in the case of total N (Table 6).The construction of regulator has not altered the available N status of the area, since present values agree with those reported by Pillai (1964) and Kabeerathumma (1969) during the pre-barrage period.

*Available phosphorus:* In general, Kuttanad soils are deficient in available P due to their high P fixation capacity. The present observation agrees with it. The mean value during rainy season was 3.17 ppm and it increased to 5.50 ppm during summer. The application of P fertilisers during additional and punja crop seasons, better organic matter decomposition and solubilisation of Fe compounds during summer enhanced the available P content. The entire study area was deficient in available P as per the soil test criteria of the state. About 67 per cent of the study area was deficient in total P also (Table 6). The presence of large quantities of Fe and Al oxides and hydroxides together with 1:1 type clays are responsible for this high P fixation.

*Available potassium:* The Kuttanad soils were relatively deficient in available K during the pre-barrage period as per the reports of Alexander and Durairaj (1968) and Nair and Money (1972), the range being 35 to 78 ppm. As per the studies of post-barrage period the range is about 124-216 ppm for available K in this area (Amma, 1988; Raju, 1988; Mathew, 1989). In the present study the mean value of available K was 293 ppm during rainy season which decreased to 179 ppm during summer. Based on soil test criteria these soils are high in available K.

The concentration of available K was high during rainy season owing to the influence of saline water during April-May which was not removed completely by early monsoon showers (May-June). During summer (December-April) the saline water entry was prevented by closing the regulator and this led to a lower value of available K.

*Available calcium and magnesium:* The mean value of available Ca was 2271 ppm during rainy season which decreased to 1519 ppm during summer. Among the basic cations, the decrease in concentration during summer was comparatively lower (33 per cent) for Ca indicating its better adsorption on exchange complex. Compared to the previous values reported (Sreedevi and Aiyer, 1974; Aiyer *et al.*, 1975; Santhakumari, 1975), there was an increase in available Ca content during the post-barrage period, evidently due to the accumulation of leachates brought down by the rivers from the upper fringes of Western Ghats and addition of the liming materials. Among the available bases, Ca recorded the highest value. A major part of the available Ca was held in exchangeable form. The water soluble fraction of available Ca was comparatively lower and was minimum during summer season.

Table 14. Available nutrient content of soils during different seasons (ppm)

| Padasekharam No. | N | | P | | K | | Ca | | Mg | | Na | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII |
| 1 | 210 | 257 | 1.82 | 1.41 | 331 | 246 | 4007 | 1670 | 339 | 314 | 2539 | 521 |
| 2 | 202 | 283 | 2.85 | 1.59 | 235 | 154 | 4032 | 1939 | 379 | 319 | 2536 | 492 |
| 3 | 293 | 443 | 0.79 | 3.88 | 282 | 149 | 1906 | 1496 | 484 | 203 | 2115 | 396 |
| 4 | 410 | 306 | 0.26 | 9.48 | 463 | 324 | 2420 | 2106 | 649 | 305 | 5158 | 1496 |
| 5 | 336 | 386 | 3.60 | 6.71 | 278 | 312 | 2046 | 1702 | 443 | 234 | 1759 | 876 |
| 6 | 293 | 405 | 1.77 | 4.23 | 238 | 200 | 2241 | 1623 | 309 | 206 | 1116 | 372 |
| 7 | 318 | 218 | 1.66 | 1.16 | 339 | 91 | 2737 | 1006 | 603 | 127 | 3875 | 305 |
| 8 | 185 | 175 | 1.57 | 1.15 | 211 | 106 | 2601 | 1065 | 407 | 221 | 1409 | 429 |
| 9 | 328 | 283 | 1.63 | 2.17 | 401 | 142 | 2896 | 684 | 472 | 129 | 2031 | 227 |
| 10 | 431 | 489 | 1.59 | 2.35 | 539 | 349 | 3011 | 2634 | 1570 | 349 | 3822 | 992 |
| 11 | 256 | 332 | 2.16 | 2.89 | 208 | 199 | 1767 | 1437 | 474 | 155 | 1091 | 308 |
| 12 | 245 | 392 | 1.16 | 6.68 | 325 | 247 | 2069 | 1529 | 750 | 175 | 1454 | 672 |
| 13 | 320 | 281 | 2.10 | 5.41 | 284 | 194 | 2684 | 1378 | 323 | 180 | 1771 | 511 |
| 14 | 222 | 254 | 0.32 | 5.11 | 313 | 262 | 1943 | 1729 | 363 | 218 | 2120 | 762 |
| 15 | 200 | 271 | 4.28 | 9.10 | 175 | 155 | 1468 | 768 | 363 | 337 | 1435 | 359 |
| 16 | 197 | 246 | 3.04 | 8.68 | 188 | 129 | 1904 | 852 | 590 | 288 | 1616 | 595 |
| 17 | 325 | 312 | 3.56 | 1.80 | 325 | 96 | 2016 | 2278 | 759 | 155 | 1966 | 376 |
| 18 | 247 | 372 | 4.15 | 3.20 | 265 | 194 | 2636 | 1853 | 491 | 104 | 1632 | 422 |
| 19 | 289 | 328 | 5.39 | 1.12 | 246 | 171 | 2745 | 1891 | 745 | 155 | 1646 | 436 |
| 20 | 234 | 268 | 4.19 | 8.05 | 197 | 84 | 1147 | 1026 | 497 | 98 | 793 | 194 |
| 21 | 240 | 418 | 4.76 | 5.84 | 181 | 131 | 1133 | 1524 | 508 | 98 | 608 | 217 |
| 22 | 363 | 388 | 5.68 | 8.89 | 330 | 162 | 1646 | 1416 | 631 | 443 | 2132 | 518 |
| 23 | 378 | 398 | 7.09 | 17.80 | 357 | 127 | 2031 | 1726 | 608 | 430 | 2775 | 321 |
| 24 | 344 | 286 | 5.22 | 10.47 | 265 | 194 | 1822 | 1576 | 442 | 618 | 1282 | 480 |
| 25 | 324 | 286 | 5.28 | 5.17 | 339 | 127 | 2898 | 1268 | 659 | 75 | 2392 | 367 |
| 26 | 281 | 288 | 4.52 | 7.41 | 270 | 134 | 1849 | 1461 | 686 | 115 | 901 | 361 |
| 27 | 272 | 257 | 5.35 | 4.75 | 322 | 161 | 1674 | 1388 | 989 | 136 | 1580 | 530 |
| **Mean** | **286** | **324** | **3.17** | **5.50** | **293** | **179** | **2271** | **1519** | **575** | **229** | **1983** | **501** |
| Range | 185 - 431 | 175-489 | 0.26-7.09 | 1.12-17.80 | 175-539 | 84-349 | 1133-4032 | 684-2634 | 309-1570 | 75-618 | 608-5158 | 194-1496 |
| CD(0.05) | 28.7 | | 1.32 | | 30.6 | | 291 | | 113 | | 340 | |
| SEm± | 9.88 | | 0.453 | | 10.5 | | 100 | | 39.0 | | 117 | |

SI = Rainy season (Before the closure of Thanneermukkom regulator)

SII = Summer season (After the closure of Thanneermukkom regulator)

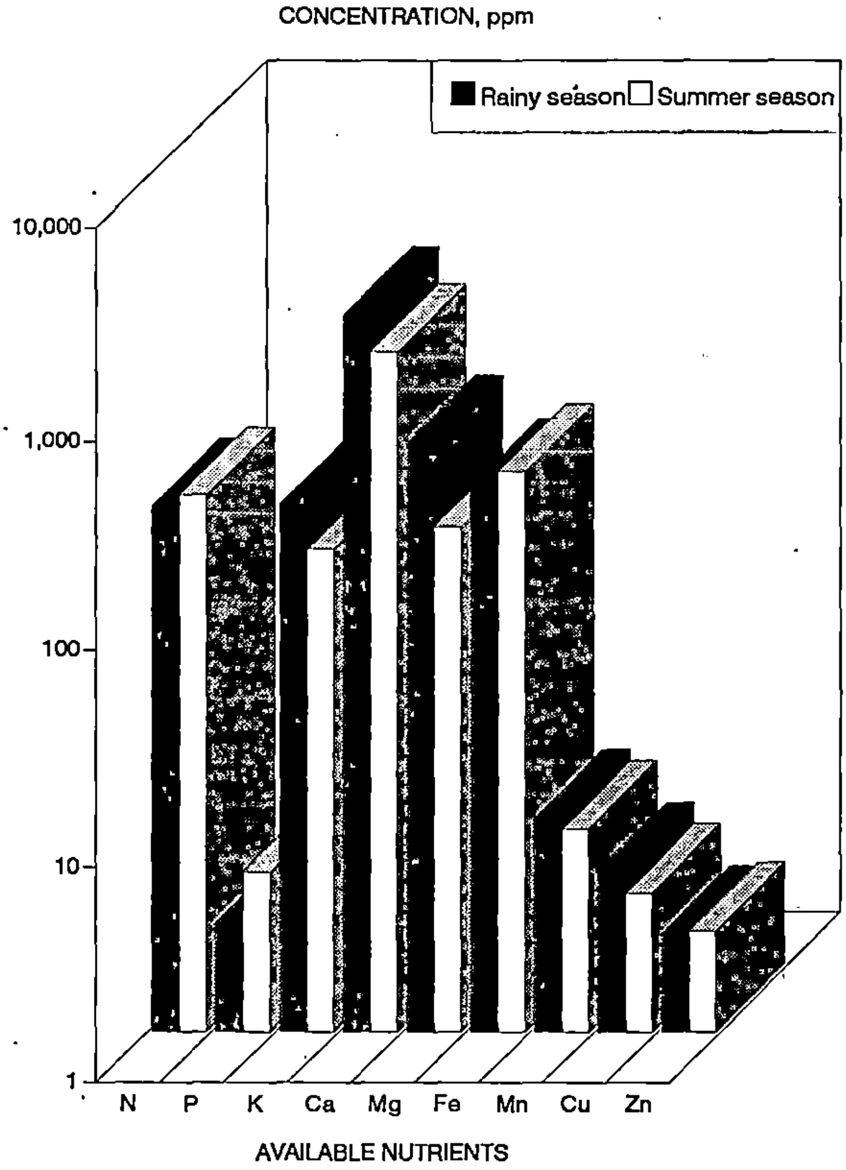


Fig 9. Available nutrients in soil during different seasons

The behaviour of Mg was similar to that of Ca. The mean value of available Mg during rainy season was 575 ppm falling to 229 ppm during summer season. The decrease was of about 61 per cent. Its greater concentration during rainy season was due to the presence of saline water that remained in the study area at the time of soil collection. Almost all the cationic elements except Fe and Zn showed a decrease in concentration during summer. However, the availability of N and P was found to increase during that period (Fig 9).

*Available iron (Table 15):* The Kuttanad soils are rich in Fe , especially the kari soils which recorded very high values for the available Fe.

Plate XIV. Arunoorupadasekharam of Aymanam village - Preparatory cultivation activities

Plate XVI. Rice fields of Kannadichal of Kumarakom village nearing harvest

Plate XVII. J Block padasekharam of Thiruvarpu village at harvest

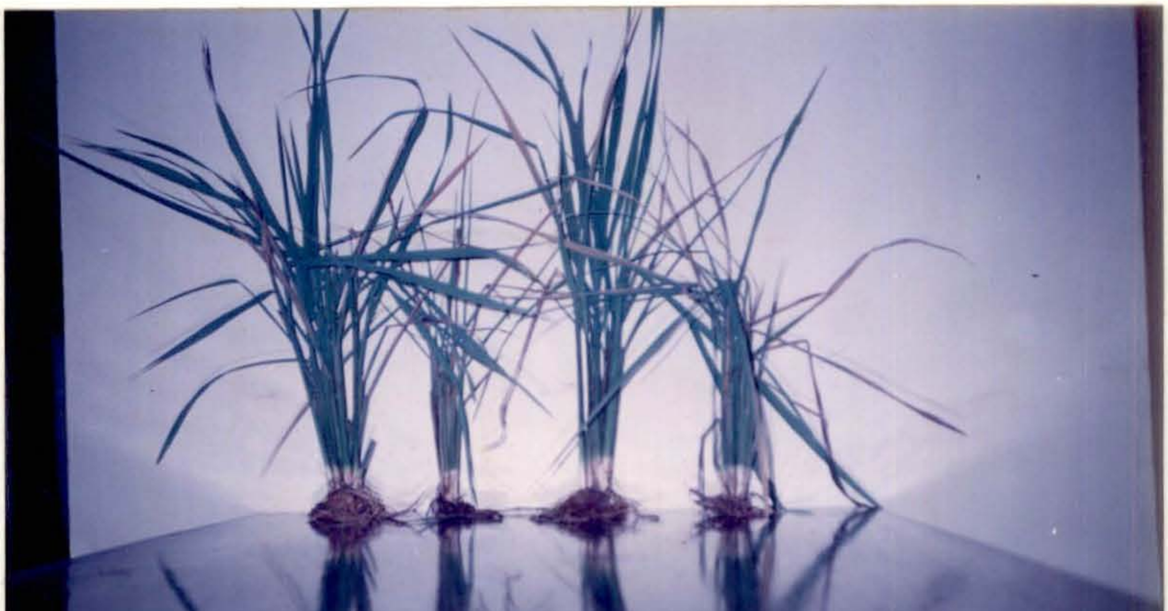


Plate XVIII. Rice plants showing symptoms of iron toxicity

Table 15. Available micronutrient content of soils during different seasons (ppm)

| Padasekharam No. | Fe | | Mn | | Cu | | Zn | |
|---|---|---|---|---|---|---|---|---|
| | SI | SII | SI | SII | SI | SII | SI | SII |
| 1 | 356 | 434 | 3.11 | 3.51 | 2.91 | 1.48 | 2.45 | 2.45 |
| 2 | 372 | 420 | 6.66 | 8.64 | 3.94 | 0.92 | 2.12 | 5.42 |
| 3 | 343 | 441 | 6.29 | 11.90 | 8.52 | 5.71 | 1.31 | 3.67 |
| 4 | 511 | 586 | 5.03 | 9.31 | 9.09 | 0.83 | 5.24 | 2.78 |
| 5 | 430 | 405 | 7.76 | 10.09 | 5.82 | 0.76 | 5.81 | 2.56 |
| 6 | 419 | 141 | 9.79 | 2.34 | 8.91 | 0.94 | 2.22 | 1.50 |
| 7 | 226 | 366 | 11.3 | 2.80 | 1.78 | 4.19 | 1.67 | 6.11 |
| 8 | 229 | 276 | 10.03 | 7.48 | 2.10 | 1.97 | 1.55 | 2.02 |
| 9 | 221 | 385 | 4.79 | 3.10 | 1.87 | 4.10 | 1.14 | 2.23 |
| 10 | 430 | 592 | 7.95 | 2.31 | 1.64 | 7.04 | 1.81 | 2.09 |
| 11 | 183 | 414 | 12.32 | 10.94 | 6.64 | 8.50 | 4.05 | 2.70 |
| 12 | 375 | 440 | 10.26 | 7.97 | 6.43 | 6.04 | 2.51 | 1.86 |
| 13 | 428 | 417 | 15.14 | 12.70 | 8.00 | 6.88 | 5.42 | 2.22 |
| 14 | 358 | 420 | 17.85 | 9.30 | 3.81 | 8.62 | 1.03 | 1.54 |
| 15 | 394 | 407 | 4.96 | 3.82 | 3.78 | 2.75 | 1.97 | 7.72 |
| 16 | 402 | 437 | 7.05 | 7.61 | 2.18 | 3.80 | 1.31 | 3.87 |
| 17 | 381 | 502 | 11.66 | 18.15 | 6.16 | 5.03 | 4.08 | 6.07 |
| 18 | 471 | 509 | 19.35 | 20.52 | 6.51 | 5.05 | 4.82 | 2.81 |
| 19 | 303 | 436 | 1 .92 | 11.70 | 1.53 | 3.00 | 8.38 | 1.57 |
| 20 | 314 | 251 | 10.16 | 8.02 | 8.01 | 3.40 | 2.97 | 2.07 |
| 21 | 247 | 391 | 10.87 | 8.87 | 7.29 | 8.75 | 1.51 | 2.64 |
| 22 | 259 | 478 | 7.33 | 5.25 | 6.69 | 5.77 | 2.31 | 2.91 |
| 23 | 507 | 351 | 9.53 | 8.88 | 10.86 | 0.51 | 2.40 | 3.10 |
| 24 | 283 | 589 | 8.11 | 16.20 | 9.29 | 10.31 | 4.28 | 3.04 |
| 25 | 491 | 457 | 11.48 | 7.04 | 7.05 | 3.97 | 1.58 | 1.40 |
| 26 | 383 | 414 | 6.37 | 9.30 | 2.47 | 7.95 | 1.15 | 1.97 |
| 27 | 350 | 416 | 11.49 | 6.00 | 5.70 | 4.63 | 1.80 | 1.22 |
| **Mean** | **358** | **421** | **9.76** | **8.65** | **5.51** | **4.40** | **2.85** | **2.95** |
| Range | 183-511 | 141-592 | 3.11-19.35 | 2.31-20.52 | 1.53-10.86 | 0.76-10.31 | 1.03-8.38 | 1.22-7.72 |
| CD(0.05) | 46.8 | | NS | | NS | | NS | |
| SEm± | 16.10 | | 1.21 | | 0.555 | | 0.345 | |

SI = Rainy season (Before the closure of Thanneermukkom regulator)
SII = Summer season (After the closure of Thanneermukkom regulator)

Fe toxicity has been identified as the most serious nutrient disorder of the area (Plate XVIII). The study area represented mainly karappadam soils where the level of Fe was not as high as that of kari. However, the present study confirmed the presence of large quantities of Fe, both total (Table 6) and available (Table 15) which were many times greater than the concentration of other micronutrient cations. Apart from the large quantity of native Fe, the persistence of soil pH below 5.0 and reduced soil condition due to submergence have kept Fe in soluble form resulting its high availability. The mean value of available Fe (DTPA) during rainy season was 358 ppm (range 183-511 ppm) and it increased to 421 ppm (range 143-592 ppm) during summer. The increase observed was of about 17.6 per cent. This was definitely in response to lowering of soil pH during summer. The interruption of free drainage by closing the regulator aggravated the situation. The soils are plentiful in available Fe as per the critical level of 4.5 ppm for DTPA extract (Tandon, 1995).

*Available manganese, copper and zinc (Table 15):* In general, the Kerala soils are well supplied with available Mn except certain pockets in Trichur, Calicut and Ernakulam districts (Rajagopal *et al.*, 1977). Lindsay and Norvell (1978) proposed the critical level of 1 ppm of DTPA extractable Mn for deficiency. Aiyer *et al.* (1975) fixed 2 ppm of exchangeable Mn as the critical limit for Kuttanad soils. Based on the above criteria the Kuttanad soils are adequately supplied with available Mn. The submergence again increases the Mn availability. The mean value of available Mn was 9.76 ppm during rainy season and it decreased to 8.65 ppm during summer. Compared to Fe, Mn was present in small quantities and Mn toxicity was not yet reported from the area.

Cu deficiency is common in newly reclaimed areas while other areas seldom show Cu deficiency. The Cu content of earth's crust varies from 50 to 700 ppm. According to Aiyer *et al.* (1975) and Rajagopal *et al.* (1977) Cu was the most deficient element in Kerala soils and in Kuttanad more than 90 per cent of the area showed Cu deficiency based on the critical level of 0.5 ppm of available Cu. In acid soils the micronutrient solubility will be greater due to the acidic condition which increases the solubility of micronutrient containing minerals. But the increased solubility will result in the loss of micronutrients and this will be aggravated under submerged condition. The mean value of available Cu was 5.51 ppm during rainy season and it decreased to 4.40 ppm during summer. Adoption of the intensive cropping, loss of Cu through flood waters and dominance of Fe might have reduced the available Cu content during summer. However, an increase in available Cu was observed on comparison with values recorded during the pre-barrage period. The continuous use of Cu containing fungicides in the area and the enhanced rate of organic matter decomposition which helped the release of Cu held in organic forms would have contributed towards the increase in Cu content. The study area was not deficient in Cu based on the critical level suggested by Aiyer *et al.* (1975) or Tandon (1994)

A widespread deficiency of Zn in Kerala except in black soils of Chitoor was reported by Rajagopal *et al.* (1977). Aiyer *et al.* (1975) also reported that 50 per cent of the area in Kuttanad was deficient in available Zn by fixing a critical level of 0.5 ppm for it. Sharma *et al.* (1986) reported a critical level of 0.55 ppm DTPA extractable and 1 ppm of 0.05 *N* HCl + 0.025 *N* $H_2SO_4$ extractable Zn in the soil. The available Zn content of the area was 2.85 ppm during rainy season and increased to 2.95 ppm during summer. As per the above criteria the study area cannot be considered as deficient in available Zn.

### *1.6 Water soluble potassium, calcium and magnesium (Table 16)*

The behaviour of water soluble fractions of K, Ca and Mg was similar to that of their available fractions during both the seasons. Here also, the concentration of the above basic cations was greater during rainy season (Fig 10) due to the influence of saline water remained

Table 16. Water soluble cations of soils during different seasons (ppm)

| Padasekharam No. | K | | Na | | Ca | | Mg | |
|---|---|---|---|---|---|---|---|---|
| | SI | SII | SI | SII | SI | SII | SI | SII |
| 1 | 133 | 76 | 1984 | 443 | 402 | 178 | 225 | 42 |
| 2 | 156 | 102 | 2242 | 462 | 502 | 330 | 271 | 114 |
| 3 | 118 | 55 | 1823 | 349 | 381 | 329 | 213 | 70 |
| 4 | 319 | 202 | 4845 | 1375 | 758 | 486 | 500 | 140 |
| 5 | 162 | 122 | 1612 | 746 | 387 | 236 | 254 | 87 |
| 6 | 142 | 60 | 994 | 325 | 294 | 186 | 255 | 85 |
| 7 | 181 | 43 | 3412 | 272 | 786 | 183 | 506 | 92 |
| 8 | 111 | 63 | 1289 | 392 | 650 | 202 | 295 | 118 |
| 9 | 268 | 70 | 2007 | 199 | 867 | 134 | 392 | 90 |
| 10 | 360 | 170 | 3684 | 837 | 1303 | 370 | 854 | 179 |
| 11 | 99 | 64 | 908 | 271 | 501 | 189 | 142 | 34 |
| 12 | 150 | 111 | 1224 | 603 | 631 | 256 | 323 | 124 |
| 13 | 116 | 86 | 1513 | 442 | 556 | 294 | 89 | 109 |
| 14 | 191 | 97 | 1913 | 592 | 538 | 206 | 113 | 87 |
| 15 | 102 | 68 | 1210 | 289 | 517 | 281 | 150 | 87 |
| 16 | 137 | 70 | 1438 | 478 | 511 | 223 | 208 | 117 |
| 17 | 225 | 60 | 1866 | 342 | 968 | 342 | 451 | 128 |
| 18 | 147 | 107 | 1472 | 401 | 557 | 319 | 290 | 54 |
| 19 | 125 | 77 | 1492 | 368 | 1129 | 229 | 469 | 106 |
| 20 | 106 | 35 | 623 | 163 | 479 | 186 | 160 | 41 |
| 21 | 82 | 56 | 502 | 170 | 446 | 154 | 253 | 66 |
| 22 | 153 | 57 | 1982 | 434 | 361 | 174 | 324 | 178 |
| 23 | 195 | 42 | 2364 | 257 | 339 | 226 | 274 | 235 |
| 24 | 143 | 87 | 1006 | 426 | 588 | 273 | 250 | 169 |
| 25 | 203 | 73 | 2101 | 346 | 754 | 214 | 367 | 56 |
| 26 | 177 | 67 | 689 | 350 | 584 | 274 | 489 | 81 |
| 27 | 209 | 83 | 1455 | 485 | 533 | 206 | 329 | 111 |
| **Mean** | **167** | **81** | **1764** | **438** | **605** | **247** | **313** | **104** |
| Range | 82-360 | 35-202 | 502-4845 | 163-1375 | 294-1303 | 134-486 | 89-854 | 34-235 |
| CD(0.05) | 20.1 | | 322 | | 90.1 | | 59.0 | |
| SEm± | 6.91 | | 111 | | 31.0 | | 20.3 | |

SI = Rainy season (Before the closure of Thanneermukkom regulator)

SII = Summer season (After the closure of Thanneermukkom regulator)

in the study area at the time of soil collection which coincides with the early south west monsoon period. The salinity intruded into the area after the opening of the Thanneermukkom regulator during summer will be washed out completely only by the end of south west monsoon.

Nearly half of the available K was present in water soluble form. It contributed 56.40 per cent of available K during rainy season and 46.10 per cent during summer season. Among the basic cations, the percentage contribution of water soluble form to available form was least for Ca (Fig 11). The percentage contribution of water soluble Ca to available Ca was 28 per cent during rainy season which decreased to 17 per cent during summer. The mean values for water soluble Ca were 606 and 247 ppm, respectively during rainy and summer seasons. Mg also followed the same trend as that of Ca but nearly more than half of the available Mg was in water soluble form.

### *1.7 Exchangeable potassium, calcium and magnesium (Table 17)*

Kerala soils, in general, record low values for CEC and total exchangeable bases compared to soils of other parts of India due to acidic nature of parent rock, intense weathering conditions, presence of low activity clays, faster organic matter decomposition and leaching of bases. The undulating topography of the state aggravates the above situation and results in

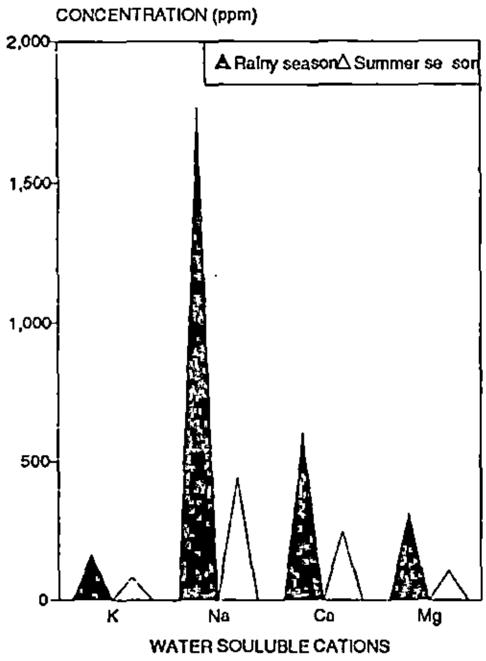


Fig 10. Water soluble cations in soil during different seasons

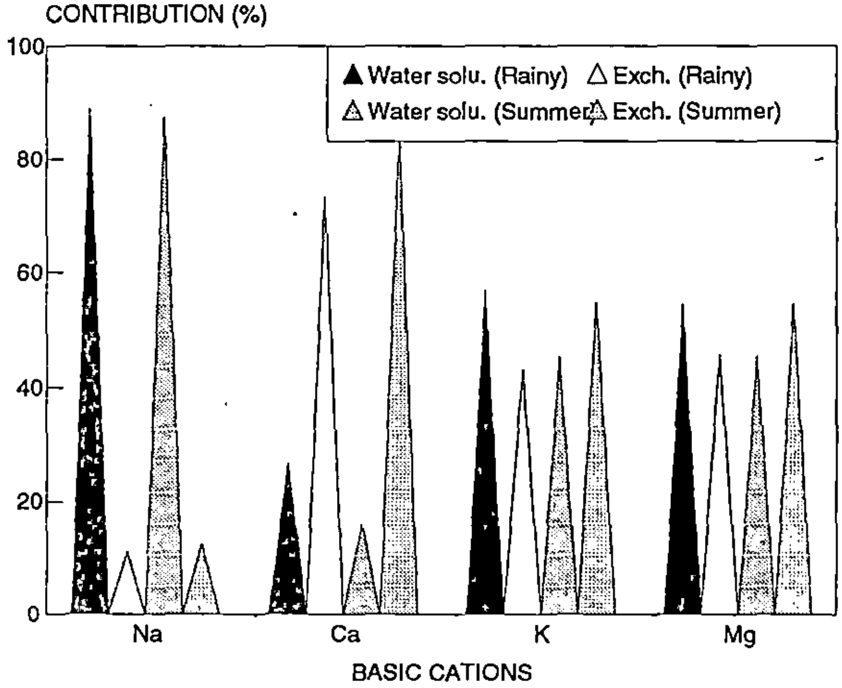


Fig 11. Contribution of water soluble and exchangble cations to their available forms during rainy and summer seasons

Table 17. Exchangeable cations of soils during different seasons [cmol(+) kg $^{-1}$]

| Pada-sekha-ram No. | K | | Na | | Ca | | Mg | | Total Ex. bases | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII |
| 1 | 0.509 | 0.436 | 2.41 | 0.34 | 18.02 | 7.46 | 0.95 | 2.27 | 21.9 | 10.5 |
| 2 | 0.201 | 0.132 | 1.28 | 0.13 | 17.60 | 8.05 | 0.90 | 1.71 | 20.0 | 10.0 |
| 3 | 0.418 | 0.239 | 1.27 | 0.24 | 7.61 | 5.84 | 2.25 | 1.10 | 11.6 | 7.4 |
| 4 | 0.367 | 0.312 | 1.37 | 0.31 | 8.32 | 8.10 | 1.24 | 1.38 | 11.3 | 10.1 |
| 5 | 0.298 | 0.484 | 0.64 | 0.48 | 8.30 | 7.33 | 1.57 | 1.22 | 10.8 | 9.6 |
| 6 | 0.245 | 0.356 | 0.53 | 0.36 | 9.74 | 7.18 | 0.45 | 1.01 | 11.0 | 8.8 |
| 7 | 0.462 | 0.122 | 2.01 | 0.12 | 9.77 | 4.12 | 0.80 | 0.29 | 13.1 | 4.7 |
| 8 | 0.255 | 0.111 | 0.52 | 0.11 | 9.75 | 4.31 | 0.93 | 0.85 | 11.5 | 5.4 |
| 9 | 0.341 | 0.183 | 0.11 | 0.18 | 10.14 | 2.75 | 0.67 | 0.33 | 11.3 | 3.4 |
| 10 | 0.459 | 0.457 | 0.60 | 0.46 | 8.55 | 11.32 | 5.95 | 1.41 | 15.5 | 13.9 |
| 11 | 0.278 | 0.345 | 0.79 | 0.35 | 6.33 | 6.51 | 2.46 | 1.14 | 9.8 | 8.2 |
| 12 | 0.445 | 0.346 | 0.99 | 0.35 | 7.14 | 6.37 | 2.84 | 0.43 | 11.4 | 7.4 |
| 13 | 0.428 | 0.279 | 1.12 | 0.28 | 10.64 | 5.43 | 1.96 | 0.59 | 14.1 | 6.6 |
| 14 | 0.316 | 0.579 | 0.90 | 0.58 | 7.03 | 7.62 | 2.09 | 1.09 | 10.3 | 9.9 |
| 15 | 0.188 | 0.223 | 0.98 | 0.22 | 4.76 | 2.44 | 1.77 | 2.08 | 7.7 | 5.1 |
| 16 | 0.130 | 0.149 | 0.77 | 0.15 | 6.97 | 3.15 | 3.19 | 1.42 | 11.1 | 5.2 |
| 17 | 0.255 | 0.092 | 0.44 | 0.09 | 5.24 | 9.68 | 2.57 | 0.23 | 8.5 | 10.1 |
| 18 | 0.303 | 0.221 | 0.69 | 0.22 | 10.39 | 7.67 | 1.68 | 0.42 | 13.1 | 8.4 |
| 19 | 0.308 | 0.239 | 0.67 | 0.24 | 8.08 | 8.30 | 2.30 | 0.41 | 11.4 | 9.3 |
| 20 | 0.233 | 0.115 | 0.74 | 0.12 | 3.34 | 4.20 | 2.81 | 0.47 | 7.1 | 4.9 |
| 21 | 0.252 | 0.193 | 0.46 | 0.19 | 3.44 | 6.85 | 2.12 | 0.27 | 6.3 | 7.5 |
| 22 | 0.451 | 0.267 | 0.65 | 0.27 | 6.43 | 6.21 | 2.56 | 2.21 | 10.1 | 9.1 |
| 23 | 0.413 | 0.217 | 1.78 | 0.22 | 8.46 | 7.51 | 2.79 | 1.67 | 13.4 | 9.7 |
| 24 | 0.311 | 0.374 | 1.20 | 0.37 | 6.17 | 9.15 | 1.60 | 3.74 | 9.3 | 13.4 |
| 25 | 0.351 | 0.139 | 1.26 | 0.14 | 10.61 | 5.27 | 2.44 | 0.16 | 14.7 | 5.6 |
| 26 | 0.236 | 0.171 | 0.92 | 0.17 | 6.32 | 5.96 | 6.33 | 0.28 | 9.1 | 6.8 |
| 27 | 0.290 | 0.199 | 0.54 | 0.20 | 5.71 | 5.96 | 5.50 | 0.21 | 12.0 | 6.5 |
| **Mean** | **0.324** | **0.259** | **0.96** | **0.26** | **8.32** | **6.47** | **2.32** | **1.05** | **11.8** | **8.1** |
| Range | 0.130-0.509 | 0.092-0.579 | 0.11-2.41 | 0.09-0.58 | 3.34-18.02 | 2.44-11.32 | 0.45-6.33 | 0.16-3.74 | 6.3-21.9 | 3.4-13.9 |
| CD (0.05) | 0.049 | | 0.206 | | 1.49 | | 0.738 | | 1.47 | |
| SEm± | 0.017 | | 0.071 | | 0.514 | | 0.254 | | 0.507 | |

SI - Rainy season (Before the closure of Thanneermukkom regulator)
SII - Summer season (After the closure of Thanneermukkom regulator)

the development of highly acidic soils. However, the Kuttanad region though highly acidic showed a better CEC due to the presence of large quantities of organic matter and the silt and clay brought down by the rivers. The behaviour of exchangeable bases was also similar to that of their available fractions (Fig 12). Among the exchangeable bases, K was present in the smallest quantity. The mean value of exchangeable K was 0.324 cmol(+) kg$^{-1}$ during rainy season and 0.259 cmol(+) kg$^{-1}$ during summer season.

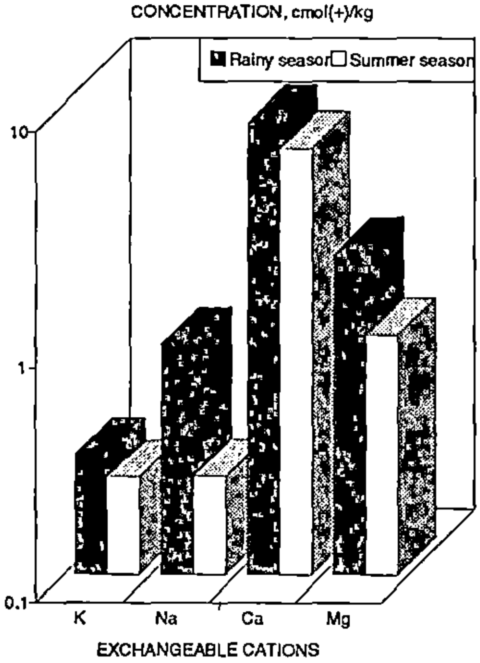


Fig 12. Exchangeable cations in soil during different seasons

Though the exchangeable K was higher during rainy season than summer, the proportion of K in total exchangeable bases followed a reverse trend(Fig 13). Ca was the dominant cation among the exchangeable bases. Greater adsorption on the exchange complex and lower solubility in water mainly contributed to the dominance of Ca in the exchange complex. The mean value of exchangeable Ca was 8.32 cmol(+) kg$^{-1}$ during rainy season and it decreased to 6.47 cmol(+) kg$^{-1}$ during summer. It contributed 70.8 and 80.4 per cent, respectively, of total exchangeable bases during the above two seasons (Fig 13). Mg occupied a position next to Ca among the exchangeable bases, recording a mean value of 2.32 cmol(+) kg$^{-1}$ of exchangeable Mg during rainy season and 1.05 cmol(+) kg$^{-1}$ during summer.

In the normal course, an increase in CEC and exchangeable bases are expected during summer. However, a reverse trend was observed in the present study (Fig 8). The decrease in CEC was due to the decrease in organic matter content and pH dependent charges during summer. The exchangeable bases in the study area were mainly contributed by sea water intrusion after the opening of Thanneermukkom regulator. Sea water being rich in bases naturally increased the exchangeable base status. The time of soil collection coincided with this period. During summer from December to April the saline water entry is prevented in the area by closing the regulator to protect the punja crop of rice and hence the area becomes a fresh water zone which decreases the exchangeable base status.

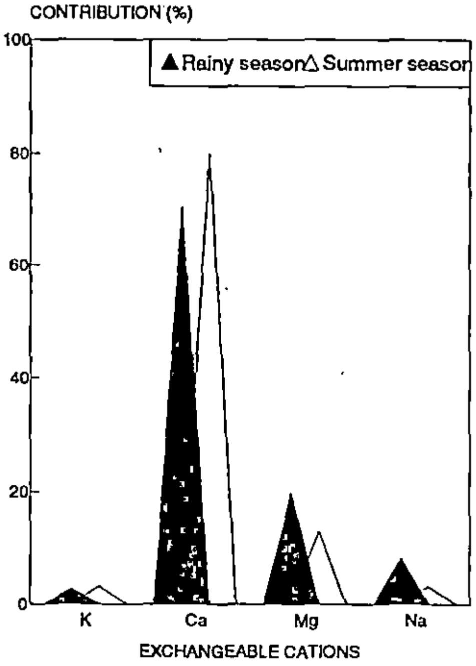


Fig 13. Contribution of exchangeable K, Na, Ca and Mg to total exchangeable bases during rainy and summer seasons

The exchangeable K was significantly and positively correlated to exchangeable Na (0.529**). Both of them showed significant positive correlation with exchangeable Ca (0.411**and 0.546**).

*1.8 Soil acidity*

The Kuttanad soils are extremely acidic in nature with maximum acidity for the kari soils compared to the karappadam and kayal lands. The major acidity contributing factors of the area are the presence of free sulphuric acid formed by the oxidation of Fe and Al sulphides, organic acids released from the decomposing materials and large quantities of Fe and Al oxides and hydroxides. The reserve acidity of the area being very high, liming to neutralise this acidity is practically impossible.

The data on acidity contributing characteristics are presented in Table 18. Their relationships with other chemical properties were presented in Table 12. The mean value of potential acidity was 25.5 cmol(+) kg$^{-1}$ during rainy season and decreased to 17.9 cmol(+) kg$^{-1}$ during summer. Contrary to the behaviour of soil pH, lower potential acidity was observed during summer, evidently due to the effect of time of soil collection. However, the behaviour of exchangeable acidity was similar to that of soil pH, while the other two forms of acidity showed an opposite pattern (Fig 14). Since the soil samples were collected during early summer, the severe soil drying was not started and that kept soil acidity at a low level. As soil dries up, acidity also increases and reaches to the maxium at the end of summer season and that was not completely washed off by the early monsoon.

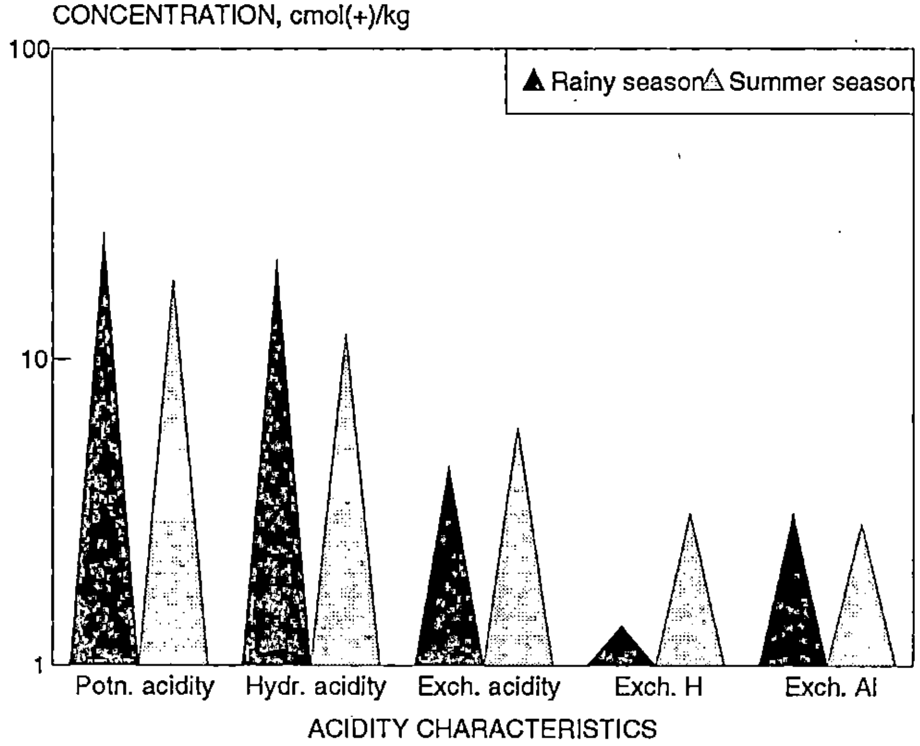


Fig 14. Acidity characteristics of soil during rainy and summer seasons

Table 18. Different forms of soil acidity during different seasons

| Padasekharam No. | Potential acidity | | Hydrolytic acidity | | Exchangeable acidity | | Exchangeable $H^+$ | | Exchangeable $Al^{3+}$ | | Al saturation, % | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cmol(+) $kg^{-1}$ | | | | | | | | | | | |
| | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII |
| 1 | 21.2 | 14.1 | 19.5 | 8.0 | 1.70 | 6.14 | 0.55 | 2.21 | 1.16 | 3.94 | 4.94 | 23.7 |
| 2 | 16.0 | 9.7 | 13.5 | 2.8 | 2.42 | 7.01 | 0.89 | 3.05 | 1.54 | 3.97 | 9.6 | 23.4 |
| 3 | 27.3 | 23.1 | 21.4 | 18.4 | 5.90 | 4.71 | 1.42 | 2.17 | 4.49 | 2.54 | 25.7 | 21.0 |
| 4 | 33.1 | 27.1 | 27.7 | 14.9 | 5.64 | 12.15 | 1.33 | 5.91 | 4.31 | 6.24 | 25.5 | 28.0 |
| 5 | 31.1 | 23.7 | 26.4 | 17.0 | 4.73 | 6.72 | 2.06 | 3.53 | 2.89 | 3.19 | 18.6 | 23.9 |
| 6 | 28.3 | 29.2 | 24.6 | 22.0 | 3.68 | 7.20 | 1.65 | 4.91 | 2.03 | 2.29 | 13.9 | 14.3 |
| 7 | 12.5 | 6.0 | 6.2 | 1.7 | 2.36 | 4.29 | 0.69 | 2.01 | 1.63 | 2.28 | 10.6 | 25.3 |
| 8 | 9.8 | 3.9 | 9.6 | 2.3 | 0.27 | 1.65 | 0.27 | 0.85 | - | 0.80 | - | 11.3 |
| 9 | 29.8 | 5.9 | 22.8 | 1.1 | 7.01 | 4.83 | 1.69 | 2.61 | 5.33 | 2.23 | 29.1 | 27.2 |
| 10 | 43.9 | 33.9 | 36.0 | 22.6 | 7.92 | 11.29 | 2.44 | 6.60 | 5.45 | 4.69 | 23.2 | 18.6 |
| 11 | 20.9 | 18.5 | 17.3 | 15.1 | 3.56 | 3.46 | 1.59 | 2.17 | 1.98 | 1.30 | 14.8 | 11.1 |
| 12 | 34.4 | 22.3 | 25.1 | 13.2 | 9.24 | 9.14 | 4.72 | 4.36 | 4.50 | 4.79 | 21.7 | 29.0 |
| 13 | 26.8 | 17.5 | 25.6 | 14.7 | 1.18 | 2.78 | 0.59 | 1.59 | 0.59 | 1.19 | 3.9 | 12.7 |
| 14 | 32.4 | 18.0 | 30.0 | 13.0 | 2.36 | 5.04 | 0.46 | 2.02 | 1.91 | 3.02 | 15.0 | 20.3 |
| 15 | 18.6 | 15.9 | 17.0 | 13.0 | 1.61 | 2.96 | 1.13 | 1.49 | 0.48 | 1.70 | 5.2 | 21.0 |
| 16 | 21.5 | 17.5 | 19.5 | 14.2 | 2.02 | 3.26 | 1.26 | 2.33 | 0.76 | 0.94 | 5.8 | 11.1 |
| 17 | 22.7 | 14.7 | 15.9 | 5.8 | 6.81 | 8.94 | 1.49 | 5.64 | 5.32 | 3.30 | 34.8 | 21.0 |
| 18 | 20.4 | 16.8 | 14.5 | 8.0 | 5.78 | 8.83 | 0.96 | 3.68 | 4.76 | 5.15 | 25.2 | 29.9 |
| 19 | 37.6 | 22.5 | 29.3 | 14.5 | 8.28 | 8.04 | 2.33 | 5.18 | 5.95 | 3.00 | 36.6 | 17.3 |
| 20 | 16.2 | 17.7 | 13.1 | 15.1 | 3.07 | 2.60 | 0.70 | 1.57 | 2.37 | 1.03 | 24.2 | 13.7 |
| 21 | 18.6 | 12.6 | 15.9 | 9.5 | 2.65 | 3.20 | 0.41 | 1.14 | 2.25 | 2.04 | 25.3 | 19.1 |
| 22 | 26.3 | 22.1 | 24.0 | 17.9 | 2.31 | 5.45 | 0.38 | 2.44 | 1.94 | 3.01 | 15.6 | 20.6 |
| 23 | 29.2 | 17.4 | 25.6 | 12.4 | 3.63 | 5.02 | 0.58 | 3.42 | 3.05 | 1.61 | 17.8 | 11.0 |
| 24 | 38.7 | 25.2 | 32.3 | 14.9 | 6.33 | 10.34 | 2.10 | 4.43 | 4.37 | 5.91 | 28.0 | 24.9 |
| 25 | 25.3 | 17.2 | 19.9 | 11.6 | 5.35 | 5.66 | 1.08 | 2.76 | 4.27 | 2.90 | 21.4 | 25.7 |
| 26 | 26.6 | 14.2 | 18.9 | 8.1 | 7.65 | 6.12 | 1.72 | 3.54 | 5.93 | 2.59 | 35.3 | 20.1 |
| 27 | 18.7 | 17.2 | 11.7 | 12.6 | 6.95 | 4.62 | 1.75 | 2.44 | 5.20 | 2.19 | 27.4 | 19.7 |
| **Mean** | **25.5** | **17.9** | **20.9** | **12.0** | **4.46** | **5.98** | **1.35** | **3.11** | **3.13** | **2.88** | **19.2** | **20.2** |
| Range | 9.8-43.9 | 3.9-33.9 | 6.2-36.0 | 1.1-22.6 | 0.27-9.24 | 1.65-12.15 | 0.27-4.72 | 0.85-6.60 | Nil-5.95 | 0.80-6.24 | Nil-49.4 | 11.0-29.9 |
| CD (0.05) | 2.17 | | 2.23 | | 0.863 | | 0.497 | | NS | | NS | |
| SEm± | 0.745 | | 0.770 | | 0.297 | | 0.171 | | 0.234 | | 1.34 | |

SI - Rainy season (Before the closure of Thanneermukkom regulator)

SII - Summer season (After the closure of Thanneermukkom regulator)

showers which was reflected on the rainy season sampling. The enhanced hydrolysis during summer might have increased exchangeable acidity. This was further confirmed from the values of different forms of acidity of profile samples collected during March - April

Table 19. Percentage contribution of acidity characteristics to potential acidity and exchangeable acidity during rainy and summer seasons

| Padasekharam No. | Per cent of potential acidity | | | | Per cent of exchangeable acidity | | | |
|---|---|---|---|---|---|---|---|---|
| | Hydrolytic acidity | | Exchangeable acidity | | Exchangeable $H^+$ | | Exchangeable $Al^{3+}$ | |
| | SI | SII | SI | SII | SI | SII | SI | SII |
| 1 | 87.5 | 56.7 | 12.5 | 43.3 | 32.4 | 36.0 | 67.6 | 64.0 |
| 2 | 84.9 | 27.8 | 15.1 | 72.2 | 36.8 | 43.5 | 63.2 | 56.5 |
| 3 | 78.4 | 79.7 | 21.6 | 20.3 | 24.1 | 46.1 | 75.9 | 53.9 |
| 4 | 83.0 | 55.0 | 17.0 | 45.0 | 23.6 | 48.6 | 76.4 | 51.4 |
| 5 | 84.8 | 71.7 | 15.2 | 28.3 | 43.6 | 52.5 | 56.4 | 47.5 |
| 6 | 87.0 | 75.3 | 13.0 | 24.7 | 44.8 | 68.2 | 55.2 | 31.8 |
| 7 | 81.1 | 28.3 | 18.9 | 71.7 | 29.2 | 46.9 | 70.8 | 53.1 |
| 8 | 97.2 | 59.0 | 2.8 | 41.0 | 100.0 | 51.5 | - | 48.5 |
| 9 | 76.5 | 18.6 | 23.5 | 81.4 | 24.1 | 54.0 | 75.9 | 46.0 |
| 10 | 82.0 | 66.7 | 18.0 | 33.3 | 30.8 | 58.5 | 69.2 | 41.5 |
| 11 | 83.0 | 81.6 | 17.0 | 18.4 | 44.7 | 62.7 | 55.3 | 37.3 |
| 12 | 73.1 | 59.2 | 26.9 | 40.8 | 51.1 | 47.7 | 48.9 | 52.3 |
| 13 | 95.6 | 84.0 | 4.4 | 16.0 | 50.0 | 57.2 | 50.0 | 42.8 |
| 14 | 92.7 | 72.2 | 7.3 | 27.8 | 19.5 | 40.1 | 80.5 | 59.9 |
| 15 | 91.3 | 81.8 | 8.7 | 18.2 | 70.2 | 50.3 | 29.8 | 49.7 |
| 16 | 90.6 | 81.1 | 9.4 | 18.9 | 62.4 | 71.5 | 37.6 | 28.5 |
| 17 | 70.0 | 39.5 | 30.0 | 60.5 | 21.9 | 63.1 | 78.1 | 36.9 |
| 18 | 71.7 | 47.6 | 28.3 | 52.4 | 16.6 | 41.7 | 83.4 | 58.3 |
| 19 | 78.0 | 64.4 | 22.0 | 35.6 | 28.1 | 64.4 | 71.9 | 35.6 |
| 20 | 81.0 | 85.3 | 19.0 | 14.7 | 22.8 | 60.4 | 77.2 | 39.6 |
| 21 | 85.8 | 75.4 | 14.2 | 24.6 | 15.5 | 35.6 | 84.4 | 64.4 |
| 22 | 91.2 | 80.1 | 8.8 | 19.9 | 16.5 | 44.8 | 83.5 | 55.2 |
| 23 | 87.6 | 71.3 | 12.4 | 28.7 | 16.0 | 68.1 | 84.0 | 31.9 |
| 24 | 83.6 | 59.1 | 16.4 | 40.9 | 33.2 | 42.8 | 66.8 | 57.2 |
| 25 | 78.9 | 67.4 | 21.1 | 32.6 | 20.2 | 48.8 | 79.8 | 51.2 |
| 26 | 71.2 | 57.0 | 28.8 | 43.0 | 22.4 | 57.8 | 77.6 | 42.2 |
| 27 | 62.9 | 73.3 | 37.1 | 26.7 | 25.4 | 52.8 | 74.8 | 47.2 |
| Mean | 82.6 | 63.7 | 17.4 | 36.3 | 34.3 | 54.4 | 65.7 | 45.6 |
| Range | 62.9-97.2 | 18.6-85.3 | 2.8-37.1 | 14.7-81.4 | 15.5-100.0 | 35.6-71.5 | Nil-84.4 | 28.5-64.4 |
| CD (0.05) | 6.77 | | 6.77 | | 7.90 | | 7.90 | |
| SEm± | 2.33 | | 2.33 | | 2.72 | | 2.72 | |

SI - Rainy season (Before the closure of Thanneermukkom regulator)

SII - Summer season (After the closure of Thanneermukkom regulator)

which recorded very high potential acidity (Table 9).

The important factors which influenced soil potential acidity were studied by correlating several properties of soil with different kinds of acidity and significant correlations were generated with organic carbon (0.521**), exchangeable acidity (0.393*), exchangeable $Al^{3+}$ (0.492*) and hydrolytic acidity (0.947**).

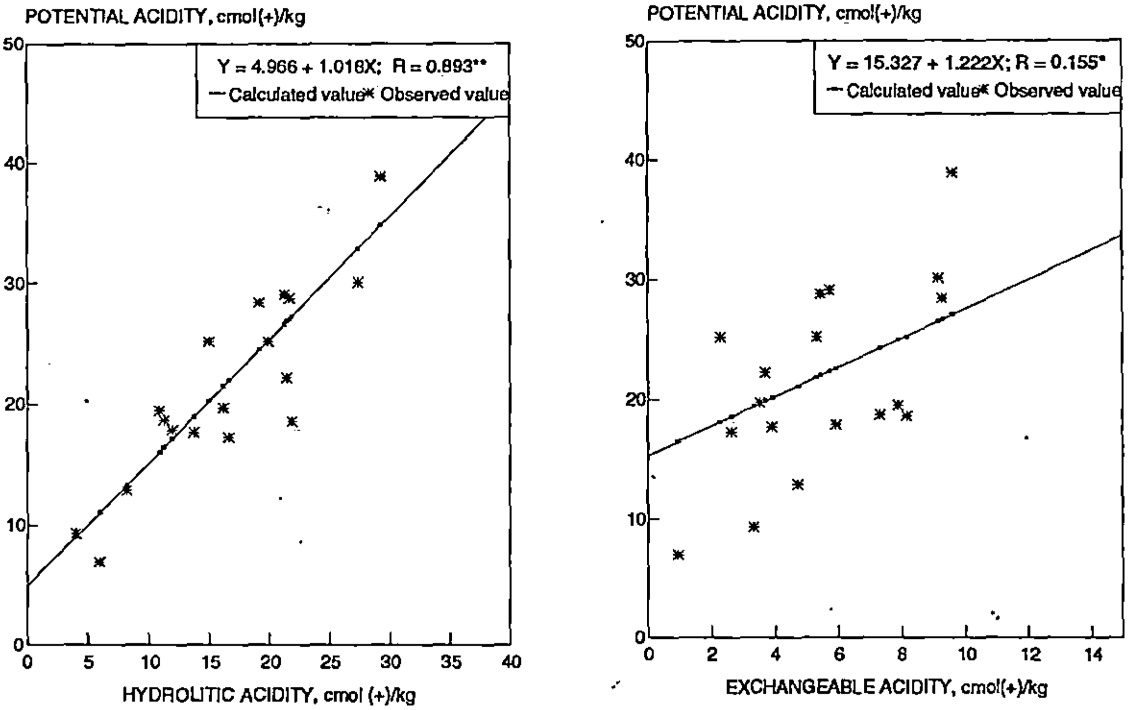


Fig 15. Relationship of potential acidity to hydrolytic and exchangeable acidity (R = Regression coefficient)

The hydrolytic acidity mainly decided the extent of potential acidity as is clear from Fig 15 which represents the regression of potential acidity to hydrolytic and exchangeable acidity. The hydrolytic acidity occupied 82.6 and 63.7 per cent of potential acidity during rainy and summer seasons, respectively (Table 19).

Hydrolytic acidity also followed the same pattern as that of potential acidity since 60-90 per cent of potential acidity was contributed by the former. The mean value observed during rainy season was 20.9 cmol(+) kg$^{-1}$ and decreased to 12.0 cmol(+) kg$^{-1}$ during summer. The decrease was due to lowering of soil pH which caused a reduction in pH dependant charges and this was reflected on hydrolytic acidity. The organic matter as well as oxides of Fe and Al usually associated with the soil clays are responsible for hydrolytic acidity (Adhikari and Si, 1991). The hydrolytic acidity was positively and significantly correlated with organic carbon (0.387$^{*}$) and CEC (0.735$^{**}$).

As compared to potential acidity exchangeable acidity was rather low in all the soils. The relatively low contribution of exchangeable acidity to total acidity was earlier reported (Sharma *et al.*, 1990; Adhikari and Si, 1991). The mean value of exchangeable acidity was 4.46 cmol(+) kg$^{-1}$ during rainy season and increased to 5.98 cmol(+) kg$^{-1}$ during summer. The increase was evidently due to decrease in pH which accelerated the hydrolysis of trivalent Al and even the dissociation of water molecules. Considerable amount of H$^{+}$ ions are released due to the dissociation of water molecules at a pH below 4.0 (Pal *et al.*, 1991). Exchangeable H$^{+}$ ion concentration increased

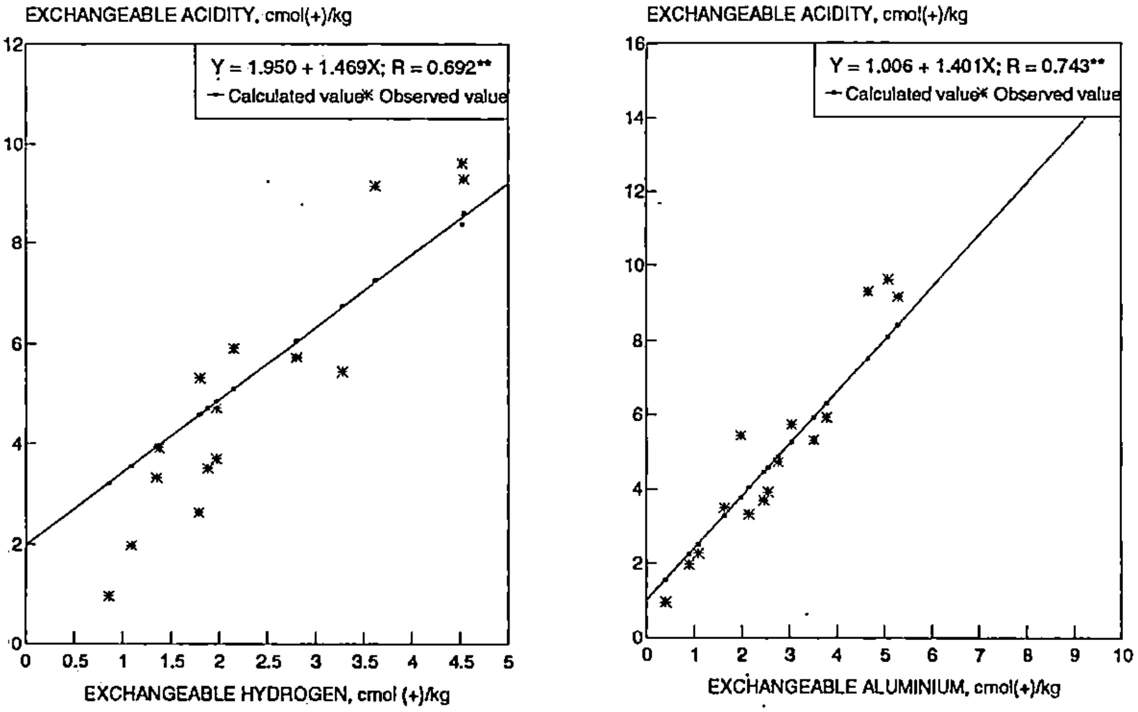


Fig 16. Relationship of exchangeable acidity to exchangeable $H^+$ and exchangeable $Al^{3+}$ (R = Regression coefficient)

from 1.35 to 3.11 cmol(+) $kg^{-1}$ during summer season. However, the other component of exchangeable acidity, i.e. exchangeable $Al^{3+}$ showed a slight decrease during summer season. The percentage contribution of exchangeable $Al^{3+}$ to ex-changeable acidity was 65.7 per cent during rainy season and decreased to 45.6 per cent during summer season (Table 19). The exchangeable $H^+$ was more prominent during summer. However, in the overall relationship exchangeable $Al^{3+}$ is more dominant in deciding the extent of exchangeable acidity in soil as observed from the Fig 16 and from the correlation coefficients (0.862**, 0.832**). The predominance of exchangeable hydrogen in summer was further confirmed from the values of exchangeable $H^+$, $Al^{3+}$ and acidity of profile samples (Table 7).

## PART 3. TOXICITY CHARACTERISTICS

The development and accumulation of toxicity characteristics in soil and water in response to the restricted water flow in Kuttanad due to the closure of Thanneermukkom regulator during summer are evaluated here, by analysing soil (0-25 cm depth), surface water and ground water from the area during rainy (before the closure of Thanneermukkom regulator) and summer (after the closure of Thanneermukkom regulator) seasons.

### A. Native toxic characteristics

### 1. Soil

*1.1 General soil properties*: The soil pH, EC, CEC and base saturation during rainy and summer seasons (before and after the closure of Thanneermukkom regulator) are presented in Table 20. The soil samples collected from 0-25 cm depth showed the same trend with respect to general soil properties as that of surface samples collected from 0-15 cm depth.

The Kuttanad soils being highly acidic in nature recorded very low pH values during both the seasons. The mean value was 4.3 during rainy season and it decreased to 3.9 during summer season. This is contrary to the result reported by Kurup and Aiyer (1973) during the pre-barrage period when mean pH values were 4.1 and 4.3, respectively, during the above two seasons in karappadam area. Thus an increase in acidity was experienced in the area during the post-barrage period. The present increase in acidity during the summer season was mainly due to the closure of the regulator which lowered the water table of the area. Increase in production of $CO_2$ and organic acids due to enhanced organic matter decomposition and reduction in accumulation of ammonia during this period also contributed towards the enhancement of acidity. The salinity of soil was considerably reduced after the closure of the regulator. The mean value was 1.25 dS $m^{-1}$ during rainy season (May-June) which decreased to 0.62 dS $m^{-1}$ during summer (January-February). The influence of saline water intruded into the area after the opening of Thanneermukkom regulator in April was not removed completely and this had influenced various soil properties. Compared to the pre-barrage values of salinity already reported (Kurup, 1967; Varghese and Aiyer, 1973; Kurup and Aiyer, 1973) there was a considerable reduction in accumulation of salinity in the study area. The reduction in salinity observed on comparison with pre-barrage period during March to May was greater than 90 per cent (Nair and Pillai, 1990)

Cation exchange capacity and total exchangeable bases were significantly influenced by the season/closure of the regulator. The mean value of CEC during rainy season was 28.5 cmol(+) $kg^{-1}$ and it decreased to 20.1 cmol(+) $kg^{-1}$ during summer. For the above properties, considerable variation between pre-barrage period and post-barrage period was not observed. The decrease in CEC during summer was due to the lowering of pH and reduction in organic matter fraction of the soil.

*1.2. Soil acidity*: The acidity contributing characteristics of the samples from 0-25 cm depth (Table 21 and Fig 17) were similar to those of surface samples. The mean value of potential acidity was 27.4 cmol(+) $kg^{-1}$ during rainy season and 20.3 cmol(+)$kg^{-1}$ during summer season. The magnitude of decrease was 26 per cent. The decrease was evidently due to the effect of time of soil collection and the reduction in hydrolytic acidity in response to the lowering of soil pH. The contribution of hydrolytic acidity to potential acidity was 83.1

per cent during rainy season and 64.5 per cent during summer season (Table 23). The hydrolytic acidity also followed a similar trend as that of potential acidity, since it contribute more than 70 per cent of the latter (Fig 18). The mean values were 22.7 and 13.8 cmol(+) kg$^{-1}$, during rainy and summer seasons, respectively. The exchangeable acidity which contributed only a small portion to potential acidity showed an increase during summer from 4.56 to 6.46 cmol(+) kg$^{-1}$. This was in conformity with the behaviour of soil pH.

Table 20. Few chemical characteristics of soils during rainy and summer seasons

| Padasekharam No. | pH | | EC, dS m$^{-1}$ | | Total exch. bases | | CEC | | ECEC | | Base saturation, % | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | cmol(+) kg$^{-1}$ | | | | | | | |
| | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII |
| 1 | 4.0 | 3.4 | 2.37 | 0.35 | 21.7 | 9.6 | 33.5 | 21.2 | 23.6 | 15.6 | 64.7 | 45.1 |
| 2 | 3.9 | 3.8 | 1.85 | 0.65 | 19.5 | 11.7 | 32.0 | 23.4 | 22.0 | 19.5 | 61.1 | 49.8 |
| 3 | 5.0 | 4.3 | 1.40 | 0.38 | 9.6 | 6.7 | 29.2 | 24.3 | 21.6 | 12.0 | 32.8 | 27.4 |
| 4 | 3.6 | 3.5 | 2.05 | 1.50 | 10.2 | 17.5 | 31.6 | 29.2 | 16.4 | 30.0 | 32.3 | 60.0 |
| 5 | 4.6 | 4.2 | 0.92 | 0.84 | 10.8 | 10.7 | 28.2 | 25.4 | 15.4 | 17.5 | 38.4 | 42.3 |
| 6 | 4.7 | 4.4 | 0.60 | 0.27 | 12.4 | 8.0 | 30.1 | 24.6 | 17.0 | 15.3 | 41.0 | 32.7 |
| 7 | 3.6 | 3.2 | 1.20 | 0.46 | 9.2 | 5.0 | 20.2 | 11.0 | 15.4 | 9.4 | 45.7 | 45.3 |
| 8 | 5.0 | 5.0 | 1.01 | 0.60 | 10.3 | 4.9 | 17.4 | 10.8 | 11.1 | 6.3 | 58.9 | 45.1 |
| 9 | 3.4 | 3.4 | 2.91 | 0.59 | 10.4 | 3.8 | 29.4 | 9.6 | 14.7 | 9.1 | 34.2 | 40.1 |
| 10 | 3.2 | 3.7 | 2.89 | 0.46 | 16.7 | 14.0 | 35.1 | 33.4 | 24.1 | 25.5 | 47.6 | 42.0 |
| 11 | 4.0 | 4.7 | 0.74 | 0.20 | 7.1 | 7.3 | 24.8 | 16.2 | 10.7 | 11.5 | 28.7 | 45.1 |
| 12 | 3.7 | 3.8 | 0.78 | 0.33 | 10.2 | 8.1 | 30.3 | 20.7 | 17.0 | 20.6 | 33.8 | 39.0 |
| 13 | 4.9 | 4.2 | 0.95 | 0.30 | 14.8 | 4.8 | 32.2 | 17.0 | 16.9 | 10.4 | 45.9 | 28.2 |
| 14 | 5.0 | 4.5 | 0.27 | 0.28 | 10.8 | 9.1 | 33.5 | 28.7 | 12.9 | 13.3 | 32.4 | 31.8 |
| 15 | 4.7 | 3.8 | 0.90 | 0.68 | 7.2 | 5.9 | 16.6 | 14.8 | 8.7 | 9.9 | 43.2 | 40.1 |
| 16 | 4.4 | 3.4 | 1.50 | 1.70 | 10.2 | 5.8 | 22.5 | 15.5 | 12.8 | 8.6 | 45.2 | 37.7 |
| 17 | 4.7 | 3.8 | 0.90 | 1.01 | 13.3 | 9.8 | 22.8 | 19.2 | 15.1 | 19.7 | 58.3 | 50.9 |
| 18 | 4.2 | 3.8 | 0.81 | 0.67 | 11.7 | 10.9 | 49.3 | 22.5 | 17.4 | 21.2 | 23.8 | 48.5 |
| 19 | 4.7 | 3.8 | 1.51 | 1.18 | 14.8 | 9.5 | 36.4 | 19.0 | 25.9 | 17.7 | 40.7 | 50.2 |
| 20 | 4.3 | 4.0 | 0.82 | 0.22 | 8.3 | 4.6 | 20.4 | 16.5 | 11.9 | 7.6 | 40.6 | 27.8 |
| 21 | 4.2 | 4.3 | 0.68 | 0.26 | 8.0 | 8.6 | 16.0 | 16.5 | 12.2 | 12.1 | 49.7 | 51.8 |
| 22 | 4.1 | 4.3 | 1.22 | 0.40 | 9.4 | 8.4 | 42.2 | 21.7 | 11.6 | 14.2 | 22.3 | 38.6 |
| 23 | 4.1 | 4.6 | 1.33 | 0.20 | 13.7 | 10.7 | 30.3 | 24.3 | 19.2 | 17.1 | 45.3 | 44.2 |
| 24 | 4.3 | 3.6 | 0.90 | 0.65 | 12.6 | 9.1 | 33.5 | 27.9 | 15.6 | 17.6 | 37.8 | 32.8 |
| 25 | 3.8 | 3.6 | 1.31 | 0.96 | 14.6 | 6.9 | 24.5 | 18.6 | 19.3 | 11.7 | 59.6 | 37.0 |
| 26 | 5.8 | 3.5 | 0.66 | 0.75 | 12.5 | 9.1 | 22.4 | 15.2 | 19.3 | 16.6 | 55.9 | 59.7 |
| 27 | 4.0 | 3.7 | 1.20 | 0.91 | 8.9 | 8.4 | 23.9 | 15.6 | 14.1 | 13.4 | 37.4 | 54.0 |
| **Mean** | **4.3** | **3.9** | **1.25** | **0.62** | **11.8** | **8.5** | **28.5** | **20.1** | **16.4** | **14.9** | **42.9** | **42.5** |
| Range | 3.2-5.8 | 3.2-5.0 | 0.27-2.91 | 0.20-1.70 | 7.1-21.7 | 3.8-17.5 | 16.0-49.3 | 9.6-33.4 | 8.7-25.9 | 6.3-30.0 | 22.3-64.7 | 27-4-60.0 |
| CD(0.05) | 0.291 | | 0.027 | | 1.48 | | 2.57 | | NS | | NS | |
| SEm ± | 0.101 | | 0.094 | | 0.508 | | 0.884 | | 0.690 | | 1.76 | |

SI = Rainy season (Before the closure of Thanneermukkom regulator)

SII = Summer season (After the closure of Thanneermukkom regulator)

Potential acidity was positively and significantly correlated with hydrolytic acidity and exchangeable $Al^{3+}$ (Table 22).

Among the components of exchangeable acidity, the exchangeable $Al^{3+}$ dominated during rainy season, occupying 62.4 per cent of the

Table 21. Different forms of soil acidity during rainy and summer seasons

| Padasekharam No. | Poten. acidity | | Hydr. acidity | | Exch. acidity | | Exch. $H^+$ | | Exch. $Al^{3+}$ | | Al saturation % | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cmol(+) kg $^{-1}$ | | | | | | | | | | | |
| | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII |
| 1 | 21.3 | 15.4 | 19.4 | 9.4 | 1.90 | 5.97 | 0.91 | 2.13 | 0.99 | 3.84 | 4.2 | 24.6 |
| 2 | 18.9 | 11.7 | 16.4 | 3.9 | 2.44 | 7.84 | 0.87 | 3.39 | 1.57 | 4.45 | 7.1 | 22.8 |
| 3 | 34.6 | 23.7 | 22.6 | 18.3 | 12.02 | 5.38 | 2.31 | 3.23 | 9.71 | 2.15 | 45.0 | 17.9 |
| 4 | 37.5 | 26.9 | 31.3 | 14.5 | 6.20 | 12.46 | 1.65 | 5.72 | 4.56 | 6.74 | 27.8 | 13.8 |
| 5 | 26.9 | 21.9 | 22.2 | 15.1 | 4.63 | 6.74 | 2.48 | 3.10 | 2.16 | 3.64 | 14.0 | 20.8 |
| 6 | 27.8 | 29.9 | 23.2 | 22.6 | 4.63 | 7.30 | 2.32 | 4.49 | 2.32 | 2.81 | 13.6 | 18.4 |
| 7 | 16.0 | 29.1 | 9.9 | 24.7 | 6.14 | 4.30 | 3.27 | 1.46 | 2.87 | 2.91 | 18.6 | 3.1 |
| 8 | 9.6 | 26.1 | 8.8 | 24.8 | 0.81 | 1.38 | 0.64 | 0.62 | 0.17 | 0.76 | 1.5 | 12.1 |
| 9 | 30.3 | 6.0 | 25.7 | 0.8 | 4.68 | 5.22 | 0.88 | 3.36 | 3.80 | 1.86 | 25.9 | 20.4 |
| 10 | 45.9 | 31.9 | 38.5 | 20.4 | 7.36 | 11.50 | 2.77 | 7.35 | 4.59 | 4.15 | 19.0 | 16.3 |
| 11 | 26.8 | 19.4 | 23.2 | 15.1 | 3.54 | 4.22 | 1.69 | 4.05 | 1.85 | 1.87 | 17.3 | 16.3 |
| 12 | 41.6 | 28.4 | 34.8 | 15.9 | 6.78 | 12.50 | 2.62 | 4.16 | 4.16 | 8.40 | 24.5 | 40.8 |
| 13 | 30.0 | 19.6 | 27.9 | 14.0 | 2.15 | 5.60 | 0.43 | 1.87 | 1.72 | 3.73 | 10.2 | 35.9 |
| 14 | 30.4 | 15.3 | 28.3 | 11.1 | 2.09 | 4.18 | 0.19 | 2.51 | 1.90 | 1.67 | 14.7 | 12.6 |
| 15 | 19.9 | 17.9 | 18.4 | 13.9 | 1.49 | 3.99 | 1.33 | 2.27 | 0.16 | 1.72 | 1.8 | 17.4 |
| 16 | 26.7 | 18.8 | 24.1 | 16.0 | 2.59 | 2.76 | 1.51 | 1.87 | 1.08 | 0.89 | 8.4 | 10.2 |
| 17 | 25.0 | 29.5 | 23.2 | 19.7 | 1.77 | 9.88 | 1.25 | 7.38 | 0.52 | 2.50 | 3.4 | 12.7 |
| 18 | 28.8 | 16.6 | 20.1 | 6.3 | 5.71 | 10.30 | 3.56 | 4.26 | 2.15 | 6.04 | 12.4 | 28.5 |
| 19 | 36.2 | 21.7 | 25.1 | 13.6 | 11.10 | 8.15 | 5.64 | 5.32 | 5.46 | 2.83 | 21.6 | 16.0 |
| 20 | 17.8 | 16.3 | 14.3 | 13.2 | 3.57 | 3.03 | 0.98 | 1.37 | 2.59 | 1.66 | 21.7 | 21.8 |
| 21 | 21.6 | 13.7 | 17.4 | 10.2 | 4.24 | 3.51 | 0.46 | 0.58 | 3.78 | 2.93 | 31.0 | 29.0 |
| 22 | 22.8 | 19.8 | 20.6 | 13.9 | 2.21 | 5.83 | 0.21 | 0.69 | 2.00 | 5.14 | 17.2 | 36.2 |
| 23 | 33.5 | 20.7 | 28.0 | 14.3 | 5.51 | 6.39 | 3.11 | 4.93 | 2.40 | 1.47 | 12.5 | 8.6 |
| 24 | 35.0 | 21.1 | 32.0 | 12.4 | 2.98 | 8.66 | 0.26 | 3.25 | 2.71 | 5.41 | 17.4 | 30.5 |
| 25 | 27.9 | 17.9 | 23.2 | 13.2 | 4.65 | 4.78 | 0.35 | 1.89 | 4.30 | 2.88 | 22.3 | 24.6 |
| 26 | 21.2 | 14.9 | 14.5 | 7.3 | 6.73 | 7.53 | 1.24 | 4.79 | 5.49 | 2.76 | 28.4 | 16.6 |
| 27 | 25.8 | 12.7 | 20.6 | 7.7 | 5.16 | 4.98 | 0.37 | 2.81 | 4.79 | 2.17 | 34.0 | 16.2 |
| **Mean** | **27.4** | **20.3** | **22.7** | **13.8** | **4.56** | **6.46** | **1.60** | **3.29** | **2.96** | **3.24** | **17.6** | **20.2** |
| Range | 9.6-45.9 | 6.0-31.9 | 8.8-38.5 | 0.8-24.8 | 0.81-12.02 | 1.38-12.50 | 0.19-3.56 | 0.58-7.38 | 0.16-9.71 | 0.76-8.40 | 1.5-45.0 | 3.1-40.8 |
| CD (0.05) | 3.63 | | 3.63 | | 1.26 | | 0.658 | | NS | | NS | |
| SEm± | 1.25 | | 1.25 | | 0.433 | | 0.227 | | 0.347 | | 1.78 | |

SI = Rainy season (Before the closure of Thanneermukkom regulator)

SII= Summer season (After the closure of Thanneermukkom regulator

Table 22. Correlation matrix showing inter-relationships among soil chemical characteristics

| Characteristics | pH | EC | CEC | ECEC | Base satn. | Poten. acidity | Hydr. acidity | Exch. acidity | Exch. H$^{+}$ | Exch. Al$^{3+}$ | Al satn. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 1.00 | | | | | | | | | | |
| EC | -0.415$^{*}$ | 1.000 | | | | | | | | | |
| CEC | -0.055 | 0.368 | 1.000 | | | | | | | | |
| ECEC | -0.214 | 0.381$^{*}$ | 0.562$^{**}$ | 1.000 | | | | | | | |
| Base satn. | 0.000 | 0.225 | -0.272 | 0.371 | 1.000 | | | | | | |
| Poten. acidity | -0.133 | 0.390$^{*}$ | 0.576$^{**}$ | 0.417$^{*}$ | -0.235 | 1.000 | | | | | |
| Hydr. acidity | -0.033 | 0.412$^{*}$ | 0.517$^{**}$ | 0.167 | -0.226 | 0.929$^{**}$ | 1.000 | | | | |
| Exch. acidity | -0.272 | -0.015 | 0.146 | 0.690$^{**}$ | -0.008 | 0.263 | -0.109 | 1.000 | | | |
| Exch. H$^{+}$ | 0.264 | -0.128 | 0.035 | 0.507$^{**}$ | 0.578$^{**}$ | 0.164 | -0.102 | 0.767$^{**}$ | 1.000 | | |
| Exch. Al$^{3+}$ | -0.159 | 0.076 | 0.174 | 0.574$^{**}$ | .41 $^{*}$ | 0.492$^{**}$ | 0.237 | 0.815$^{**}$ | 0.261 | 1.000 | |
| Al satn. | -0.093 | -0.115 | -0.036 | 0.114 | 0.584$^{**}$ | 0.070 | -0.115 | 0.508$^{**}$ | 0.286 | 0.851$^{**}$ | 1.000 |

$^{*}$ Significant at 5% level $^{**}$ Significant at 1% level

exchangeable acidity. Exchangeable H$^{+}$ was the dominant form during summer, contributing 51.3 per cent to exchangeable acidity (Table 23). The decrease in pH during summer enhanced the rate of hydrolysis of trivalent Al, releasing more H$^{+}$ ions. Since the soil pH was below 4.0 it may even result in the dissociation of water molecules and the release of H$^{+}$ ions. The contribution from exchangeable H$^{+}$ to exchangeable acidity increases as the pH decreases (Panda, 1987). The surface samples and profile samples also expressed similar behaviour.

Among the components of potential acidity a noticeable increase was observed during summer only for exchangeable H$^{+}$ which was reflected on exchangeable acidity also by showing an enhancement. This was clearly evident from Fig 18. The other component of exchangeable acidity i.e exchangeable aluminium also showed a slight increase during the summer season (after the closure of Thanneermukkom regulator) but its contribution towards the increase was comparatively very small.

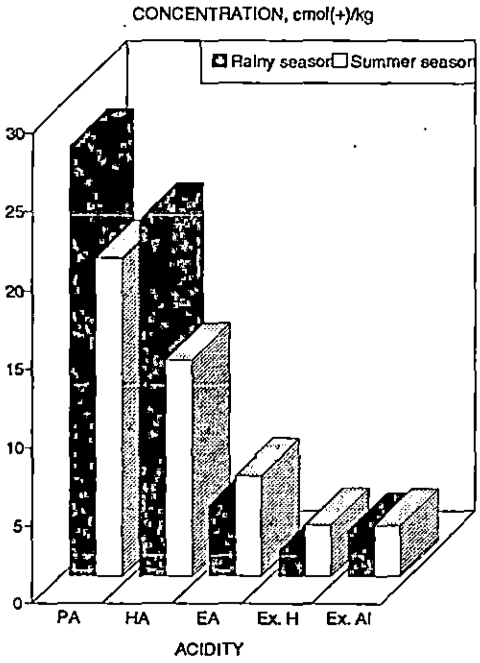


Fig 17. Different forms of soil acidity during rainy and summer seasons. (PA - Potential acidity; HA - Hydrolytic acidity; EA - Exchangeable acidity)

Table 23. Percentage contribution of acidity contributing characteristics to potential acidity and exchangeable acidity during rainy and summer seasons

| Padasekharam No. | Per cent of potential acidity | | | | Per cent of exchangeable acidity | | | |
|---|---|---|---|---|---|---|---|---|
| | Hydrolytic acidity | | Exchangeable acidity | | Exchangeable H$^+$ | | Exchangeable Al$^{3+}$ | |
| | SI | SII | SI | SII | SI | SII | SI | SII |
| 1 | 91.1 | 61.1 | 8.9 | 39.9 | 47.9 | 35.7 | 52.1 | 64.3 |
| 2 | 87.1 | 33.0 | 12.9 | 67.0 | 35.7 | 43.2 | 64.3 | 56.8 |
| 3 | 65.3 | 77.3 | 34.7 | 22.5 | 19.2 | 60.0 | 80.8 | 40.0 |
| 4 | 83.5 | 53.7 | 16.5 | 46.3 | 26.5 | 66.7 | 73.5 | 33.3 |
| 5 | 82.8 | 69.2 | 17.2 | 30.8 | 53.4 | 46.0 | 46.7 | 54.0 |
| 6 | 83.3 | 75.5 | 16.7 | 24.5 | 50.0 | 61.5 | 50.0 | 38.5 |
| 7 | 61.7 | 85.0 | 38.3 | 15.0 | 53.3 | 33.4 | 46.7 | 66.6 |
| 8 | 91.6 | 94.7 | 8.4 | 5.3 | 79.0 | 45.0 | 21.0 | 55.0 |
| 9 | 84.6 | 12.6 | 15.4 | 87.4 | 18.8 | 64.4 | 81.2 | 35.6 |
| 10 | 84.0 | 56.3 | 16.0 | 43.7 | 37.6 | 63.9 | 62.4 | 36.1 |
| 11 | 86.8 | 78.2 | 13.2 | 21.8 | 47.7 | 96.0 | 52.3 | 4.0 |
| 12 | 83.7 | 69.0 | 16.3 | 31.0 | 38.6 | 45.5 | 61.4 | 54.5 |
| 13 | 92.8 | 56.0 | 7.2 | 44.0 | 20.0 | 32.8 | 80.0 | 67.2 |
| 14 | 93.1 | 52.7 | 6.9 | 27.3 | 9.1 | 40.0 | 90.9 | 60.0 |
| 15 | 92.5 | 77.7 | 7.5 | 22.3 | 89.3 | 56.9 | 10.7 | 43.1 |
| 16 | 90.3 | 85.3 | 9.7 | 14.7 | 58.3 | 67.8 | 41.7 | 32.2 |
| 17 | 93.0 | 66.5 | 7.0 | 34.5 | 70.6 | 74.7 | 29.4 | 25.3 |
| 18 | 69.8 | 37.9 | 30.2 | 62.1 | 62.3 | 41.4 | 37.7 | 58.6 |
| 19 | 69.3 | 62.5 | 30.7 | 37.5 | 50.8 | 65.3 | 49.2 | 34.7 |
| 20 | 80.0 | 81.4 | 20.0 | 18.6 | 27.5 | 43.2 | 72.5 | 54.8 |
| 21 | 80.4 | 74.3 | 19.6 | 25.7 | 10.8 | 16.5 | 89.2 | 83.5 |
| 22 | 90.3 | 70.5 | 9.7 | 29.5 | 9.5 | 11.8 | 90.5 | 88.2 |
| 23 | 83.6 | 69.1 | 16.4 | 30.9 | 56.5 | 77.0 | 43.5 | 23.0 |
| 24 | 91.5 | 58.9 | 8.5 | 41.1 | 9.0 | 37.6 | 91.0 | 62.4 |
| 25 | 83.3 | 73.5 | 16.7 | 26.5 | 7.5 | 39.7 | 92.5 | 60.3 |
| 26 | 68.3 | 49.3 | 31.7 | 50.7 | 18.4 | 63.4 | 81.6 | 36.6 |
| 27 | 80.0 | 60.7 | 20.0 | 39.3 | 7.2 | 56.4 | 92.8 | 43.6 |
| **Mean** | **83.1** | **64.5** | **16.9** | **34.8** | **37.6** | **51.3** | **62.4** | **48.6** |
| Range | 61.7-93.1 | 12.6-94.7 | 6.9-38.3 | 5.3-87.4 | 7.2-89.3 | 11.8-96.0 | 10.7-92.8 | 4.0-88.2 |
| CD (0.05) | 7.79 | | 7.63 | | 9.56 | | 9.56 | |
| SEm± | 2.68 | | 2.62 | | 3.29 | | 3.29 | |

SI = Rainy season (Before the closure of Thanneermukkom regulator)

SII= Summer season (After the closure of Thanneermukkom regulator)

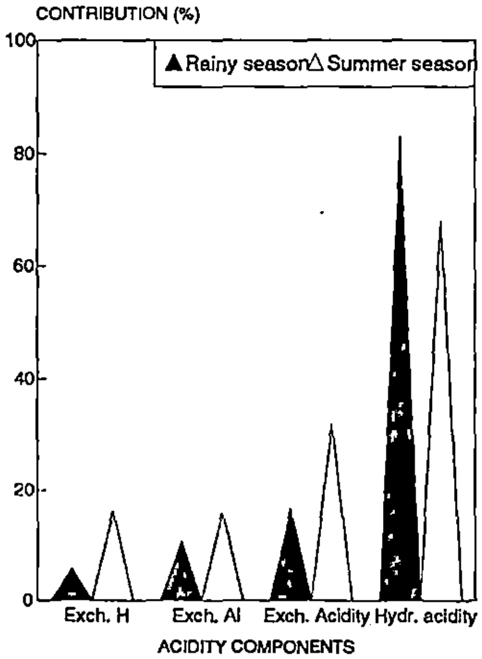


Fig 18. Percentage contribution of different components of acidity to potential acidity during rainy and summer seasons

Since the data on different forms of soil acidity during the pre-barrage period were not available, the comparison with present values was not possible. However, based on the difference in pH, an increase in soil acidity during the post-barrage period was confirmed.

*2.3 Potassium, sodium, calcium and magnesium*: The concentration of different fractions of the bases was greater during the rainy season, evidently due to the influence of saline water that remained in the area during the time of soil collection. The decrease in concentration during summer was the result of the closure of Thanneermukkom regulator and thereby preventing saline water entry.

The mean value of available K was 287 ppm during rainy season and decreased to 189 ppm during summer (Table 24). About half of available K was present in water soluble form. During the pre-barrage period the area was said to be deficient in available K (Alexander and Durairaj, 1968; Nair and Money, 1972; Sreedevi and Aiyer, 1974). Compared to that, an increase in available K was observed during post-barrage period.

With regard to Na, a reverse trend was observed. Na was the dominant cation of the exchange complex during the pre-barrage period (Nair and Pillai, 1990). The closure of Thanneermukkom regulator prevents the saline water intrusion into area and this reduced the Na content considerably. The available Na content of 1806 ppm during rainy season decreased to 467 ppm during summer (Table 24). More than 80 per cent of available Na was present in water soluble form.The exchangeable Na was present in negligible quantities.

Among the basic cations, Ca was present in large quantities. The available Ca content was 2278 ppm during rainy season and decreased to 1602 ppm during summer (Table 25). Major part of available Ca remained in exchangeable form. Compared to the values reported by Sreedevi and Aiyer (1974), there was a considerable increase in Ca content during the post-barrage period. Frequent addition of liming materials and better strength of adsorption made Ca the most dominant cation among the exchangeable bases.

The behaviour of Mg was similar to that of Ca and it occupied a position next to Ca, among the exchangeable bases (Table 25).

The different fractions of K, Na, Ca and Mg were positively and significantly correlated with each other and their inter-relationships are presented in Table 26.

Table 24. Available, water soluble and exchangeable K and Na in soils during rainy and summer seasons

| Padasekharam No. | K | | | | | | Na | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Available | | Water soluble | | Exchangeable | | Available | | Water soluble | | Exchangeable cmol(+) kg $^{-1}$ | |
| | ppm | | | | cmol(+) kg $^{-1}$ | | ppm | | | | | |
| | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII |
| 1 | 325 | 264 | 134 | 85 | 0.490 | 0.458 | 2502 | 520 | 1984 | 427 | 2.251 | 0.408 |
| 2 | 243 | 176 | 136 | 108 | 0.275 | 0.174 | 2437 | 515 | 2230 | 457 | 0.807 | 0.254 |
| 3 | 246 | 81 | 100 | 47 | 0.373 | 0.085 | 2044 | 484 | 1797 | 409 | 1.075 | 0.327 |
| 4 | 482 | 373 | 348 | 225 | 0.343 | 0.380 | 4489 | 710 | 4312 | 574 | 0.767 | 0.594 |
| 5 | 251 | 421 | 148 | 137 | 0.263 | 0.728 | 1827 | 783 | 1647 | 692 | 0.781 | 0.911 |
| 6 | 231 | 206 | 140 | 47 | 0.231 | 0.407 | 988 | 356 | 830 | 280 | 0.687 | 0.329 |
| 7 | 262 | 117 | 154 | 52 | 0.277 | 0.166 | 1212 | 364 | 1068 | 262 | 0.623 | 0.443 |
| 8 | 211 | 124 | 117 | 62 | 0.241 | 0.158 | 1374 | 399 | 1291 | 331 | 0.363 | 0.299 |
| 9 | 400 | 187 | 280 | 75 | 0.307 | 0.286 | 2024 | 246 | 1987 | 209 | 0.159 | 0.162 |
| 10 | 535 | 335 | 349 | 192 | 0.476 | 0.368 | 3562 | 926 | 3416 | 799 | 0.662 | 0.551 |
| 11 | 200 | 185 | 119 | 58 | 0.209 | 0.324 | 812 | 299 | 691 | 282 | 0.528 | 0.077 |
| 12 | 328 | 186 | 187 | 86 | 0.359 | 0.255 | 1420 | 549 | 1263 | 380 | 0.687 | 0.734 |
| 13 | 318 | 188 | 126 | 131 | 0.490 | 0.146 | 1874 | 425 | 1610 | 408 | 1.151 | 0.071 |
| 14 | 304 | 337 | 151 | 132 | 0.390 | 0.526 | 1848 | 411 | 1677 | 362 | 0.746 | 0.215 |
| 15 | 182 | 142 | 108 | 76 | 0.191 | 0.168 | 1390 | 403 | 1165 | 313 | 0.980 | 0.385 |
| 16 | 207 | 141 | 160 | 94 | 0.119 | 0.120 | 1558 | 626 | 1453 | 470 | 0.457 | 1.341 |
| 17 | 300 | 102 | 162 | 45 | 0.351 | 0.145 | 2075 | 341 | 1924 | 318 | 0.653 | 0.099 |
| 18 | 276 | 142 | 148 | 92 | 0.326 | 0.127 | 1651 | 545 | 1514 | 462 | 0.594 | 0.360 |
| 19 | 218 | 152 | 104 | 111 | 0.292 | 0.106 | 1875 | 424 | 1701 | 337 | 0.758 | 0.378 |
| 20 | 228 | 81 | 138 | 49 | 0.231 | 0.081 | 714 | 163 | 504 | 152 | 0.910 | 0.047 |
| 21 | 231 | 137 | 112 | 61 | 0.304 | 0.195 | 700 | 234 | 563 | 195 | 0.597 | 0.170 |
| 22 | 245 | 108 | 116 | 53 | 0.331 | 0.142 | 1638 | 415 | 1493 | 385 | 0.632 | 0.129 |
| 23 | 342 | 124 | 230 | 166 | 0.288 | 0.148 | 2366 | 342 | 1775 | 290 | 2.571 | 0.225 |
| 24 | 280 | 293 | 124 | 114 | 0.399 | 0.460 | 1459 | 568 | 1226 | 426 | 1.014 | 0.617 |
| 25 | 418 | 189 | 223 | 76 | 0.500 | 0.290 | 2343 | 521 | 2010 | 369 | 1.449 | 0.664 |
| 26 | 255 | 149 | 156 | 76 | 0.252 | 0.185 | 947 | 542 | 714 | 394 | 1.011 | 0.647 |
| 27 | 238 | 163 | 138 | 63 | 0.255 | 0.255 | 1648 | 489 | 1487 | 304 | 0.699 | 0.802 |
| **Mean** | **287** | **189** | **163** | **89** | **0.317** | **0.255** | **1806** | **467** | **1605** | **381** | **0.878** | **0.416** |
| Range | 182-535 | 81-421 | 100-349 | 47-225 | 0.119-0.500 | 0.081-0.728 | 700-4489 | 163-926 | 504-4312 | 152-799 | 0.159-2.571 | 0.047-1.341 |
| CD (0.05) | 2.57 | | 21.0 | | NS | | 292 | | 287 | | 0.010 | |
| SEm± | 0.884 | | 7.23 | | 0.022 | | 101 | | 99 | | 0.003 | |

SI = Rainy season (Before the closure of Thanneermukkom regulator)

SII = Summer season (After the closure of Thanneermukkom regulator)

Table 25. Available, water soluble and exchangeable Ca and Mg in soils during rainy and summer seasons

| Pada-sekharam No. | Ca | | | | | | Mg | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Available | | Water soluble | | Exchangeable cmol(+) kg $^{-1}$ | | Available | | Water soluble | | Exchangeable cmol(+) kg $^{-1}$ | |
| | ppm | | | | | | ppm | | | | | |
| | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII |
| 1 | 4000 | 1501 | 404 | 171 | 17.98 | 6.65 | 348 | 287 | 241 | 50 | 0.90 | 2.05 |
| 2 | 4014 | 1966 | 503 | 328 | 17.55 | 8.19 | 378 | 450 | 279 | 84 | 0.82 | 3.04 |
| 3 | 1986 | 1548 | 423 | 430 | 7.82 | 5.59 | 429 | 155 | 392 | 77 | 0.31 | 0.65 |
| 4 | 2401 | 3412 | 750 | 494 | 8.25 | 14.59 | 714 | 323 | 611 | 89 | 0.86 | 1.95 |
| 5 | 1995 | 1894 | 307 | 291 | 8.44 | 8.01 | 460 | 219 | 299 | 88 | 1.34 | 1.09 |
| 6 | 2490 | 1498 | 297 | 187 | 10.97 | 6.55 | 367 | 180 | 311 | 90 | 0.46 | 0.75 |
| 7 | 2029 | 931 | 561 | 204 | 7.34 | 3.64 | 420 | 175 | 303 | 87 | 0.98 | 0.73 |
| 8 | 2403 | 991 | 575 | 220 | 9.14 | 3.86 | 385 | 165 | 324 | 99 | 0.51 | 0.55 |
| 9 | 2611 | 776 | 797 | 179 | 9.07 | 2.98 | 425 | 157 | 364 | 107 | 0.51 | 0.42 |
| 10 | 2799 | 2811 | 1010 | 383 | 8.95 | 12.14 | 1613 | 307 | 817 | 193 | 6.64 | 0.96 |
| 11 | 1602 | 1267 | 616 | 176 | 4.93 | 5.46 | 423 | 253 | 250 | 81 | 1.45 | 1.44 |
| 12 | 2168 | 1351 | 620 | 203 | 7.74 | 5.74 | 718 | 162 | 349 | 122 | 1.45 | 1.35 |
| 13 | 2713 | 1241 | 515 | 359 | 10.99 | 4.41 | 412 | 118 | 155 | 98 | 2.14 | 0.16 |
| 14 | 2584 | 1710 | 950 | 263 | 8.17 | 7.23 | 331 | 237 | 146 | 99 | 1.54 | 1.15 |
| 15 | 1458 | 717 | 597 | 149 | 4.31 | 2.84 | 323 | 358 | 119 | 54 | 1.69 | 2.54 |
| 16 | 1642 | 689 | 474 | 157 | 5.84 | 2.66 | 481 | 263 | 240 | 57 | 2.00 | 1.72 |
| 17 | 2166 | 2181 | 458 | 318 | 8.54 | 9.31 | 717 | 190 | 268 | 164 | 3.75 | 0.22 |
| 18 | 2584 | 2274 | 517 | 379 | 10.33 | 9.48 | 514 | 171 | 457 | 57 | 0.47 | 0.95 |
| 19 | 2921 | 1738 | 970 | 304 | 9.76 | 7.17 | 629 | 101 | 150 | 78 | 3.99 | 1.88 |
| 20 | 1427 | 883 | 428 | 130 | 5.00 | 3.76 | 514 | 117 | 257 | 33 | 2.14 | 0.70 |
| 21 | 1110 | 1717 | 332 | 156 | 3.89 | 7.80 | 614 | 140 | 234 | 94 | 3.17 | 0.39 |
| 22 | 1369 | 1423 | 314 | 198 | 5.28 | 6.13 | 616 | 427 | 240 | 190 | 3.14 | 1.98 |
| 23 | 2165 | 2071 | 422 | 414 | 8.72 | 8.29 | 402 | 497 | 144 | 249 | 2.16 | 2.07 |
| 24 | 2381 | 1893 | 427 | 303 | 9.77 | 7.95 | 353 | 436 | 179 | 295 | 1.45 | 0.12 |
| 25 | 2750 | 1367 | 650 | 252 | 10.50 | 5.57 | 563 | 86 | 305 | 43 | 2.15 | 0.36 |
| 26 | 2549 | 1872 | 602 | 298 | 9.74 | 7.87 | 608 | 153 | 425 | 109 | 1.52 | 0.37 |
| 27 | 1208 | 1520 | 615 | 181 | 2.97 | 7.00 | 800 | 130 | 199 | 87 | 5.01 | 0.36 |
| **Mean** | **2278** | **1602** | **561** | **264** | **8.59** | **6.70** | **539** | **231** | **298** | **106** | **1.95** | **1.11** |
| Range | 1110-4014 | 717-3412 | 297-1010 | 130-494 | 2.97-17.98 | 2.66-14.59 | 323-1613 | 86-497 | 119-817 | 33-295 | 0.31-6.64 | 0.12-3.04 |
| CD (0.05) | 319 | | 79.6 | | 1.57 | | 113 | | 61.0 | | 0.703 | |
| SEm ± | 110 | | 27.4 | | 0.538 | | 39.0 | | 21.1 | | 0.242 | |

SI = Rainy season (Before the closure of Thanneermukkom regulator

SII = Summer season (After the ckosure of Thanneermukkom regulator)

Table 26. Correlation matrix showing inter-relationships among available, water soluble and exchangeable K, Ca, Mg and Na.

| Characteristics | Av. K | WS K | Ex. K | Av. Ca | WS Ca | Ex. Ca | Av. Mg | WS Mg | Ex. Mg | Av. Na | WS Na | Ex. Na |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Av. K | 1.000 | | | | | | | | | | | |
| WS K | 0.882** | 1.000 | | | | | | | | | | |
| Ex. K | 0.790** | 0.408* | 1.000 | | | | | | | | | |
| Av. Ca | 0.563** | 0.520** | 0.415* | 1.000 | | | | | | | | |
| WS Ca | 0.584** | 0.685** | 0.239 | 0.578** | 1.000 | | | | | | | |
| Ex. Ca | 0.456* | 0.373 | 0.400* | 0.962** | 0.335 | 1.000 | | | | | | |
| Av. Mg | 0.597** | 0.666** | 0.289 | 0.314 | 0.661** | 0.142 | 1.000 | | | | | |
| WS Mg | 0.623** | 0.722** | 0.267 | 0.447* | 0.633** | 0.306 | 0.812** | 1.000 | | | | |
| Ex. Mg | 0.307 | 0.348 | 0.141 | 0.050 | 0.421* | -0.083 | 0.766** | 0.297 | 1.000 | | | |
| Av. Na | 0.733** | 0.793** | 0.386* | 0.585** | 0.714** | 0.439* | 0.675** | 0.739** | 0.350 | 1.000 | | |
| WS Na | 0.728** | 0.800** | 0.369 | 0.565** | 0.726** | 0.411* | 0.691** | 0.760** | 0.359 | 0.994** | 1.000 | |
| Ex. Na | 0.411* | 0.337 | 0.359 | 0.399* | 0.223 | 0.388* | 0.194 | 0.172 | 0.137 | 0.520** | 0.430* | 1.000 |

* Significant at 5% level    ** Significant at 1% level    WS - Water soluble

*1.4. Iron:* The problem of Fe toxicity is often encountered in Kuttanad soils and this is more serious in kari and karappadom soils rather than in kayal soils (Aiyer *et al.*, 1975). The extreme acidic soil reaction and reduced soil condition due to submergence maintained large quantities of Fe in soluble form. The different fractions of Fe in soil are presented in Table 27.

Major portion of total Fe in soils is in the form of free oxides. The mean value of free Fe during rainy season was 6.62 per cent and increased to 6.75 per cent during summer. Free Fe indicated the quantity of Fe that can be reduced within the soil. However, only a small portion of the free Fe is solubilised and present in readily available form, even then the Fe status of the area is very high (Fig 19).

The available Fe extracted by DTPA extractant and double acid (0.05 *N* HCl + 0.025 *N* $H_2SO_4$) showed only slight variation. The mean value of DTPA extractable Fe was 373 ppm during rainy season and increased to 429 ppm during summer. Available Fe status of the study area was very high based on the critical level suggested by Tandon (1995).

Table 27. Different forms of Fe in soils during rainy and summer seasons

| Padasekharam No. | Free Fe, % | | Available Fe, ppm | | | | Exchangeable Fe cmol(+) kg $^{-1}$ | | Water soluble Fe ppm | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | DTPA | | Double acid | | | | | |
| | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII |
| 1 | 2.93 | 6.14 | 369 | 426 | 343 | 684 | 0.170 | 0.211 | 23.4 | 31.3 |
| 2 | 2.79 | 4.37 | 389 | 529 | 372 | 524 | 0.162 | 0.215 | 15..2 | 43.0 |
| 3 | 8.56 | 7.01 | 346 | 486 | 362 | 452 | 0.152 | 0.197 | 11.6 | 15.4 |
| 4 | 10.11 | 7.32 | 556 | 571 | 442 | 490 | 0.132 | 0.363 | 14.9 | 15.6 |
| 5 | 6.84 | 5.92 | 440 | 303 | 348 | 350 | 0.097 | 0.255 | 14.4 | 15.9 |
| 6 | 6.41 | 6.14 | 441 | 103 | 429 | 222 | 0.223 | 0.323 | 19.5 | 24.7 |
| 7 | 2.87 | 4.00 | 249 | 358 | 249 | 345 | 0.146 | 0.129 | 10.4 | 23.3 |
| 8 | 2.96 | 2.62 | 244 | 257 | 249 | 565 | 0.197 | 0.126 | 19.9 | 26.9 |
| 9 | 6.42 | 4.34 | 242 | 389 | 215 | 335 | 0.099 | 0.186 | 6.5 | 38.9 |
| 10 | 5.79 | 10.54 | 442 | 798 | 359 | 671 | 0.213 | 0.372 | 16.7 | 18.0 |
| 11 | 9.01 | 10.56 | 182 | 407 | 174 | 424 | 0.159 | 0.333 | 10.6 | 15.9 |
| 12 | 9.42 | 8.26 | 382 | 395 | 311 | 371 | 0.216 | 0.264 | 14.9 | 14.3 |
| 13 | 10.03 | 8.46 | 439 | 400 | 541 | 428 | 0.221 | 0.282 | 13.6 | 15.5 |
| 14 | 3.23 | 7.07 | 362 | 391 | 343 | 345 | 0.278 | 0.257 | 11.4 | 12.8 |
| 15 | 3.16 | 2.62 | 375 | 411 | 236 | 378 | 0.157 | 0.276 | 15.6 | 16.9 |
| 16 | 1.59 | 2.85 | 401 | 456 | 339 | 484 | 0.146 | 0.265 | 17.6 | 19.6 |
| 17 | 6.73 | 6.68 | 484 | 498 | 452 | 389 | 0.233 | 0.208 | 18.2 | 15.7 |
| 18 | 9.47 | 7.37 | 477 | 567 | 395 | 533 | 0.168 | 0.255 | 42.0 | 13.9 |
| 19 | 8.37 | 7.82 | 310 | 437 | 576 | 1031 | 0.279 | 0.165 | 32.9 | 15.5 |
| 20 | 8.52 | 6.83 | 313 | 231 | 302 | 222 | 0.184 | 0.221 | 15.6 | 12.7 |
| 21 | 8.70 | 9.66 | 262 | 420 | 243 | 290 | 0.155 | 0.241 | 14.1 | 13.3 |
| 22 | 4.08 | 6.12 | 261 | 502 | 254 | 442 | 0.235 | 0.364 | 15.1 | 26.7 |
| 23 | 9.88 | 7.10 | 522 | 368 | 483 | 361 | 0.222 | 0.357 | 18.1 | 14.3 |
| 24 | 5.99 | 7.91 | 288 | 505 | 275 | 441 | 0.216 | 0.423 | 19.0 | 19.7 |
| 25 | 9.47 | 6.72 | 523 | 463 | 453 | 465 | 0.088 | 0.165 | 7.8 | 16.0 |
| 26 | 8.01 | 7.47 | 403 | 448 | 382 | 413 | 0.095 | 0.332 | 6.0 | 20.5 |
| 27 | 7.26 | 10.32 | 366 | 456 | 317 | 427 | 0.055 | 0.194 | 3.1 | 13.0 |
| **Mean** | **6.62** | **6.75** | **373** | **429** | **350** | **447** | **0.174** | **0.259** | **15.9** | **19.6** |
| Range | 1.59-10.11 | 2.62-10.56 | 182-556 | 103-798 | 174-576 | 222-1031 | 0.055-0.279 | 0.126-0.423 | 3.1-42.0 | 12.7-43.0 |
| CD (0.05) | NS | | 55.2 | | 60.4 | | 0.034 | | NS | |
| SEm ± | 0.287 | | 18.9 | | 20.8 | | 0.012 | | 1.57 | |

Free Fe = Citrate-dithionite extractable Fe

Double acid = 0.05 *N* HCl + 0.025 *N* $H_2SO_4$

SI = Rainy season (before the closure of Thanneermukkom regulator)

SII = Summer season (after the closure of Thanneermukkom regulator)

Compared to available Fe, the exchangeable Fe content was very low and the mean value increased from 0.174 cmol(+) kg$^{-1}$ during rainy season to 0.259 cmol(+) kg$^{-1}$ during summer season. The water soluble Fe also followed the same trend as that of exchangeable Fe and the corresponding values were 15.9 and 19.6 ppm, respectively. The exchangeable + water soluble

Plate XIX. Reddish scum of ferric oxide in padasekharams of Kumarakom village

Plate XX. Iron sulphide deposition in kari lands of Karumadi

Fe constituted less than 20 per cent of available Fe indicating a major portion of available Fe was present in organically complexed form.

Since the data on above fractions of Fe during the pre-barrage period were not available, the comparison with present Fe status was not possible. However, the quantity of available Fe present is sufficient to cause Fe toxicity in the area and will be more severe during the summer season due to the greater quantity of Fe and reduction in concentration of exchangeable bases during that period. Fe toxicity has been reported for Fe levels varying from 20 ppm (Van Breeman and Moorman, 1978) to 400 ppm (IRRI, 1964). In presence of adequate concentration of nutrients especially the basic cations, the plants tolerate Fe up to a few hundred ppm (Ottow *et al.*, 1982). However, an intensification of Fe toxicity during summer compared to rainy season can be expected in the study area due to the decrease in exchangeable base content and increase in available Fe during that period.

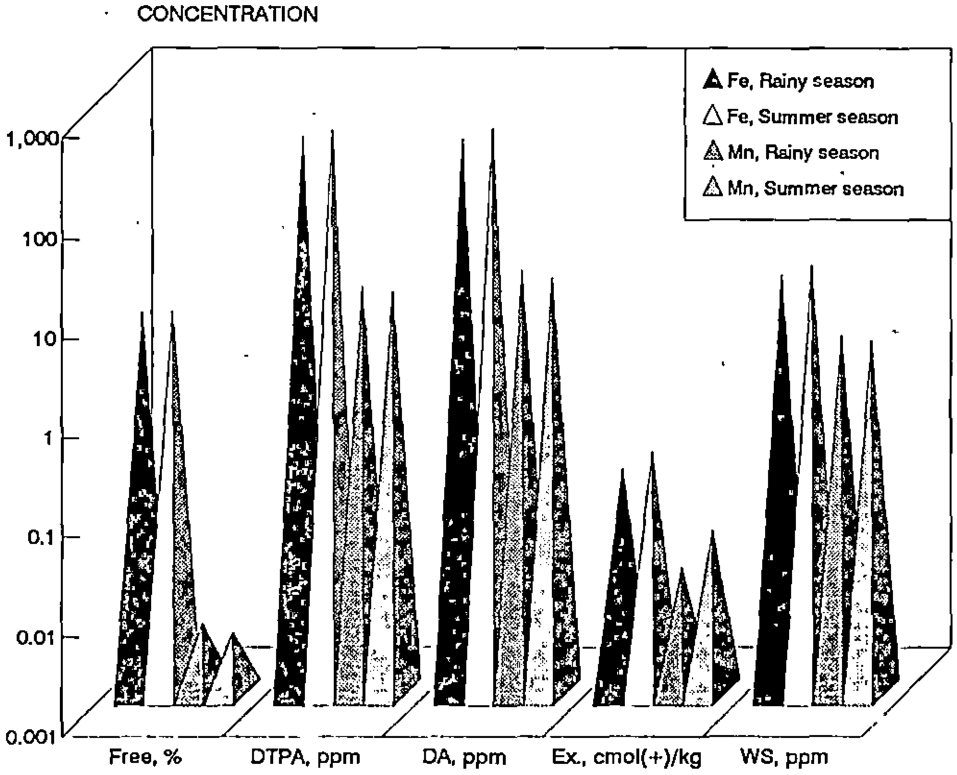


Fig 19. Different fractions of Fe and Mn in soil during rainy and summer seasons. (DA - Double acid; WS - Water soluble)

*1.5. Manganese*: Kuttanad soils are fairly rich in Mn and its concentration varied from 10.9 to 49.7 ppm (Pisharody, 1965; Aiyer *et al.*, 1975; Rajendran and Aiyer, 1981). The different fractions of Mn in the study area are presented in Table 28.

Table 28. Different forms of Mn in soils during rainy and summer seasons

| Padasekharam No. | Free Mn % | | Available Mn | | | | Exchangeable Mn cmol(+) kg $^{-1}$ | | Water soluble Mn, ppm | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | DTPA | | Double acid | | | | | |
| | | | ppm | | | | | | | |
| | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII |
| 1 | 45.6 | 59.4 | 3.10 | 3.07 | 2.7 | 4.8 | 0.018 | 0.016 | 2.20 | 0.82 |
| 2 | 28.3 | 47.8 | 7.17 | 10.11 | 9.4 | 26.2 | 0.011 | 0.066 | 2.28 | 8.66 |
| 3 | 78.5 | 36.1 | 6.69 | 13.93 | 33.5 | 15.5 | 0.011 | 0.019 | 2.47 | 0.86 |
| 4 | 93.3 | 45.8 | 6.65 | 9.43 | 16.1 | 40.0 | 0.012 | 0.103 | 2.39 | 0.69 |
| 5 | 75.0 | 35.0 | 12.43 | 7.43 | 27.6 | 10.2 | 0.014 | 0.015 | 3.49 | 0.53 |
| 6 | 44.5 | 29.2 | 16.68 | 11.12 | 17.0 | 15.7 | 0.012 | 0.050 | 0.37 | 0.75 |
| 7 | 40.1 | 24.4 | 18.10 | 2.62 | 19.0 | 2.9 | 0.009 | 0.008 | 2.27 | 1.02 |
| 8 | 57.5 | 26.4 | 10.93 | 7.11 | 12.8 | 4.4 | 0.008 | 0.027 | 1.79 | 3.31 |
| 9 | 36.4 | 34.0 | 5.31 | 3.94 | 9.1 | 3.3 | 0.027 | 0.012 | 5.69 | 1.20 |
| 10 | 57.3 | 49.8 | 8.72 | 2.30 | 22.9 | 19.2 | 0.040 | 0.067 | 10.39 | 0.82 |
| 11 | 42.5 | 32.3 | 16.45 | 12.04 | 22.5 | 9.9 | 0.022 | 0.044 | 5.39 | 0.93 |
| 12 | 34.5 | 26.3 | 10.92 | 9.12 | 15.1 | 8.1 | 0.037 | 0.018 | 9.68 | 0.92 |
| 13 | 56.7 | 28.4 | 22.15 | 11.75 | 26.2 | 7.8 | 0.003 | 0.021 | 0.77 | 1.31 |
| 14 | 93.5 | 33.5 | 20.06 | 7.69 | 46.4 | 6.6 | 0.016 | 0.010 | 4.24 | 4.44 |
| 15 | 43.7 | 43.0 | 4.77 | 31.15 | 3.7 | 25.4 | 0.003 | 0.040 | 0.66 | 0.15 |
| 16 | 58.1 | 52.6 | 6.81 | 28.56 | 9.7 | 28.2 | 0.003 | 0.023 | 0.67 | 6.33 |
| 17 | 45.0 | 46.8 | 12.75 | 17.72 | 11.7 | 19.1 | 0.013 | 0.085 | 0.83 | 9.45 |
| 18 | 56.8 | 39.8 | 25.29 | 22.74 | 24.1 | 31.3 | 0.050 | 0.066 | 13.35 | 9.71 |
| 19 | 58.7 | 46.9 | 25.15 | 11.99 | 26.5 | 12.1 | 0.058 | 0.123 | 13.18 | 26.20 |
| 20 | 23.6 | 25.4 | 10.06 | 7.61 | 12.1 | 10.7 | 0.009 | 0.053 | 1.27 | 0.87 |
| 21 | 28.1 | 32.8 | 11.46 | 9.60 | 12.6 | 10.5 | 0.007 | 0.053 | 1.74 | 0.94 |
| 22 | 48.8 | 35.6 | 7.53 | 4.74 | 9.7 | 15.4 | 0.010 | 0.056 | 0.71 | 2.84 |
| 23 | 66.1 | 27.3 | 9.77 | 4.32 | 9.1 | 13.8 | 0.007 | 0.047 | 1.92 | 3.48 |
| 24 | 50.5 | 40.4 | 8.83 | 13.18 | 12.3 | 10.2 | 0.001 | 0.020 | 0.35 | 2.73 |
| 25 | 47.4 | 38.8 | 12.82 | 6.47 | 19.0 | 13.7 | 0.026 | 0.013 | 5.58 | 1.29 |
| 26 | 49.1 | 43.4 | 12.34 | 10.72 | 18.1 | 11.9 | 0.040 | 0.043 | 5.58 | 2.04 |
| 27 | 44.6 | 39.1 | 13.04 | 6.08 | 17.3 | 17.7 | 0.028 | 0.012 | 7.0 | 1.30 |
| **Mean** | **52.0** | **37.8** | **12.0** | **10.6** | **17.3** | **14.6** | **0.018** | **0.041** | **3.94** | **3.47** |
| Range | 23.6-93.5 | 24.4-59.4 | 3.10-25.29 | 2.30-28.56 | 2.7-46.4 | 2.9-40.0 | 0.001-0.057 | 0.001-0.123 | 0.35-13.35 | 0.15-26.20 |
| CD (0.05) | 7.46 | | NS | | NS | | 0.011 | | NS | |
| SEm ± | 2.57 | | 1.25 | | 1.900 | | 0.044 | | 0.670 | |

Free Mn - Citrate dithionite extractable; Double acid - 0.05 *N* HCl + 0.025 *N* $H_2SO_4$; SI = Rainy season (before the closure of Thanneermukkom regulator); SII = Summer season (after the closure of Thanneermukkom regulator)

In general, the different fractions of Mn showed a decrease during the summer season. The acidic soil reaction and reduced soil condition due to submergence kept Mn in soluble form. The heavy monsoon showers have removed a part of this which resulted in reduction in Mn content. The mean value of free Mn was 52.0 ppm during rainy season and it decreased to 37.8 ppm during summer. Compared to Fe, the above values were very low (Fig 19). The available Mn extracted by DTPA and double acid (0.05 *N* HCl + 0.025 *N* $H_2SO_4$) differed slightly and double acid extracted more Mn. The mean values for double acid extractable Mn were 17.3 and 14.6 ppm, during rainy and summer seasons, respectively. The exchangeable Mn was present only in negligible quantity. The mean value of water soluble Mn was 3.94 ppm during rainy season and decreased to 3.47 ppm during summer. Here also, the comparison with pre-barrage period was not possible due to want of data for the particular area.

*1.6. Other elements*: A uniform deficiency of Cu was reported from Kuttanad region which mainly constitutes reclaimed soils. In the case of Zn, more than 50 per cent of the area was reported to be deficient (Rajagopal *et al.*, 1977). But certain parts of Kuttanad contain substantial amount of Zn, which sometimes attains toxic levels (Kuruvila and Patnaik, 1994). The Cu and Zn extracted by DTPA and double acid (0.05 *N* HCl + 0.025 *N* $H_2SO_4$) are examined here (Table 29). DTPA extracted more Cu than diacid and the mean values were 6.44 and 4.89 ppm, during rainy and summer seasons, respectively. For Zn, larger quantity was extracted by double acid and the mean values were 5.63 and 5.26 ppm, respectively during the above two seasons. The area was not deficient in Cu or Zn since their contents were above the critical level of 0.5 ppm suggested by Aiyer *et al.* (1975) for Kuttanad region or the levels fixed by Tandon (1995). Compared to the values reported by Aiyer *et al.* (1975), there was an increase in available Cu and Zn during the post-barrage period but not to the extent of toxicity. The application of Cu based fungicides may also play a role in increasing the Cu content of the area.

The heavy metals like Cd and Pb were not detected in the DTPA extract for most of the soil samples collected. In a few cases a concentration between 0.10 to 0.15 ppm for the above elements were recorded irrespective of the closure/opening of the regulator.

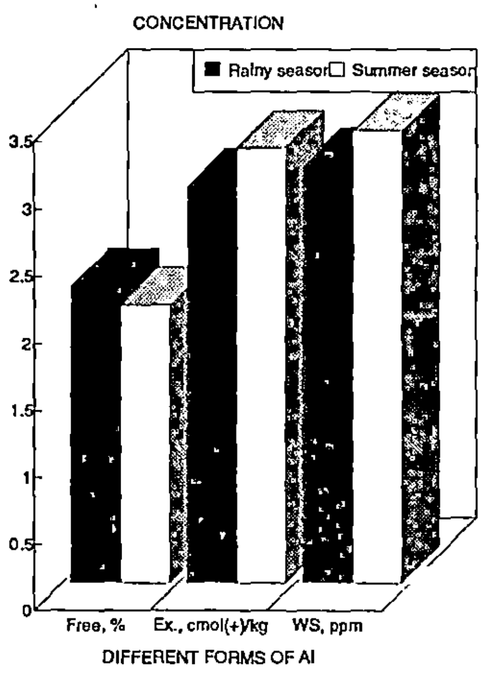


Fig 20. Different forms of Al in soil during different seasons

The soil contained sufficiently large quantities of free Al and the mean values were 2.22 and 2.08 per cent, during rainy and summer seasons, respectively (Table 29). The Kuttanad soils are inherently rich in Al (Money, 1961a; Kabeerathumma and Patnaik, 1978; Abraham, 1984. Though the soil contained large quantities of free Al, the water soluble Al was very low (Fig. 20) apparantely due to the submerged condition and the consequent rise in pH. However, the

Table 29. Available Cu, Zn and different fractions of Al in soils during rainy and summer seasons

| Padasekharam No. | Available Cu, ppm | | | | Available Zn, ppm | | | | Al | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DTPA | | Double acid | | DTPA | | Double acid | | Free, % | | Water soluble ppm | |
| | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII |
| 1 | 2.92 | 1.43 | 0.30 | 0.68 | 2.74 | 0.82 | 5.80 | 1.02 | 2.20 | 1.83 | 2.51 | 1.88 |
| 2 | 3.96 | 1.41 | 0.63 | 0.47 | 2.08 | 4.16 | 5.35 | 9.83 | 1.92 | 2.75 | 3.42 | 3.22 |
| 3 | 9.46 | 7.74 | 2.69 | 2.58 | 1.15 | 2.06 | 9.23 | 3.87 | 2.45 | 2.37 | 7.33 | 6.41 |
| 4 | 9.97 | 0.81 | 1.07 | 0.89 | 6.75 | 2.69 | 6.43 | 4.94 | 3.35 | 2.75 | 6.01 | 7.32 |
| 5 | 6.44 | 5.46 | 2.30 | 4.37 | 6.44 | 1.53 | 11.51 | 1.09 | 2.49 | 2.23 | 3.39 | 4.46 |
| 6 | 9.34 | 0.67 | 1.85 | 2.25 | 2.45 | 0.90 | 3.71 | 5.62 | 2.22 | 2.15 | 4.13 | 4.57 |
| 7 | 2.08 | 4.02 | 0.53 | 1.46 | 1.44 | 5.95 | 3.20 | 2.04 | 1.40 | 1.64 | 3.22 | 3.13 |
| 8 | 2.11 | 1.82 | 1.60 | 0.28 | 1.53 | 5.12 | 4.16 | 3.03 | 1.68 | 1.31 | 2.12 | 2.98 |
| 9 | 1.97 | 3.94 | 0.25 | 0.90 | 1.37 | 1.97 | 2.27 | 2.09 | 1.46 | 1.49 | 5.13 | 1.91 |
| 10 | 1.73 | 1.15 | 0.39 | 2.56 | 1.84 | 2.30 | 5.74 | 8.30 | 2.29 | 3.83 | 3.91 | 9.88 |
| 11 | 8.69 | 9.72 | 1.23 | 4.58 | 4.99 | 2.96 | 3.39 | 5.28 | 1.73 | 1.67 | 2.11 | 2.14 |
| 12 | 6.04 | 7.30 | 1.55 | 1.35 | 2.86 | 1.62 | 3.49 | 3.38 | 2.25 | 1.86 | 4.03 | 2.22 |
| 13 | 12.10 | 6.47 | 0.86 | 2.94 | 0.70 | 1.96 | 5.15 | 3.60 | 2.58 | 1.59 | 1.89 | 1.95 |
| 14 | 6.46 | 9.67 | 1.90 | 2.63 | 0.23 | 1.38 | 4.56 | 4.94 | 2.71 | 1.81 | 1.21 | 2.32 |
| 15 | 3.38 | 2.69 | 1.66 | 0.60 | 1.99 | 8.06 | 2.65 | 12.21 | 1.53 | 1.53 | 0.10 | 2.13 |
| 16 | 1.60 | 4.13 | 0.33 | 1.25 | 1.20 | 3.57 | 7.34 | 3.88 | 1.88 | 1.68 | 1.38 | 2.09 |
| 17 | 6.50 | 4.63 | 1.25 | 1.36 | 4.25 | 5.68 | 3.75 | 5.45 | 2.40 | 2.32 | 0.40 | 4.85 |
| 18 | 6.72 | 5.11 | 3.45 | 0.47 | 4.13 | 3.13 | 5.60 | 8.06 | 2.69 | 1.95 | 2.10 | 3.15 |
| 19 | 6.22 | 2.87 | 1.79 | 0.44 | 13.10 | 1.57 | 20.05 | 9.56 | 2.19 | 2.01 | 4.03 | 5.19 |
| 20 | 8.99 | 2.93 | 5.00 | 3.58 | 2.57 | 2.15 | 8.92 | 3.90 | 2.19 | 1.63 | 1.38 | 2.12 |
| 21 | 7.57 | 11.00 | 2.16 | 4.29 | 1.51 | 2.58 | 3.24 | 3.90 | 2.03 | 2.40 | 2.25 | 2.87 |
| 22 | 6.85 | 6.17 | 1.43 | 2.37 | 2.91 | 2.85 | 4.85 | 8.30 | 1.9 | 2.07 | 6.22 | 2.07 |
| 23 | 13.22 | 4.21 | 2.40 | 2.90 | 2.70 | 3.48 | 4.79 | 6.63 | 3.11 | 2.23 | 7.32 | 2.01 |
| 24 | 9.88 | 8.41 | 3.50 | 3.31 | 4.20 | 2.73 | 6.30 | 4.92 | 2.10 | 2.37 | 7.82 | 3.17 |
| 25 | .97 | 3.88 | 1.86 | 2.88 | 1.95 | 1.29 | 2.32 | 3.24 | 2.79 | 1.89 | 0.11 | 3.10 |
| 26 | 6.85 | 9.69 | 3.19 | 3.40 | 1.06 | 2.04 | 3.89 | 3.83 | 1.95 | 2.77 | 0.18 | 2.18 |
| 27 | 5.97 | 4.56 | 2.21 | 2.53 | 1.77 | 1.30 | 4.42 | 9.05 | 2.40 | 1.95 | 0.17 | 1.79 |
| **Mean** | **6.44** | **4.89** | **1.76** | **2.12** | **2.95** | **2.81** | **5.63** | **5.26** | **2.22** | **2.08** | **3.11** | **3.37** |
| Range | 1.60 - 13.22 | 0.67 - 11.00 | 0.25 - 5.00 | 0.28 - 4.58 | 0.23 - 13.10 | 0.82 - 8.06 | 2.27 - 20.05 | 1.02 - 12.21 | 1.40 - 3.35 | 1.31 - 3.83 | 0.10 - 7.82 | 1.79 - 9.88 |
| CD (0.05) | 1.42 | | NS | | NS | | NS | | NS | | NS | |
| SEm± | 0.488 | | 0.182 | | 0.444 | | 0.588 | | 0.079 | | 0.341 | |

Free Al - Citrate dithionite extractable

Double acid - 0.05 *N* HCl + 0.025 *N* $H_2SO_4$

S I = Rainy season (before the closure of Thanneermukkom regulator)

SII = Summer season (after the closure of Thanneermukkom regulator)

soil showed a marginal increase in exchangeable $Al^{3+}$ during summer (Table 21). The closure of regulator has not influenced Al content of soil like that of Fe and the present values showed only marginal variation from that of pre-barrage period.

## 2. Water

The water quality problem is minor in Kerala, compared to other parts of India and is mainly confined to the coastal areas due to sea water intrusion. The Kuttanad region is such a coastal area lying 0.5 to 2.2 m below msl and periodically inundated by saline water due to the tidal inflow from the sea during summer. Sea water intrusion and the consequent crop failure was a regular phenomenon in Kuttanad during the pre-barrage period. The construction of Thanneermukkom regulator has restricted the frequent intrusion of sea water into the area and thereby the punja crop was protected. However, this had resulted in the stagnation of water on the southern side of the regulator while the northern side of the regulator through which the water drains out has free access to the sea. On the southern side of the regulator, the stagnation of water and the re-use of stagnant water frequently for all purposes including domestic uses further deteriorates considerably the quality of water due to the accumulation of various organic and inorganic constituents which create several environmental and health problems. The various quality attributes of surface (Tables 30 and 32) and ground water (Tables 31 and 33) during rainy and summer seasons (before and after the closure of Thanneermukkom regulator) are evaluated, and the comparison with pre-barrage period was not possible due to want of similar studies taken up during pre-barrage period.

The water of the study area was mildly acidic in reaction. Surface water recorded a mean pH of 6.7 during rainy season and decreased to 5.9 during summer. For ground water the corresponding values were 6.7 and 6.3, respectively. During rainy season the pH values of ground and surface water were the same. The total quantity of water involved is so high during rainy season that it is difficult to impose a pH change in such a large waterbody and hence no difference was observed in pH. The decrease in pH during summer was due to the lowering of water table by the closure of the regulator and the release of subsoil acidity due to partial drying of soil. The northern side of the regulator through which water drains out to the sea recorded a higher pH during summer compared to the southern side where the water flow is restricted. Since the free passage of sea water is possible on the northern side, it caused an increase in pH.

As per the WHO (1971) and ISI (1991) standards, the pH of the water for domestic purposes should be within the range of 6.5-7.5. Based on this, the water quality is rated as poor in the study area during summer. About 60-67 per cent of the area recorded a pH below 6.5. For irrigation water, pH is not an accepted criterion of water quality because it tends to be buffered by soil and most crops can tolerate a wide range of pH. But the leaching of acid waters from rice fields and adjacent canals are injurious to aquatic organisms like fish and may even lead to their mortality (Nair and Pillai, 1990). Since aquaculture is widely practised in the area, the danger posed to it due to the acidity of water may be high. However, the preferred pH is around neutrality.

Another parameter which decides the quality of water is salinity which is measured in terms of electrical conductivity. For surface water the mean value was 0.28 dS $m^{-1}$ during rainy season and it increased to 0.51 dS $m^{-1}$ during summer. The corresponding values for ground

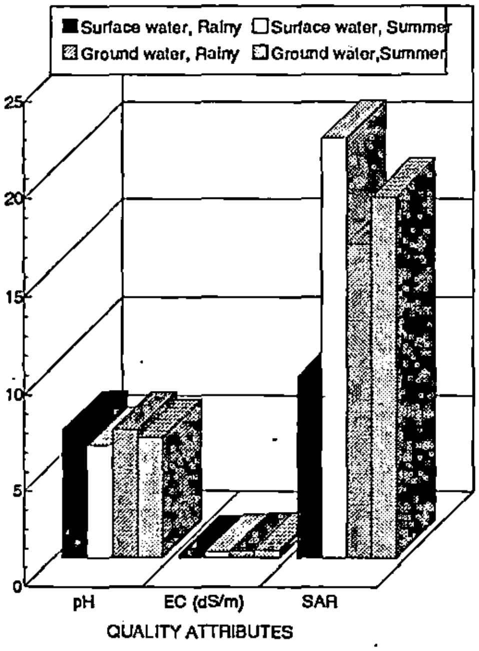


Fig 21. Few quality attributes of surface and ground water during different seasons

water were 0.37 and 0.42 dS $m^{-1}$ respectively. The increase in EC (Fig 21) during summer was evidently due to the lowering of water table and the accumulation of fertiliser residues from agricultural fields since the free flow of water from the sea is prevented by closing the regulator. This result was in contrary to the variation of soil EC which decreased during summer. This was evidently due to the difference in the period of soil collection. The soil samples were collected during early monsoon period (May-June) since proper soil sampling was not possible during the heavy monsoon season due to the flooded condition of the area. Water sample collection alone was possible at that time. As per the standards of irrigation water (Ayers, 1975; Ayers and westcot, 1985) the permissible limit for no problem of salinity, the EC value should be below 0.75 dS $m^{-1}$. Judged from this, the water of the study area is not of bad quality. For domestic purposes also the maximum acceptable limit is same as above (WHO, 1971). The lake water on the northern side of regulator recorded a very high EC during the summer season.

The major elemental constituents of water, in general, are sodium, calcium and magnesium in the form of chlorides, sulphates and bicarbonates. In the study area also the major elemental constituents were Na, K, Ca and Mg in the form of chlorides and sulphates both in surface (Fig 22) as well as in ground water (Fig 23). The water soluble P is usually absent in surface or ground water. Here also, the concentration of water soluble P was in traces, evidently due to its low mobility and high fixation in soils. The mean value of K in surface water was 1.92 ppm during rainy season and 5.95 ppm during summer season. In ground water, the mean K content was 3.8 and 4.4 ppm, during rainy and summer seasons, respectively. The increase in concentration during summer was due to the decrease in the volume of waterbody and accumulation of fertiliser residues from rice fields. The K concentration in drainage water from agricultural fields was in the range of 0.4 to 4 ppm and this range, in normal cases, is safe for irrigation and domestic purposes (Lal *et al.*, 1993). In general, the K content of water is evaluated on the basis of EC and as per the EC values the water quality was not poor. The permissible limit of K in drinking water is 10 ppm (ISI, 1991) and ground water recorded values much below this limit. Ca and Mg are identified as the dominant cations of water. The allowable maximum for domestic purposes is 75 ppm for Ca and 50 ppm for Mg (WHO, 1971; ISI, 1991). For safe irrigation, the ratio between Mg and Ca + Mg should be less than 1.5 (Ayers, 1975; Ayers and Westcot, 1985) since higher concentration of Mg deteriorates the soil structure particularly when water is Na

Table 30. Quality attributes of surface water during rainy and summer seasons

| Padasek-haram No. | pH | | EC, dS m$^{-1}$ | | P | | K | | Ca | | Mg | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | ppm | | | | | | | |
| | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII |
| 1 | 6.7 | 6.5 | 0.18 | 0.68 | 0.01 | 0.02 | 1.82 | 4.00 | 18.0 | 16.0 | 7.20 | 7.20 |
| 2 | 6.8 | 6.7 | 0.20 | 0.52 | 0.01 | 0.05 | 1.85 | 5.30 | 20.0 | 16.0 | 7.20 | 7.20 |
| 3 | 7.0 | 7.0 | 0.15 | 0.31 | 0.01 | 0.02 | 1.06 | 3.60 | 10.0 | 10.0 | 8.40 | 12.00 |
| 4 | 7.0 | 7.0 | 0.84 | 0.30 | 0.01 | 0.02 | 5.14 | 3.80 | 24.0 | 12.0 | 6.00 | 11.00 |
| 5 | 4.8 | 6.4 | 0.28 | 0.54 | 0.06 | 0.01 | 0.48 | 7.00 | 8.0 | 16.0 | 15.60 | 13.20 |
| 6 | 7.0 | 4.8 | 0.31 | 0.50 | 0.02 | 0.02 | 2.01 | 4.00 | 10.0 | 14.0 | 15.60 | 9.60 |
| 7 | 6.8 | 6.5 | 0.31 | 0.58 | 0.01 | 0.05 | 1.23 | 6.00 | 18.0 | 16.0 | 7.20 | 12.00 |
| 8 | 7.0 | 6.8 | 0.26 | 0.50 | 0.02 | 0.01 | 1.06 | 6.60 | 17.0 | 14.0 | 7.20 | 14.40 |
| 9 | 7.9 | 6.5 | 0.15 | 0.55 | 0.02 | 0.03 | 0.68 | 11.30 | 22.0 | 18.0 | 6.00 | 6.00 |
| 10 | 6.9 | 4.8 | 0.26 | 0.55 | 0.05 | 0.01 | 1.25 | 5.80 | 24.0 | 24.0 | 4.80 | 7.20 |
| 11 | 6.2 | 6.3 | 0.44 | 0.47 | 0.08 | 0.01 | 1.80 | 2.60 | 14.0 | 10.0 | 7.20 | 10.80 |
| 12 | 6.8 | 3.7 | 0.27 | 1.33 | 0.06 | 0.01 | 0.20 | 27.50 | 8.0 | 48.0 | 14.40 | 6.00 |
| 13 | 6.4 | 5.5 | 0.54 | 1.42 | 0.08 | 0.01 | 6.61 | 11.30 | 24.0 | 10.0 | 13.20 | 6.00 |
| 14 | 6.8 | 6.6 | 0.10 | 0.32 | 0.07 | 0.01 | 1.23 | 6.20 | 12.0 | 8.0 | 14.40 | 7.20 |
| 15 | 6.9 | 6.7 | 0.12 | 0.58 | 0.23 | 0.01 | 2.44 | 6.60 | 18.0 | 16.0 | 15.60 | 16.80 |
| 16 | 6.7 | 6.4 | 0.20 | 0.55 | 0.11 | 0.07 | 2.65 | 5.80 | 20.0 | 16.0 | 8.40 | 13.20 |
| 17 | 7.0 | 6.9 | 0.23 | 0.45 | 0.05 | 0.01 | 1.82 | 1.80 | 18.0 | 18.0 | 8.20 | 24.0 |
| 18 | 6.5 | 5.9 | 0.30 | 0.52 | 0.05 | 0.01 | 2.16 | 5.00 | 18.0 | 16.0 | 10.80 | 12.00 |
| 19 | 6.9 | 6.2 | 0.17 | 0.43 | 0.05 | 0.02 | 1.14 | 3.70 | 20.0 | 16.0 | 8.40 | 9.60 |
| 20 | 6.9 | 6.1 | 0.10 | 0.66 | 0.01 | 0.01 | 0.85 | 4.20 | 18.0 | 16.0 | 8.20 | 3.60 |
| 21 | 6.8 | 6.1 | 0.10 | 0.49 | 0.01 | 0.01 | 0.92 | 2.10 | 18.0 | 14.0 | 8.00 | 4.80 |
| 22 | 6.8 | 4.8 | 0.34 | 0.60 | 0.01 | 0.01 | 2.13 | 3.60 | 26.0 | 20.0 | 8.40 | 2.40 |
| 23 | 6.7 | 4.7 | 0.21 | 0.54 | 0.02 | 0.02 | 1.35 | 4.40 | 22.0 | 24.0 | 6.00 | 8.40 |
| 24 | 6.9 | 4.8 | 0.32 | 0.61 | 0.02 | 0.03 | 2.28 | 5.60 | 18.0 | 16.0 | 8.00 | 16.80 |
| 25 | 7.0 | 7.0 | 0.27 | 0.44 | 0.06 | 0.03 | 1.64 | 5.20 | 14.0 | 14.0 | 1.20 | 19.20 |
| 26 | 6.8 | 5.1 | 0.27 | 0.51 | 0.02 | 0.02 | 1.71 | 2.60 | 12.0 | 10.0 | 1.20 | 7.20 |
| 27 | 6.9 | 3.7 | 0.59 | 0.94 | 0.07 | 0.02 | 4.20 | 5.00 | 14.0 | 22.0 | 10.80 | 4.80 |
| **Mean** | **6.7** | **5.9** | **0.28** | **0.51** | **0.05** | **0.02** | **1.92** | **5.95** | **17.2** | **16.7** | **8.80** | **9.30** |
| Range | 4.8-7.9 | 3.7-7.0 | 0.10-0.84 | 0.31-1.42 | 0.01-0.23 | 0.01-0.07 | 0.20-6.61 | 1.80-27.50 | 8.0-24.0 | 8.0-48.0 | 1.20-15.60 | 2.40-19.20 |
| CD (0.05) | 0.436 | | 0.108 | | 0.019 | | 2.06 | | NS | | NS | |
| SEm± | 0.150 | | 0.037 | | 0.007 | | 0.707 | | 1.27 | | 0.822 | |
| N | 6.8 | 6.2 | 0.48 | 9.97 | 0.02 | 0.01 | 8.4 | 675 | 36 | 58 | 16.2 | 33.6 |
| S | 6.8 | 5.9 | 0.50 | 1.80 | 0.02 | 0.02 | 8.6 | 1.2 | 34 | 18 | 16.4 | 7.2 |

SI = Rainy season (before the closure of Thanneermukkom regulator)

SII = Summer seaason (after the closure of Thanneermukkom regulator)

N = Northern side of Thanneermukkom regulator; S = Southern side of Thanneermukkom regulator

Table 31. Quality attributes of ground water during rainy and summer seasons

| Padasekharam No. | pH | | EC, dS $m^{-1}$ | | K | | Ca | | Mg | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | ppm | | | | | |
| | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII |
| 1 | 6.9 | 6.7 | 0.28 | 0.44 | 3.6 | 3.0 | 8.2 | 16.2 | 4.0 | 7.6 |
| 2 | 7.0 | 7.0 | 0.18 | 0.48 | 3.9 | 3.2 | 8.0 | 15.6 | 4.4 | 8.8 |
| 3 | 7.0 | 7.0 | 0.20 | 0.45 | 3.9 | 3.1 | 8.2 | 16.0 | 4.2 | 10.0 |
| 4 | 7.0 | 6.9 | 0.21 | 0.59 | 2.8 | 2.8 | 8.8 | 12.2 | 5.0 | 8.4 |
| 5 | 6.9 | 6.3 | 0.37 | 1.20 | 6.2 | 3.0 | 26.0 | 18.2 | 2.4 | 6.2 |
| 6 | 7.0 | 6.6 | 0.37 | 0.84 | 5.2 | 10.0 | 32.0 | 22.6 | 2.4 | 6.4 |
| 7 | 6.6 | 6.3 | 0.36 | 0.32 | 2.1 | 4.1 | 10.0 | 16.2 | 4.4 | 6.2 |
| 8 | 6.4 | 6.3 | 0.36 | 0.30 | 3.0 | 1.2 | 9.2 | 20.2 | 4.2 | 6.8 |
| 9 | 6.8 | 6.4 | 0.50 | 0.27 | 2.2 | 4.2 | 10.0 | 14.8 | 6.2 | 8.4 |
| 10 | 6.4 | 6.5 | 0.38 | 0.44 | 3.3 | 2.0 | 8.2 | 18.2 | 5.3 | 6.2 |
| 11 | 6.4 | 6.4 | 0.38 | 0.29 | 2.8 | 5.2 | 11.6 | 22.0 | 4.2 | 4.8 |
| 12 | 7.0 | 6.6 | 0.36 | 0.29 | 4.5 | 3.8 | 6.8 | 24.0 | 3.2 | 8.0 |
| 13 | 6.8 | 6.4 | 0.32 | 0.32 | 2.8 | 3.6 | 8.2 | 14.6 | 3.6 | 6.2 |
| 14 | 6.6 | 6.3 | 0.38 | 0.29 | 3.2 | 4.0 | 8.8 | 16.2 | 4.2 | 6.0 |
| 15 | 6.8 | 6.2 | 0.40 | 0.28 | 5.2 | 2.9 | 10.4 | 14.1 | 3.8 | 1.2 |
| 16 | 7.0 | 6.3 | 0.45 | 0.44 | 4.8 | 2.8 | 8.4 | 12.3 | 4.2 | 1.2 |
| 17 | 6.7 | 6.2 | 0.48 | 0.18 | 3.4 | 3.6 | 10.2 | 14.5 | 3.6 | 4.2 |
| 18 | 6.8 | 6.3 | 0.52 | 0.25 | 4.2 | 3.2 | 10.1 | 8.2 | 4.0 | 8.2 |
| 19 | 6.9 | 6.3 | 0.42 | 0.24 | 4.0 | 3.0 | 10.4 | 9.2 | 4.2 | 6.8 |
| 20 | 6.8 | 6.7 | 0.43 | 0.30 | 4.2 | 1.0 | 16.6 | 12.7 | 9.6 | 6.2 |
| 21 | 7.0 | 6.5 | 0.40 | 0.28 | 3.0 | 1.6 | 10.2 | 14.6 | 2.8 | 6.0 |
| 22 | 6.8 | 5.4 | 0.29 | 0.42 | 2.0 | 2.6 | 16.2 | 26.0 | 1.2 | 6.0 |
| 23 | 7.2 | 5.6 | 0.31 | 0.40 | 2.8 | 2.8 | 12.4 | 13.0 | 2.3 | 3.2 |
| 24 | 6.8 | 5.4 | 0.30 | 0.40 | 2.2 | 4.0 | 15.0 | 16.2 | 2.8 | 4.2 |
| 25 | 4.0 | 6.1 | 0.44 | 0.74 | 7.8 | 13.8 | 16.0 | 26.1 | 13.2 | 6.0 |
| 26 | 6.2 | 6.0 | 0.36 | 0.44 | 4.2 | 10.2 | 8.4 | 22.0 | 5.3 | 8.4 |
| 27 | 6.8 | 5.6 | 0.48 | 0.31 | 4.0 | 14.7 | 17.4 | 24.0 | 2.6 | 6.8 |
| **Mean** | **6.7** | **6.3** | **0.37** | **0.42** | **3.8** | **4.4** | **12.1** | **17.0** | **4.3** | **6.2** |
| Range | 4.0-7.2 | 5.4-7.0 | 0.18-0.52 | 0.18-1.20 | 2.0-6.2 | 1.0-14.7 | 8.0-32.0 | 8.2-26.1 | 1.2-13.2 | 1.2-10.0 |
| CD (0.05) | 0.263 | | NS | | NS | | 2.42 | | 1.17 | |
| SEm± | 0.090 | | 0.034 | | 0.427 | | 0.833 | | 0.403 | |

S I = Rainy season (before the closure of Thanneermukkom regulator)

S II = Summer season (after the closure of Thanneermukkom regulator)

dominated and highly saline. The concentrations of Ca and Mg in both surface as well as in ground water were within this limit.

Na is the most abundant cation in all natural waters whereas its presence is least desirable. Excess of Na ions characterises that the water is saline or alkaline depending up on its occurrence in association with chloride/sulphate or carbonate/bicarbonate ions and accordingly the irrigated soil may develop salinity or sodicity problem. The sodium absorption ratio (SAR) is one of the most important indices of water quality based on which salinity/sodicity hazard is evaluated. In the study area the average Na content of surface water was 34.1 ppm during rainy season and it increased to 77.9 ppm during summer.The corresponding SAR values were 9.47 and 21.6. For safe irrigation SAR value should be below 10 (Richards, 1954). As per Richards (1954) classification, water quality during summer was included under the class moderately unsafe for irrigation. For ground water the average Na content during rainy season was 46.2 ppm and 63.3 ppm during summer season.The corresponding SAR values were 16.2 and 18.6, respectively.Based on the above classification the ground water was placed under moderately safe class (SAR 10-18) during rainy season and moderately unsafe class (SAR 18-26) during summer.The ground water quality was more poor compared to surface water during rainy season, evidently due to the influence of leachates and underlying soil layers. Influence of leachates from the upper fringes of Western Ghats on the ground water quality of Kuttanad has been earlier reported by Jacob (1980).

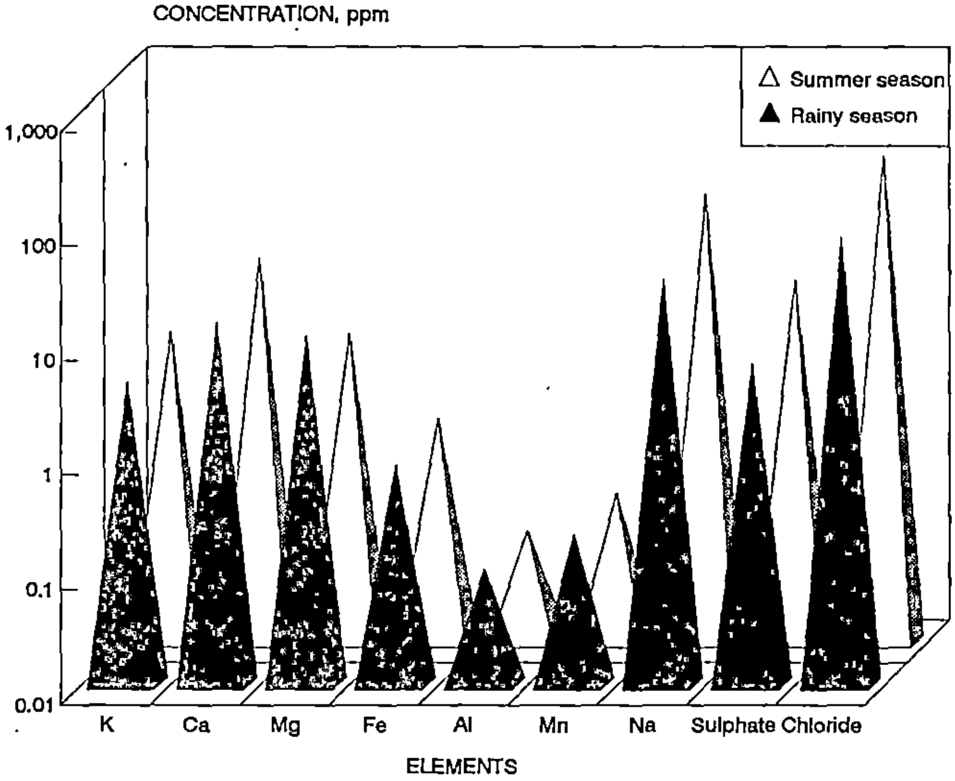


Fig 22. Elemental concentration in surface water during rainy and summer seasons

Based on the level of Na for specific toxicity effect on plants also the study area recorded a value below the permissible maximum prescribed by Ayers (1975). For domestic purposes, the ionic concentration in water is generally evaluated on the basis of EC. However, the level of Na in ground water exceeded the limit of 20 ppm prescribed by OECD (1986) but was far below the level suggested by WHO (1971) of 200 ppm. The lake water on the northern side of the regulator recorded very high values for Na, K, Ca and Mg during summer compared to the southern side due to the frequent entry of sea water under tidal influence. The data on concentration of various elements in ground water are presented in Fig 23.

Among the micronutrient elements present, Fe predominated. The mean value of Fe in surface water was 0.79 ppm during rainy season and 0.87 ppm during summer. For ground water, the corresponding values were 0.85 and 1.31 ppm, respectively. Here also the ground water registered a higher content. The permissible maximum concentration for Fe in irrigation water is 5.0 ppm and for drinking water it is 0.3 ppm as per the standards derived by the National Academy of Sciences and National Academy of Engineering (1972) and ISI (1991). The Fe content of the area did not exceed the permissible limit for irrigation water. The quality of drinking water was very poor as per ISI (1991) standards and it has to be purified before use.

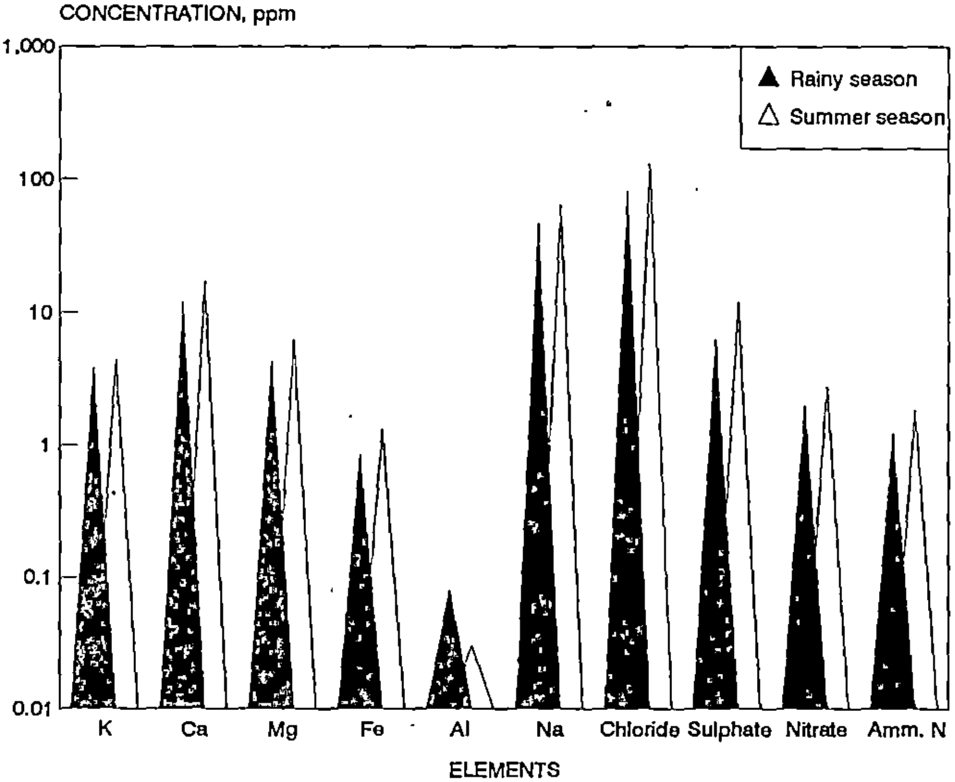


Fig 23. Elemental concentration in ground water during rainy and summer seasons

Plate XXI. An estuary at the meeting place of Pennar (Tributery of Meenachil river) with Vembanad lake

Plate XXII. A water-way at Cheepumkal, Kumarakom village

Plate XXIII. A feeder canal at Kumarakom

Plate XXIV. Practicing aquaculture with giant fresh water prawn in kayal lands of Kutanad

Plate XXV. Relics of mangroves at Vembanad lake

Table 32. Toxic characteristics of surface water during rainy and summer seasons (ppm)

| Pada-sekha-ram No. | Fe | | Mn | | Al | | Na | | $SO_4$-S | | $Cl^-$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII |
| 1 | 1.84 | 1.69 | 0.09 | 0.02 | 0.10 | 0.06 | 19.4 | 7.5 | 0.05 | 0.10 | 99 | 227 |
| 2 | 1.84 | 1.25 | 0.01 | 0.10 | 0.07 | 0.04 | 20.2 | 87.5 | 3.23 | 5.91 | 85 | 170 |
| 3 | 0.69 | 0.43 | 0.06 | 0.18 | 0.07 | 0.02 | 15.2 | 50.0 | 2.69 | 10.80 | 71 | 114 |
| 4 | 0.87 | 0.48 | 0.08 | 0.08 | 0.10 | 0.02 | 12.6 | 46.0 | 6.45 | 14.20 | 99 | 138 |
| 5 | 0.91 | 0.87 | 0.04 | 0.06 | 0.15 | 0.06 | 32.5 | 90.0 | 10.21 | 20.40 | 85 | 170 |
| 6 | 0.87 | 0.70 | 0.05 | 0.08 | 0.07 | 0.06 | 40.2 | 82.5 | 6.99 | 9.70 | 71 | 170 |
| 7 | 0.60 | 0.60 | 0.42 | 0.43 | 0.10 | 0.05 | 32.2 | 97.5 | 0.10 | 0.16 | 85 | 156 |
| 8 | 0.87 | 0.69 | 0.61 | 0.79 | 0.07 | 0.03 | 28.4 | 81.3 | 3.23 | 3.23 | 92 | 156 |
| 9 | 0.43 | 0.38 | 0.14 | 0.17 | 0.07 | 0.05 | 20.2 | 80.0 | 2.69 | 6.45 | 99 | 170 |
| 10 | 0.96 | 1.25 | 0.10 | 0.13 | 0.13 | 0.25 | 22.6 | 85.0 | 6.45 | 11.30 | 107 | 185 |
| 11 | 0.96 | 1.25 | 0.48 | 0.06 | 0.06 | 0.01 | 35.2 | 52.0 | 2.69 | 10.80 | 85 | 128 |
| 12 | 0.96 | 1.08 | 0.69 | 0.04 | 0.07 | 0.70 | 25.0 | 137.5 | 3.23 | 45.20 | 99. | 284 |
| 13 | 1.25 | 0.69 | 0.69 | 0.09 | 0.11 | 0.12 | 90.0 | 137.5 | 18.81 | 21.50 | 99 | 440 |
| 14 | 0.60 | 0.84 | 0.07 | 0.10 | 0.08 | 0.04 | 15.2 | 50.0 | 3.23 | 7.00 | 99 | 114 |
| 15 | 0.87 | 0.91 | 0.07 | 0.03 | 0.06 | 0.05 | 60.4 | 73.8 | 7.53 | 21.50 | 71 | 156 |
| 16 | 0.87 | 0.83 | 0.05 | 0.05 | 0.06 | 0.05 | 105.0 | 62.5 | 6.45 | 16.10 | 85 | 170 |
| 17 | 0.60 | 0.75 | 0.10 | 0.15 | 0.07 | 0.02 | 62.0 | 68.8 | 5.91 | 17.20 | 71 | 128 |
| 18 | 0.93 | 1.17 | 0.28 | 0.39 | 0.10 | 0.05 | 42.2 | 80.0 | 7.53 | 26.90 | 92 | 170 |
| 19 | 0.60 | 0.21 | 0.10 | 0.08 | 0.07 | 0.05 | 20.2 | 52.5 | 8.06 | 19.90 | 71 | 128 |
| 20 | 0.17 | 0.17 | 0.07 | 0.06 | 0.13 | 0.05 | 14.4 | 20.0 | 2.69 | 8.10 | 43 | 199 |
| 21 | 0.87 | 2.95 | 0.08 | 0.10 | 0.13 | 0.02 | 12.2 | 20.0 | 3.23 | 4.80 | 43 | 57 |
| 22 | 0.36 | 1.08 | 0.30 | 0.32 | 0.16 | 0.27 | 45.8 | 82.5 | 16.13 | 12.80 | 71 | 170 |
| 23 | 0.43 | 0.69 | 0.28 | 0.42 | 0.14 | 0.18 | 20.4 | 70.0 | 7.53 | 12.90 | 64 | 156 |
| 24 | 0.36 | 0.67 | 0.39 | 0.86 | 0.14 | 0.20 | 41.0 | 85.0 | 7.53 | 14.00 | 71 | 156 |
| 25 | 0.60 | 0.73 | 0.09 | 0.02 | 0.08 | 0.01 | 15.0 | 75.0 | 7.53 | 8.10 | 57 | 156 |
| 26 | 0.43 | 0.65 | 0.07 | 0.11 | 0.08 | 0.01 | 17.5 | 80.0 | 3.76 | 23.10 | 57 | 142 |
| 27 | 0.60 | 0.60 | 0.07 | 0.15 | 0.15 | 0.01 | 55.0 | 137.5 | 11.29 | 23.10 | 43 | 142 |
| Mean | **0.79** | **0.87** | **0.20** | **0.19** | **0.10** | **0.09** | **34.1** | **77.9** | **6.12** | **14.00** | **78** | **169** |
| Range | 0.17-<br>1.84 | 0.17-<br>2.95 | 0.01-<br>0.69 | 0.02-<br>0.86 | 0.06-<br>0.16 | 0.01-<br>0.70 | 12.2-<br>105.0 | 20.0-<br>137.5 | 0.05-<br>18.81 | 0.10-<br>45.20 | 42.6-<br>106.5 | 114-<br>284 |
| CD(0.05) | NS | | NS | | NS | | 12.4 | | 3.51 | | 24.5 | |
| SEm± | 0.516 | | 0.029 | | 0.019 | | 4.26 | | 1.21 | | 8.46 | |
| N | 0.285 | 0.964 | 0.02 | 0.06 | 0.01 | 0.19 | 126 | 1531.3 | 5.8 | 57.5 | 344 | 3067 |
| S | 0.314 | 0.872 | 0.02 | 0.02 | 0.01 | 0.14 | 114 | 6.2 | 24.7 | 340 | 340 | 582 |

S I = Rainy season (before the closure of Thanneermukkom regulator)

SII = Summer season (after the closure of Thanneermukkom regulator)

N = Northern side of Thanneermukkom regulator; S = Southern side of Thanneermukkom regulator

Table 33. Toxic characteristics of ground water during rainy and summer seasons (ppm)

| Padasekharam No. | Fe | | Al | | Na | | $SO_4$-S | | $Cl^-$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII |
| 1 | 0.46 | 0.91 | 0.10 | 0.03 | 33.0 | 39.4 | 5.4 | 10.8 | 57 | 114 |
| 2 | 0.50 | 0.92 | 0.11 | 0.02 | 34.6 | 38.4 | 5.7 | 10.7 | 54 | 128 |
| 3 | 0.43 | 0.90 | 0.10 | 0.02 | 33.2 | 42.6 | 5.9 | 11.3 | 57 | 128 |
| 4 | 0.34 | 0.88 | 0.09 | 0.05 | 38.4 | 38.4 | 4.8 | 10.2 | 43 | 114 |
| 5 | 1.06 | 1.20 | 0.07 | 0.02 | 53.0 | 67.5 | 5.9 | 26.4 | 57 | 114 |
| 6 | 0.96 | 0.92 | 0.09 | 0.02 | 40.2 | 68.8 | 7.5 | 16.2 | 61 | 128 |
| 7 | 0.74 | 0.92 | 0.06 | 0.02 | 38.6 | 62.4 | 6.6 | 14.0 | 99 | 128 |
| 8 | 0.82 | 0.78 | 0.06 | 0.02 | 40.4 | 70.6 | 6.5 | 12.6 | 106 | 132 |
| 9 | 0.78 | 0.60 | 0.06 | 0.02 | 25.4 | 78.6 | 7.0 | 13.9 | 99 | 142 |
| 10 | 0.78 | 0.84 | 0.06 | 0.01 | 60.6 | 42.3 | 5.9 | 12.8 | 128 | 116 |
| 11 | 0.86 | 0.96 | 0.07 | 0.01 | 35.2 | 92.6 | 7.9 | 14.4 | 85 | 128 |
| 12 | 1.15 | 0.72 | 0.06 | 0.02 | 18.8 | 42.0 | 5.6 | 6.8 | 99 | 142 |
| 13 | 0.92 | 0.80 | 0.07 | 0.02 | 26.4 | 40.0 | 7.2 | 10.2 | 92 | 142 |
| 14 | 0.78 | 0.70 | 0.07 | 0.02 | 38.6 | 62.4 | 6.4 | 6.8 | 108 | 128 |
| 15 | 0.88 | 1.80 | 0.10 | 0.02 | 40.1 | 82.0 | 7.5 | 11.3 | 99 | 149 |
| 16 | 0.78 | 1.62 | 0.09 | 0.02 | 48.2 | 84.2 | 9.7 | 10.2 | 99 | 142 |
| 17 | 0.78 | 0.88 | 0.09 | 0.02 | 62.0 | 78.6 | 7.5 | 7.6 | 85 | 142 |
| 18 | 0.83 | 0.92 | 0.08 | 0.02 | 84.0 | 78.0 | 7.5 | 11.3 | 71 | 128 |
| 19 | 0.81 | 0.88 | 0.09 | 0.01 | 86.0 | 80.0 | 7.4 | 10.6 | 70 | 128 |
| 20 | 0.69 | 0.92 | 0.07 | 0.02 | 38.2 | 75.0 | 11.3 | 7.6 | 99 | 142 |
| 21 | 0.78 | 0.95 | 0.07 | 0.02 | 36.4 | 82.0 | 7.5 | 8.4 | 85 | 142 |
| 22 | 2.05 | 5.46 | 0.16 | 0.06 | 35.0 | 47.5 | 4.3 | 16.1 | 85 | 114 |
| 23 | 1.60 | 2.81 | 0.12 | 0.06 | 42.2 | 52.8 | 1.6 | 14.2 | 71 | 114 |
| 24 | 1.60 | 4.32 | 0.10 | 0.06 | 36.4 | 54.6 | 1.6 | 16.7 | 68 | 128 |
| 25 | 0.69 | 1.00 | 0.07 | 0.06 | 75.1 | 62.5 | 5.9 | 11.3 | 57 | 128 |
| 26 | 0.58 | 0.96 | 0.07 | 0.06 | 68.6 | 66.8 | 5.9 | 7.5 | 57 | 132 |
| 27 | 0.42 | 0.82 | 0.08 | 0.06 | 66.5 | 78.2 | 4.8 | 11.3 | 57 | 128 |
| **Mean** | **0.85** | **1.31** | **0.08** | **0.03** | **46.2** | **63.3** | **6.3** | **11.9** | **80** | **130** |
| Range | 0.34-2.05 | 0.60-5.46 | 0.06-0.16 | 0.01-0.06 | 18.8-86.0 | 38.4-92.6 | 1.6-11.3 | 6.8-26.4 | 43-128 | 114-149 |
| CD (0.05) | 0.329 | | 0.009 | | 7.70 | | 2.00 | | 7.82 | |
| SEm± | 0.113 | | 0.003 | | 2.67 | | 0.688 | | 2.69 | |

SI = Rainy season (before the closure of Thanneermukkom regulator)

SII = Summer season (after the closure of Thanneermukkom regulator)

The Mn content of the surface water was 0.20 ppm during rainy season and 0.19 ppm during summer. As per the above standards the concentration of Mn allowed is 0.20 ppm and 0.05 ppm for irrigation and drinking water, respectively. The Mn content of the irrigation water is approaching the limit and in future there is every chance for its increase, unless suitable management measures are adapted. In ground water Mn was not detected. In the study area Al was present only in minute quantities both in surface as well as in ground water. However, Even this concentration in ground water was above the maximum level prescribed by ISI (1991) for drinking water and hence is sufficient to cause health hazards. Heavy metals like Cd and Pb were not detected in surface and ground water. On the northern side of the regulator the concentra-tion of Fe, Mn and Al showed only marginal variation from that of southern side, evidently due to their low concentration in sea water.

Among the anions, sulphates, chlorides and nitrates were detected in surface water as well as in ground water. The mean value of chloride in surface water was 78 ppm during rainy season which increased to 169 ppm during summer. For ground water the corresponding values were 80 and 130 ppm, respectively. Unlike Na ions, the chloride ions neither influenced the physical properties of the soil nor are adsorbed by the soil. For this reason, the absolute chloride ion content has not found any importance as a general criterion in the evaluation of the quality of irrigation water. The WHO (1971) and ISI (1991) acceptable maximum for chloride content in drinking water is 200 ppm and the area falls within the safe limits. In terms of specific toxicity effect of chloride, the area faces the danger during summer season since the chloride content of surface water exceeded the critical limit of 142 ppm (Ayers, 1975). The lake water of Vembanad on either side of regulator exceeded the above permissible limits.

The area is also facing pollution due to accumulation of nitrates in waterways and canals, since large quantities of N fertiliser residues are released into the environment, from the rice fields through drainage water (Table 46). In ground water also N fertiliser residues were detected (Table 34). The mean value of $NO_3$-N during rainy season was 2.0 ppm which increased to 2.74 ppm during summer.

Table 34. Ammoniacal and nitrate N in ground water during different seasons (ppm)

| Padasekharam No. | $NH_4$-N | | $NO_3$-N | |
|---|---|---|---|---|
| | SI | SII | SI | SII |
| 1 | 2.0 | 3.2 | 2.5 | 4.3 |
| 2 | 1.2 | 2.0 | 1.8 | 5.2 |
| 3 | 1.8 | 2.8 | 3.1 | 3.8 |
| 4 | 1.8 | 2.9 | 2.3 | 2.0 |
| 5 | 0.5 | 0.8 | 4.0 | 3.2 |
| 6 | 3.2 | 2.0 | 0.6 | 0.4 |
| 7 | 1.0 | 1.6 | 1.3 | 1.5 |
| 8 | 1.4 | 2.0 | 0.8 | 1.5 |
| 9 | 1.0 | 2.0 | 5.0 | 4.2 |
| 10 | 2.0 | 3.1 | 1.2 | 3.2 |
| 11 | 1.0 | 2.7 | 1.5 | 2.5 |
| 12 | 0.5 | 1.9 | 0.3 | 2.5 |
| 13 | 0.8 | 1.3 | 0.6 | 2.0 |
| 14 | 0.3 | 0.8 | 1.8 | 3.2 |
| 15 | 1.2 | 1.5 | 2.2 | 3.0 |
| 16 | 2.0 | 2.0 | 3.8 | 3.9 |
| 17 | 1.2 | 2.0 | 4.4 | 4.0 |
| 18 | 0.5 | 1.0 | 2.0 | 2.2 |
| 19 | 0.4 | 0.8 | 1.5 | 1.0 |
| 20 | 0.8 | 1.3 | 1.8 | 1.2 |
| 21 | 1.0 | 1.1 | 2.2 | 2.5 |
| 22 | 1.2 | 2.5 | 2.5 | 3.3 |
| 23 | 1.5 | 1.7 | 1.9 | 2.5 |
| 24 | 1.3 | 1.5 | 2.0 | 2.5 |
| 25 | 1.1 | 1.2 | 1.3 | 3.2 |
| 26 | 1.0 | 1.5 | 1.2 | 3.0 |
| 27 | 1.8 | 2.5 | 2.0 | 2.5 |
| **Mean** | **1.24** | **1.84** | **2.00** | **2.74** |
| Range | 0.3-3.2 | 0.8-3.2 | 0.3-5.0 | 0.4-5.2 |
| CD(0.05) | 0.114 | | 0.172 | |
| SEm± | 0.056 | | 0.084 | |

SI = Rainy season (Before the closure of Thanneermukkom regulator)

SII = Summer season (After the closure of Thanneermukkom regulator)

For $NH_4$-N, the corresponding values were 1.24 and 1.84 ppm, respectively. The increase in concentration was evidently due to the release of N fertiliser residues through the drainage water from the punja rice fields. Both forms of N were below the critical levels suggested by WHO (1971) and ISI (1991).However, the danger from pollution of waterbodies by N fertiliser residues should be seriously looked into and suitable management measures advocated.

The $SO_4$-S content of surface water was 6.12 ppm during rainy season and it increased to 14.00 ppm during summer. For ground water the corresponding values were 6.3 and 11.9 ppm, respectively. As per the standards proposed by the National Academy of Sciences and the National Academy of Engineering (1972) the sulphate content should not exceed the permissible maximum of 67 ppm of $SO_4$-S in water. Both surface as well as ground water were within this limit. Even the lake water on either side of the regulator did not exceed the above limit.

Among the anions, chloride was the dominant one indicating most of the bases were present as chloride salts, though some quantity was present in sulphate form also (Fig 24). This was further confirmed from the correlation coefficients between EC and chloride ($0.817^{**}$) and with sulphate ($0.644^{**}$) in surface water (Table 35). Similar relationships were observed for ground water also (Table 36).

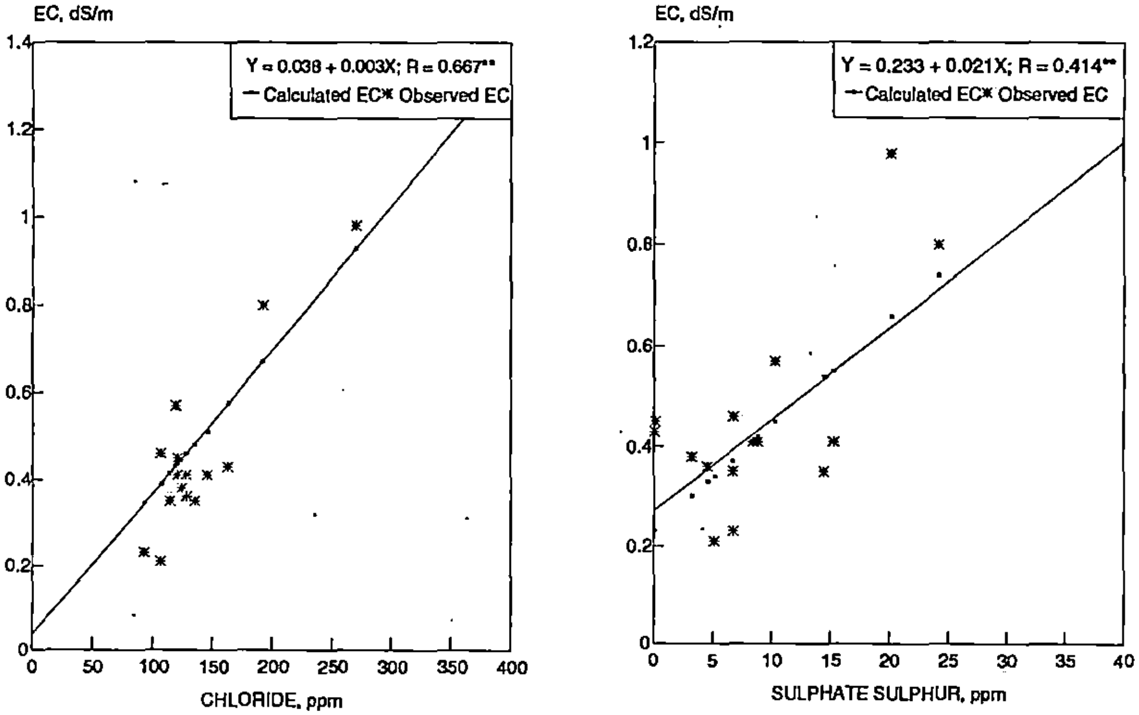


Fig 24. Relationship of EC to chloride and sulphate in water (R = Regression coefficient)

Table 35. Correlation matrix showing inter-relationships among quality attributes of surface water

| Characteristics | pH | EC | K | Na | Ca | Al | SO -S | $Cl^-$ |
|---|---|---|---|---|---|---|---|---|
| pH | 1.000 | | | | | | | |
| EC | -0.613$^{**}$ | 1.000 | | | | | | |
| K | -0.487$^{**}$ | 0.773$^{**}$ | 1.000 | | | | | |
| Na | -0.578$^{**}$ | 0.724$^{**}$ | 0.657$^{**}$ | 1.000 | | | | |
| Ca | -0.310 | 0.254 | 0.549$^{**}$ | 0.485$^{**}$ | 1.000 | | | |
| Al | -0.507$^{**}$ | 0.398$^{**}$ | 0.642$^{**}$ | 0.187 | 0.739$^{**}$ | 1.000 | | |
| SO -S | -0.596$^{**}$ | 0.644$^{**}$ | 0.682$^{**}$ | 0.592$^{**}$ | 0.428$^{**}$ | 0.472$^{*}$ | 1.000 | |
| Cl | -0.500$^{**}$ | 0.817$^{**}$ | 0.681$^{**}$ | 0.723$^{**}$ | 0.437$^{**}$ | 0.510$^{**}$ | 0.513$^{**}$ | 1.000 |

$^{*}$ Significant at 5% level $^{**}$ Significant at 1% level

Table 36. Correlation matrix showing inter-relationships among quality attributes of ground water

| Characteristics | pH | EC | K | Na | Ca | Al | SO -S | $Cl^-$ |
|---|---|---|---|---|---|---|---|---|
| pH | 1.000 | | | | | | | |
| EC | -0.406$^{**}$ | 1.000 | | | | | | |
| K | -0.453$^{**}$ | 0.389$^{*}$ | 1.000 | | | | | |
| Na | -0.426$^{**}$ | 0.425$^{*}$ | 0.543$^{**}$ | 1.000 | | | | |
| Ca | -0.380$^{*}$ | 0.371$^{*}$ | 0.488$^{**}$ | 0.427$^{*}$ | 1.000 | | | |
| Al | -0. 491$^{**}$ | 0.378$^{*}$ | 0.613 $^{**}$ | 0.411$^{*}$ | 0.651$^{**}$ | 1.000 | | |
| SO -S | -0.511$^{**}$ | 0.428$^{**}$ | 0.647 $^{**}$ | 0.536 $^{**}$ | 0.607 $^{**}$ | 0.472$^{*}$ | 1.000 | |
| Cl | -0.478$^{**}$ | 0.521$^{**}$ | 0.652$^{**}$ | 0.685$^{**}$ | 0.489$^{**}$ | 0.783$^{**}$ | 0.575$^{**}$ | 1.000 |

$^{*}$ Significant at 5% level $^{**}$ Significant at 1% level

In general, salinity is always associated with alkalinity due to dominance of carbonates and bicarbonates. Because of the dominance of chlorides and sulphates the contribution of salinity is unable to create any alkalinity due to the neutral nature of salts involved and the native acidity is never neutralised. This finally contribute to a situation which we refer as acid saline soils.

On evaluating the various toxic parameters persisting in the study area, it was observed that the area was subject to severe water pollution and its impact is reflected on various soil properties. The pH, SAR and Fe and Al contents of ground water exceeded the permissible limits for domestic purposes (ISI, 1991). In the case of surface water, SAR and $Cl^-$ content were far greater than the allowed maximum for irrigation water (Ayers, 1975). The Mn content of surface water is approaching the critical level for irrigation which may also contribute towards environmental contamination. Though the level of other nutrients in the surface water was within the limits permitted, it was sufficient to cause eutrophication as manifested by the luxurious growth of algae and other water weeds in canals and waterways leading to oxygen depletion and death of aquatic organisms. Apart from the above qualitative aspects, the entire Kuttanad is also facing severe pollution of water by the high level of coliform bacteria due to improper sanitation facilities (IDMR, 1989).

### B. Introduced toxic characteristics

Rice cultivation in Kuttanad region is characterised by the profuse use of fertilisers, pesticides and herbicides. Among the agrochemicals, only a part is taken up by the crop and rest will remain in the environment. Since the tract is traversed by a large number of waterways and canals the residues of agrochemicals may spread to the entire area within a short span of time. The closure of Thanneermukkom regulator from December to April, which is the major cultivation season of Kuttanad results in the stagnation of water with heavy load of fertiliser and pesticide residues. The indiscriminative use of agrochemicals may hamper the ecosystem in the long run, though some immediate benefits are obtained.

#### 1. Pesticide residues (Table 37)

Among the pesticides, organochlorine pesticides are highly persistent in the environment due to their chemical stability, low water solubility and low volatility. The major forms of chlorinated hydrocarbon pesticides identified in the area were ∝-HCH, γ-HCH and DDT (Fig 25 and Table 37).

In soil, the concentration of ∝-HCH ranged from 0.047 to 0.240 ppb during rainy season with a mean value of 0.162 ppb. During summer the mean value increased to 0.647 ppb (range 0.320-0.839 ppb). The increase was of about 4 times. The run-off from rice fields containing residues of pesticides, get accumulated in the region since the free drainage is restricted during summer by closing the regulator. In rainy season most of the applied pesticides are washed off by the rain water.

The concentration of ∝-HCH in water during rainy season ranged from 0.175 to 0.467 ppb with a mean value of 0.302 ppb. It increased to a range of 0.400 to 0.934 ppb with a mean of 0.631 ppb during summer. The concentration was greater in water compared to soil. The attributed reasons are that the pesticides applied during the current season might have remained in water itself since it require more time for its entry into soil layers. The prevention of water flow towards the sea results in accumulation of pesticide residues in the stagnating water and the reuse of this water further enhanced their concentration. The pesticides already entered into the soil complex might not have been fully extracted by the extractant used even though the recovery of the method was high in that soil.

The γ-HCH content was very low compared to the ∝-HCH in soil. The mean value of γ-HCH was 0.020 ppb (range 0.002-0.038 ppb) during rainy season. The values increased to a range of 0.028 to 0.062 ppb with a mean of 0.045 ppb during summer. Here also water showed higher concentration. The mean values were 0.126 and 0.173 ppb, during rainy and summer seasons, respectively. The higher concentrations of ∝-HCH and γ-HCH were observed in the sediments from Alleppey, compared to other parts of Kerala. The highest concentration was observed during the post monsoon period due to the run-off from rice fields (Balakrishnan and Ouseph, 1995).

The concentration of DDT was much higher in soil and water compared to HCH, either due to

Table 37. Residual concentration (ppb) of chlorinated hydrocarbon pesticides in soil and water during rainy and summer seasons

| Pada-sekharam No. | Soil | | | | | | Water | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | α-HCH | | γ-HCH | | DDT | | α-HCH | | γ-HCH | | DDT | |
| | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII | SI | SII |
| 1 | 0.047 | 0.320 | 0.013 | 0.028 | 0.05 | 0.05 | 0.258 | 0.526 | 0.104 | 0.140 | 0.02 | 0.05 |
| 2 | 0.052 | 0.339 | 0.012 | 0.029 | 0.20 | 0.98 | 0.232 | 0.561 | 0.100 | 0.158 | 0.01 | 0.19 |
| 3 | 0.160 | 0.527 | 0.018 | 0.037 | 2.71 | 7.20 | 0.360 | 0.672 | 0.106 | 0.142 | 1.82 | 3.10 |
| 4 | 0.135 | 0.511 | 0.021 | 0.056 | 3.84 | 7.43 | 0.258 | 0.618 | 0.121 | 0.151 | 0.95 | 2.34 |
| 5 | 0.098 | 0.480 | 0.011 | 0.030 | 0.02 | 0.02 | 0.316 | 0.621 | 0.105 | 0.138 | 0.01 | 0.01 |
| 6 | 0.056 | 0.406 | 0.016 | 0.032 | 2.92 | 6.31 | 0.336 | 0.716 | 0.112 | 0.146 | 0.16 | 2.41 |
| 7 | 0.220 | 0.780 | 0.031 | 0.056 | 11.92 | 16.42 | 0.426 | 0.791 | 0.210 | 0.248 | 4.41 | 6.87 |
| 8 | 0.190 | 0.721 | 0.031 | 0.058 | 0.64 | 2.31 | 0.376 | 0.816 | 0.180 | 0.251 | 0.06 | 0.10 |
| 9 | 0.212 | 0.764 | 0.038 | 0.062 | 0.18 | 1.80 | 0.391 | 0.834 | 0.110 | 0.262 | 0.05 | 0.07 |
| 10 | 0.166 | 0.600 | 0.025 | 0.056 | 8.71 | 12.65 | 0.296 | 0.684 | 0.141 | 0.196 | 3.65 | 5.08 |
| 11 | 0.240 | 0.818 | 0.009 | 0.036 | 0.10 | 0.12 | 0.318 | 0.764 | 0.042 | 0.101 | 0.01 | 0.01 |
| 12 | 0.200 | 0.720 | 0.012 | 0.041 | 7.90 | 12.45 | 0.416 | 0.934 | 0.072 | 0.124 | 2.35 | 4.72 |
| 13 | 0.234 | 0.800 | 0.036 | 0.059 | 0.08 | 0.10 | 0.386 | 0.870 | 0.091 | 0.138 | 0.04 | 0.04 |
| 14 | 0.218 | 0.786 | 0.029 | 0.058 | 0.70 | 1.46 | 0.346 | 0.732 | 0.168 | 0.202 | 0.12 | 0.46 |
| 15 | 0.110 | 0.576 | 0.002 | 0.037 | 2.34 | 4.21 | 0.259 | 0.226 | 0.132 | 0.186 | 0.56 | 0.61 |
| 16 | 0.162 | 0.680 | 0.010 | 0.029 | 1.01 | 0.82 | 0.181 | 0.400 | 0.125 | 0.138 | 0.10 | 0.11 |
| 17 | 0.151 | 0.603 | 0.012 | 0.028 | 7.00 | 8.26 | 0.268 | 0.501 | 0.146 | 0.192 | 1.80 | 2.41 |
| 18 | 0.096 | 0.520 | 0.018 | 0.040 | 0.20 | 0.43 | 0.175 | 0.564 | 0.132 | 0.181 | 0.03 | 0.07 |
| 19 | 0.143 | 0.618 | 0.007 | 0.038 | 12.63 | 17.80 | 0.284 | 0.501 | 0.116 | 0.210 | 3.96 | 6.08 |
| 20 | 0.126 | 0.635 | 0.012 | 0.046 | 1.24 | 4.21 | 0.176 | 0.325 | 0.103 | 0.186 | 0.16 | 0.85 |
| 21 | 0.130 | 0.612 | 0.012 | 0.036 | 4.60 | 1.38 | 0.240 | 0.445 | 0.161 | 0.165 | 1.08 | 0.21 |
| 22 | 0.234 | 0.800 | 0.036 | 0.062 | 2.81 | 4.20 | 0.316 | 0.816 | 0.164 | 0.196 | 0.37 | 1.25 |
| 23 | 0.208 | 0.821 | 0.029 | 0.056 | 6.35 | 12.46 | 0.208 | 0.519 | 0.132 | 0.152 | 1.28 | 3.61 |
| 24 | 0.189 | 0.786 | 0.021 | 0.053 | 14.21 | 20.60 | 0.467 | 0.721 | 0.151 | 0.186 | 3.79 | 10.34 |
| 25 | 0.220 | 0.751 | 0.019 | 0.048 | 6.04 | 14.62 | 0.380 | 0.696 | 0.120 | 0.151 | 1.00 | 4.65 |
| 26 | 0.216 | 0.839 | 0.033 | 0.059 | 10.41 | 17.83 | 0.252 | 0.604 | 0.148 | 0.167 | 3.76 | 7.44 |
| 27 | 0.160 | 0.660 | 0.128 | 0.062 | 8.30 | 10.85 | 0.245 | 0.585 | 0.106 | 0.161 | 2.89 | 4.60 |
| **Mean** | **0.162** | **0.647** | **0.020** | **0.045** | **4.34** | **6.92** | **0.302** | **0.631** | **0.126** | **0.173** | **1.28** | **2.51** |
| Range | 0.047-0.240 | 0.320-0.839 | 0.002-0.038 | 0.028-0.062 | 0.02-14.21 | 0.02-20.60 | 0.175-0.467 | 0.226-0.934 | 0.042-0.210 | 0.101-0.262 | 0.01-4.41 | 0.01-10.34 |
| CD (0.05) | 0.038 | | 0.023 | | 5.61 | | 0.047 | | 0.011 | | 3.15 | |
| SEm± | 0.013 | | 0.008 | | 1.93 | | 0.016 | | 0.004 | | 1.08 | |

SI = Rainy season (Before the closure of Thanneermukkom regulator)

SII = Summer season (After the ckosure of Thanneermukkom regulator)

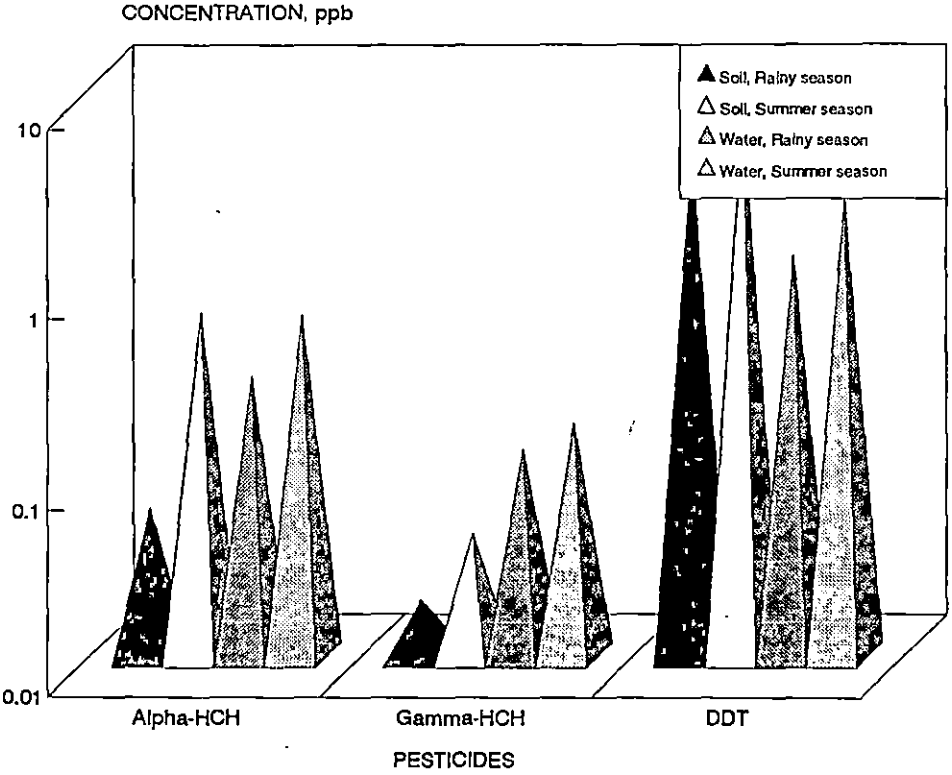


Fig 25. Residual concentration of chlorinated hydrocarbon pesticides in soil and water during different seasons

slower dissipation rate or application in large quantities. Its concentration in soil ranged from 0.02 to 14.21 ppb with a mean of 4.34 ppb during rainy season. During summer it further increased to a mean value of 6.92 ppb with a range of 0.10 to 20.60 ppb. The padasekharams showed large variation in residual concentration of DDT. The mean values for water during the above two seasons were 1.28 ppb (range 0.01-4.41 ppb) and 2.51 ppb (0.01 -10.34 ppb) of DDT, respectively. Though the use of this chemical for agricultural purposes was banned it was present in large quantities. The use of DDT for hygienic purposes may contribute towards its accumulation in soil and water. There has been some reports on the incidence of using DDT as a protectant for preservation of concentrated organic manures like bonemeal and it is likely that the use of such manures may contaminate the soil. IDMR (1989) also reported the toxic accumulation of DDT in water, sediments and organic tissue samples and the concentration was highest during the month of January near the Thanneermukkom regulator in the sediment (1 mg $l^{-1}$).

Organophosphorus compounds were detected only in traces in the area. This might be due to their rapid degradation in soil. The samples were collected 3 weeks before harvest. Hence the applied organophosphorus compounds might have got degraded and lost by that time.

As per the specifications of OECD (1986) and ISI (1991) the presence of even the traces of pesticides is not allowable in drinking water and water for domestic purposes. From this point of view, the water of the region is highly contaminated with chlorinated hydrocarbon pesticide residues.

The National Academy of Sciences and the National Academy of Engineering (1972) permit a maximum concentration of 50 ppb for DDT and 5 ppb for HCH in surface and ground water. According to Sebastin (1994) the acceptable maximum for pesticide residues in water with regards to the safety of aquatic lives is zero ppm. In the present context of greater environmental awareness, acceptability of ecofriendly farming and considering the ability of pesticides to accumulate and magnify in various organisms, the zero level of concentration of pesticide residues in water is the preferred criterion with regards to environmental safety. The chlorinated hydrocarbon residues recorded in soil and water even a month after the period of peak plant protection activities in Kuttanad were not negligible. In that context, the area is considered to be highly vulnerable to pesticide pollution posing serious health hazard to the people and mortality to aquatic organisms like fish as well as duck.

## 2. Fertiliser residues

*2.1. Nitrogen*: Nitrogen plays a major role among the plant nutrients. The average recovery of N under submerged condition is 40 per cent indicating that the extent of loss is much greater than the recovery (Savant and Datta, 1982). The losses of N take place by leaching, run-off, seepage, volatilization and denitrification depending upon the soil conditions, contributing towards environmental pollution. The peculiar hydrophysiography of the area favours the leaching loss of nitrogen leading to the pollution of waterways and canals.

In the study area, the farmers applied 45 kg N ha$^{-1}$ as factomphos (20:20) at the time of basal dressing i.e., 2-3 weeks after sowing. The mean value of $NH_4$-N in soil before fertiliser application was 133 ppm during additional crop season and the value increased to 136 ppm, 4-7 days after fertiliser application (Table 38) but before letting out the water. The mean values for $NO_2$-N + $NO_3$-N were 17.9 and 18.5 ppm, respectively, during the above two stages. Out of the added N, only a small portion was accounted in soil. A part of it might have been taken up by the crop and the rest might have remained in water or lost.

The $NH_4$-N content of water showed considerable increase due to basal application of N fertiliser (Table 39). The mean value increased from 6.65 to 11.86 ppm. The $NO_2$-N + $NO_3$-N also followed the same trend and the mean values were 4.91 and 6.70 ppm, respectively, before and after fertiliser application. The quantum of N held in standing water was considerably greater at this period, major part of which was likely to be lost through the drainage water and contaminated the waterways and canals in the area. The permissible maximum concentration for $NH_4$-N is 16 ppm in water and a concentration above this is lethal to the marine lives like fish and prawn (Sebastin, 1994). Based on this criterion the $NH_4$-N released from these padasekharams to the waterways or canals through drainage water did not create any problem to the marine lives. However, the padasekharams of Arpookkara village showed values near to the tolerance limit and in Chalakari padasekharam the values exceeded the limit. For $NO_3$-N, the permissible maximum is 20 ppm for the safe life of aquatic species (Sebastin, 1994) and for domestic uses it is 10 ppm (WHO, 1971; ISI, 1991 ). The study area recorded values below the critical levels.

Table 38. Ammoniacal N, nitrite + nitrate N and available P and K in soils during additional crop season 1993-94, ppm

| Padasekharam No. | $NH_4$-N | | | | $NO_2$-N + $NO_3$-N | | | | Available P | | Available K | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Basal | | Topdressing | | Basal | | Topdressing | | Basal | | Basal | | Topdressing | |
| | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 |
| 1 | 101 | 104 | 98 | 98 | 16.6 | 16.8 | 11.9 | 12.9 | 1.51 | 4.72 | 232 | 238 | 192 | 206 |
| 2 | 104 | 104 | 100 | 103 | 15.9 | 16.8 | 11.9 | 12.6 | 2.02 | 5.39 | 220 | 231 | 184 | 198 |
| 3 | 149 | 155 | 138 | 151 | 23.0 | 23.4 | 17.3 | 17.5 | 1.79 | 6.00 | 141 | 148 | 122 | 126 |
| 4 | 182 | 187 | 176 | 177 | 27.0 | 27.5 | 20.1 | 20.9 | 1.22 | 4.71 | 238 | 246 | 190 | 200 |
| 5 | 175 | 193 | 163 | 168 | 28.0 | 29.3 | 20.0 | 20.2 | 2.63 | 7.19 | 241 | 268 | 202 | 212 |
| 6 | 173 | 174 | 159 | 163 | 23.9 | 22.6 | 15.8 | 16.0 | 2.01 | 5.46 | 192 | 201 | 160 | 170 |
| 7 | 97 | 106 | 87 | 88 | 12.0 | 13.5 | 9.3 | 11.2 | 1.86 | 4.75 | 129 | 136 | 92 | 102 |
| 8 | 107 | 101 | 90 | 93 | 10.8 | 11.7 | 2.9 | 4.2 | 1.72 | 5.00 | 142 | 144 | 98 | 104 |
| 9 | 150 | 147 | 145 | 146 | 17.3 | 18.6 | 11.3 | 12.7 | 1.92 | 7.25 | 138 | 168 | 94 | 106 |
| 10 | 193 | 204 | 180 | 184 | 24.2 | 24.5 | 19.8 | 20.8 | 2.59 | 6.45 | 268 | 272 | 203 | 214 |
| 11 | 107 | 112 | 103 | 104 | 20.4 | 20.8 | 15.0 | 15.3 | 1.42 | 4.85 | 196 | 221 | 162 | 167 |
| 12 | 73 | 77 | 62 | 66 | 13.9 | 15.5 | 11.3 | 12.2 | 1.38 | 5.24 | 204 | 225 | 154 | 170 |
| 13 | 130 | 134 | 127 | 129 | 21.1 | 21.8 | 11.4 | 12.6 | 1.94 | 6.62 | 158 | 181 | 108 | 119 |
| 14 | 99 | 104 | 91 | 93 | 12.4 | 13.3 | 10.2 | 11.3 | 0.45 | 3.26 | 206 | 211 | 144 | 162 |
| 15 | 109 | 116 | 94 | 97 | 17.3 | 18.6 | 13.5 | 14.4 | 4.66 | 10.70 | 197 | 206 | 150 | 154 |
| 16 | 104 | 111 | 90 | 94 | 15.9 | 16.3 | 13.0 | 12.8 | 3.81 | 8.18 | 130 | 144 | 84 | 98 |
| 17 | 173 | 176 | 161 | 164 | 14.6 | 14.9 | 10.4 | 11.4 | 4.25 | 11.30 | 141 | 166 | 91 | 99 |
| 18 | 113 | 115 | 98 | 100 | 16.8 | 17.9 | 11.6 | 12.3 | 4.31 | 10.50 | 153 | 162 | 107 | 114 |
| 19 | 105 | 108 | 93 | 93 | 18.0 | 17.8 | 12.8 | 13.2 | 5.12 | 12.60 | 136 | 168 | 80 | 89 |
| 20 | 114 | 114 | 97 | 98 | 18.8 | 19.0 | 12.6 | 13.1 | 4.81 | 10.20 | 122 | 148 | 76 | 92 |
| 21 | 99 | 100 | 81 | 85 | 17.7 | 18.3 | 13.1 | 13.7 | 5.24 | 10.80 | 127 | 136 | 75 | 85 |
| 22 | 178 | 181 | 158 | 158 | 17.0 | 17.9 | 13.4 | 13.6 | 6.73 | 11.20 | 176 | 192 | 118 | 129 |
| 23 | 185 | 190 | 168 | 168 | 18.1 | 18.7 | 12.9 | 13.2 | 7.21 | 13.40 | 187 | 200 | 131 | 138 |
| 24 | 187 | 150 | 142 | 150 | 20.8 | 21.3 | 14.8 | 15.7 | 5.95 | 12.60 | 154 | 171 | 112 | 124 |
| 25 | 145 | 150 | 130 | 133 | 15.9 | 16.8 | 11.0 | 11.8 | 4.26 | 9.31 | 137 | 166 | 104 | 120 |
| 26 | 119 | 122 | 105 | 105 | 10.8 | 11.9 | 9.6 | 11.3 | 5.01 | 9.45 | 189 | 204 | 147 | 158 |
| 27 | 129 | 132 | 120 | 124 | 12.9 | 13.4 | 10.0 | 11.2 | 6.26 | 11.30 | 164 | 182 | 128 | 139 |
| **Mean** | **133** | **136** | **121** | **123** | **17.9** | **18.5** | **12.8** | **13.7** | **3.41** | **8.09** | **175** | **190** | **130** | **140** |
| Range | 73-193 | 77-204 | 62-180 | 66-184 | 10.8-28.0 | 11.7-29.3 | 2.9-20.1 | 4.2-20.9 | 0.45-7.21 | 3.26-13.4 | 122-268 | 136-272 | 75-203 | 85-214 |
| CD (0.05) | NS | | 1.12 | | 0.233 | | 0.196 | | 0.520 | | 3.57 | | 3.04 | |
| SEm± | 1.25 | | 0.386 | | 0.080 | | 0.068 | | 0.179 | | 1.23 | | 0.179 | |

T1 - Prior to fertilizer application

T2 - After fertilizer application

Table 39. Ammoniacal N, nitrite + nitrate N andd K in field water during additional crop season 1993-94, ppm

| Padasekharam No. | $NH_4$-N | | | | $NO_2$-N + $NO_3$-N | | | | K | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Basal | | Top dressing | | Basal | | Top dressing | | Basal | | Top dressing | |
| | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 |
| 1 | 8.43 | 15.02 | 4.55 | 6.18 | 4.90 | 7.0 | 2.31 | 3.49 | 1.81 | 3.20 | 1.26 | 3.29 |
| 2 | 7.20 | 13.18 | 4.90 | 5.75 | 2.87 | 5.35 | 1.80 | 2.86 | 1.72 | 4.15 | 1.57 | 4.33 |
| 3 | 12.31 | 16.75 | 5.21 | 7.26 | 3.15 | 5.38 | 1.05 | 2.65 | 3.25 | 5.45 | 3.00 | 5.15 |
| 4 | 9.14 | 15.94 | 4.28 | 7.08 | 6.42 | 7.84 | 2.31 | 3.48 | 1.05 | 4.37 | 1.15 | 2.79 |
| 5 | 5.28 | 10.38 | 3.15 | 6.72 | 3.46 | 6.30 | 2.48 | 3.61 | 3.20 | 6.82 | 3.00 | 5.16 |
| 6 | 3.46 | 8.97 | 2.10 | 4.39 | 4.28 | 6.75 | 3.30 | 4.39 | 2.65 | 4.93 | 2.42 | 3.44 |
| 7 | 2.38 | 8.24 | 1.85 | 3.90 | 2.50 | 3.05 | 2.01 | 2.15 | 5.21 | 6.76 | 3.16 | 6.27 |
| 8 | 4.01 | 14.01 | 2.80 | 4.46 | 3.56 | 4.34 | 1.96 | 2.46 | 4.64 | 7.31 | 2.78 | 3.79 |
| 9 | 3.85 | 10.46 | 2.46 | 4.05 | 6.34 | 7.30 | 4.31 | 5.15 | 2.85 | 6.89 | 2.64 | 4.26 |
| 10 | 12.00 | 17.31 | 6.38 | 9.31 | 4.49 | 6.25 | 4.79 | 5.35 | 3.21 | 6.36 | 2.49 | 4.67 |
| 11 | 7.33 | 10.13 | 3.50 | 5.75 | 6.21 | 7.91 | 2.31 | 4.16 | 4.38 | 7.84 | 3.11 | 5.51 |
| 12 | 6.48 | 10.38 | 3.85 | 5.39 | 3.18 | 4.30 | 2.06 | 3.08 | 2.47 | 7.25 | 2.06 | 5.08 |
| 13 | 6.73 | 12.39 | 3.16 | 6.04 | 3.34 | 5.13 | 2.16 | 3.70 | 3.93 | 8.18 | 1.86 | 4.00 |
| 14 | 5.39 | 11.48 | 3.50 | 5.88 | 2.50 | 5.20 | 2.09 | 3.66 | 8.28 | 10.34 | 3.14 | 5.23 |
| 15 | 9.16 | 15.40 | 4.76 | 7.44 | 8.05 | 9.45 | 3.28 | 4.38 | 10.0 | 14.45 | 3.21 | 5.23 |
| 16 | 5.42 | 10.60 | 2.94 | 5.38 | 7.31 | 7.85 | 1.45 | 2.90 | 9.42 | 11.64 | 2.89 | 5.10 |
| 17 | 7.36 | 11.41 | 3.58 | 6.78 | 8.41 | 9.38 | 2.31 | 3.54 | 7.20 | 9.35 | 3.24 | 6.37 |
| 18 | 8.12 | 10.28 | 6.40 | 8.36 | 7.28 | 9.41 | 3.76 | 4.91 | 4.86 | 7.94 | 1.26 | 3.78 |
| 19 | 7.30 | 11.38 | 4.28 | 6.15 | 4.39 | 7.06 | 2.11 | 3.76 | 5.33 | 8.38 | 1.78 | 3.91 |
| 20 | 4.32 | 8.91 | 3.21 | 5.01 | 3.28 | 5.39 | 1.06 | 1.79 | 2.14 | 4.68 | 2.01 | 3.55 |
| 21 | 3.80 | 7.74 | 3.08 | 5.46 | 3.16 | 6.20 | 2.06 | 3.38 | 3.10 | 5.00 | 2.29 | 4.05 |
| 22 | 7.16 | 11.41 | 4.13 | 6.09 | 6.25 | 8.24 | 3.14 | 4.20 | 3.10 | 5.87 | 2.40 | 3.94 |
| 23 | 6.12 | 12.36 | 3.45 | 5.93 | 5.98 | 6.91 | 2.66 | 3.70 | 2.89 | 4.13 | 2.27 | 4.27 |
| 24 | 6.00 | 11.12 | 4.23 | 6.18 | 5.05 | 6.78 | 2.46 | 2.96 | 4.38 | 6.98 | 3.13 | 4.78 |
| 25 | 7.13 | 12.34 | 4.00 | 6.06 | 5.19 | 7.25 | 3.10 | 4.75 | 3.35 | 5.62 | 2.14 | 4.20 |
| 26 | 7.40 | 11.68 | 3.85 | 5.93 | 5.63 | 6.90 | 2.74 | 3.81 | 4.22 | 7.30 | 2.27 | 3.91 |
| 27 | 6.34 | 10.30 | 3.66 | 6.71 | 5.25 | 7.18 | 1.91 | 2.94 | 3.87 | 6.28 | 1.78 | 3.28 |
| **Mean** | **6.65** | **11.86** | **3.82** | **6.06** | **4.91** | **6.70** | **2.50** | **3.60** | **4.17** | **6.94** | **2.38** | **4.42** |
| Range | 2.38-12.31 | 7.74-16.75 | 1.85-6.40 | 3.90-9.31 | 2.50-8.41 | 3.05-9.45 | 1.05-4.79 | 1.79-5.35 | 1.05-9.42 | 3.20-14.45 | 1.15-3.24 | 2.79-6.37 |
| CD (0.05) | 0.967 | | 0.235 | | 0.290 | | 0.156 | | 0.359 | | 0.218 | |
| SEm± | 0.333 | | 0.081 | | 0.099 | | 0.054 | | 0.124 | | 0.075 | |

T1 - Prior to fertilizer application; T2 - After fertilizer application

Table 40. Ammoniacal N, nitrite + nitrate N and available P and K in soils (ppm) during punja season 1993-94

| Padasekharam No. | $NH_4$-N | | | | $NO_2$-N + $NO_3$-N | | | | Available P | | Available K | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Basal | | Top dressing | | Basal | | Top dressing | | Basal | | Basal | | Top dressing | |
| | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 |
| 1 | 82.5 | 85.3 | 80.4 | 81.3 | 15.8 | 16.5 | 13.0 | 13.6 | 1.62 | 4.51 | 218 | 236 | 152 | 170 |
| 2 | 78.3 | 79.4 | 69.7 | 74.5 | 17.6 | 18.1 | 13.9 | 14.3 | 2.00 | 5.14 | 221 | 224 | 164 | 174 |
| 3 | 104.6 | 108.3 | 92.3 | 96.2 | 15.8 | 16.7 | 14.1 | 14.8 | 1.61 | 3.82 | 156 | 171 | 132 | 140 |
| 4 | 92.4 | 93.2 | 81.3 | 84.2 | 18.1 | 19.2 | 13.6 | 14.8 | 1.10 | 3.46 | 228 | 230 | 108 | 111 |
| 5 | 70.6 | 77.7 | 74.1 | 76.5 | 18.9 | 19.3 | 15.1 | 16.4 | 2.01 | 3.91 | 232 | 244 | 178 | 192 |
| 6 | 76.3 | 80.3 | 70.5 | 77.7 | 17.2 | 17.5 | 14.9 | 15.3 | 1.71 | 3.28 | 185 | 198 | 139 | 141 |
| 7 | 77.5 | 82.7 | 72.3 | 75.9 | 16.1 | 16.6 | 14.0 | 14.3 | 1.42 | 4.41 | 141 | 160 | 140 | 158 |
| 8 | 70.8 | 76.6 | 66.4 | 73.1 | 17.1 | 17.5 | 15.4 | 16.7 | 1.50 | 4.21 | 128 | 141 | 112 | 124 |
| 9 | 74.3 | 79.3 | 70.2 | 74.2 | 15.2 | 16.2 | 15.8 | 16.7 | 1.71 | 3.78 | 130 | 142 | 126 | 141 |
| 10 | 91.4 | 93.9 | 81.6 | 85.2 | 18.4 | 19.3 | 16.7 | 17.6 | 2.05 | 5.15 | 274 | 286 | 219 | 239 |
| 11 | 80.3 | 83.5 | 72.7 | 77.0 | 17.6 | 18.0 | 14.9 | 16.1 | 1.27 | 3.46 | 186 | 193 | 152 | 157 |
| 12 | 77.9 | 79.4 | 71.3 | 74.4 | 13.7 | 13.9 | 14.1 | 15.0 | 1.16 | 3.70 | 200 | 208 | 174 | 178 |
| 13 | 90.2 | 92.3 | 80.3 | 85.8 | 15.9 | 16.7 | 15.6 | 16.0 | 1.45 | 3.71 | 155 | 176 | 131 | 152 |
| 14 | 78.3 | 80.4 | 72.1 | 76.3 | 16.7 | 17.9 | 16.2 | 16.7 | 0.67 | 0.96 | 191 | 200 | 144 | 153 |
| 15 | 68.4 | 72.3 | 65.1 | 70.3 | 15.1 | 16.1 | 12.7 | 13.4 | 3.25 | 8.31 | 192 | 206 | 166 | 181 |
| 16 | 71.3 | 75.4 | 66.2 | 70.8 | 15.6 | 16.7 | 12.1 | 12.7 | 3.40 | 8.28 | 134 | 139 | 131 | 144 |
| 17 | 65.5 | 68.7 | 60.5 | 64.1 | 15.0 | 16.1 | 13.1 | 13.5 | 3.40 | 8.50 | 132 | 144 | 128 | 136 |
| 18 | 70.2 | 72.7 | 66.4 | 70.1 | 15.1 | 16.2 | 12.4 | 13.7 | 3.51 | 9.06 | 150 | 168 | 142 | 155 |
| 19 | 68.9 | 70.9 | 62.4 | 67.3 | 16.7 | 17.6. | 14.6 | 15.1 | 4.21 | 9.26 | 125 | 130 | 110 | 131 |
| 20 | 70.3 | 74.5 | 65.9 | 68.4 | 16.9 | 17.8 | 13.1 | 13.8 | 4.23 | 9.75 | 134 | 139 | 120 | 136 |
| 21 | 63.7 | 68.1 | 60.1 | 64.3 | 16.5 | 16.8 | 15.1 | 16.2 | 5.18 | 10.00 | 107 | 118 | 94 | 105 |
| 22 | 73.5 | 75.6 | 70.2 | 74.3 | 18.1 | 18.9 | 15.7 | 16.6 | 6.14 | 10.38 | 154 | 170 | 134 | 148 |
| 23 | 77.9 | 79.1 | 70.1 | 75.2 | 17.7 | 18.3 | 15.1 | 15.8 | 6.65 | 11.01 | 171 | 175 | 153 | 169 |
| 24 | 69.2 | 74.2 | 64.4 | 66.3 | 18.1 | 18.8 | 17.1 | 17.9 | 5.02 | 9.45 | 162 | 184 | 136 | 141 |
| 25 | 72.5 | 73.4 | 68.6 | 72.2 | 18.6 | 19.8 | 17.6 | 18.7 | 3.85 | 8.61 | 130 | 145 | 116 | 121 |
| 26 | 92.4 | 95.8 | 82.5 | 87.3 | 16.7 | 17.4 | 14.6 | 15.4 | 4.02 | 8.72 | 168 | 181 | 144 | 162 |
| 27 | 90.4 | 94.8 | 83.4 | 87.6 | 18.6 | 19.8 | 17.6 | 18.7 | 4.13 | 9.01 | 164 | 182 | 135 | 153 |
| **Mean** | **77.7** | **81.0** | **71.9** | **74.8** | **16.7** | **17.4** | **14.6** | **15.4** | **2.90** | **6.44** | **169** | **186** | **140** | **152** |
| Range | 63.7-104.6 | 68.1-108.3 | 60.5-92.3 | 64.1-96.2 | 13.7-18.9 | 13.9-19.8 | 12.1-17.6 | 12.7-18.7 | 0.67-6.65 | 0.96-11.01 | 107-274 | 118-286 | 94-219 | 105-239 |
| CD (0.05) | 0 629 | | 2.46. | | 0.125 | | 0.125 | | 0.568 | | 2.13 | | 2.28 | |
| SEm± | 0.217 | | 0.847 | | 0.043 | | 0.043 | | 0.196 | | 0.732 | | 0.785 | |

T1 - Prior to fertilizer application; T2 - After fertilizer application

Table 41. Ammoniacal N, nitrite+nitrate N and K in field water (ppm) during punja season 1993-94

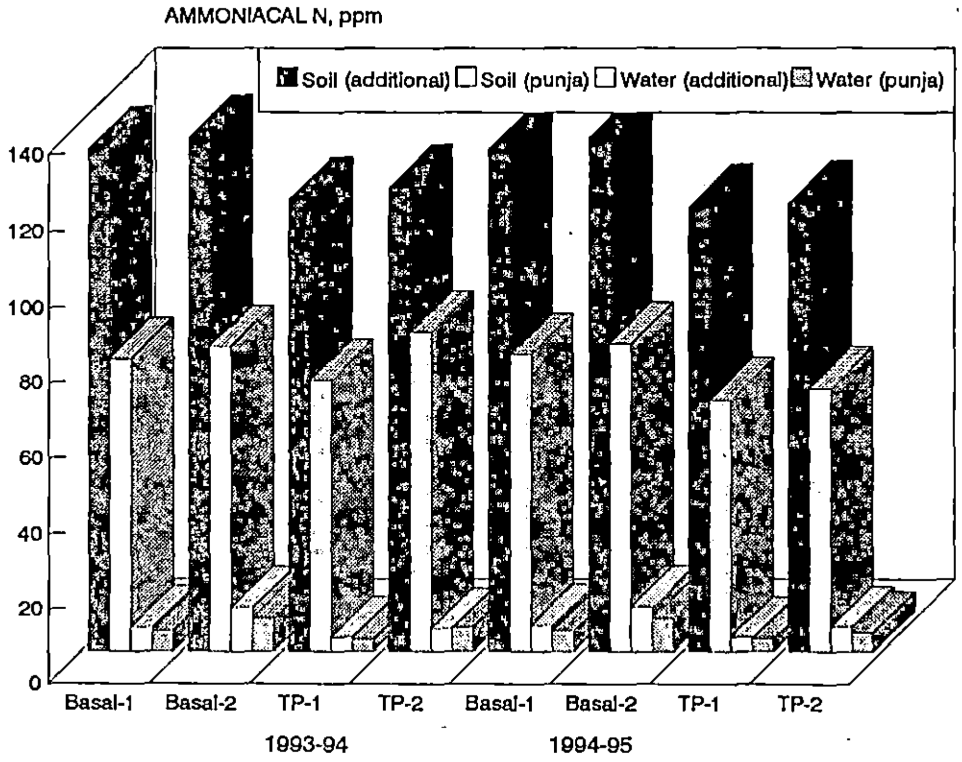
| Pada-sekharam No. | $NH_4$-N | | | | $NO_2$-N + $NO_3$-N | | | | K | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Basal | | Topdressing | | Basal | | Topdressing | | Basal | | Topdressing | |
| | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 |
| 1 | 4.20 | 7.36 | 3.82 | 6.14 | 5.27 | 7.28 | 3.72 | 4.30 | 2.81 | 4.60 | 1.72 | 3.84 |
| 2 | 6.11 | 9.80 | 3.95 | 5.99 | 3.51 | 6.26 | 2.94 | 3.85 | 3.24 | 5.28 | 2.14 | 4.72 |
| 3 | 8.35 | 10.20 | 4.66 | 6.82 | 3.75 | 6.18 | 1.78 | 2.25 | 4.45 | 6.15 | 2.94 | 4.92 |
| 4 | 8.02 | 10.45 | 5.32 | 7.91 | 6.32 | 9.09 | 4.32 | 4.50 | 6.06 | 7.94 | 3.17 | 5.31 |
| 5 | 5.14 | 8.35 | 3.14 | 6.48 | 4.14 | 8.10 | 2.10 | 2.62 | 5.24 | 7.01 | 3.28 | 5.67 |
| 6 | 4.12 | 8.07 | 2.06 | 6.04 | 4.50 | 8.06 | 2.65 | 3.06 | 3.72 | 5.12 | 1.72 | 4.35 |
| 7 | 3.16 | 6.82 | 2.18 | 4.87 | 3.21 | 5.87 | 1.01 | 1.78 | 2.65 | 3.86 | 1.89 | 4.25 |
| 8 | 3.71 | 7.50 | 2.35 | 6.39 | 3.76 | 6.34 | 1.52 | 2.46 | 2.14 | 2.91 | 2.01 | 4.04 |
| 9 | 3.25 | 7.85 | 1.81 | 5.06 | 5.84 | 7.95 | 3.21 | 4.81 | 2.88 | 3.57 | 2.04 | 4.58 |
| 10 | 8.96 | 12.31 | 5.78 | 8.94 | 4.05 | 8.96 | 2.16 | 3.62 | 3.53 | 4.43 | 1.96 | 3.97 |
| 11 | 6.40 | 9.28 | 4.74 | 8.76 | 6.28 | 9.37 | 3.72 | 4.96 | 4.32 | 5.18 | 2.74 | 3.98 |
| 12 | 5.28 | 8.93 | 3.24 | 7.14 | 4.20 | 6.85 | 1.86 | 3.20 | 4.05 | 6.07 | 2.58 | 5.07 |
| 13 | 4.31 | 8.30 | 2.95 | 5.80 | 3.15 | 6.90 | 1.52 | 2.82 | 3.26 | 7.95 | 1.08 | 3.46 |
| 14 | 4.08 | 8.18 | 2.86 | 6.16 | 2.77 | 5.81 | 1.70 | 2.97 | 3.05 | 5.19 | 1.57 | 4.02 |
| 15 | 7.20 | 10.26 | 3.79 | 7.41 | 7.68 | 10.23 | 4.26 | 5.38 | 3.80 | 4.65 | 2.64 | 5.72 |
| 16 | 5.17 | 8.71 | 2.46 | 5.96 | 7.55 | 10.98 | 5.21 | 5.86 | 4.21 | 5.04 | 2.28 | 4.94 |
| 17 | 6.33 | 9.38 | 3.38 | 7.05 | 8.89 | 10.96 | 5.16 | 6.96 | 3.65 | 5.48 | 1.66 | 4.02 |
| 18 | 6.78 | 9.14 | 3.91 | 7.81 | 8.08 | 10.72 | 4.92 | 5.98 | 3.05 | 5.09 | 2.07 | 3.87 |
| 19 | 6.70 | 9.95 | 4.20 | 7.92 | 4.18 | 6.97 | 2.35 | 4.10 | 3.16 | 5.87 | 1.74 | 3.95 |
| 20 | 4.10 | 10.75 | 2.65 | 6.28 | 4.20 | 8.31 | 2.04 | 3.07 | 1.80 | 4.06 | 1.72 | 2.98 |
| 21 | 3.86 | 6.79 | 1.73 | 4.16 | 4.25 | 7.62 | 2.38 | 3.94 | 2.42 | 4.12 | 2.04 | 4.05 |
| 22 | 6.05 | 9.68 | 3.08 | 6.79 | 7.16 | 9.19 | 3.45 | 4.26 | 3.62 | 5.92 | 2.78 | 4.64 |
| 23 | 5.32 | 9.06 | 2.94 | 6.13 | 6.28 | 7.86 | 3.50 | 4.71 | 4.43 | 5.87 | 3.14 | 5.35 |
| 24 | 4.86 | 8.39 | 2.09 | 5.64 | 5.65 | 7.96 | 3.08 | 4.94 | 3.85 | 6.04 | 2.94 | 5.08 |
| 25 | 6.15 | 10.42 | 3.14 | 6.95 | 5.01 | 7.75 | 2.87 | 3.80 | 4.40 | 6.72 | 3.18 | 6.94 |
| 26 | 6.32 | 9.87 | 3.54 | 7.06 | 5.48 | 8.32 | 3.56 | 4.67 | 3.82 | 5.18 | 2.04 | 5.65 |
| 27 | 6.10 | 10.07 | 3.18 | 6.36 | 6.35 | 8.97 | 3.15 | 4.50 | 3.75 | 5.43 | 2.12 | 5.07 |
| **Mean** | **5.56** | **9.11** | **3.29** | **6.59** | **5.24** | **8.11** | **2.96** | **4.05** | **3.61** | **5.36** | **2.27** | **4.61** |
| Range | 3.16-8.96 | 6.82-12.31 | 1.73-5.78 | 4.16-8.94 | 2.77-8.89 | 5.81-10.98 | 1.01-5.21 | 1.78-6.96 | 1.80-6.06 | 2.91-7.95 | 1.08-3.28 | 2.98-6.94 |
| CD (0.05) | 0.276 | | 0.234 | | 0.291 | | 0.175 | | 0.328 | | 0.319 | |
| SEm± | 0.095 | | 0.080 | | 0.100 | | 0.060 | | 0.110 | | 0.077 | |

T1 - Prior to fertilizer application; T2 - After fertilizer application

At the time of topdressing (45 kg N $ha^{-1}$ as urea) the value of $NH_4$-N decreased further to 121 ppm, evidently due to crop uptake and other type of losses (Table 38). The mean value increased to 123 ppm, 4-7 days after fertiliser application. The above value was lower compared to the basal application of fertiliser. The uptake might be greater during this stage since the crop is well established and the root density will be high resulting faster uptake of nutrients.

The mean value of $NO_2$-N + $NO_3$-N of soil before topdressing was 12.8 ppm and after it, the value increased to 13.7 ppm (Table 38). Here also soil accounted only a small portion of applied N. However, the amount of $NO_3$-N found in a continuously flooded soil is insignificant because of its high instability. The $NO_2$-N + $NO_3$-N exist in the surface oxidised layer, rice rhizosphere and flood water in a continuously submerged rice field. Their movement in response to the concentration gradient results in their loss by denitrification (Savant and Datta, 1982).

The $NH_4$-N and $NO_2$-N + $NO_3$-N contents of water were lower at the time of topdressing, compared to the basal application due to better crop uptake (Table 39). The mean value of $NH_4$-N before topdressing was 3.82 ppm which increased to 6.06 ppm after topdressing

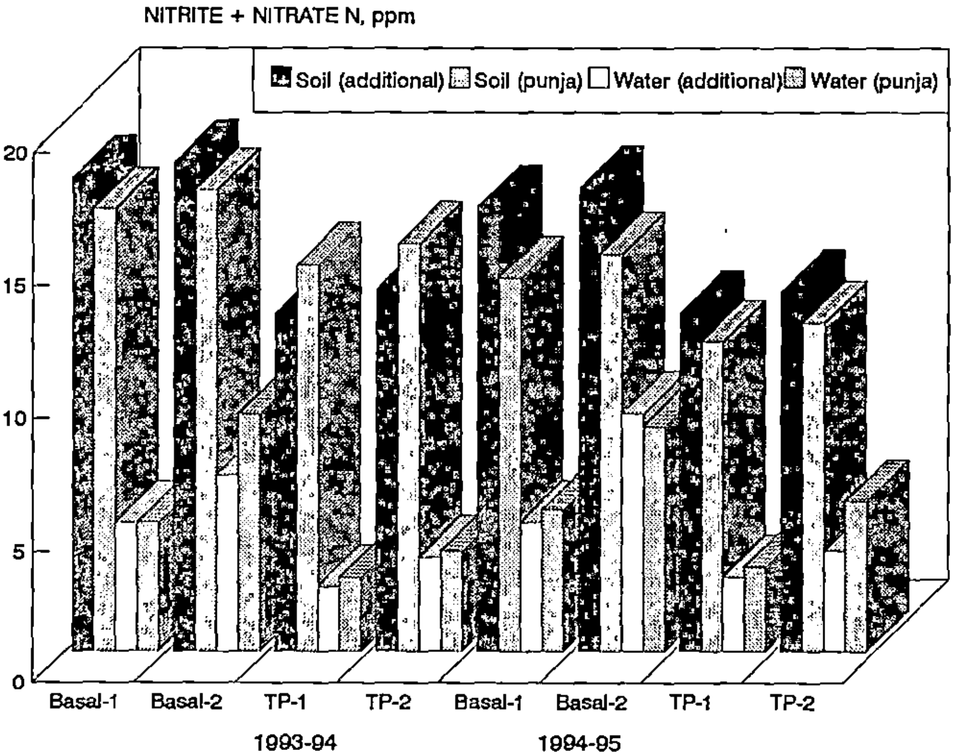


(TP - Topdressing; 1 - prior to and 2 - after fertiliser application

Fig 26. $NH_4$-N concentration in soil and water during additional and punja crop seasons of 1993-94 and 1994-95 in water. The corresponding values for $NO_2$-N + $NO_3$-N were 2.50 and 3.60 ppm respectively. This was also within the maximum permissible limits. However, the contribution towards environmental contamination by different forms of N is not negligible (Fig 26 and Fig 27).

During punja season, 1993-94 also the same trend was observed (Table 40) but the values of $NH_4$-N in soil were reduced considerably, evidently due to better aeration which would have resulted in the mineralisation of ammonium to nitrate. The mean value before basal dressing was 77.7 ppm which increased to 81.0 ppm after it. For $NO_2$-N + $NO_3$-N, not much variation was observed and this indicated the possibility of greater loss of N by denitrification during summer. The $NH_4$-N content of water also decreased during punja season, while $NO_2$-N + $NO_3$-N showed an increase during the same period (Table 41) evidently due to better oxidation and accumulation in water.

At the time of topdressing the mean value of $NH_4$-N in soil further decreased to 71.9 ppm. After topdressing the value increased to 74.8 ppm. For $NO_2$-N + $NO_3$-N, the corresponding values were 14.6 and 15.4 ppm, respectively. In water, $NH_4$-N content did not show much variation from that of additional crop season, 1993-94. However, $NO_2$-N + $NO_3$-N showed a marginal increase during that period.



(TP - Topdressing; 1 - prior to and 2 - after fertiliser application

Fig 27. $NO_2$-N + $NO_3$-N concentration in soil and water during additional and punja crop seasons of 1993-94 and 1994-95

The same trend as that of 1993-94 was observed during 1994-95 also with regard to content of $NH_4$-N and $NO_2$-N + $NO_3$-N before and after fertiliser application (Tables 42, 43,

Table 42. Ammoniacal N, nitrite + nitrate N and K in soils (ppm) during additional crop season 1994-95

| Pada-sekharam No. | $NH_4$-N | | | | $NO_2$-N + $NO_3$-N | | | | Available P | | Available K | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Basal | | Topdressing | | Basal | | Topdressing | | Basal | | Basal | | Topdressing | |
| | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 |
| 1 | 108 | 111 | 96 | 100 | 16.0 | 16.7 | 12.6 | 13.7 | 2.51 | 6.31 | 218 | 228 | 187 | 199 |
| 2 | 112 | 117 | 105 | 107 | 16.3 | 16.8 | 13.1 | 14.4 | 2.03 | 5.72 | 220 | 232 | 182 | 192 |
| 3 | 156 | 160 | 123 | 126 | 20.4 | 20.8 | 17.2 | 17.8 | 2.15 | 5.94 | 151 | 174 | 161 | 177 |
| 4 | 172 | 176 | 156 | 159 | 24.6 | 25.6 | 18.6 | 19.3 | 1.51 | 4.75 | 242 | 250 | 191 | 199 |
| 5 | 178 | 184 | 170 | 171 | 25.3 | 26.1 | 18.8 | 19.5 | 2.32 | 6.42 | 240 | 255 | 188 | 200 |
| 6 | 178 | 183 | 165 | 169 | 22.3 | 23.2 | 17.5 | 18.1 | 1.91 | 5.21 | 184 | 189 | 151 | 161 |
| 7 | 100 | 104 | 90 | 92 | 13.2 | 13.9 | 10.0 | 11.1 | 1.96 | 5.36 | 131 | 142 | 97 | 103 |
| 8 | 94 | 96 | 84 | 87 | 9.9 | 10.6 | 9.3 | 10.0 | 1.63 | 4.79 | 152 | 164 | 98 | 108 |
| 9 | 153 | 156 | 134 | 138 | 15.1 | 15.7 | 12.6 | 13.3 | 2.65 | 6.05 | 132 | 149 | 90 | 104 |
| 10 | 174 | 178 | 138 | 141 | 22.6 | 23.4 | 17.9 | 18.4 | 2.42 | 5.79 | 260 | 267 | 206 | 216 |
| 11 | 100 | 102 | 95 | 96 | 18.9 | 19.7 | 13.3 | 13.9 | 1.40 | 5.21 | 190 | 202 | 151 | 164 |
| 12 | 62 | 66 | 60 | 64 | 13.2 | 14.2 | 9.7 | 10.3 | 1.52 | 4.78 | 192 | 197 | 156 | 170 |
| 13 | 128 | 130 | 111 | 114 | 20.1 | 21.1 | 13.1 | 14.2 | 1.92 | 4.21 | 161 | 171 | 132 | 144 |
| 14 | 107 | 110 | 94 | 97 | 12.9 | 13.8 | 8.1 | 9.1 | 0.80 | 3.92 | 200 | 212 | 158 | 165 |
| 15 | 105 | 109 | 93 | 96 | 15.7 | 16.4 | 11.6 | 11.9 | 5.12 | 9.07 | 192 | 203 | 161 | 170 |
| 16 | 104 | 110 | 94 | 97 | 15.1 | 16.0 | 10.6 | 11.7 | 3.78 | 7.46 | 141 | 160 | 114 | 128 |
| 17 | 170 | 175 | 155 | 158 | 12.8 | 12.7 | 9.8 | 11.0 | 4.56 | 9.98 | 144 | 158 | 108 | 120 |
| 18 | 121 | 122 | 105 | 107 | 16.1 | 16.7 | 11.2 | 11.7 | 4.12 | 9.72 | 150 | 164 | 112 | 127 |
| 19 | 108 | 110 | 94 | 95 | 17.0 | 17.4 | 11.6 | 12.1 | 5.07 | 10.15 | 135 | 151 | 94 | 102 |
| 20 | 120 | 122 | 105 | 107 | 17.6 | 18.4 | 12.3 | 13.3 | 4.02 | 9.32 | 127 | 134 | 88 | 100 |
| 21 | 97 | 100 | 90 | 93 | 16.1 | 16.7 | 11.4 | 12.0 | 5.20 | 9.85 | 126 | 148 | 91 | 109 |
| 22 | 169 | 172 | 151 | 157 | 15.0 | 16.0 | 12.8 | 13.6 | 7.01 | 10.75 | 180 | 192 | 151 | 164 |
| 23 | 184 | 187 | 163 | 166 | 16.6 | 17.2 | 13.1 | 13.9 | 7.11 | 11.20 | 204 | 219 | 179 | 192 |
| 24 | 198 | 199 | 168 | 171 | 18.2 | 19.1 | 14.7 | 15.0 | 6.28 | 9.71 | 182 | 200 | 166 | 181 |
| 25 | 152 | 155 | 137 | 138 | 15.0 | 16.0 | 12.5 | 13.5 | 4.31 | 9.82 | 171 | 190 | 158 | 174 |
| 26 | 122 | 126 | 109 | 111 | 13.1 | 13.9 | 10.3 | 11.2 | 5.00 | 9.75 | 201 | 218 | 174 | 186 |
| 27 | 118 | 120 | 99. | 103 | 12.8 | 13.7 | 9.7 | 10.7 | 6.18 | 10.3 | 192 | 205 | 181 | 196 |
| **Mean** | **133** | **136** | **118** | **119** | **16.8** | **17.5** | **12.8** | **13.6** | **3.50** | **7.46** | **179** | **191** | **145** | **157** |
| Range | 62-198 | 66-199 | 60-170 | 64-171 | 9.9-25.3 | 10.6-26.1 | 8.1-18.8 | 9.1-19.5 | 0.80-7.11 | 3.92-11.2 | 126-260 | 142-267 | 88-206 | 100-216 |
| CD (0.05) | 0.570 | | NS | | 0.089 | | 0.103 | | 0.334 | | 3.27 | | 1.44 | |
| SEm± | 0.196 | | 2.60 | | 0.031 | | 0.035 | | 0.115 | | 1.12 | | 0.496 | |

T1 - Prior to fertilizer application

T2 - After fertilizer application

Table 43. Ammoniacal N, nitrite + nitrate N and K in field water (ppm) during additional crop season 1994-95

| Pada-sekharam No. | $NH_4$-N | | | | $NO_2$-N + $NO_3$-N | | | | K | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Basal | | Topdressing | | Basal | | Topdressing | | Basal | | Topdressing | |
| | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 |
| 1 | 8.01 | 16.02 | 6.21 | 7.38 | 3.82 | 7.55 | 2.51 | 3.62 | 2.05 | 6.28 | 1.72 | 4.01 |
| 2 | 9.26 | 16.41 | 5.78 | 7.25 | 3.26 | 7.28 | 2.25 | 3.15 | 1.92 | 5.97 | 1.61 | 3.72 |
| 3 | 10.87 | 15.92 | 6.39 | 8.14 | 3.15 | 6.45 | 2.18 | 3.79 | 2.86 | 5.72 | 1.82 | 3.91 |
| 4 | 9.07 | 16.48 | 4.21 | 6.39 | 6.45 | 9.08 | 4.26 | 4.82 | 1.05 | 4.32 | 0.95 | 2.85 |
| 5 | 6.20 | 10.76 | 2.75 | 5.75 | 3.72 | 6.86 | 1.82 | 2.16 | 2.82 | 6.43 | 2.15 | 4.62 |
| 6 | 4.41 | 9.35 | 2.02 | 5.38 | 4.10 | 7.16 | 2.06 | 2.75 | 2.75 | 6.08 | 2.12 | 4.73 |
| 7 | 2.31 | 8.32 | 1.31 | 5.05 | 2.81 | 6.35 | 1.21 | 2.05 | 5.11 | 9.25 | 3.32 | 5.47 |
| 8 | 3.85 | 8.75 | 1.58 | 4.28 | 3.26 | 7.91 | 1.86 | 2.62 | 4.56 | 9.08 | 2.41 | 5.92 |
| 9 | 3.62 | 8.60 | 1.62 | 4.16 | 6.01 | 10.32 | 2.32 | 2.82 | 3.05 | 8.16 | 2.15 | 4.87 |
| 10 | 10.40 | 16.49 | 4.32 | 7.30 | 4.30 | 8.95 | 1.89 | 2.91 | 3.38 | 8.21 | 2.20 | 4.38 |
| 11 | 7.53 | 14.32 | 3.25 | 6.58 | 6.00 | 10.40 | 3.12 | 4.06 | 4.41 | 8.06 | 2.80 | 5.25 |
| 12 | 7.02 | 12.86 | 3.62 | 5.68 | 4.15 | 8.71 | 2.87 | 3.65 | 2.60 | 6.75 | 1.79 | 3.82 |
| 13 | 6.85 | 11.90 | 3.50 | 5.71 | 4.02 | 7.39 | 2.91 | 3.58 | 3.10 | 7.18 | 1.88 | 4.06 |
| 14 | 5.12 | 10.80 | 2.91 | 6.20 | 2.80 | 7.05 | 1.32 | 2.39 | 3.52 | 7.25 | 1.52 | 3.91 |
| 15 | 11.40 | 16.20 | 6.51 | 8.37 | 7.01 | 10.12 | 4.71 | 5.28 | 6.85 | 10.41 | 3.45 | 6.24 |
| 16 | 10.20 | 16.01 | 5.48 | 8.12 | 7.35 | 10.80 | 4.62 | 5.71 | 7.21 | 11.23 | 3.21 | 5.96 |
| 17 | 8.75 | 14.30 | 3.25 | 6.44 | 7.82 | 11.40 | 4.66 | 6.05 | 7.15 | 10.98 | 3.38 | 6.28 |
| 18 | 7.85 | 14.70 | 3.50 | 6.50 | 6.94 | 11.60 | 4.31 | 5.64 | 4.92 | 8.73 | 2.92 | 4.72 |
| 19 | 7.42 | 13.80 | 4.21 | 8.28 | 5.31 | 10.70 | 3.28 | 4.19 | 6.05 | 9.35 | 4.21 | 6.93 |
| 20 | 4.05 | 10.10 | 2.18 | 5.16 | 4.20 | 8.41 | 2.18 | 3.26 | 2.12 | 5.92 | 1.25 | 3.65 |
| 21 | 4.21 | 9.87 | 2.06 | 4.91 | 4.26 | 9.25 | 2.32 | 3.72 | 2.18 | 6.01 | 1.20 | 4.04 |
| 22 | 7.16 | 12.50 | 3.43 | 4.65 | 5.21 | 10.30 | 2.63 | 3.54 | 3.07 | 6.72 | 2.15 | 3.85 |
| 23 | 8.20 | 12.80 | 4.21 | 7.38 | 5.68 | 9.87 | 3.21 | 4.26 | 2.89 | 6.16 | 2.44 | 3.92 |
| 24 | 7.05 | 12.30 | 4.10 | 7.14 | 5.16 | 9.60 | 3.19 | 4.71 | 4.18 | 7.85 | 2.50 | 4.02 |
| 25 | 7.85 | 13.20 | 4.25 | 7.39 | 5.20 | 9.14 | 2.92 | 4.02 | 4.52 | 7.94 | 2.62 | 3.41 |
| 26 | 6.93 | 11.40 | 4.18 | 8.12 | 4.85 | 9.06 | 2.85 | 4.06 | 3.92 | 6.25 | 2.52 | 4.26 |
| 27 | 7.44 | 12.60 | 4.90 | 8.65 | 5.86 | 10.80 | 3.72 | 4.92 | 3.75 | 7.89 | 2.44 | 4.78 |
| **Mean** | **7.15** | **12.04** | **3.77** | **6.53** | **4.92** | **8.98** | **2.86** | **3.84** | **3.77** | **7.56** | **2.32** | **4.58** |
| Range | 2.31-10.87 | 8.32-16.49 | 1.31-6.51 | 4.16-8.65 | 2.80-7.82 | 6.35-11.60 | 1.21-4.66 | 2.05-6.05 | 1.05-7.21 | 4.32-11.23 | 0.95-3.45 | 2.85-6.93 |
| CD (0.05) | 0.363 | | 0.314 | | 0.280 | | 0.125 | | 0.225 | | 0.218 | |
| SEm± | 0.125 | | 0.108 | | 0.096 | | 0.043 | | 0.078 | | 0.075 | |

T1 - Prior to fertilizer application; T2 - After fertilizer application

Table 44. Ammoniacal N, nitrite + nitrate N and available P and K in soils 9ppm) during punja season 1994-95

| Pada-sekharam No. | $NH_4$-N | | | | $NO_2$-N + $NO_3$-N | | | | Available P | | Available K | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Basal | | Topdressing | | Basal | | Topdressing | | Basal | | Basal | | Topdressing | |
| | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 |
| 1 | 85.0 | 88.6 | 78.6 | 81.3 | 13.9 | 14.4 | 10.1 | 10.9 | 1.81 | 4.60 | 212 | 220 | 161 | 176 |
| 2 | 82.3 | 85.3 | 72.4 | 74.5 | 15.1 | 15.5 | 13.2 | 13.7 | 2.20 | 4.80 | 216 | 224 | 172 | 181 |
| 3 | 94.8 | 96.1 | 86.2 | 88.3 | 13.2 | 13.5 | 10.0 | 10.9 | 1.52 | 3.78 | 161 | 171 | 130 | 148 |
| 4 | 92.3 | 95.7 | 82.3 | 86.1 | 15.1 | 16.1 | 12.1 | 13.0 | 1.32 | 3.80 | 232 | 244 | 181 | 182 |
| 5 | 71.6 | 72.8 | 60.5 | 63.2 | 15.3 | 15.9 | 12.4 | 12.7 | 1.89 | 4.35 | 226 | 232 | 194 | 200 |
| 6 | 72.4 | 75.6 | 59.4 | 62.1 | 15.6 | 16.3 | 11.6 | 12.0 | 1.80 | 3.75 | 180 | 194 | 158 | 107 |
| 7 | 74.4 | 79.3 | 61.2 | 66.7 | 14.3 | 15.1 | 11.1 | 11.8 | 1.42 | 3.46 | 142 | 155 | 128 | 139 |
| 8 | 72.1 | 75.2 | 60.8 | 64.8 | 14.8 | 15.6 | 11.3 | 12.1 | 1.56 | 3.80 | 120 | 136 | 104 | 121 |
| 9 | 73.8 | 76.1 | 60.6 | 63.2 | 15.1 | 16.1 | 12.4 | 13.1 | 1.62 | 3.90 | 132 | 148 | 116 | 132 |
| 10 | 85.6 | 87.1 | 72.3 | 75.1 | 16.3 | 17.3 | 12.8 | 13.6 | 2.20 | 4.80 | 261 | 274 | 194 | 204 |
| 11 | 82.4 | 83.8 | 68.7 | 71.3 | 15.0 | 15.7 | 12.6 | 13.0 | 1.60 | 3.92 | 186 | 198 | 161 | 176 |
| 12 | 78.6 | 81.3 | 68.6 | 70.4 | 12.7 | 14.0 | 11.2 | 11.8 | 1.45 | 3.90 | 204 | 219 | 172 | 180 |
| 13 | 92.2 | 96.7 | 81.3 | 83.2 | 13.1 | 13.6 | 12.1 | 12.8 | 1.50 | 3.80 | 158 | 174 | 126 | 132 |
| 14 | 81.3 | 86.3 | 70.4 | 71.8 | 14.3 | 15.3 | 12.3 | 13.1 | 0.64 | 2.45 | 194 | 216 | 162 | 184 |
| 15 | 72.4 | 76.1 | 61.5 | 64.3 | 12.8 | 13.2 | 10.0 | 10.7 | 3.41 | 6.75 | 188 | 207 | 156 | 172 |
| 16 | 70.3 | 74.1 | 58.3 | 62.1 | 13.5 | 14.2 | 10.3 | 10.8 | 3.80 | 7.30 | 130 | 151 | 106 | 118 |
| 17 | 71.2 | 73.2 | 59.2 | 62.8 | 10.5 | 13.6 | 10.0 | 11.3 | 3.61 | 7.21 | 132 | 148 | 114 | 122 |
| 18 | 66.8 | 69.0 | 58.3 | 62.1 | 12.1 | 12.7 | 12.1 | 13.1 | 3.15 | 6.80 | 141 | 155 | 128 | 136 |
| 19 | 64.4 | 67.8 | 50.5 | 54.1 | 11.6 | 12.5 | 9.3 | 10.1 | 3.80 | 6.90 | 138 | 148 | 121 | 139 |
| 20 | 70.3 | 74.2 | 58.7 | 61.7 | 14.5 | 14.9 | 11.1 | 11.8 | 4.70 | 8.25 | 130 | 151 | 112 | 128 |
| 21 | 71.4 | 73.8 | 59.0 | 63.1 | 14.4 | 15.1 | 11.1 | 12.3 | 4.81 | 9.00 | 131 | 147 | 114 | 132 |
| 22 | 72.5 | 75.4 | 61.3 | 64.2 | 14.2 | 15.1 | 11.1 | 12.3 | 6.21 | 10.45 | 151 | 161 | 126 | 141 |
| 23 | 79.8 | 81.2 | 63.4 | 66.7 | 15.1 | 15.3 | 12.1 | 12.9 | 5.55 | 9.80 | 162 | 174 | 144 | 155 |
| 24 | 80.4 | 83.8 | 78.6 | 71.3 | 14.7 | 15.2 | 12.3 | 13.1 | 5.35 | 9.30 | 160 | 176 | 143 | 150 |
| 25 | 88.6 | 91.0 | 72.4 | 75.3 | 15.1 | 15.8 | 13.4 | 14.3 | 4.05 | 8.16 | 148 | 160 | 123 | 136 |
| 26 | 91.5 | 92.6 | 77.8 | 75.3 | 15.4 | 16.3 | 13.0 | 13.9 | 3.92 | 7.80 | 154 | 164 | 127 | 139 |
| 27 | 90.3 | 93.2 | 76.0 | 79.2 | 15.8 | 16.6 | 13.5 | 12.4 | 4.10 | 8.36 | 163 | 177 | 141 | 154 |
| **Mean** | **78.9** | **81.7** | **66.8** | **69.8** | **14.1** | **15.0** | **11.7** | **12.4** | **2.92** | **5.97** | **168** | **182** | **141** | **153** |
| Range | 64.4-94.8 | 67.8-96.7 | 50.5-86.2 | 62.1-88.3 | 10.5-16.3 | 12.5-17.3 | 9.3-13.5 | 10.1-14.3 | 0.64-6.21 | 2.45-10.45 | 120-261 | 136-274 | 104-194 | 107-204 |
| CD (0.05) | 0439 | | 0.333 | | 0.460 | | 0.085 | | 0.326 | | 1.56 | | 1.89 | |
| SEm± | 0.151 | | 0.115 | | 0.159 | | 0.029 | | 0.112 | | 0.538 | | 0.653 | |

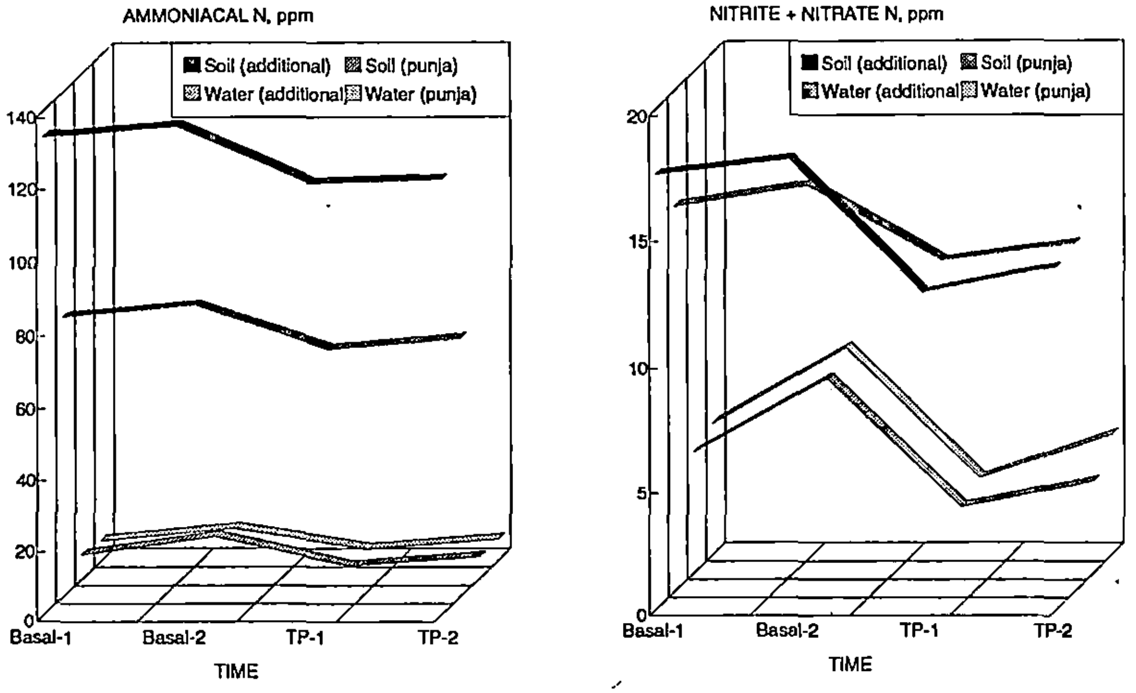
T1 - Prior to fertilizer application

T2 - After fertilizer application

Table 45. Ammoniacal N, nitrite+nitrate N and K in field water (ppm) during punja season 1994-95

| Pada-sekh-aram No. | $NH_4$-N | | | | $NO_2$-N + $NO_3$-N | | | | K | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Basal | | Topdressing | | Basal | | Topdressing | | Basal | | Topdressing | |
| | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 |
| 1 | 6.00 | 8.26 | 4.82 | 6.13 | 4.87 | 7.32 | 2.80 | 5.20 | 3.21 | 4.79 | 1.82 | 3.96 |
| 2 | 6.41 | 8.71 | 4.90 | 6.28 | 4.48 | 7.05 | 3.15 | 5.10 | 3.14 | 4.80 | 2.31 | 4.44 |
| 3 | 7.28 | 9.50 | 5.26 | 7.05 | 3.70 | 6.92 | 2.14 | 4.08 | 4.50 | 6.14 | 2.78 | 4.78 |
| 4 | 7.41 | 9.28 | 5.15 | 7.46 | 6.54 | 10.48 | 3.82 | 5.67 | 6.12 | 7.95 | 3.14 | 5.16 |
| 5 | 5.65 | 8.31 | 3.72 | 5.13 | 4.18 | 8.16 | 2.43 | 5.03 | 5.04 | 7.14 | 3.04 | 5.26 |
| 6 | 5.05 | 8.06 | 2.98 | 3.46 | 4.60 | 7.20 | 2.06 | 4.04 | 3.51 | 6.98 | 1.82 | 3.95 |
| 7 | 3.05 | 7.10 | 1.86 | 3.25 | 3.38 | 6.25 | 1.28 | 3.87 | 2.07 | 5.14 | 1.05 | 3.48 |
| 8 | 3.26 | 6.85 | 1.92 | 3.08 | 3.16 | 5.48 | 2.43 | 3.44 | 2.00 | 4.02 | 1.16 | 3.26 |
| 9 | 3.71 | 7.24 | 2.05 | 4.06 | 5.64 | 10.44 | 3.29 | 4.95 | 2.75 | 4.35 | 1.78 | 4.05 |
| 10 | 9.05 | 11.82 | 4.79 | 5.95 | 4.10 | 9.21 | 3.04 | 6.05 | 3.76 | 5.16 | 1.89 | 3.76 |
| 11 | 7.05 | 10.31 | 3.28 | 4.76 | 6.48 | 10.40 | 3.87 | 6.15 | 4.50 | 5.75 | 2.94 | 4.95 |
| 12 | 5.01 | 8.14 | 3.16 | 4.94 | 4.60 | 7.39 | 2.94 | 5.28 | 4.25 | 6.08 | 3.20 | 5.72 |
| 13 | 4.28 | 7.35 | 2.76 | 3.82 | 3.78 | 6.14 | 2.78 | 5.07 | 3.08 | 5.87 | 1.88 | 3.94 |
| 14 | 3.91 | 6.46 | 1.82 | 2.91 | 2.90 | 5.80 | 1.46 | 3.47 | 3.00 | 5.21 | 1.75 | 3.88 |
| 15 | 6.75 | 10.38 | 3.90 | 4.98 | 8.41 | 10.31 | 4.35 | 7.19 | 3.91 | 5.43 | 2.46 | 4.96 |
| 16 | 5.82 | 9.07 | 2.76 | 4.62 | 7.60 | 10.26 | 5.02 | 7.45 | 4.10 | 5.87 | 2.97 | 5.03 |
| 17 | 6.45 | 11.41 | 3.55 | 5.42 | 8.94 | 11.34 | 5.10 | 7.38 | 3.54 | 5.42 | 2.87 | 5.16 |
| 18 | 7.01 | 12.30 | 4.28 | 6.71 | 8.00 | 10.48 | 4.98 | 5.67 | 3.05 | 5.16 | 2.68 | 4.87 |
| 19 | 6.90 | 11.91 | 3.96 | 7.06 | 5.16 | 8.47 | 3.21 | 5.75 | 3.09 | 4.77 | 2.07 | 4.04 |
| 20 | 4.20 | 7.62 | 2.47 | 5.18 | 4.10 | 6.45 | 3.05 | 5.48 | 2.80 | 4.81 | 2.04 | 4.16 |
| 21 | 4.15 | 7.40 | 2.65 | 5.06 | 4.06 | 6.92 | 2.96 | 5.30 | 2.51 | 4.64 | 1.87 | 3.98 |
| 22 | 6.25 | 9.38 | 3.48 | 6.43 | 8.16 | 11.38 | 3.78 | 7.74 | 3.54 | 5.92 | 3.27 | 6.76 |
| 23 | 5.82 | 8.94 | 2.87 | 5.21 | 7.18 | 10.46 | 3.56 | 6.96 | 4.28 | 6.36 | 3.44 | 6.14 |
| 24 | 5.23 | 8.72 | 2.66 | 5.79 | 5.64 | 9.25 | 3.48 | 7.05 | 3.96 | 7.06 | 2.76 | 5.78 |
| 25 | 6.28 | 10.41 | 2.46 | 6.75 | 5.06 | 8.71 | 3.95 | 7.06 | 4.50 | 6.94 | 2.50 | 6.34 |
| 26 | 6.50 | 10.05 | 3.78 | 5.78 | 5.25 | 8.06 | 3.04 | 6.85 | 3.92 | 6.78 | 1.88 | 4.66 |
| 27 | 6.25 | 9.79 | 3.91 | 6.46 | 6.10 | 9.41 | 3.87 | 7.47 | 4.18 | 7.06 | 2.19 | 4.79 |
| **Mean** | **5.73** | **9.07** | **3.41** | **5.32** | **5.41** | **8.51** | **3.25** | **5.73** | **3.65** | **5.76** | **2.35** | **4.68** |
| Range | 3.05-9.05 | 6.46-11.91 | 1.82-5.26 | 2.91-7.06 | 2.90-8.94 | 5.48-11.38 | 1.28-5.10 | 3.44-7.74 | 2.00-6.12 | 4.02-7.95 | 1.05-3.44 | 3.26-6.76 |
| CD (0.05) | 0.329 | | 0.295 | | 0.303 | | 0.307 | | 0.228 | | 0.149 | |
| SEm± | 0.113 | | 0.101 | | 0.104 | | 0.106 | | 0.079 | | 0.051 | |

T1 - Prior to fertilizer application; T2 - After fertilizer applicationm



(TP - Topdressing; 1 - prior to and 2 - after fertiliser application)

(TP - Topdressing; 1 - prior to and 2 - after fertiliser application)

Fig 28. Concentration of $NH_4$-N and $NO_2$-N + $NO_3$-N in soil and water during additional and punja crop seasons (pooled means)

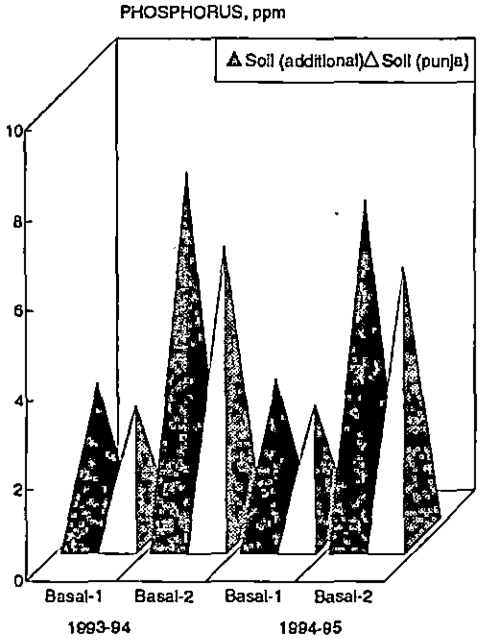
44 and 45) and hence the pooled mean (Table 46 and Fig 27) for the above two seasons did not show much variation from the individual values. IDMR (1989) reported a concentration of 0.2 ppm of $NH_4$-N and 5.0 ppm of $NO_3$-N in waterways and canals of Kuttanad. The highest concentration was observed in Thanneermukkom area.

Since the quantities of different forms of N released into the waterways and canals are not negligible, their contribution towards the contamination of the environment has to be seriously looked into and suitable measures chalked out to reduce contamination to the minimum extent possible.

$NH_4$-N was significantly and positively correlated with $NO_2$-N + $NO_3$-N at the time of basal dressing (0.552**) and $NH_4$-N at the time

2.2 *Phosphorus*: The study area was generally deficient in available P due to the high P fixation capacity of soil. The mean value of available P during additional crop season, 1993-94 before basal application of fertiliser (@ 45 kg $P_2O_5$ $ha^{-1}$ as factomphos) was 3.41 ppm and it increased to 8.09 ppm after fertiliser application (Table 38). About half of the applied P only was accounted in soil and rest of the P might have lost by fixation, since these soils were of very high P fixing capacity. The Kuttanad soils contain very low available P due to their high P fixation capacity (Kuruvila and Patnaik, 1994).

The water soluble P present in the area was practically nil since it recorded a concentration below 0.05 ppm in water and hence not presented here. The very low mobility of P and high P fixation capacity of soils are responsible



(1 - prior to and 2 - after fertiliser application)

Fig 29. Available Phosphorus concentration in soil during additional and punja crop seasons of 1993-94 and 1994-95

During punja 1993-94 the values of available P was slightly lower (Table 40) compared to that of additional crop of the same year. The punja cultivation without any fallowing after additional crop results in continuous crop uptake and removal of available P from soil and thus lowers the available P content.

The behaviour of available P during additional and punja crop seasons of 1994-95 (Tables 42 and 44, respectively) was similar to that of 1993-94. The pooled mean values of available P are presented in Table 46.

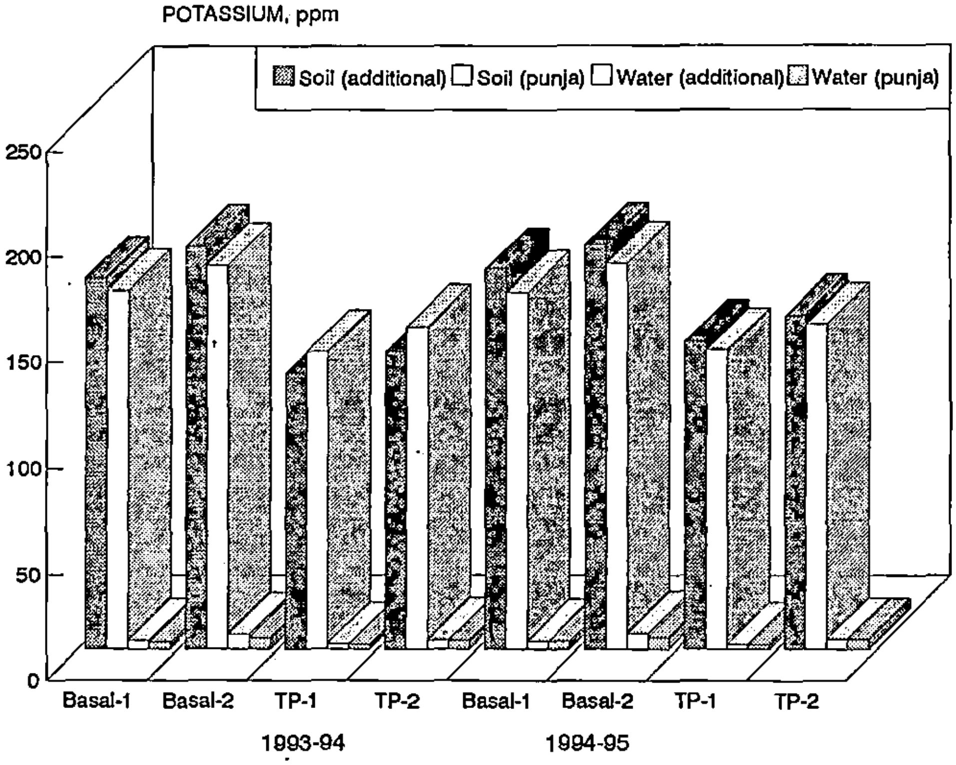
2.3 *Potassium*: The study area recorded comparatively higher values for available K. The mean value of available K before basal application of K fertiliser was 175 ppm which increased to 190 ppm after fertiliser application during the additional crop season, 1993-94 (Table 38). The free flow of sea water within the study areas resulted in the higher values for available K. The increase observed due to fertiliser application was considerably high indicating that the farmers are applying higher quantities of K fertiliser than that recommended as per package of practices (KAU, 1993). The quantity of fertiliser applied by the farmers varied from 50 to 65 kg $K_2O$ $ha^{-1}$, while the recommendation is 45 kg $K_2O$ $ha^{-1}$ for medium duration rice.

The K content of water during this period was 4.17 ppm before fertiliser application and it increased to 6.94 ppm after fertiliser application (Table 38). Considerable amount of K applied was also lost through the drainage water, though the loss was not as severe as that of N. The K concentration of drainage water from recently fertilised fields ranged from 0.4 to 4 ppm and the plants and aquatic species are not affected by K content around this range. Low concentration of K in water has a fertilising effect on plants (Lal *et al.*, 1993).

At the time of topdressing the mean value of available K in soil before fertiliser application was 130 ppm which increased to 140 ppm after fertiliser application (Table 38). In field water, the corresponding values for K were 2.38 and 4.42 ppm, respectively (Table 39).

During punja season the mean value of available K was 169 ppm before basal dressing and it increased to 181 ppm after the addition of K fertiliser (Table 40). At the time of topdressing the mean values were 140 and 152 ppm, before and after fertiliser application, respectively. The K content of water followed the same trend as that of additional crop, 1993-94 (Table 40).

The trend was similar during the additional (Tables 42 and 43) and punja crops (Tables 44 and 45) of 1994-95 also. The pooled mean values are presented in Table 46.



(TP - Topdressing; 1 - prior to and 2 - after fertiliser application

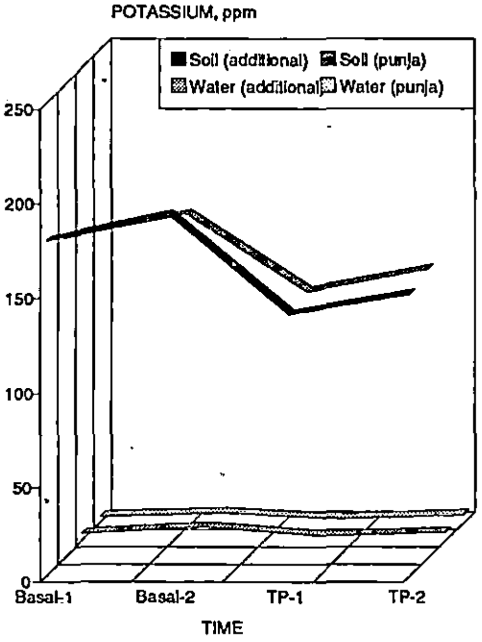
Fig 30. Concentration of available K in soil and K in water during additional and punja crop seasons of 1993-94 and 1994-95

Table 46. Pooled mean values of different forms of N in soil and water, available P and K in soil and K in water (ppm)

| Charac-teristics | | Cropping seasons | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Additional | | | | Punja | | | |
| | | Basal | | Topdressing | | Basal | | Topdressing | |
| | | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 |
| Soil | $NH_4$-N | 133 | 136 | 120 | 121 | 78.3 | 81.4 | 69.4 | 72.3 |
| | $NO_2$-N+$NO_3$-N | 17.4 | 18.0 | 12.7 | 13.7 | 15.4 | 16.2 | 13.2 | 13.9 |
| | Available P | 3.46 | 7.78 | - | - | 2.91 | 6.20 | - | - |
| | Available K | 177 | 191 | 138 | 149 | 169 | 182 | 141 | 153 |
| Water | $NH_4$-N | 6.90 | 11.95 | 3.80 | 6.30 | 5.65 | 9.09 | 3.35 | 5.96 |
| | $NO_2$-N+$NO_3$-N | 4.92 | 7.84 | 2.68 | 3.72 | 5.33 | 8.31 | 3.11 | 4.89 |
| | K | 3.97 | 7.25 | 2.35 | 4.50 | 3.63 | 5.56 | 2.31 | 4.65 |

T1 = Prior to fertiliser application; T2 = After fertiliser application

The pooled mean values of K are presented in Fig 31.



(TP - Topdressing; 1 - prior to and 2 - after fertiliser application)

Fig. 31 Concentration of available K in soil and soluble K in water during additional and punja crop seasons (pooled means)

From the study it was observed that considerable portion of fertiliser applied to the soil is lost mainly through the drainage water. Under submerged conditions the major means for the loss of nutrients is through the drainage water. Among the nutrients, the loss through drainage water was maximum for N since it is lost from the soil in the forms of ammoniacal, nitrite and nitrate N. The loss of N was mainly in ammoniacal form in the study area since it is the major form of N in the flooded soil. The loss of P through water was practically nil. A considerable quantity of K is also lost from the soil through drainage water.Though the fertiliser residues released through the drainage water did not exceed the tolerance limit at present, the quantity released. into the surrounding environment is not negligible since this concentration may be sufficient to cause eutrophication in canals and waterways. Hence better nutrient management strategies involving ecofriendly farming systems along with improved regulator operation have to be adopted to minimise the damage to the life supporting systems of Kuttanad.

# *Summary*

# SUMMARY

The present experiment consisted of three parts viz., (1) Morphology and physicochemical characteristics, (2) Fertility characteristics and (3) Toxicity characteristics. In part 1, fifteen profile samples were collected from the villages Arpookkara, Aymanam, Kumarakom, Thiruvarpu and Kaipuzha of North Kuttanad to study the morphological and physicochemical characteristics. Surface samples (0-15 cm depth) were collected from the 27 padasekharams of the above sites to study the fertility characteristics of the area during rainy and summer seasons (before and after the closure of Thanneermukkom regulator). Under part 3, bulk soil samples (0-25 cm depth), surface water and ground water from the same area were collected during the same period to study the accumulation of various toxicity factors including pesticide and fertiliser residues.

**Part 1**

(1) Morphological characteristics of soils expressed a great deal of heterogeneity. The hue of the soil matrix varied from 7.5 to 10 YR with a colour change of dark brown to black. Bleached eluvial horizons were noted in well developed profiles. Random deposits of lime shells and illuvial accumulation of humus were observed in subsurface layers. Faint to prominent reddish yellow or brown mottles of hue 7.5 to 10 YR were observed.

(2) Soil texture varied from sandy to clayey. The soils were sticky and plastic with subangular blocky structure. Large number of rice roots and reddish yellow or brown root canals were observed in surface soil.

(3) Sand, silt and clay contents showed wide variation among the soil profiles and their ranges were 1.8 to 93.1, 2.4 to 56.3 and 1.0 to 69.5 per cent, respectively. This variation was reflected on each and every physical property of soil.

(4) Apparent and absolute specific gravity of profiles varied from 0.79 to 1.36 and 1.38 to 2.69, respectively. Water holding capacity varied from 37.0 to 90.3 per cent. Pore space and volume expansion ranged from 40.9 to 66.3 and 0.59 to 28.71 per cent, respectively. The range observed for hydraulic conductivity was 0.37 to 59.10 cm $h^{-1}$.

(5) Soils of the study area were invariably acidic with a pH range of 3.0 to 5.0 in surface soil. The lower layers were more acidic.

(6) Salinity of the area has been considerably reduced after the commissioning of Thanneermukkom regulator. Presently the area is mildly saline during summer and the EC of the surface soils ranged from 0.33 to 2.63 dS $m^{-1}$. Subsoil layers showed still higher values due to salt accumulation in lower layers. The contribution of Na to soil salinity was high. The total Na content varied from 280 to 8640 ppm and was concentrated mainly in lower layers.

(7) Soils contained large quantities of organic matter, either decomposed, partially decomposed or undecomposed resulting wide variation in organic carbon content. In surface soils organic carbon content varied from 0.12 to 5.62 per cent while in subsurface layers the range was 0.07 to 16.22 per cent.

(8) The CEC varied from 7.6 to 28.9 cmol(+) $kg^{-1}$ in surface soil. C1 horizon of profile I recorded the highest value due to its high OC content. CEC was highly correlated to clay ($0.413^{*}$) and OC ($0.567^{**}$). In Kuttanad soils, organic carbon is the major factor that decides

the soil CEC which is evident from its relationship with organic carbon. ECEC of the surface soils ranged from 5.75 to 20.84 cmol(+) $kg^{-1}$. Percentage base saturation also showed great variation among the soil layers.

(9) Wide variation was observed for total nutrient content in the area. Total N concentration was 0.02 to 0.54 per cent in surface soil. The sandy layers showed very low total N.

(10) Total P content of surface soils ranged from 69 to 982 ppm. Sixty seven per cent of the area was categorised under medium and remaining 33 per cent under low in total P.

(11) Total K, Ca and Mg content of the profiles varied from 560 to 5000 ppm, 0.20 to 1.80 and 0.06 to 1.92 per cent, respectively.

(12) Total S content of the area varied from 0.15 to 7.12 per cent. The S status of the area was very high, especially in Kaipuzha village. However, the large quantities of Fe present in the soil protect the crop from S toxicity.

(13) The total and available (DTPA) Fe content of the surface soils ranged from 1.62 to 10.30 per cent and 121 to 516 ppm, respectively. The concentration in subsurface layers were greater than surface soils.

(14) The ranges observed for total Mn, Cu and Zn contents were 34 to 354, 2 to 84 and 8 to 122 ppm, respectively. Cu was present in smallest quantity.

(15) Total Al content of the samples ranged from 0.82 to 10.16 per cent. The exchangeable Al content of surface layers ranged from 0.33 to 5.99 cmol(+) $kg^{-1}$.

(16) Among the available nutrients, soil was highly deficient in available P and medium to high in available N. For available K, 13.3 per cent was rated under low, 78.7 per cent under medium and 8 per cent under high. The soils were not deficient in Ca or Mg. Available S content ranged from 380 to 10528 ppm.

(17) The ranges observed for available Mn, Cu and Zn were 0.50 to 12.86, 0.1 to 8.85 and 0.19 to 5.45 ppm, respectively, in surface soil. In general, their concentration increased with depth.

(18) Chloride content of the area ranged from 246 to 1721 ppm in surface horizon and lower layers recorded greater values.

(19) Water soluble and exchangeable cations followed the same trend as that of total cations. Among the exchangeable cations Ca was the dominant cation followed by Mg.

(20) Soils of the study area were extremely acidic in nature. The potential acidity of the surface horizons ranged from 2.8 to 92.7 cmol(+) kg and it increased with depth. The soil acidity is mainly pH dependent ($0.993^{**}$) and exchangeable acidity is present in very small amounts ($0.489^{**}$).

(21) Soil profiles were classified up to subgroup level. Profile IX was classified under Inceptisol order with subgroup Fluventic Dystropept. All other profiles were grouped under Entisols. Profiles I, II, III, VI, VI, X, XI, XII, XIII, XIV and XV were grouped under Typic Sulfaquents, profile V under Typic Tropopsamment, profile VII under Typic Tropofiuvent and profile VIII under Typic Fluvaquent at subgroup level.

**Part 2**

(1) In general, most of the soil properties were significantly influenced by the season /closure of Thanneermukkom regulator. Soils of the

area were highly acidic with an average pH of 4.4 during rainy season and decreased to 4.0 during summer. Compared to the pre-barrage period, an increase in soil acidity was observed.

(2) Salinity intrusion into Kuttanad was considerably reduced after the construction of Thanneermukkom regulator. The average soil EC was 1.35 dS $m^{-1}$ during rainy season which decreased to 0.67 dS $m^{-1}$ during summer, evidently due to prevention of salinity intrusion.

(3) The variation in salinity was reflected on Na content of the area ($0.730^{**}$). Available Na content was 1983 ppm during rainy season which decreased to 501 ppm during summer. Water soluble and exchangeable Na also followed the same trend. Water soluble Na constitute more than 87 per cent of available Na.

(4) Soil organic carbon content during rainy season was 3.66 per cent and decreased to 3.45 per cent during summer. Compared to the pre-barrage period a decrease in organic carbon content was noted.

(5) CEC and ECEC of the study area were 25.8 and 19.6 cmol(+) $kg^{-1}$, respectively during rainy season. The mean values decreased to 19.6 and 13.9 cmol(+) $kg^{-1}$, respectively, during summer. The percentage reduction observed for ECEC from CEC was greater during rainy season indicating the presence of more pH dependent charges during that period. CEC and ECEC were significantly and positively correlated to OC ($0.631^{**}$, $0.715^{**}$) and potential acidity ($0.813^{**}$, $0.522^{**}$). The percentage base saturation was below 50.

(6) The available N and P contents of the area were not altered by the construction of the regulator. The average available N content of the area was 284 ppm during rainy season and increased to 324 ppm during summer. The mean value of available P was 3.17 ppm during rainy season which increased to 5.50 ppm during summer. About 67 per cent of the area was rated as low in available P.

(7) During the post-barrage period an increase in concentrations of available K, Ca and Mg was observed. The area was not deficient in any of the above elements. A reduction was observed in their contents during summer.

(8) The area was rated as high in available Fe content. The average value of DTPA extractable Fe was 353 ppm during rainy season and increased to 421 ppm during summer. The construction of the regulator did not influence the available Fe content of the area.

(9) The study area was not deficient in micronutrient cations. During rainy season the mean values of available Mn, Cu and Zn were 9.76, 5.51 and 2.85 ppm, respectively. The corresponding values during summer were 8.65, 4.40 and 2.95 ppm, respectively.

(10) Water soluble and exchangeable cations followed the same trend as that of available forms.

(11) The study area recorded very high potential acidity. The mean values were 25.5 and 17.9 cmol(+) $kg^{-1}$, during rainy and summer seasons, respectively. Potential acidity was mainly pH dependent. The hydrolytic acidity contributed 87.6 and 63.7 per cent, of it during rainy and summer seasons, respectively. Exchangeable acidity occupied a minor share. All the acidity characteristics were significantly correlated with OC and CEC.

(12) The exchangeable acidity was rather low compared to potential acidity. The mean values were 4.46 and 5.98 cmol(+) $kg^{-1}$, during rainy and summer seasons, respectively. Among its

components exchangeable $Al^{3+}$ was dominant (67%) during rainy season and exchangeable $H^+$ (54%) during summer.

## Part 3

(1) The general soil properties of bulk soil samples followed the same trend as that of profile and surface samples. Soil pH and EC were significantly influenced by both the seasons and the regulator. An increase in acidity and a reduction in soil EC, CEC, ECEC and available nutrients were observed during the summer season.

(2) The free Fe content was very high in the soil. The mean value was 6.62 per cent during rainy season and increased to 6.75 per cent during summer. Available Fe extracted by both DTPA and diacid also followed the same trend, showing greater concentration during summer. The available Fe content was sufficient to cause severe Fe toxicity during both the seasons. The exchangeable and water soluble Fe were present in negligible quantities.

(3) Compared to Fe, Mn content of the area was very small but sufficiently above the critical level. The free Mn content was 52.0 ppm during rainy season which decreased to 37.8 ppm during summer.The available, water soluble and exchangeable Mn also showed a decrease during summer season. The study area was not deficient in available Cu and Zn.

(4) Soil contained large quantities of free Al. The mean values were 2.22 and 2.08 per cent during rainy and summer seasons, respectively.The water soluble Al content was very low.

(5) Water of the study area was mildly acidic in reaction. Surface water and ground water recorded a pH of 6.7 during rainy season. During summer, the pH reduced to 5.9 for surface water and 6.3 for ground water. The water quality was poor during summer since more than 60 per cent of the area recorded a pH below 6.5

(6) EC of surface and ground water were below the critical level for irrigation and domestic purposes during rainy and summer seasons. For surface water the mean values were 0.28 and 0.51 dS $m^{-1}$, and for ground water the mean values were 0.37 and 0.42 dS $m^{-1}$, respectively during the above seasons.

(7) Among the various elements present in water Na and $Cl^-$ were the dominant ions. The surface water recorded a concentration of 34.1 ppm during rainy season and 77.9 ppm during summer for Na. For ground water the corresponding values were 46.2 and 63.3 ppm respectively. Based on SAR values both surface and ground water were rated as moderately unsafe for irrigation during summer. In both the waters P was present in traces only.

(8) The concentrations of K, Ca and Mg in surface and ground water were well below the critical levels suggested, during both the seasons. K concentration was 1.92 ppm during rainy season and increased to 5.95 ppm during summer. For ground water the corresponding values were 3.8 and 4.4 ppm, respectively.

(9) Among the micronutrients Fe was the dominant element. However, its concentration in water was below the critical limit for irrigation, but far exceeded the level for drinking water. Fe content was greater in ground water compared to surface water.

(10) Mn content of surface water has approached the critical limit for irrigation. In ground water Mn was not detected.

(11) Al was present in minute quantities in surface and ground water, but the Al content of ground water exceeded the ISI limit for domestic purposes. Cu, Zn, Cd and Pb were not detected in surface as well as in ground water.

(12) The $Cl^-$ content of surface and ground water during summer was sufficient to cause specific toxicity effect. The $Cl^-$ content of surface water was 78 ppm during rainy season and increased to 169 ppm during summer. For ground water the corresponding values were 80 and 130 ppm, respectively. $SO_4$-S content was well below the critical levels suggested.

(13) The chlorinated hydrocarbon pesticides identified in the area were $\alpha$-HCH, $\gamma$-HCH and DDT. The concentration of $\alpha$-HCH in soil was 0.162 ppb during rainy season and increased to 0.647 ppb during summer. For water the corresponding values were 0.302 and 0.631 ppb, respectively. The concentration of $\gamma$-HCH was very small compared to $\alpha$-HCH. Its concentration in soil was 0.020 ppb during rainy season which increased to 0.045 ppb during summer. In water the corresponding values were 0.126 and 0.173 ppb.

(14) Among the chlorinated hydrocarbons DDT was present in larger quantities. The average value of DDT in soil was 4.34 ppb during rainy season and increased to 6.92 ppb during summer. For water the corresponding values were 1.28 and 2.51 ppb, respectively.

(15) Considerable quantities of fertiliser residues were released in to the area through the drainage water. The highest concentration was observed for $NH_4$-N during additional crop season. The mean values were 133 and 136 ppm, before and after basal fertiliser application. The values were reduced to 120 and 121 ppm respectively, at the time of top dressing. For water the corresponding values were 6.90, 11.95 and 3.80 and 6.30 ppm, respectively. During punja season also, the trend was same, but the values were slightly lower.

(16) Accumulation of $NO_2$ and $NO_3$-N were comparatively low in the area due to the persistence of aquic moisture regime. However, smaller quantities of nitrite+nitrate N were detected both in soil and water. In soil the concentration at basal application and topdressing with fertilisers were 17.4, 18.0 and 12.7 and 13.7, ppm respectively, before and after fertiliser application. For water the corresponding values were 4.92, 7.84, 2.68 and 3.72, ppm respectively. During punja season the values showed slight variation both in soil and water from that of additional crop season.

(17) Available P status of the area was low. Loss of P through drainage water was nil.

(18) A sizable quantity of K was also subjected to loss through drainage water, though the level was not as high as that of N. Available K of the area before basal application of K fertiliser was 177 ppm and increased to 191 ppm after it. At the time of top dressing the values were 138 and 149 ppm, respectively. In water, the K contents were 3.97, 7.25 and 2.35 and 5.0 ppm, respectively, before and after fertiliser application. During punja season also a similar trend was observed.

(19) From the study it was observed that the study area is subjected to severe environmental pollution due to the enhancement of existing native toxic factors like soil acidity and concentration of Fe, Al, Mn etc., and accumulation of introduced toxic factors like pesticides and fertiliser residues. The closure of Thanneermukkom regulator during summer season aggravates the above situation.

# *References*

# REFERENCES

Abichandani, C. T. and Patnaik, S. 1958. Nitrogen changes and fertiliser losses in lowland waterlogged soils. *J. Indian Soc. Soil Sci.* **6** : 87-93

Abraham, A. 1984. The release of soluble aluminium in soils under submerged conditions and its effects on rice. Ph.D. thesis, Kerala Agricultural University, Vellanikkara, Trichur

Adhikari, M. and Si, S. K. 1991. Studies on different forms of iron and aluminium and their release in relation to acidity of some acid soils. *J. Indian Soc. Soil Sci.* **39** : 252-255

Agnihotri, N. P., Pandey, S. Y., Jain, H. K. and Srivastava, K. P. 1977. Persistence of aldrin, dieldrin, lindane, heptachlor and *p,p*-DDT in soil. *J. ent. Res.* 1 : 80-91

Agnihotri, N. P., Pandey, S. Y., Jain, H. K. and Srivastava, K. P. 1981. Persistence, leaching and movement of chlorpyriphos, disulfoton, fensulfothion, monocrotophos and tetrachlorofenvinphos in soil. *Indian J. agric. Chem.* 14 : 27-31

Ahmad, N., Harsas, W., Marol, R.S., Morton, M. and Pollack, J. K. 1988. Total DDT and dieldrin content of human adipose tissue. *Bull. environ. Contam. Toxicol.* 41 : 802-808

Aiyer, R. S. and Nair, C. S. 1979. Phosphate fractions of Kerala rice soils in relation to their occurrence and pedogenesis. Agric. Res. J. Kerala **17** : 39-43

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

Aiyer, S. P. 1946. The placement of minor elements in rice. *Indian Fmg* 7(3) : 11-14

Alexander, M. T. and Durairaj, D. J. 1968. Influence of soil reaction on certain soil properties and availability of major nutrients in Kerala state. *Agric. Res. J. Kerala* 6 : 15-19

Amma, K. P. P. 1988. Reductive transformation of iron and sulphate in anaerobic soils. M.Sc.(Ag) thesis, Kerala Agricultural University, Vellanikkara, Trichur

Amma, M. K., Abraham, A. and Aiyer, R. S. 1979. Extractable aluminium in the rice soils of Kerala. *Agric. Res. J. Kerala* 17 : 44-49

Ananthanarayana, R. and Hanumantharaju, T. H. 1994. Nature of soil acidity and lime requirement in the agro-climatic zones of Shimoga district, Karnataka. *J. Indian Soc. Soil Sci.* **42** : 361-364

Antony, P. C. and Koshy, M. M. 1985. The moisture retention characteristics and hydraulic conductivity of alluvial (Entisol) and brown hydromorphic (Alfisol) soils of Kerala. *Agric. Res. J. Kerala* 23 : 31-34

Antony, P. C. and Koshy, M. M. 1988. Properties of red and laterite soils when submerged under saline waters of different concentrations. *Agric. Res. J. Kerala* **26** : 290-292

APHA, 1985. *Standard methods for the examination of water and waste water.* American Public Health Association, Blatimore, Maryland, USA

Aravindakshan, M. and Joseph, C. A. 1985. The Kuttanad eco-system. *Five Decades of Rice Research in Kuttanad.* Kerala Agricultural University, Vellanikkara, Trichur

Ayers, R. S. 1975. Quality of water for irrigation. *Proc. Irrig. Drain. Div., Specialty Conf.,* Am. Soc. Civ. Eng. August 13-15, Logan, Utah, p. 24-56

Ayers, R. S. and Westcot, D. W. 1985. Water Quality for Agriculture. *Irrigation and Drainage.* FAO Bull. No. 29, Rome

Balakrishnan, M. and Ouseph, P. P. 1995. HCH concentration in sediment and fish along the coast of Kerala. *Proceedings of the Seventh Kerala Science Congress,* Palghat, Kerala. State Committee on Science, Technology and Environment, Trivandrum, Kerala, p. 84-86

Bhargava, G. P. and Abrol, I. P. 1984. Morphology and characteristics of some acid sulphate soils in Kerala state. *J. Indian Soc. Soil Sci.* 32 : 137-145

Bhatnagar, V. K., Patel, J. S. Variya, M. R., Venkaiah, K., Shah, M. P. and Kashyap, S. K. 1992. Levels of organochlorine insecticides in human blood from Ahmedabad (rural), India. *Bull. environ.Contam. Toxicol.* 48 :302-307

Black, C. A., Evans, D. D., Ensminger, L. E., White, J. L. and Clark, F. E. 1965. *Methods of Soil Analysis.* Part 1. Am. Soc. Agron. Inc., Madison, Wisconsin, USA

Bremner, J. M. and Keeney, D. R. 1965. Steam distillation methods for determination of ammonium, nitrate and nitrite. *Anal. Chim. Acta* 32 : 485-495

Brinkman, R. and Singh, V. P. 1982. Rapid reclamation of brackish water fish ponds in acid sulphate soils. *Proceedings of the International Symposium on Acid Sulphate Soils, Bangkok.* International Institute for Land Reclamation and Improvement, Wageningen, Netherlands, p. 318-328

Brito-Mutunayagam, A. P. A. 1948. Study of the causes of failure of paddy crops in Kaipuzha. *Univ. Trav. Res. Report,* p. 151

Brito-Mutunayagam, A. P. A. 1961. Potash status of soils of Kerala state. *Agric. Res. J. Kerala* 1: 49-51

Broadbent, F. E. 1978. Mineralisation of organic nitrogen in paddy soils. *Soils and Rice.* International Rice Research Institute, Los Banos, Philippines, p. 105-118

Chattopadhyay, S. and Sidharthan, S. 1985. *Regional Analysis of the Greater Kuttanad, Kerala.* Technical Report No. 43. Centre for Earth Science Studies, Trivandrum

Chesnin, L. and Yien, C. R. 1951. Turbidimetric determination of available sulphates. *Proc. Soil Sci. Soc. Am.* 15 : 149-151

Cochran, W. G. and Cox, G. M. 1965. *Experimental Designs.* John Wiley and Sons Inc., New York

Coleman, N. T., Weed, S. B. and Mc Gracksen, R. J. 1959. Cation exchange capacity and exchangeable cations in piedmont soils of North Carolina. *Proc. Soil Sci. Soc. Am.* 23 : 146-149

DEEM, 1987. *Eco-degradation at Kuttanad.* Documentation of the Experience in Environmental Management.Environmental Services Group, World Wildelife Fund, India, New Delhi, p. 41

Drego, J., Murty, N. B. K. and Raghu, K. 1990. $^{14}$C-HCH in a flooded soil with green manuring. *J. agric. Fd Chem.* 26 : 357-364

Dureja, P., Walia, S. and Kumar, J. 1990. Photochemical reactions of organophosphorus pesticides. *Pestic. Res. J.* 2 : 1-10

Gajbhiye, V. T. 1989. Comparative studies on volatilization losses of aldrin, DDT and lindane in soil under field condition. Ph.D. thesis, Indian Agricultural Research Institute, New Delhi

Gajbhiye, V. T. and Agnihotri, N. P. 1991. Volatilization of lindane from soil. Pestic. Res. J. **3** : 151-158

Gajbhiye, V. T. and Agnihotri, N. P. 1992. Volatilization of aldrin from soil. *Pestic. Res. J.* **4** : 11-23

Ghosh, S. K., Das, S. K. and Deb, D. L. 1973. Physical, chemical and mineralogical characteristics of kari soils from Kerala. *National Symposium on Acid Sulphate and other Acid Soils of India, Abstract of Papers*, Trivandrum, p. 2

Ghosh, S. K., Das, S. K. and Deb, D. L. 1976. Physical, chemical and mineralogical characterisation of acid sulphate soils from Kerala. *Bull. Indian Soc. Soil Sci.* **11** : 117-133

Godwin, W. G. 1986. Fertility investigations on the soils of south Kerala in relation to their physiographic positions. M.Sc.(Ag) thesis, Kerala Agricultural University, Vellanikkara, Trichur

Gopalaswamy, V. 1961. Studies on the soils of Kuttanad. The nature of clay minerals present. *Agric. Res. J. Kerala* **1** : 65-69

Gopinath, V. 1973. Distribution of copper and zinc in the acid peat (kari) soils of Kerala. M.Sc.(Ag) thesis, Kerala Agricultural University, Vellanikkara, Trichur

Goto, S. and Kato, S. 1980. *Analytical Methods of Pesticide Residues.* Soft Science Co. Tokyo

Gupta, G. P. 1974. The influence of temperature on the chemical kinetics of submerged soils. Ph.D. thesis, Indian Agricultural Research Institute, New Delhi

Hegde, T.M., Rao, N. N. and Bidappa, C. C. 1980. Evaluation of sulphur status of different rice soils : I. *Mysore J. agric. Sci.* **14** : 171-176

Hesse, P. R. 1971. *A Text Book of Soil Chemical Analysis.* John Murray Publishers Ltd., London

Holmgren, G. G. S. 1967. A rapid citrate dithionite extractable iron procedure. *Soil Sci. Soc. Am. Proc.* **31**: 210-211

Hsu, P. H. 1963. Effect of intial pH, phosphate and silicate on the determination of aluminium with aluminon. *Soil Sci.* **96** : 230-238

IDMR, 1989. *Kuttanad Water Balance Study. Indo Duch Mission Report.* Vol. 1, Government of Kerala, Trivandrum, p. 57

IRRI, 1964. *Annual Report 1963.* International Rice Research Institute, Los Banos, Philippines, p. 199

ISI, 1991. *Drinking Water Standards. Indian Standards IS-10500.* Indian Standards Institute, New Delhi

Jackson, M. L. 1958. *Soil Chemical Analysis.* Prentice Hall Inc. Eagle Wood Cliffs, N. J., USA. Reprint (1973) by Prentice Hall of India (Pvt) Ltd., New Delhi

Jacob, C. I. 1966. Sulphur status of Kerala soils. M.Sc.(Ag) thesis, University of Kerala, Trivandrum

Jacob, V. C. 1980. Ground water regime monitoring under ecosystem studies in Kuttanad basin on completion of Thanneermukkom barrage, Alleppey district, Kerala. *Geology and Geomorphology of Kerala.* Special Publication No. 5. Geological Survey of India, Trivandrum

Jakobsen, P., Patrick, W. H. Jr. and Williams, B. G. 1981. Sulphide and methane formation in soils and sediments. *Soil Sci.* **132** : 279-287

Jayman, T. C. Z. and Sivasubramaniam, S. 1974. The use of ascorbic acid to eliminate interference from iron in the aluminon method for determining aluminium in plant and soil extracts. *Analyst* 99 : 296-301

John, L. and Thomas, J. 1990. Dynamics of applied nitrogen in karappadom soils of Kuttanad. *Rice in Wetland Ecosystem*. Kerala Agricultural University, Vellanikkara, Trichur. p. 103-110

Johnkutty, I. and Anilakumar, K. 1990. Electrochemical properties of submerged rice soils in high rainfall areas. *Rice in Wetland Ecosystem*. Kerala Agricultural University, Vellanikkara, Trichur, p. 98-104

Kabeerathumma, S. 1969. Effect of liming on exchangeable cations and availability of nutrients in acid soils of Kuttanad. M.Sc.(Ag) thesis, University of Kerala, Trivandrum

Kabeerathumma, S. 1975. Chemistry of low productive acid laterite and acid sulphate soils and their amelioration for growing rice. Ph.D. thesis, Orissa University of Agriculture and Technology, Bhubaneshwar

Kabeerathumma, S. and Bidappa, C. C. 1975. Influence of liming on exchangeable potassium of two acid sulphate soils of Kerala. *Agric. Res. J. Kerala* **13** : 67-69

Kabeerathumma, S. and Nair, N. C. 1973. Effect of liming on exchangeable cations and pH of acid soils of Kuttanad. *Agric. Res. J. Kerala* 11 : 9-13

Kabeerathumma, S. and Patnaik, S. 1978. Effect of submergence on the availability of toxic and deficient nutrients in acid sulphate soils of Kerala. *Agric. Res. J. Kerala* **16** : 181-187

Kabeerathumma, S. and Patnaik, S. 1980. Studies on change of lime potential of acid sulphate soils of Kerala on submergence. *Agric. Res. J. Kerala* **18** : 229-235

Kaphilia, B. S. and Seth, T. S. 1983. Chlorinated pesticide residue in human adipose tissue of normal and exposed human population. *Indian J. Medical Res.* 77 : 245-247

KAU, 1984. *Research Report 1982-83*. Kerala Agricultural University, Vellanikkara, Trichur, p. 243-244

KAU, 1988. *Annual Report, AICRP on Agricultural Drainage, Karumadi*. Kerala Agricultural University, Vellanikkara, Trichur

KAU, 1993. *Package of Practices Recommendations*. Directorate of Extension Education, Kerala Agricultural University, Mannuthy, Trichur

KAU, 1994. *A Glimpse to Problem Soils of Kerala*. Kerala Agricultural University, Vellanikkara, Trichur

Kearney,P. C. and Helling, C. S. 1969. Reactions of pesticides in soils. *Residue Rev.* **25** : 25-44

Khan, S. U. 1982. Bound pesticide residues in soil and plants. *Residue Rev.* **84** : 1-24

Koshy, M. M. 1970. The chemical nature of organic complexes in Kerala soils. *Curr. Sci.* **39** : 353-354

Koshy, M. M. 1971. Organic P in relation to the organic carbon and nitrogen contents of some Kerala soil types. *Agric. Res. J. Kerala* **9** : 94-95

Koshy, M. M. and Bitro-Mutunayagam, A. P. A. 1961. Fixation and availability of P in soils of Kerala. *Agric. Res. J. Kerala* **1** : 70-77

Koshy, M. M., Panikar, M. S. N. and Varghese, A. 1977. *Kari Lands of Alleppey - Research and Improvement Project*. Government of Kerala, Trivandrum

KSSP, 1978. *Report of the Study Team on Kuttanad.* Kerala Sasthra Sahitya Parishad, Trivandrum

KSSP, 1992. *Kuttanad, Facts and Fallacy.* Kerala Sastra Sahitya Parishad, Kozhikode

Kumar, Y. 1989. Persistence and translocation of deltamethrin in cowpea. Ph.D. thesis, Indian Agricultural Research Institute, New Delhi

Kumar, Y. and Agnihotri, N. P. 1991. Persistence of deltamethrin in soil. *Pestic. Res. J.* **3** : 87-92

Kurup, T. K. B. 1967. Fertility investigation on rice soils of Kuttanad, Kerala. M.Sc.(Ag) thesis, University of Kerala, Trivandrum

Kurup, T. K. B. and Aiyer, R. S. 1973. Seasonal variations in soil reaction and salt content of Kuttanad rice soils. *Agric. Res. J. Kerala* **11** : 57-60

Kuruvila, V. O. 1974. Chemistry of low productive acid sulphate soils of Kerala and other amelioration for growing rice. Ph.D. thesis, Utkal University, Bhubaneswar

Kuruvila, V. O. and Patnaik, S. 1994. Problems associated with the low productivity of acid sulphate soils in Kerala. Abstr. Keralam. *Int. Cong. Kerala Studies.* 4 : AKG Centre for Research and Studies, Trivandrum, p. 27-29

Lal, P., Chippa, B. R. and Kumar, A. 1993. *Salt Affected Soils and Crop Production.* Agro Botanical Publishers, Bikaner

Laskar, B. K., Debnath, N. C., De, G. K. and Basak, R. K. 1991. Nitrogen mineralisation in potential acid sulphate soils. *J. Indian Soc. Soil Sci.* 39 : 564-566

Leela, K. 1967. Forms, availability and distribution of S in representative soil profiles of Kerala state. M.Sc.(Ag) thesis, University of Madras, Madras

Lindsay, W. L. and Norvell, W. A. 1978. Development of a DTPA soil test for zinc, copper, iron and manganese. *Soil Sci. Soc. Am. J.* **42** : 421-428

Mandal, L. N. 1961. Transformation of iron and manganese in waterlogged rice soils. *Soil Sci.* **91** : 121-127

Mandal, L. N. 1984. Soil research in relation to rice. *J. Indian Soc. Soil Sci.* **32** : 575-578

Mandal, L. N. 1991. Transformation and availability of iron and manganese in flooded rice soils. *Proceedings of Summer Institute on Nutrient Transformation and Management in Flooded Soil - Rice Ecosystem.* Central Rice Research Institute, Cuttack, Orissa, p. 182-193

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

Marykutty, K. C. 1986. Factors governing response of rice to liming in Kerala soils. Ph.D. thesis, Kerala Agricultural University, Vellanikkara, Trichur

Marykutty, K. C. and Aiyer, R. S. 1987. Effect of liming and washing on soil characters. *Agric. Res. J. Kerala 25* : 27-35

Marykutty, K. C. and Aiyer, R. S. 1990. Principal component analysis for grouping acid soils. *Rice in Wetland Ecosystem.* Kerala Agricultural University, Vellanikkara, Trichur, p. 87-97

Mathai, J. and Rajendran, C. P. 1983. *Integrated Environmental Study of the Coastal Zone between Latitudes 9° 15' and 9° 45' (Kerala) - Geology and Tectonics.* Technical Report

No. 27. Centre for Earth Science Studies, Trivandrum

Mathew, C. P. 1989. Sulphur status of the Kuttanad soils of Kerala. M.Sc.(Ag) thesis, Kerala Agricultural University, Vellanikkara, Trichur

Mathew, E. K., Nair, M. and Raju, T. D. 1993. *Drainage and Rice Productivity in Acid Saline Soils of Kuttanad.* Kerala Agricultural University, Vellanikkara, Trichur

Mathews, R. P. and Jose, A. I. 1984. Effect of submergence on inorganic P fixation and available P in two acid rice soils of Kerala. *Agric. Res. J. Kerala* **22** : 107-112

Matsumura, F. 1988. Biotic degradation of pollutants. *Ecotoxicology and Climate.* John Wiley and Sons, New York

Meher, H. C., Agnihotri, N. P. and Sethi, C. L. 1985. Persistence of carbofuran in soil and its bioefficacy against nematodes. *Indian J. Nematol.* **15** : 71-77

Meher, H. C., Agnihotri, N. P. and Sethi; C. L. 1989. Persistence of aldicarb residues on cowpea *(Vigna ungiculata)* and soil under tropical conditions. *Indian J. agric. Sci.* **59** : 771-777

Mehlich, A. 1939. Use of triethanolamine acetate-barium hydroxide buffer for the determination of some base exchange properties and lime requirement of soil. *Soil Sci. Soc. Am. Proc.* **3** : 162-166

Mehlich, A. 1953. Rapid determination of cation and anion exchange properties and pHe of soils. *J. Assoc. Off. Agric. Chem.* **36** : 445-457

Menon, G. P. K. 1975. Morphological and physicochemical properties of the kayal soils of Kuttanad, Kerala State. M.Sc.(Ag) thesis, Kerala Agricultural University, Vellanikkara, Trichur

Misra, U. K., Satapathy, S. and Panda, N. 1989. Characterisation of some acid soils of Orissa : I. Nature of soil acidity. *J. Indian Soc. Soil Sci.* **37** : 22-28

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

Money, N. S. 1961a. Studies on the soils of Kuttanad, Part I. Toxic factors. *Agric. Res. J. Kerala* **1** : 52-58

Money, N. S. 1961b. Studies on soils of Kuttanad, Part II. Microbiological nitrogen transformations in acid peat soils of Kuttanad. *Agric. Res. J. Kerala* **1** : 59-64

Money, N. S. and Sukumaran, K. M. 1973. *Chemical, Microbilogical and Agronomic Aspects of the Acid Saline Water-logged Soils of Kerala.* Technical Bull. No.1. Directorate of Extension Education, Kerala Agricultural University, Mannuthy, Trichur

Nair, C. B. 1970. Studies on copper and zinc status of Kerala rice soils and the response to these elements by IR8. M.Sc.(Ag) thesis, Kerala Agricultural University, Vellanikkara, Trichur

Nair, G. K. N. and Iyer, N. 1948. Studies on kari soils. *Univ. Trav. Dept. Res. Rep.*, Trivandrum, p. 148-150

Nair, H. K. 1986. Assessment of the factors governing response to phosphorus in the rice soils of Kerala.Ph.D. thesis, Kerala Agricultural University, Vellanikkara, Trichur

Nair, J. Y. and Subramoney, N. 1969. Studies on $H_2S$ injury to rice plants. *Agric. Res. J. Kerala* **7** : 21-24

Nair, K. M. and Padmaja, P. 1983. Phosphorus fixing capacity of major rice soils of Kerala. *Agric. Res. J. Kerala* **21** : 63-65

Nair, K. N. S. 1973. *Working Paper on Development of Kuttanad. Problems and Prospects.* State Planning Board, Trivandrum

Nair, P. G. and Money, N. S. 1972. Studies on some chemical and mechanical properties of the salt affected rice soils of Kerala. *Agric. Res. J. Kerala* **10** : 51-53

Nair, P. K. and Aiyer, R. S. 1968. Status of available silica in rice soils of Kerala state : I. Evaluation of different methods for determination of available silica in soil. *Agric. Res. J. Kerala* **10** : 51-53

Nair, P. V. R. and Pillai, V. K. 1990. Changing ecology of the Vembanad lake.*Rice in Wetland Ecosystem*. Kerala Agricultural University, Vellanikkara, Trichur, p. 280-285

National Academy of Sciences and National Academy of Engineering, 1972.*Water Quality Criteria.* U.S. Govt. Printing Office, Washington DC

Neue, H. E. and Mamaril, C. P. 1984. Zinc, sulphur and other micronutrients in wetland soils. *Wetland soils : Characterisation, Classification and Utlisation.* International Rice Research Institute, Los Banos, Philippines, p. 307-321

OECD, 1986. *Water Pollution by Fertilisers and Pesticides.* Organisation for Economic Cooperation and Development, Paris

Ottow, J. C. G., Benckiser, G. and Watanabe, I. 1982. Iron toxicity as a multiple nutritional stress. *Trop. agric. Res. Ser.* **15** : 167-169

Page, A. L. 1982. *Methods of Soil Analysis.* Part 2. 2nd ed. Am. Soc. Agron. Inc., Madison, Wisconsin, USA

Pal, S., Laskar, B. K., De, G. K. and Debanath, N. C. 1991. Nature of some acid sulphate soils occurring in the coastal areas of West Bengal. *J. Indian Soc. Soil Sci.* **39** : 56-62

Panda, D., Mahata, K. R., Sen, H. S. and Patnaik, S. 1989. Transformation and loss of nitrogen due to leaching and ammonia volatalization in wet land rice (*Oryza sativa* L.) soil. *Indian J. agric. Sci.* **59** : 91-96

Panda, D., Samantaray, R. N. and Patnaik, S. 1988. Management of fertiliser nitrogen for direct sown, rainfed lowland rice (*Oryza sativa* L.). *J. agirc. Sci. Camb.* **110** : 475-479

Panda, N. 1987. Acid soils of eastern India. *J. Indian Soc. Soil Sci.* **35** : 568-581

Panda, N. and Koshy, M. M. 1982. Chemistry of acid soils. *Review of Soil Research in India*, Part I, *12th int. Congr. Soil Sci.*, New Delhi, India. p. 160-168

Panse, V. G. and Sukhatmae, P. V. 1985. *Statistical Methods for Agricultural Workers.* 4th ed., ICAR, New Delhi

Patrick, W. H. Jr. 1981. The role of inorganic redox systems in controlling reduction in paddy soils. *Proceedings of International Symposium on Paddy Soil, Beijing.* Institute of Soil Science, Academia Sinica, Beijing, p. 107-117

Patrick, W. H. Jr. and Mahapatra, I. C. 1968. Transformation and availability to rice of nitrogen and phosphorus in waterlogged soils. *Adv. Agron.* **20** : 323-353

Patrick, W. H. Jr. and Reddy, K. R. 1976. Nitrification-denitrification reaction in flooded soils and sediment, dependance on oxygen supply and ammonium diffusion. *J. environ. Quality* 5 : 469-472

Patrick, W. H. Jr. and Reddy, C. N. 1978. Chemical changes in rice soils. *Soils and Rice*. International Rice Research Institute, Los Banos, Philippines, p. 361-379

Perkins, A. F. 1970. *Analytical Methods for Atomic Absorption Spectrophotometry*. Perkin Elmer Corporation, USA

Pillai, S. V. 1964. Physico-chemical and microbilogical studies on some kari soils of Kerala. M.Sc.(Ag) thesis, Kerala Agricultural University, Vellanikkara, Trichur

Pillai, S. V. and Subramoney, N. 1967. Physicochemical and microbiological studies on the kari soils of Kerala. *Agric. Res. J. Kerala* **5** : 54-64

Pillai, T. K. V. 1940. *The Travancore State Manual* Vol.3. Govt. of Travancore, Trivandrum

Piper, C. S. 1942. *Soil and Plant Analysis*. Asian reprint, 1966. Hans Publishers, Bombay

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

Pisharody, P. N. and Brito-Mutunayagam, A. P. A. 1966. Manganese status of rice soils of Kerala. *Agric. Res. J. Kerala* **4** : 39-46

Ponnamperuma, F. N. 1972. Chemistry of submerged soils. *Adv. Agron.* **24** : 29-88

Prabhuraj, D. K. and Murthy, A. S. P. 1994. Forms of acidity in some acid soils. *J. Indian Soc. Soil Sci.* **42** : 455-456

Praseedom, R. 1970. Distribution of copper and zinc in soils of Kerala. M.Sc.(Ag) thesis, Kerala Agricultural University, Vellanikkara, Trichur

Praseedom, R. and Koshy, M. M. 1975. Zn status of Kerala soils. *Agric. Res. J. Kerala* **13** : 1-4

Prema, D. 1992. Status, availability and transformation of magnesium in acid soils of Kerala. Ph.D. thesis, Kerala Agricultural University, Vellanikkara, Trichur

Rajagopal, B. S., Brahmaprakash, G. P., Reddy, D. R., Singh, U. D. and Sethunathan, N. 1984. Effect of persistence of selected carbamate pesticides in soils. *Residue Rev.* **93** : 1-99

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

Rajendran, P. and Aiyer, R. S. 1981. A comparative study of the efficacy of the different extractants for zinc and manganese in relation to plant availability. *Madras agric. J.* **68** : 546-553

Raju, P. V. 1988. Effect of drying and wetting on the physical, physico-chemical and chemical properties of the submerged soils of Kuttanad. M.Sc.(Ag) thesis, Kerala Agricultural University, Vellanikkara, Trichur

Ramesh, A. Tanabe, S., Tatsukawa, R., Subramanian, A. N., Palanichamy, S., Mohan, D. and Venugopalan, V. K. 1989. Seasonal variation of organochlorine insecticide residues in air from Porto Novo, South India. *Environ. Pollu.* **62** : 213-222

Rekhi, R. S., Meelu, O. P. and Gupta, R. K. 1982. Lysimeter studies on recovery of $^{15}$N-labelled urea in wetland rice. *Pl. Soil* 66 : 57-67

Richards, L. A. (ed.) 1954. *Diagnosis and Improvement of Saline and Alkali Soils. USDA Handbook*. United States Department of Agriculture, Washington DC

Rosalind, R. S. 1995. Organochlorine insecticide contamination in the inland ecosystem of

Kerala. M.Sc.(Ag.) thesis, Kerala Agricultural University, Vellanikkara, Trichur

Rose, A. H. 1976. *Chemical Microbiology*. Butterworth and Co (Publishers) Ltd., London

Sahrawat, K. L. 1979. Evaluation of some chemical extractants for determination of exchangeable ammonium in tropical rice soil. *Commun. Soil Sci. Plant Anal.* **10** : 1005-1013

Sahrawat, K. L. 1980. Is nitrate reduced to ammonium in waterlogged acid sulphate soil. *Pl. Soil* **57** : 147-149

Samuel, T., Agarwal, M. C. and Pillai, M. K. K. 1988. Persistence and binding of DDT and gamma-HCH in a sandy loam soil under field conditions in Delhi, India. *Pestic. Sci.* **22** : 1-15

Santhakumari, G. 1975. Morphological and physico-chemical properties of karappadom soils of Kuttanad region of Kerala state. M.Sc.(Ag) thesis, Kerala Agricultural University, Vellanikkara, Trichur

Savant, S. K. and De Datta, S. K. 1982. Nitrogen transformations in wetland rice soils. *Adv. Agron.* **35** : 241-302

Sebastian, C. D. 1994. *A Manual on Seed Production and Farming of Giant Freshwater Prawn, Macrobrachium rosenbergi.* The Marine Products Export Development Authority, Cochin

Segeren, W. A. and Smits. H. 1974. Drainage of newly reclaimed marine clayey sediments, peat soils and acid sulphate soils. *Drainage Principles and Application*. International Institute for Land Reclamation and Improvement, Wageningen, Netherlands

Sethunathan, N., Adhya, T. K., Barik, S. and Sharmila, M. 1991. Degradation and significance of degradation products of commonly used insecticides in Indian rice soils. *Pesticide Transformation Products*. American Chemical Society,Washington

Sethunathan, N., Siddaramappa, R., Rajaram, K. P., Barik, S. and Wahid, P. A. 1977. Parathion : residues in soil and water. *Residue Rev.* **68** : 91-122

Sharma, B. L., Rathore, S. B., Dubey, S. B., Khamparia, R. S. and Sinha, S. B. 1986. Response of rice to zinc and evaluation of some soil test methods for zinc. *J. Indian Soc. Soil Sci.* **12** : 381-384

Sharma, S. P., Sharma, P. L. and Tripathi, B. R. 1990. Forms of acidity in some acid soils of India. *J. Indian Soc. Soil Sci.* **38** : 189-195

Siddiqui, M., Saxena, M. and Krishnamurti, C. 1981. Storage of DDT and BHC in adipose tissue of India males. *Int. J. Environ. Anal. Chem.* **10** : 197-204

Singh, G., Kathpal, T. S., Spencer, W. F., Yadav, G. S. and Kushwaha, K. S. 1989. Dissipation behaviour of hexachlorocyclohexane isomers in flooded rice soil. *J. environ. Sci. Health* **24** : 335-348

Singh, R. N., Diwakar, D. P. S. and Singh, A. K. 1993. Nature of acidity in soils developed on granite gneiss and Mahananda alluvium. *J. Indian Soc. Soil Sci.* **41** : 29-32

Snedecor, G. W. and Cochran, W. G. 1967. *Statistical Methods*. 6th ed. Oxford and IBH Pub. Co., Calcutta

Soil Survey Staff, 1987. *Keys to Soil Taxonomy*. SMSS Technical Monograph No. **6**. Ithaca, New York

Soil Survey Staff, 1992. *Soil Survey Laboratory Methods Manual*. Soil Survey Investigations Report No. **42** Version 2. USDA, [illegible]

National Soil Survey Centre and Soil Conservation Service, Washington DC

SPPL, 1992. *Indian Pesticide Directory.* 3rd ed. Scientia Publication Pvt. Ltd., Bombay

Sreedevi, S. and Aiyer, R. S. 1974. Potassium status of acid rice soils of Kerala state. *J. Indian Soc. Soil Sci.* **22** : 321-328

Sreedevi, S., Varghese, T. and Aiyer, R. S. 1975. Potassium status of the major rice soils of Kerala state in relation to their granulometric composition. *Agric. Res. J. Kerala* **13** : 58-62

Subbiah, B. V. and Asija, G. L. A. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Curr. Sci.* **25** : 259-260

Subramoney, N. 1958. Chemical and mineralogical studies on the acid peats of Kerala. Ph.D. thesis, University of Travancore, Trivandrum

Subramoney, N. 1959. Sulphur bacterial cycle : probable mechanism of toxicity in acid soils of Kerala. *Sci. Cult.* **25** : 637-638

Subramoney, N. 1961. Studies on soils of Kuttanad, Toxic factors, Part I. *Agric Res. J. Kerala* 1: 53-57

Subramoney, N. 1965. Injury to paddy seedlings by production of $H_2S$ under field conditions. *J. Indian Soc. Soil Sci.* **23** : 95-98

Subramoney, N. and Kurup, T. K. B. 1961. Investigation of the phenomenon of scum formation in paddy fields of Kerala state. *J. Indian Soc. Soil Sci.* **9** : 253-255

Sunilkumar, K. B., Visalakshi, A., Varghese, G., Mathew, J. S, Koshy, M. M. and Antony, V. C. 1994. Organochlorine contamination in Kuttanad - A natural wetland in Kerala. *National Symposium on Management of Ecosystem and Sustainable Utilisation of Biological Resources,* Trivandrum, *Abstract of Papers*, p. 7

Tandon, H. L. S. (ed) 1995. *Methods of Analysis of Soils, Plants, Waters and Fertilisers.* Fertiliser Development and Consultation Organisation, New Delhi

Tong, G. Z. 1983. Pedogenesis of paddy soil and its significance in soil classification. *Soil Sci.* **135** : 5-10

Trolldenier, G. 1977. Mineral nutrition and reduction processes in the rhizosphere of rice. *Pl. Soil* **47** : 193-202

Van Breeman, N. 1973. Dissolved aluminium in acid sulphate soils and acid mine waters. *Soil Sci. Soc. Am. Proc.* **37** : 694-697

Van Breeman, N. and Moorman, F. R. 1978. Iron toxic soils. In *Soils and rice,* International Rice Research Institute, Los Banos, Philippines, p. 56-61

Van Mensvoort, M. E., Lantin, R. S., Brinkman, R. and Van Breeman, N. 1984. Toxicities of wetland soils. *Wetland Soils : Characterisation, Classification and Utilisation.* International Rice Research Institute, Los Banos, Philippines, p. 123-138

Varghese, G. 1971. Studies on nutrient status of the alluvial soils of Kerala with special reference to the distribution of copper and zinc. M.Sc.(Ag) thesis, Kerala Agricultural University, Vellanikkara, Trichur

Varghese, T. and Aiyer, R. S. 1973. *Influence of Geomorphological and Climatic Factors on the Soil Formation of Kerala.* Special publication No. 5, Geological Survey of India, Trivandrum, p. 69-79

Varghese, T., Thampi, P. S. and Money, N. S. 1970. Some preliminary studies on Pokkali saline soils of Kerala. *J. Indian Soc. Soil Sci.* **18** : 65-69

Varghese, V. P. 1973. Morphological and physico-chemical properties of the acid soils of Kerala. M.Sc.(Ag) thesis, Kerala Agricultural University, Vellanikkara, Trichur

Venugopal, V. K. and Koshy, M. M. 1976a. Exchangeable cations of some important soil profiles of Kerala. *Agric. Res. J. Kerala* **14** : 37-42

Venugopal, V. K. and Koshy, M. M. 1976b. CEC in relation to the mechanical composition and organic matter status of some soil profiles of Kerala. *Agric. Res. J. Kerala* **14** : 58-63

Venugopal, V. K. and Koshy, M. M. 1978. CEC and chemical composition of some important soil groups of Kerala. *Agric. Res. J. Kerala* **16** : 233-234

Verma, A. and Pillai, M. K. K. 1990. Bound residues of DDT and HCH in wheat and their bioavailability to rats. *Chemosphere* **21** : 1315-1320

Verma, A. and Pillai, M. K. K. 1991. Bioavailability of soil bound residues of DDT and HCH to certain plants. *Soil Biol. Biochem.* **23** : 347-351

Vijayalakshmi, H. N. 1988. Microbial metabolism of carbofuran in soils. M.Sc.(Ag) thesis, University of Agricultural Sciences, Bangalore

Walkley, A. and Black, I. A. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* **37** : 29-34

Watanabe, P. S. and Olsen, S. R. 1965. Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soil. *Proc. Soil Sci., Am.* **29** : 677-678

WHO, 1971. *International Standards for Drinking Water.* World Health Organisation, Geneva

Yuan, T. L. 1959. Determination of exchangeable hydrogen in soils by titration method. *Soil Sci.* **88** : 164-167

Zachariah, P. K. and Sankarasubramoney, H. 1961. Relationship between the available nitrogen content and organic carbon as determined by Walkley and Black's method for the typical soils of Kerala. *Agric. Res. J. Kerala* **1** : 106-108

# MORPHOLOGICAL, PHYSICAL AND CHEMICAL CHARACTERISATION OF THE SOILS OF NORTH KUTTANAD

By

**K. C. MANORAMA THAMPATTI**

**ABSTRACT OF A THESIS**

Submitted in partial fulfilment of the requirement for the degree

***Doctor of Philosophy in Agriculture***

Faculty of Agriculture
Kerala Agricultural University

**Department of Soil Science and Agricultural Chemistry**
**COLLEGE OF HORTICULTURE**
**VELLANIKKARA, THRISSUR 680 654**

**1997**

# ABSTRACT

An investigation was carried out at the College of Horticulture, Vellanikkara during 1992 to 1995 to evaluate the morphological, physical and chemical characteristics of soils of North Kuttanad and to assess the extent of toxic factors that pertained in the soil due to restricted movement of water under the influence of Thanneermukkom regulator.The study was carried out in three parts, viz., (1) Morphology and physicochemical characteristics, (2) Fertility characteristics and (3) Toxicity characteristics. Fifteen soil profile were drawn from North Kuttanad to study the morphology and physicochemical characteristics of the area. The fertility characteristics were studied by collecting 97 surface soil samples (0-15 cm depth) from 27 padasekharams of the area during rainy and summer seasons (before and after the closure of Thanneermukkom regulator). Toxicity characteristics of the area were studied by collecting bulk soil samples (0-25 cm depth), surface water and ground water from the above sites during the same period.

Morphological and physicochemical properties of the soils showed great degree of variation. Soils were dark brown to black in colour, sticky and plastic, subangular blocky in structure and sandy to clayey in texture, with random deposits of lime shells and humus. Presence of faint to prominent reddish yellow or brown mottles, rice roots and root canals were some of the special characteristics observed in the soil profiles.

Soils of the area were highly acidic and mildly saline. Both soil acidity and salinity increased with depth. Organic carbon, CEC and ECEC of the area were higher compared to other parts of Kerala, but the base saturation was comparatively lower. The area was rich in almost all the essential nutrients except P. Fe, Al and S were present in toxic concentrations. Potential acidity of the area was very high and more than 70 per cent of it was contributed by hydrolytic acidity and the rest by exchangeable acidity. All the acidity characteristics increased with depth. The profile IX was grouped under order Inceptisol and all others under order Entisol.

On evaluating the fertility characteristics of the area it was observed that the area experienced an increase in soil acidity and availability of N, P, Fe and Zn and a decrease in salinity, CEC, ECEC and available K, Ca, Mg, Mn and Cu. However, the availability of all nutrients except P was above the deficiency level. Fe was present in toxic quantities. On a general comparison with that of pre-barrage period, the area experienced a reduction in salinity and an enhancement in soil acidity and availability of K, Ca and Mg. The Na content was reduced considerably in response to the reduction in salinity. The exchangeable and water soluble cations followed the same trend as that of available cations. Among the exchangeable cations Ca was the dominant basic cation instead of Na which occupied the same place during pre-barrage period.

Acidity characteristics of surface samples behaved similar to that of profile samples. Potential acidity and hydrolytic acidity recorded higher values during rainy season while exchangeable acidity was greater during summer. Among the components of exchangeable acidity exchangeable $Al^{3+}$ dominated during rainy season, and exchangeable $H^+$ during summer. The overall influence was greater for exchangeable $Al^{3+}$ as evidenced from the higher correlation coefficient ($0.862^{**}$).

The general soil properties and acidity characteristics of the bulk soil samples were similar to that of surface samples, showing a

reduction in pH, EC, CEC and available, exchangeable and water soluble cations during summer compared to the rainy season.

Among the different fractions of Fe, free and available forms were present in large quantities while exchangeable and water soluble forms were present in negligible quantities. All the fractions expressed a higher concentration during summer indicating more chances for severe Fe toxicity during that period. Mn was also present in large quantities. Compared to Fe, the concentration of different fractions of Mn were very small. The availability of Cu and Zn were also above the critical levels. The area was rich in Al. Reverse to that of Fe the different fractions of Al showed a lower concentration during summer. The free Al content was three times lesser than that of free Fe, while in exchangeable form Al expressed a higher concentration. The water soluble Al was very low.

Surface water and ground water of the area were mildly acidic and saline during rainy season and they showed an increase during summer. The acidity exceeded the permissible maximum but the salinity was maintained below the permissible limit for agricultural and domestic purposes.

Among the various elements present in water, Na and $Cl^-$ were the dominant ions expressing greater concentrations during summer in both surface and ground water. Based on SAR they were rated as moderately unsafe for irrigation during summer. The concentrations of K, Ca and Mg were within the permissible maximum for agricultural and domestic purposes. P was present only in traces. The Fe content was greater for ground water than surface water and it exceeded the permissible limit for drinking water. Though Mn was absent in ground water, it has already reached up to the permissible maximum in surface water. Al content exceeded the permissible maximum for domestic purposes. Cu, Zn, Cd and Pb were not detected in water. $SO_4$-S, $NH_4$-N and $NO_2$+$NO_3$-N contents of both surface and ground water were well below the critical levels suggested, but $Cl^-$ contents of both were sufficient to cause specific toxicity effect.

The chlorinated hydrocarbon pesticides identified in the area were α-HCH, γ-HCH and DDT. They showed higher concentration during summer. Among the chlorinated hydrocarbons, DDT was present in larger quantities, though it was banned for agricultural uses, followed by α-HCH. The concentration of γ-HCH was comparatively small.

The accumulation of fertiliser residues in the area was not so negligible. The highest concentration was observed for $NH_4$-N during additional crop season, at the time of basal dressing, both in soil and water. During punja season, a decrease of 55 to 60 per cent in soil and 10 to 12 per cent in water for $NH_4$-N was observed. The content of $NO_2$+$NO_3$-N was comparatively low in soil due to continuous submergence. In water it was not as low as that of soil, indicating a major portion of $NO_2$+$NO_3$-N retained in water. P content of the area was very low. Its loss through drainage water was nil.

A sizable quantity of K was also subjected to loss through drainage water, though the extent of loss was well below the level of N. Here also highest concentration was noted during additional crop season at the time of basal dressing both in soil and water.

The study indicated that the area is subjected to severe pollution due to the accumulation of native toxic factors as well as residues of pesticides and fertilisers. The closure of Thanneermukkom regulator aggravates the situation by restricting the water movement.